POLLUTION CONTROL HEARINGS BOARD

STATE OF WASHINGTON

NISQUALLY DELTA ASSOCIATION, a non-profit organization, and ED KENNEY, Appellants, v. STATE OF WASHINGTON DEPARTMENT OF ECOLOGY, Appellee.	PCHB No. 22-057 DECLARATION OF WYATT F. GOLDING IN SUPPORT OF APPELANTS' MOTION FOR PARTIAL SUMMARY JUDGMENT

Wyatt Golding hereby declares as follows:

1. I am the attorney for appellants Nisqually Delta Association and Ed Kenney in the above-captioned action. I make this declaration based on personal knowledge.

2. Attached hereto as Exhibit A is the Biosolids General Permit.

3. Attached hereto as Exhibit B is the Biosolids General Permit SEPA Checklist 2021.

4. Attached hereto as Exhibit C is the Biosolids General Permit SEPA DNS 2021.

5. Attached hereto as Exhibit D is the response to comments, June 2022.

6. Attached hereto as Exhibit E is the PFAS Chemical Action Plan.

ZIONTZ CHESTNUT
2101 FOURTH AVENUE, SUITE 1230
SEATTLE, WASHINGTON 98121
TEL. (206) 448-1230; FAX (206) 448-1230

7. Attached hereto as Exhibit F is the MTCA PFAS Focus Sheet.

8. Attached hereto as Exhibit G is the PFAS Fish Consumption Advisory 334-470.

9. Attached hereto as Exhibit H is the EPA PFAS Roadmap.

10. Attached hereto as Exhibit I is the Microplastics Study.

11. Attached hereto as Exhibit J are the comments of Ed Kenney on the draft permit.

12. Attached hereto as Exhibit K is the EPA Biosolids 2020-2021 Biennial Report.

13. Attached hereto as Exhibit L is the PFAS Concentrations in Effluent, Influent, Solids, and Biosolids.

I declare under penalty of perjury under the laws of the State of Washington that the foregoing is correct.

Dated this 12th day of May, 2023.

ZIONTZ CHESTNUT

s/Wyatt F. Golding
Wyatt F. Golding, WSBA No. 44412
Ziontz Chestnut
2101 Fourth Avenue, Suite 1230
Seattle, WA 98121
wgolding@ziontzchestnut.com
(206) 448-1230 | Phone
(206) 448-0962 | Fax

Attorneys for Appellants
Nisqually Delta Association and Ed Kenney

CERTIFICATE OF SERVICE

I certify that on May 12, 2023, I served a copy of the foregoing Declaration of Wyatt F. Golding in Support of Appellants' Motion for Partial Summary Judgment upon the parties as indicated below:

Jonathan C. Thompson
Attorney General of Washington
Ecology Division
PO Box 40117
Olympia, WA 98504-0117
Jonathan.Thompson@atg.wa.gov

Via Email

Dylan Stonecipher
Attorney General of Washington
Ecology Division
PO Box 40117
Olympia, WA 98504-0117
Dylan.Stonecipher@atg.wa.gov

Via Email

Dated this 12th day of May, 2023.

/s/ Laura Bartholet
Paralegal/Legal Assistant

ZIONTZ CHESTNUT
2101 FOURTH AVENUE, SUITE 1230
SEATTLE, WASHINGTON 98121
TEL. (206) 448-1230; FAX (206) 448-1230

EXHIBIT A

Statewide General Permit for Biosolids Management

Issued: June 15, 2022

Effective: July 15, 2022

Expires: July 14, 2027

Laurie G. Davies

Laurie G. Davies, Program Manager June 15, 2022

Solid Waste Management Program

Washington State Department of Ecology

June 2022

Publication 21-07-006

Publication and Contact Information

This document is available on the Department of Ecology's website at:
https://fortress.wa.gov/ecy/publications/summarypages/2107006.html

For more information contact:

Solid Waste Management Program
P.O. Box 47600
Olympia, WA 98504-7600
Phone: 360-407-6900

Washington State Department of Ecology — www.ecology.wa.gov

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Bellevue 425-649-7000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Union Gap 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

ADA Accessibility

The Department of Ecology is committed to providing people with disabilities access to information and services by meeting or exceeding the requirements of the Americans with Disabilities Act (ADA), Section 504 and 508 of the Rehabilitation Act, and Washington State Policy #188.

To request an ADA accommodation, contact Ecology by phone at 360-407-6900 or email at SWMpublications@ecy.wa.gov. For Washington Relay Service or TTY call 711 or 877-833-6341. Visit Ecology's website for more information.

Statewide General Permit for Biosolids Management

Solid Waste Management Program

Washington State Department of Ecology

Olympia, Washington

Table of Contents

Contents

List of Figures and Tables

Figures

Tables

1. Overview and Changes

1.1. Introduction

The Washington State Legislature authorized Ecology to implement a state biosolids management program (Chapter 70A.225 RCW - *Municipal Sewage Sludge-Biosolids*[1]). The state biosolids program is based on rules adopted by the Department of Ecology (Chapter 173-308 WAC - *Biosolids Management*[2]). Ecology issues this general permit to implement the rules, including additional or more stringent requirements that may be necessary to ensure proper management of biosolids in specific circumstances.

Ecology uses accepted best management practices from state and federal guidelines and other authoritative sources to determine permit conditions, and to establish additional or more stringent requirements for individual sites and facilities. Input from the public may also inform the agency and lead to additional or more stringent requirements for a specific facility or land application site. Examples of commonly used state guidance include Ecology's *Biosolids Management Guidelines* - WDOE 93-80[3], and *Managing Nitrogen from Biosolids* – WDOE 99-508[4]. The U.S. Environmental Protection Agency's (EPA) *Control of Pathogens and Vector Attraction Reduction in Sewage Sludge*[5] is an important federal guidance document. Other authoritative sources include, but are not limited, to University Cooperative Extension publications on crop nutrient needs and soil sampling.

Unless modified by this permit or an approval of coverage under this permit, the rules in Chapter 173-308 WAC are applicable. The state biosolids program, including this General Permit for Biosolids Management, intends to comply with all applicable federal rules adopted pursuant to the federal Clean Water Act, as it existed on February 4, 1987.

The state biosolids program:

- Regulates facilities that produce, treat or land apply sewage sludge or biosolids.
- Regulates beneficial uses of biosolids including application to agricultural lands, forestlands, disturbed lands, lawns and home gardens and other sites where the public might have close contact.
- Does not regulate landfill or incineration *units* where biosolids are disposed.

All facilities that qualify as a *Treatment Works Treating Domestic Sewage* (TWTDS) are subject to the applicable requirements of this permit. Existing facilities that do not have active biosolids programs are automatically covered under this permit on its effective date. Facilities with active

[1] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.226&full=true
[2] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308&full=true
[3] https://apps.ecology.wa.gov/publications/SummaryPages/9380.html
[4] https://apps.ecology.wa.gov/publications/SummaryPages/99508.html
[5] https://www.epa.gov/biosolids/control-pathogens-and-vector-attraction-sewage-sludge

septage or active biosolids management programs must apply for coverage under the general permit, or an individual permit if approved to do so by Ecology.

1.1.1. Explanation of the Terms "Sewage Sludge", "Biosolids", and "Septage"

Sewage sludge is the solid, semisolid, or liquid residue generated during the treatment of domestic sewage in a treatment works. *Biosolids* are produced by treating sewage sludge to meet standards that allow them to be beneficially used for their nutrient and soil conditioning value.

Septage is a type of biosolids that comes from septic tanks and similar systems. **In this permit, when we use the term *septage*, we mean *only* septage.**

When a facility mixes septage, sewage sludge or biosolids together in any combination, the mixture must be treated to the same standards for biosolids produced from the treatment of sewage in a wastewater treatment plant.

1.1.2. Jurisdiction

This permit applies to facilities located on, and biosolids management activities that occur on, lands under the jurisdiction of the State of Washington.

Treatment works subject to the state permit program must have consent from Ecology and the receiving jurisdiction, *prior* to exporting biosolids to an out of state jurisdiction.

Treatment works located outside the jurisdiction of the state that export sewage sludge or biosolids into state jurisdiction, must do so in accordance with WAC 173-308-130[6], and *may* be required to obtain coverage under this permit and/or pay a fee.

1.1.3. Persons Required to Apply for Coverage under this Permit

Unless you are obtaining an individual permit in accordance with WAC 173-308-310[7], you must apply for coverage under this permit if you own or operate a treatment works treating domestic sewage, including but not limited to:

- Publicly owned treatment works.
- Privately owned treatment works that treat *only* domestic sewage, or treat domestic sewage *separately* from industrial wastewater.
- Septage management facilities (SMF).
- Beneficial use facilities (BUF).
- Facilities that compost biosolids, unless exempt under WAC 173-308-310(1)(a)[7].
- Facilities designated by Ecology as a treatment works treating domestic sewage in accordance with WAC 173-308-310(1)(b)[7]

[6] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-130
[7] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-310

- Facilities that mix non-exceptional quality biosolids with other material, including other biosolids.
- Facilities that combine septage with biosolids for treatment, prior to beneficial use.

1.1.4. Activities Regulated Under this Permit

All TWTDS are subject to coverage under this permit. This permit establishes standards and requirements for the following:

- Treatment of sewage sludge or biosolids prior to beneficial use, disposal in a landfill, or incineration.
- Application of non-exceptional quality biosolids to the land, including agricultural lands, forestlands, land reclamation sites, and public contact sites.
- Application of septage to the land.
- Disposal of sewage sludge in municipal solid waste landfills or incinerators.
- Selling or giving away biosolids in bags or other containers with a capacity of one metric ton (1.1 U.S. tons), or less.
- Storing sewage sludge or biosolids.
- Transferring sewage sludge or non-exceptional quality biosolids from one facility to another, including for incineration or disposal in a landfill.
- Composting non-exceptional quality biosolids.
- Producing and selling or giving away exceptional quality biosolids derived from non-exceptional quality biosolids.

1.1.5. Local Health Jurisdiction Involvement

Ecology may authorize a local jurisdictional health authority to assist in implementation and administration of permits. When applying for coverage under this permit, contact Ecology to find out the status of delegation agreements in the areas where you treat, store, transfer, or apply biosolids to the land. Regardless of delegation, you should always be responsive to the inquiries of a local jurisdictional health authority.

1.1.6. Role of EPA

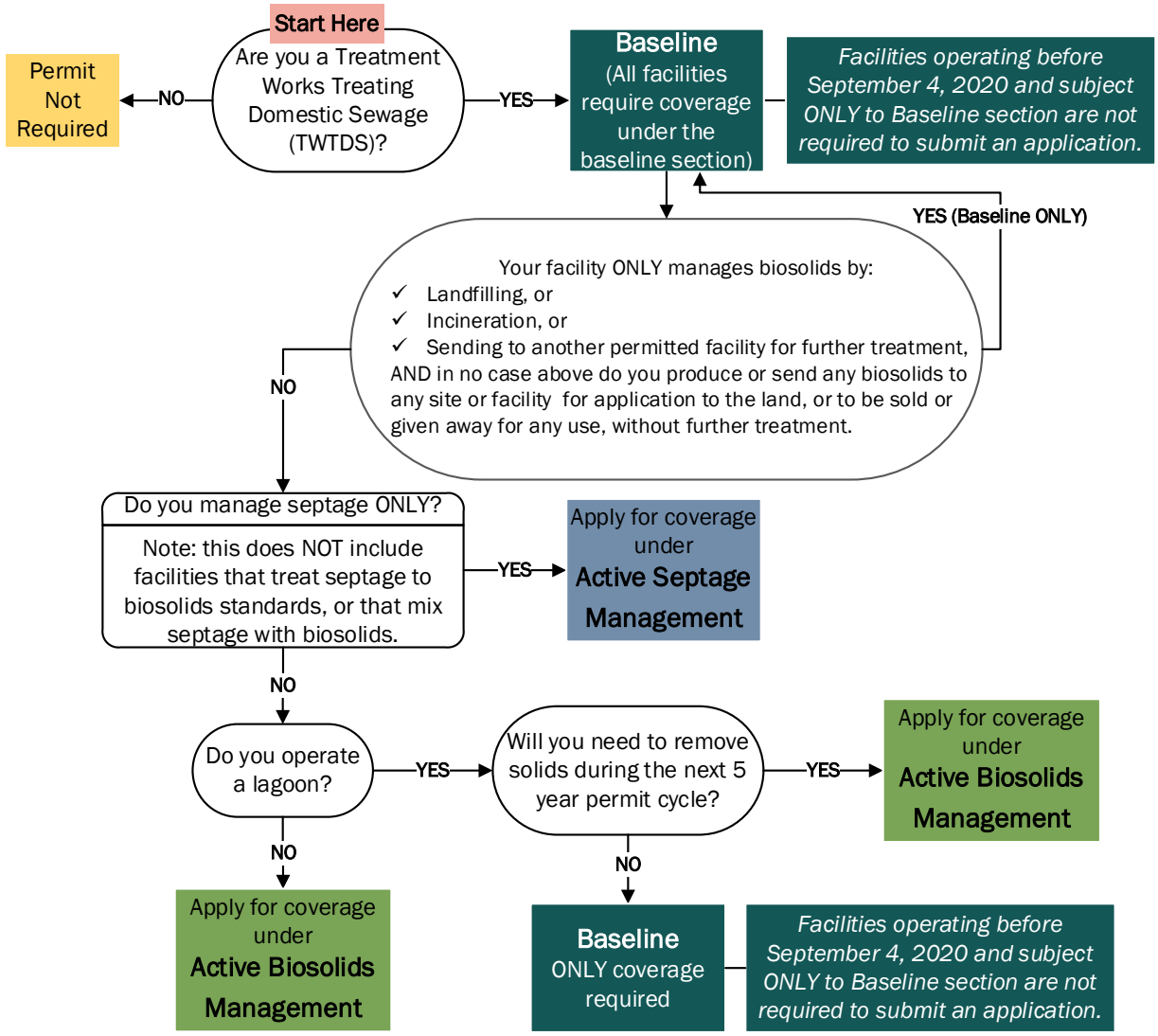
The United States Environmental Protection Agency (EPA) has a responsibility for implementing a national biosolids management program and establishes requirements and management practices for the use and disposal of biosolids in 40 CFR Part 503[8]. EPA and Ecology work cooperatively on program implementation. EPA provides periodic technical assistance to the state. In return, the state provides information on request to EPA regarding biosolids management in Washington.

[8] eCFR :: 40 CFR Part 503 -- Standards for the Use or Disposal of Sewage Sludge

1.2. Structure of this General Permit

The flowchart below provided by Ecology can be used to identify what sections of the permit your facility is subject to. Facilities should consult their regional biosolids coordinators with any questions.

Figure 1 – Permit Sections Flow Chart



1.2.1. Baseline Section

The Baseline section (2) establishes general requirements that are applicable to all facilities. It also establishes specific requirements for some facilities so that they are not required to submit a permit application.

Sections (3) and (4) cover active septage management facilities and active biosolids management facilities, respectively. Facilities without active management programs do not require coverage under section (3) or (4).

The active biosolids management and active septage management portions of this permit are not applicable if:

- You *only* send biosolids to another facility for further treatment before final use or disposal.
- You *only* dispose of the biosolids you produce in a landfill or incinerator (you may be required to develop and implement a beneficial use program).
- You operate a surface impoundment and do not expect to remove solids during the five-year term of this permit. *Note: If you operate a wastewater treatment facility with a surface impoundment and believe you will need to remove solids during the five-year term of the permit, you are also subject to section (4) for active biosolids management programs. Please contact your regional biosolids coordinator for guidance.*
- **AND** in *no* case above do you produce or send any biosolids to any site or facility for application to the land, or to be sold or given away for any use, without further treatment.

1.2.2. Active Septage Management Section

Section (3) of this permit applies to facilities that treat and/or land apply *only* septage.

Pumpers and others who *only* service onsite wastewater treatment systems and/or portable toilets and similar systems, and do *not* treat or land apply septage, are not subject to this permit.

If you receive only septage and treat it to standards for biosolids derived from sewage sludge, you are subject to section (4) for facilities with active biosolids management programs.

You are subject to the active septage management section (3) of this permit if:

- You treat *only* septage (not a mixture of septage and biosolids). Facilities that mix septage and biosolids fall under section (4) of this permit for facilities with active biosolids management programs.
- You land apply *only* septage. This does not include facilities that treat septage to biosolids standards for pathogen reduction, vector attraction reduction, and pollutants. Those facilities fall under section (4) of the permit, for facilities with active biosolids management programs.

1.2.3. Active Biosolids Management Section

Section (4) of this permit applies to facilities with active biosolids management programs, but not those that manage only septage (1.2.2 above).

You are subject to the active biosolids management section (4) of this permit if:

- You apply biosolids (or septage treated to standards for biosolids generated at a wastewater treatment plant) to sites approved *specifically for you.*
- You sell or give away biosolids you treat to *exceptional quality* standards.
- You treat and send biosolids to another facility for land application.

- You treat septage to meet Class A or B pathogen reduction.
- You treat septage, sewage sludge, or biosolids together in any combination to meet Class A or B pathogen reduction.
- You are a *beneficial use facility* (BUF) as defined in WAC 173-308-080[9].
- You receive non-exceptional quality biosolids for further treatment, except for compost facilities operating only under a local solid waste permit in accordance with WAC 173-308-310(1)(a)[7]
- You operate a surface impoundment and expect to remove solids during the five-year term of the permit. Consult your regional biosolids coordinator for guidance.

[9] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-080

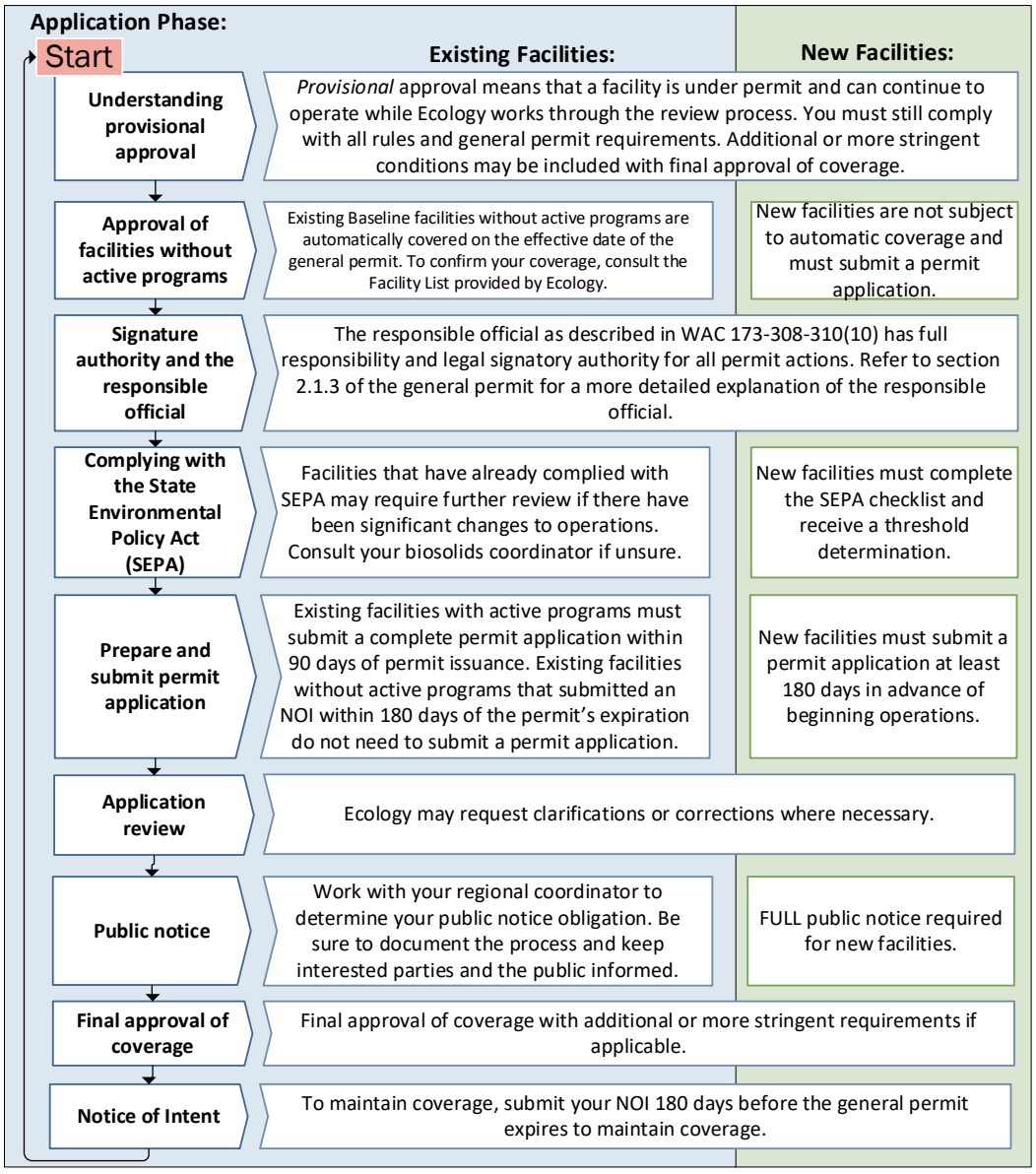
2. Baseline Requirements Applicable to All Facilities

The requirements of this section apply to all persons and facilities required to obtain permit coverage under this permit.

2.1. Understanding and Complying with the Permit System

The flow chart below provided by Ecology provides an overview of the permit application process for new and existing facilities.

Figure 2 – Permit Application Process Flow Chart.



2.1.1. Provisional Approval

***Key Concept**: A facility obtains provisional approval to operate, by submitting at the appropriate times, a permit application, or a Notice of Intent to continue coverage under a forthcoming permit. Provisionally approved facilities are under permit, but subject to additional or more stringent requirements prior to receiving final approval of coverage.*

Provisional approval means that a facility demonstrates recognition of its obligation to apply for coverage under a renewing general permit, and to comply with all applicable requirements of state biosolids rules and this permit. Provisional means that Ecology can add additional or more stringent conditions with final approval of coverage. In the meantime, a facility with provisional approval is under permit and can continue to operate.

Ecology may prohibit a new facility from operating under provisional approval if the agency has not received a complete and correct application, or if the facility has not complied with requirements of the State Environmental Policy Act or this permit as required.

Facilities with provisional approval must operate in compliance with the requirements of federal and state rules, the applicable requirements of the general permit, and in accordance with their application and associated plans. ***Operators are responsible to know and comply with state and federal program requirements***. A facility cannot justify noncompliance by proposing in a plan or other document in a manner contrary to requirements of the rules or general permit. ***Operators must be sure their biosolids coordinator is aware of any changes to operations, including any planned changes from the previous permit***.

Provisional approval carries existing *approved* BUFs from one permit to the next. *New* BUFs cannot receive or apply biosolids to the land under provisional approval. To operate, a new BUF must have final approval of coverage with an approved general land application plan, or at least one approved site specific land application plan.

2.1.2. Automatic Coverage for Some Facilities.

***Key concept**: Approval of coverage is final on the effective date of this permit for facilities that do not have an active biosolids or septage management program, if they have previously complied with application and notice of intent requirements, and have no significant changes to biosolids management practices.*

Facilities that do not have active management programs will be automatically covered on the effective date of this permit if they have undergone environmental review and have no significant changes in biosolids management practices from the previous permit cycle. A permit application is not required from these facilities if they submitted a Notice of Intent to continue coverage, prior to expiration of the previous general permit.

Facilities that propose significant changes in biosolids management from the previous permit cycle, are not eligible for automatic coverage, must submit a permit application, and are subject to further permit review, evaluation under SEPA, and public notice prior to approval.

2.1.3. Responsible Official and Signature Authority

***Key concept**: The person responsible for signing permit-related documents is usually not the operator. The responsible official cannot delegate authority to sign an application, submit a notice of intent, or request a modification of permit coverage (including a new land application site). The responsible official may delegate authority to submit reports and other required documentation. Delegation must be in writing and on file with Ecology.*

The signature of the responsible official is required:

- For a permit application
- For any request to modify the terms of permit coverage, including the addition of a new land application site
- For a notice of intent to continue coverage under a forthcoming permit
- In response to an enforcement action or other legal proceeding

Table A1: Identifying the Responsible Official

Facility Type	Who is the Responsible Official?
Major or Class 1 POTW	An executive or manager with *overall authority* for operation of the treatment works, such as the plant superintendent or director of public works.
Minor POTW	Mayor, county executive, or in the case of a county or special purpose district with multiple minor POTWs, an executive or official with overall responsibility for operation of all facilities.
Special Purpose Districts	The executive director or manager of the district.
Federal	Either a principal executive officer or ranking elected official. For purposes of this section, a principal executive officer of a federal agency includes either of the following: (A) The chief executive officer of the agency. (B) A senior executive officer having responsibility for the overall operations of a principal geographic unit of the agency.
Sole Proprietorships, Registered Partnerships, and Limited Liability Companies.	The proprietor or a partner with legal authority to make decisions on behalf of the company.
Private Corporations	A president, secretary, treasurer, or vice president of the corporation in charge of a principal business function, or any other person who performs similar policy-making or decision-making functions for the corporation.

2.1.3.2. Delegation of Signature Authority

Table A2: When Signature Delegation can be Authorized

Responsible Official Signature Required	Can signature authority be delegated?
Permit application	No
Permit modification, including new land application site	No
Notice of Intent to apply for coverage	No
Annual report	Yes. Upload signature delegation letter at the end of the online report.
Interim reports, data, minor changes and clarifications	Yes. Upload signature delegation letter, at the end of the annual report process, or send to office where report is due.

An example signature Delegation Authority Letter can be found on Ecology's webpages.

2.1.4. Complying with the State Environmental Policy Act (SEPA)

***Key concept**: SEPA is a process that often runs parallel with, but is separate from the permit application process. Identify the SEPA Lead Agency and SEPA Responsible Official before you begin preparing your application. There is an opportunity to coordinate public notice requirements. Do not proceed with, or encourage a local agency to proceed with SEPA public notice until you have verified timing with Ecology. Make an informed decision. Use Ecology's SEPA resources online[10].*

If further SEPA review is required for your proposal, it is to your advantage to open that line of communication early in project planning. Begin by verifying the SEPA Lead Agency and the SEPA staff with whom you will work. If a local government entity such as a publicly owned treatment works is making a proposal, the SEPA Lead Agency is generally a local government body. For privately owned facilities, the SEPA Lead Agency will be either a local government body or Ecology.

The application package and SEPA Checklist work hand-in-hand. If another agency is the SEPA Lead Agency, Ecology will expect the application packet to include the SEPA Threshold Determination, associated SEPA Checklist, and if required, proof of public notice often referred to as an Affidavit of Publication." Ecology cannot accept a verbal assurance about the determination of the SEPA Responsible Official. If Ecology is the SEPA Lead Agency, we will expect a complete application package, including a SEPA checklist, prior to making our threshold determination.

If SEPA and biosolids permit processes are running in parallel, it is possible to issue a combined public notice. The combined public notice includes opportunity for public review and comment on both the SEPA threshold determination and the biosolids permit. That will extend the SEPA review period from fourteen days, to the minimum required for the biosolids general permit, of thirty days. If you post a combined public notice, you must include contact information for the

[10] https://ecology.wa.gov/regulations-permits/SEPA-environmental-review

SEPA Lead Agency as well as Ecology. Alternatively, you may complete the public review process for SEPA process before proceeding with public notice on your permit application.

2.1.5. Preparing a Permit Application

***Key Concept**: Review application requirements before you begin. Ecology will work with applicants, but may reject applications that are substantially incomplete or incorrect. A poor application will delay final approval, may reflect unfavorably on your operations in the view of the public, and your activities may be restricted.*

You can obtain the current version of the Application for Coverage form, from Ecology's biosolids webpages[11].

Identify the Ecology regional biosolids coordinator for your proposal. You can find contact information on the application form or online[12]. Identify your facility's responsible official – the person with authority to sign your application (see 2.1.3), and identify the SEPA Lead Agency and SEPA Responsible Official or SEPA staff you will work with (see 2.1.4).

Ecology will not approve public notice until your application is complete, correct, and prepared in a manner that a reasonably knowledgeable person can understand.

2.1.6. Submitting a Permit Application

***Key concept**: Reduce delays in processing by submitting a complete and correct permit application. Follow instructions provided within the application, and supplemental direction from your regional biosolids coordinator.*

When an application is required, you must submit a complete and correct application, including all associated plans and other documentation. You can find instructions on how to submit an application and required contents in the application form and online[11].

The application process for new facilities (not individual land application sites) is the same as for existing facilities, with the following exceptions and points of emphasis:

- New facilities must apply at least 180 days in advance of beginning operations. You may not submit an application for coverage with the assumption that you can immediately begin work.
- New facilities always require a completed SEPA checklist and threshold determination.
- New facilities require full public notice, including notice of your permit application and SEPA threshold decision, and notice of a public hearing if applicable.

[11] https://ecology.wa.gov/Biosolids-fees-forms-annual-reports
[12] https://ecology.wa.gov/Biosolids

2.1.7. Ecology Review of Applications and Other Documents

***Key Concept**: Your application and all related documentation and correspondence are a matter of public record. The review process ensures that your application is ready for public review. Ecology will not approve public notice if your application is inadequate.*

Ecology will review all documentation submitted as part of the permit application process. We may ask you to clarify or correct your application, or to submit additional information. Ecology may determine that changes and/or supplemental information are necessary to support your proposal. Ecology may add additional or more stringent requirements as a condition of final approval of coverage.

2.1.8. Public Notice Requirements

***Key Concept**: Determine your public notice obligations (including SEPA). Be sure to document all steps you take to inform the public and specific interested parties. Pay special attention to anyone you identify as, or who has notified you asking to be identified as, an "interested party." You are responsible for notice. Ecology can coordinate and assist you.*

All facilities applying for permit coverage for the first time, or proposing a permit modification, must meet the public notice requirements of WAC 173-308-310(13)[7]. There are different reasons and standards for public notice under this permit, including:

- Initial / new facility application.
- Renewing facility coverage and applying non-exceptional quality biosolids or septage to the land.
- Modification of existing coverage, including the addition of a general land application plan or a new land application site.
- Compliance with requirements of the State Environmental Policy Act.
- In response to an enforcement action or administrative order.
- When otherwise required by Ecology.

Do not undertake public notice until you have consulted with your regional biosolids coordinator. Work with both your regional biosolids coordinator and SEPA Responsible Official to determine notice requirements and timing. Applicants are responsible for the cost of publication of notice (in newspapers and other places) associated with obtaining coverage under this permit, and any modifications. This includes the cost of printing and posting signs when required.

2.1.8.1. Interested Parties

You must ensure notification of permit actions, including modifications, to ***all*** interested parties. Someone is an interested party if:

- They have informed you in writing.
- They have commented on your permit application or other public process, and provided their contact information.
- They have attended a public event for your permit, and provided contact information (whether or not they have commented).

Important: Be sure to notify your regional biosolids coordinator if anyone asks you to include them on your interested parties list. Failure to notify interested parties can jeopardize your permit status.

2.1.9. Public Hearings

Key Concept*: Not all applications or proposals require a public hearing. If you think a hearing may be required, discuss that with your regional coordinator early in your application process.*

A permit application or proposal does not require a public hearing *unless* Ecology stipulates. Ecology may require a public hearing if the agency believes there is a significant public interest in your application or proposal. We may make that determination independently, or based on comments we receive during the public notice period. Applicants are responsible for costs of a public hearing.

If you believe Ecology will likely require a public hearing for your project, you can save time and reduce costs by foregoing the initial notice and request for comments (where people might request a hearing), and going directly to notification for the public hearing. If you think this would help with your permit process, discuss how to proceed with your regional biosolids coordinator.

2.1.10. Final Approval of Coverage

Key concept*: A final approval of coverage (including approval of permit modifications) may contain additional or more stringent requirements specifically for your facility. Be sure to review and understand them, in addition to the other requirements of the general permit.*

After the comment period closes, Ecology will evaluate all comments received. Once we complete our review, we will issue a final determination in writing. An approval of coverage may or may not contain additional or more stringent requirements.

Ecology will notify interested parties regarding final approvals, but you must ensure notification to anyone who has advised you that they are an interested party. See 2.1.8 and 2.1.8.1.

2.1.11. Permit modifications.

Significant changes in biosolids management practices, including but not limited to the addition of new land application sites, are permit modifications. Ecology will approve permit modifications per the process in 2.1.3 – 2.1.10 above.

2.1.12. Notice of Intent

***Key Concept**: Submit your notice of intent promptly if you want to preserve coverage into the new permit, and avoid significant additional processes and fees. Be sure you update your contact information, and that the responsible official (see 2.1.3) signs the notice of intent.*

Before this permit expires, Ecology will notify facilities to submit a Notice of Intent to continue coverage. A completed and properly signed Notice of Intent is due to Ecology no later than 180 days before this permit expires. The Notice of Intent represents a facility's commitment to continue coverage under the next general permit. The Notice of Intent preserves coverage under an expired permit until the expired permit is formally canceled or a replacement has been issued. *Failure to submit a Notice of Intent may result in loss of coverage, the need to reapply as a new facility and revisit public notice, and significant additional fees*. You must submit your Notice of Intent on a form and in a manner specified by Ecology. New approvals (e.g. new facilities) and modifications of existing approved coverage (e.g. a new land application site for an existing facility) cannot be granted under the authority of an expired permit.

2.2. Obtaining and Maintaining Coverage

All facilities subject to coverage under the current general permit, except existing Baseline only facilities, must submit a complete permit application within 90 days of issuance of a new or replacement general permit.

Ecology may grant a request for an extension of up to 90 additional days for the submittal of a permit application, after approval of written justification from the facility responsible official. Facilities wishing to request an extension should work through their regional biosolids coordinator.

New facilities must submit a complete permit application 180 days in advance of beginning operations.

2.3. Maintaining Contact Information

All facilities must notify regional coordinators of any changes to contact information. This includes providing *and* updating as necessary the name, title, physical address, mailing address, and a valid, *actively monitored* email address for the following contacts.

- *Responsible Official*: The person who has full responsibility and legal signatory authority for all permit actions. Refer to 2.1.3 of this permit for an explanation of the Responsible Official.
- *Primary Contact*: The person who will normally serve as the first line of communication for routine permit and operational inquiries.
- *Billing Contact*: The person who will receive all invoices and assure timely payment of fees.

2.3.1. Identifying the Responsible Official

All permittees must identify a responsible official. *The responsible official may serve as the primary contact and/or billing contact*. The responsible official is typically not the operator (see 2.1.3). All facilities must notify Ecology within 30 days of any change in information for the contacts above.

2.3.2. Email List Membership Required

All facilities must provide and maintain at least one point of contact on the Ecology-Biosolids email list maintained by Ecology. This email list is the mechanism of general communication on technical and permit related issues. Permittees must monitor email list communications and respond if required. You can subscribe or manage your subscription here[13].

2.4. Requirements for Transporting Sewage Sludge or Biosolids

Transportation of biosolids must be consistent with an Ecology-approved spill response plan.

All generators are responsible for ensuring the safe and properly documented transportation of biosolids they generate, from the time of generation through the time of final use or disposal. This does not apply to septic pumping trucks that are not required to obtain coverage under this permit, including those that deliver septage to septage management facilities, because they are not identified as generators.

Any facility subject to this permit is responsible for the performance of any contractor or subcontractor they retain for the transportation of biosolids. Transporters must comply with Title 81 RCW and rules adopted thereunder, as applicable.

[13] https://public.govdelivery.com/accounts/WAECY/subscriber/new?topic_id=WAECY_47

Non-exceptional quality biosolids may be transported only to another facility for further treatment, an approved land application site, an approved storage site, or an approved disposal facility.

2.4.1. Transporting non-exceptional quality biosolids out of the jurisdiction of the State of Washington

Generators must have approval from Ecology and the receiving regulatory authority before transporting non-exceptional quality biosolids out of the jurisdiction of the State of Washington

2.4.2. Accepting Biosolids from Federal, Tribal, or Out of State Facilities

Treatment works must have written approval from Ecology before accepting biosolids from a federal, tribal, or out of state facility.

This provision is not meant to impact pumping trucks servicing onsite wastewater systems, and delivering septage to facilities within state jurisdiction. This provision is meant to identify out of jurisdiction facilities that participate in the state program and ensure that they are treated the same as those within state jurisdiction.

Treatment works subject to this permit, may not accept biosolids for further treatment or disposal unless the generating treatment works complies with the following requirements.

Generating facilities must:

- Comply with the requirements of WAC 173-308-130[3] and WAC 173-308-320[14].
- Have and comply with an Ecology approved spill response plan.
- Ensure that a copy of the spill response plan is available to drivers, and in the event of a spill, ensure that drivers understand what to do.
- Ensure that an accurate record of all loads is kept and available for inspection, including the source of biosolids, the destination of biosolids, the amount transported, how that was determined (scale ticket, calculation based on solids content), and the date of transportation and delivery.
- Ensure that the generating and receiving facilities receive a copy of the record of biosolids transported.

2.5. Surface Impoundments and Tanks Used for Storage and Treatment

All facilities must store and treat biosolids consistent with approved plans, and in a manner that is not likely to result in harm to human health or the environment. Facilities storing biosolids for more than two years must have a documented commitment to beneficial use on file with Ecology.

[14] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308&full=true#173-308-320

2.5.1. Surface Impoundments Used for Storage or Treatment

Surface impoundments must be designed and operated in accordance with the standards of Chapter 173-350 WAC – *Solid Waste Handling Standards*[15], unless they are operating in compliance with a current state, or federal water pollution control permit, or another environmental permit.

The following requirements do not apply to surface impoundments at septage management facilities and facilities that mix primarily septage with smaller amounts of biosolids (mixing facilities) unless specified as an additional or more stringent requirement as part of the permit approval process.

Facilities that operate surface impoundments must annually report:

- The estimated remaining capacity for biosolids accumulation to the nearest half foot.
  - Capacity must not include any portion of freeboard required to preserve the structural integrity of the surface impoundment or to prevent it from overtopping.
- The estimated year when solids removal will be required to stay within capacity or prevent violations of discharge limits
- Begin planning and notify Ecology at least one year in advance of solids removal. *Ecology encourages a planning horizon of two years to ensure availability of alternatives and reduce project costs.*
- Analyze for the pollutants in WAC 173-308-160 Table 1[16], within 24 months of the date this permit is issued, unless biosolids were analyzed on or after September 1, 2019.
  - Notify the regional biosolids coordinator if the concentration of any pollutant is above 90% of the value in WAC 173-308-160 Table 3 or the Table 1 value for Molybdenum.

2.5.2. Tanks Used for Storage or Treatment

This section does not apply to wastewater treatment plants operating under an NPDES or State Waste Discharge Permit.

Facilities storing biosolids in tanks must:

- Do so in a manner that would not be likely to result in the contamination of groundwater, surface water, air, or land under current conditions or in the case of fire or flood.
- Protect tanks from damage by placement of bollards or other devices.
- Maintain tanks to avoid leakage and catastrophic failure.
- Submit and follow an inspection and maintenance schedule consistent with requirements for the type of tank in service.

[15] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-330
[16] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-160

2.6. Requirements for Disposal in a Municipal Solid Waste Landfill or Incinerator

Disposal includes landfill disposal and incineration. Per statute, the State of Washington recognizes biosolids as a valuable and beneficial commodity. Ecology will not approve permit applications for disposal or incineration of biosolids except as described in this section.

Any treatment works transferring biosolids to another facility for the purpose of disposal must have written approval from Ecology, and meet the criteria for disposal on an *emergency*, *temporary* or *long-term* basis as specified in 2.6.3 below.

2.6.1. Incineration

This permit authorizes the wastewater treatment plants with existing incinerators listed below, to continue incinerating sewage sludge (in keeping with the definitions in Chapter 173-308[2], descriptions in 40 CFR Part 503[8], and 40 CFR Part 62, Subpart LLL[17]) or biosolids they generate, and to accept sewage sludge or biosolids for incineration from other facilities when they meet applicable requirements of 2.6.3:

- Anacortes WWTP
- Bellingham Post Point WWTP
- Edmonds WWTP
- Lynnwood WWTP
- Vancouver Westside WWTF

2.6.2. Landfill Disposal

Facilities disposing in a landfill must meet the applicable requirements in 2.6.3 below, comply with the landfill disposal requirements in WAC 173-308-300[18], and provide Ecology with written approval from the local health jurisdiction where the biosolids will be disposed.

2.6.3. Terms of Disposal

2.6.3.1. Justification for Disposal on an Emergency Basis

This permit approves the disposal of biosolids for all facilities for up to one year when disposal meets the definition of *disposal on an emergency basis* in WAC 173-308-080[9].

Any facility undertaking emergency disposal must notify Ecology in writing, including a summary of the conditions warranting disposal.

[17] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-62/subpart-LLL?toc=1
[18] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-300

2.6.3.2. Justification for Disposal on a Temporary Basis

Ecology may approve disposal for up to five years when a facility meets the conditions for *disposal on a temporary basis* in WAC 173-308-080[9].

2.6.3.3. Justification for Disposal on a Long-term Basis

Ecology may approve disposal as a preferred method of management for five years or longer when a facility meets the conditions for *disposal on a long-term basis* in WAC 173-308-080[9].

2.7. Requirements for Transferring Biosolids to Another Person or Facility

Transferring means changing the possession of biosolids. Biosolids may be transferred from one facility to another, including to an individual person, only as follows:

2.7.1. Transfer of Exceptional Quality Biosolids for Unrestricted Use

When biosolids are transferred to another person for unrestricted use:

- The biosolids must meet criteria to be classified as exceptional quality.
- The requirements in WAC 173-308-260[19], including providing a label or information sheet must be met.

2.7.2. Transfer of Non-Exceptional Quality Biosolids:

Non-exceptional quality biosolids may be transferred only to a properly permitted facility provided that:

- There are no specific conditions of coverage for either the sending or receiving facility prohibiting the transfer of biosolids.
- Both the sending and receiving facility exchange information needed to comply with this permit and Chapter 173-308-WAC[2]. This includes, but is not limited to, information on biosolids quality and the permit status of each facility.

[19] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-260

2.9. Duty to Comply

You must comply with all conditions of this permit, all applicable requirements of Chapter 173-308 WAC[2], and all applicable requirements of other laws and rules for which the Department of Ecology has responsibility, including but not limited to:

- Title 90 RCW[20] – Water Rights – Environment
- Title 70A RCW[1] – Environmental Health and Safety
- Chapter 43.21C RCW[23] – State Environmental Policy and the State Environmental Policy Act (SEPA) rules adopted under chapter 197-11 WAC or applicable local ordinances.

You must abide by all commitments in your permit application, including those in any plans and other operating documents unless modified through the permit review and final approval of coverage process.

You may not use any provision of your application or any associated plans or other documents to justify noncompliance with any provisions of Chapter 173-308 WAC[2] or the conditions of this general permit.

You must comply with any additional or more stringent requirements developed as a condition of final coverage under this permit.

2.10. Permit Modification, Revocation and Reissuance, and Termination

Ecology may modify, revoke and reissue, or terminate coverage under this permit for cause. Permit conditions remain in effect until Ecology acts, even if you file a request to modify, revoke and reissue, or terminate coverage under this permit, or notify Ecology of planned changes or anticipated noncompliance.

Ecology may modify or revoke and reissue your coverage under this permit in accordance with WAC 173-308-310(23)[7]. Ecology may terminate your coverage under this permit in accordance with WAC 173-308-310(24)[7].

2.11. Continuing Coverage and Duty to Reapply

If you wish to continue an activity regulated by this permit after its expiration date, you must submit a Notice of Intent at least 180 days in advance of its expiration date and subsequently apply for coverage under a new permit in accordance with WAC 173-308-310. Failure to comply with these requirements can result in loss of permit coverage.

[20] https://apps.leg.wa.gov/rcw/default.aspx?Cite=90

2.12. Need to Halt or Reduce Activity Not a Defense

It is not a defense for a permit holder in an enforcement action to argue that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of this permit.

2.13. Duty to Mitigate

You must take all reasonable steps to minimize or prevent biosolids use or disposal that may adversely affect human health or the environment. This includes, but is not limited to, the proper operation and maintenance of equipment, adequate laboratory controls, and appropriate quality assurance procedures.

2.14. Duty to Provide Information to Ecology

You must furnish to Ecology on request, any records required by Chapter 173-308 WAC[2], or as a condition of approval under this permit.

You must furnish any information requested by Ecology to determine compliance with this permit, or to determine whether cause exists for modifying, revoking and reissuing, or terminating coverage.

2.15. Inspection and Entry

Upon presentation of credentials and other documents as may be required by law, you must allow Ecology or an authorized representative of Ecology, to:

- Enter the premises where a regulated facility or activity is located or conducted, or where related records are kept.
- Have access to and copy, during reasonable times, any records required under this permit.
- Inspect during reasonable times any facilities, equipment (including monitoring and control equipment), practices, or operations regulated or required under this permit.
- Sample or monitor during reasonable times, to assure permit compliance or as otherwise authorized by state law, Chapter 70A.226 RCW[1], and the Clean Water Act, any substances, parameters, or practices at any location.

2.16. Monitoring and Records

You must monitor and report monitoring results annually as required in 2.17 of this permit, and in accordance with your NPDES permit or State Waste Discharge Permit, if applicable.

You must retain all records and data used to complete your application for coverage under this permit:

- For a period of at least 5 years from the date of the application, and
- Until a new application has been submitted and permit coverage is approved, or
- Longer if required by other applicable laws or regulations.

You must retain all records related to annual report submittals for five years after the due date of the respective annual report.

2.17. Signatory Requirements

The responsible official must sign the application for coverage, and all subsequent proposals to modify coverage. See 2.1.3.

2.18. Reporting and Notification

Some facilities have a separate obligation to report to U.S. EPA in accordance with 40 CFR part 503[8]. This permit does not address federal reporting requirements.

You must report to or notify Ecology as follows.

2.18.1. Annual Reports

You must submit an annual report for the previous calendar year, in the format and using the means specified by Ecology by March 1, of each year.

2.18.2. Planned Changes

You must notify your regional biosolids coordinator and any applicable delegated local health jurisdiction, in advance of significant changes in your biosolids management practices, including planned physical alterations or additions to your facility. Significant changes are permit modifications and require agency approval.

2.18.3. Requirement to Self-Report Noncompliance

You must report any noncompliance to Ecology within 24 hours of becoming aware. Unless waived in writing by Ecology, you must submit a written explanation of the noncompliance within 5 days. Each written explanation must include:

- A description of the noncompliance.
- The cause of the noncompliance.
- The period of noncompliance, including exact dates and times, and, if the noncompliance has not been corrected, the anticipated time it is expected to continue.
- Steps taken or planned to reduce, eliminate, and prevent reoccurrence of the noncompliance.

2.18.4. Reporting in Event of a Spill

You must report any spill to the Ecology regional office immediately, to the regional biosolids coordinator within 24 hours, and as otherwise specified in your approved spill prevention and response plan.

2.18.5. Other Information

If you become aware that you failed to submit any relevant facts, or you submitted incorrect information in a permit application or a report, you must immediately notify your regional biosolids coordinator, and follow with a written explanation.

2.18.6. Transferring Permit Coverage

Coverage under this permit is transferable only as provided in WAC 173-308-310(22)[7].

Any facility wishing to transfer permit coverage must file a complete notice of transfer with Ecology, no later than thirty days before the proposed date of transfer.

The new permit holder is responsible for any unpaid fees or penalties, on the date of the transfer.

2.19. Penalties

If you willfully violate any provisions of this permit or any provisions of chapter 70A.226 RCW[1] or any order issued pursuant to chapter 70A.226 RCW, without sufficient cause, you are guilty of a gross misdemeanor. Willful violation of this chapter, or a permit or order issued pursuant to this chapter is punishable by a fine of up to ten thousand dollars and costs of prosecution, or by imprisonment for up to three hundred sixty-four days, or by both. Each day of violation may be deemed a separate violation.

In addition to any other penalty provided by law, if you violate any provisions of Chapter 70A.226 RCW or rules or orders adopted or issued pursuant to it, you are subject to a penalty of

up to five thousand dollars a day for each violation. Each violation is a separate violation. In the case of a continuing violation, each day of violation is a separate violation. An act of commission or omission that procures, aids, or abets in the violation is also considered a violation under this section.

2.20. Obtaining and Providing Information

Whenever you transfer biosolids to another person or facility, you must provide notice and necessary information for the receiving person or facility to comply with the requirements of this permit and Chapter 173-308 WAC[2].

2.21. Final Coverage: Additional or More Stringent Requirements

On a case-by-case basis, Ecology may impose requirements that are in addition to or more stringent than the requirements in this permit.

All additional or more stringent requirements become a part of the permit and are fully enforceable. You may appeal any additional or more stringent requirements only as described in 2.24 of this permit.

2.22. Compliance Schedules

A schedule with tasks and milestones leading to compliance with the requirements of this permit and Chapter 173-308 WAC[2] may be established by mutual agreement. A compliance schedule may not extend deadlines established under the Clean Water Act or Chapter 70A.226 RCW[1]. Compliance schedules must be established in accordance with the requirements of WAC-173-308-310(16)[7].

2.23. Permit Fees and Penalties Due

You must pay permit fees annually, within forty-five days of receiving the invoice. Fees are determined and issued in accordance with WAC 173-308-320[21]. Failure to pay permit fees can result in revocation of your permit.

You must pay penalties as specified in an accompanying administrative order or other legal documents.

When coverage under this permit is transferred, the new permit holder is responsible for any unpaid fees or penalties, on the date of the transfer.

[21] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-320

2.24. Recordkeeping Requirements

You must keep records and certification statements in accordance with 2.15 of this permit and WAC 173-308-290[22].

2.25. Appeals

Any aggrieved person may appeal this permit as provided by applicable law including, but not limited to, Chapter 43.21B RCW[23] and Chapter 34.05 RCW[24]. You must file your appeal within 30 days of the issuance date listed on the cover page.

[22] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-290
[23] https://app.leg.wa.gov/rcw/default.aspx?cite=43.21B
[24] https://app.leg.wa.gov/rcw/default.aspx?cite=34.05

3. Active Septage Management

This section applies to all Active Septage Management Facilities, in addition to the Baseline section.

This section does not apply to:

- Facilities that treat and manage septage as *biosolids originating from sewage sludge* (i.e. to meet pollutant limits, Class A or B pathogen reduction, and vector attraction reduction), including but not limited to POTWs and compost facilities that accept septage for treatment (applicable under section (4)).
- Facilities that mix septage with biosolids derived from sewage sludge (see section (4)) including compost facilities that accept both.

If you apply both septage and biosolids from wastewater treatment plants to the land, but manage them separately, you are subject to the requirements of this section and section (4).

3.1. Obtaining and Maintaining Coverage

You must apply for coverage, obtain coverage, and maintain coverage under this permit. Refer to Section (2) for details on the permit process.

3.2. Public Notice Required

Facilities must obtain approval from Ecology before issuing public notice of permit actions.

Notices required to be published or posted under this permit must meet Ecology standards as to content, overall dimension, font size, and placement.

3.2.1. Who Must Provide Public Notice

You must comply with public notice requirements in WAC 173-308-310(13)[7] if you have an active septage management program *or* you propose or are required to modify the terms of your coverage under this permit, and when otherwise required by Ecology. Modifications include but are not limited to the addition of new land application plans and significant changes to existing management practices. You do not have to conduct public notice if:

- You only rely on a BUF for land application of septage, or you only transfer non-exceptional quality biosolids to another facility for further treatment.

3.2.2. State Environmental Policy Act

You must comply with applicable SEPA requirements. Applicants may combine the public notice required under SEPA with notice required for the biosolids program in WAC 173-308-310[7], with the approval of the SEPA Responsible Official. See 2.14 and 2.18.

When conducting separate notice under the State Environmental Policy Act, approval for compliance with SEPA rests with the SEPA Lead Agency.

3.2.3. Identification and Notice to Interested Parties

All facilities must maintain a list of interested parties during the life of the permit and must maintain a record of attempts to notify each interested party on the list, whenever public notification is required, including when notification is undeliverable to the interested party. If notice is returned as undeliverable, and all methods to reach the interested party are exhausted, they may be removed from the facility's interested party list. The facility must provide documentation of the notice attempts and failed delivery(s) to Ecology prior to removing the individual from the interested parties list. Ecology may assist with interested party notification, but it is the permit holder's responsibility to ensure notification to interested parties.

All facilities must provide their interested parties list to Ecology on request.

A person is an interested party, if:

- They request a facility to place them on their interested parties list.
- They attend a public meeting or hearing offered by Ecology's state biosolids program and provide an email or physical mailing address. *Persons do not have to comment or testify during a meeting or hearing in order to be interested parties. Persons who attend without signing in, or who do not provide contact information, do not qualify as interested parties.*
- They notify Ecology of their interest in a specific facility. Ecology will share this information with the facility.

If an interested party provides both an email and physical mailing address, the facility must notify using both addresses, or confirm receipt of notification by one.

For the purposes of notifying organizations that may be interested, notification to the president (or other officers if specified by the organization) constitutes notice to all members of the organization, *except* where members have made individual requests for separate notification.

3.3. Removing Manufactured Inerts

Prior to land application, septage must meet the requirements for removal of manufactured inerts in WAC 173-308-205[25].

Materials removed by screening are solid waste and materials must be contained on site in a manner that does not present a threat to human health or the environment, consistent with

[25] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-205

the requirements of WAC 173-350-040 [26], until lawfully disposed of in the municipal solid waste handling system.

3.4. Requirements for Sampling, Analysis, and Process Monitoring

This section contains the *minimum* requirements for sampling and analysis of septage and soils when you prepare septage for beneficial use.

3.4.1. Representative Sampling

You must collect samples that are representative of the septage or soils you are characterizing. Samples must represent the quality of septage at the time it is transferred, used, or disposed.

You must collect samples at times and locations that will capture septage representative of the stage of treatment.

You must collect a sufficient number of samples to meet requirements for characterization of pathogen reduction, vector attraction reduction, nitrogen, and any other required macro or micronutrients.

3.4.2. Sampling and Analysis Plans

You must submit a sampling and analysis plan for all septage and soil sampling activities.

Soil sampling and analysis plans must conform to cooperative extension guidelines or generally accepted guidance, or be prepared by a soil scientist, agronomist, crop adviser, or other certified or licensed professional. A list of approved analysis methods is maintained on Ecology's webpage. Making it available outside the permit document allows for more efficient maintenance, as analytical methods change, or are updated from time to time.

[26] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-040

At a minimum, plans must address:

- When you will collect samples, including calendar timing and with respect to treatment processes as appropriate.
- Where you will collect samples (i.e. the physical point in the process, or location).
- The number of samples you will collect for each analyte, and how you will determine the location for sample collection.
- How you will collect samples including a description of the supplies and equipment needed, and onsite manipulation such as compositing or subsampling.
- How you will handle and care for samples from the time of collection to the time of analysis or delivery to an accredited laboratory for analysis, including sample preservation, chain of custody, and compliance with holding time requirements.

Except for onsite sampling of pH adjustment, all samples, including soil samples and surface or groundwater samples, must be analyzed by a lab properly accredited in the appropriate matrix, if accreditation is available

You may identify a lab appropriate for your needs by searching Ecology's web[27].

3.4.3. Frequency of Process Monitoring

You must monitor pH adjustment as applicable in 3.6.7

3.4.4. Frequency of Septage Analysis

You must monitor pH adjustment as applicable in 3.6.7

3.4.5. Point of Compliance

The point of compliance for a sample is the date on which the sample is taken, not the date on which results are subsequently reported. It is a violation of this permit to use or distribute biosolids that fail to meet applicable standards.

3.4.6. Analytical Methods and Holding Times

You must use approved analytical methods, and conform to sample preservation and holding time requirements for each analyte in accordance with the specifications of the analytical method used.

The appropriate methods specified in 40 CFR 503.8, 40 CFR 136, and WAC 173-308 are approved unless otherwise specified in an Ecology final sampling and analysis plan or final approval of coverage.

[27] https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Laboratory-Accreditation/How-to-choose-an-analytical-laboratory

3.5. Sites Where Septage Cannot be Applied

Application of septage to *public contact sites*, lawns, and home gardens is prohibited.

3.6. Requirements When Septage is Applied to the Land

This section contains the requirements for the land application of septage. It does not apply to *septage managed as biosolids originating from sewage sludge*.

3.6.1. Site Specific Land Application Plans

You must submit a site specific land application plan (SSLAP) meeting the content requirements in Appendix B, for every site where septage will be applied to the land. You are **not** required to submit a SSLAP for septage sent to a BUF, if the conditions in WAC 173-308-310(8)(g)[7] have been met.

3.6.2. General Land Application Plans

Submit a General Land Application Plan (GLAP) meeting the content requirements of Appendix A if you intend to develop other land application sites during the life of your permit coverage.

3.6.3. Soil Testing Required

You must test all new land application sites for the pollutants in Table 1 of WAC 173-308-160[16], including nitrate and other nutrients if specified.

Testing of soils for pollutants and nutrients must be consistent with an approved sampling and analysis plan.

3.6.4. Application Rates

You must apply septage to the land at a rate not exceeding the rate determined by equation 1.

Equation 1 – Annual Application Rate for Septage

AAR = N ÷ 0.0026

AAR = maximum annual application rate in gallons per acre per 365-day period

N = amount of nitrogen in pounds per acre per 365-day period needed by the crop or vegetation grown on the land (subtract any nitrogen supplied by other sources—for example, commercial fertilizers or manures)

Equation 2 – Calculating Drive Length of Spreader per Load

Drive length (in feet) = gallons in spreader / spread width (in feet) x 43,560 / AAR *or*

Drive length (in feet) = gallons in spreader/ (AAR / 43,560) / spread width

AAR = annual application rate in gallons per acre per 365-day period determined by Equation 1

3.6.5. Pollutants

EPA developed the application rate formula in Equation 1 with consideration of acceptable pollutant loading. Testing for pollutants in WAC 173-308-160 is not required for septage applied to land unless it is managed as biosolids originating from a treatment works (refer to Section 4).

3.6.6. Pathogen and Vector Attraction Reduction

The requirements for pathogen and vector attraction reduction for septage are based on the percent by volume of septage from households, and whether or not septage will be injected or tilled into the soil. You must keep records for each load or batch of septage you apply to the land. You must be able to show compliance with 3.6.7 and 3.6.7.1 below.

3.6.7. Septage must be treated or applied to the land as follows:

Except as allowed in 3.6.7.1:

- You must raise the pH of the septage by the addition of alkali, to at least 12 for a minimum of thirty minutes.
- You must conduct at least two pH tests for each load of septage applied to the land.

  The first test must occur *after* the addition of lime or alkali, and show that a pH of at least 12 has been attained.

  The second test must occur at least 30 minutes after the first test to show that a pH of at least 12 has been retained.

  If the pH is less than 12 when the second test is conducted, the process must be restarted.

- Sampling must be representative of the septage that is applied to the land.
- You must keep records of each sampling event including the date, time, and result for each sample.

3.6.7.2. Alternative to pH adjustment for septage 75% or more by volume from household septic tanks

When a load or batch of septage is 75% or more by volume from household septic tanks, as an alternative to pH adjustment, you may:

- Inject the septage below the surface of the land so that no significant amount of the septage is on the surface within 1 hour after injection, or
- Incorporate the septage into the soil within 6 hours after application.

3.7. Landowner Consent

You must obtain written consent of all landowners prior to applying non-exceptional quality biosolids to the land for the first time on any parcel. The landowner must consent to allow access for Ecology inspections, and agree to comply with requirements for site management and access in Chapter 173-308 WAC[2].

3.8. Site Management and Public Access Restrictions

The site management and public access restrictions in this subsection apply when septage is applied to the land.

3.8.1. Crop Harvest Waiting Periods

The time between the last application of septage and crop harvesting must adhere to the waiting periods in Table S1.

Table S1: Crop Harvesting Restrictions for Septage

Crop Type	Examples	Does the harvested part of plant contact septage?	Length of time the septage remains on soil surface prior to incorporation in the soil	Waiting period until harvest is allowed
Above ground food crops	Cherries, wheat	No	Not applicable	30 days
Above ground food crops	Lettuce, cucumbers, strawberries	Yes	Not applicable	14 months
Root food crops	Onions, potatoes	Yes	≥4 months	20 months
Root food crops	Onions, potatoes	Yes	<4 months	38 months
Feed crops	Rangeland, pasture, hay, feed corn.	Not applicable	Not applicable	30 days
Fiber crops	Trees, cotton	Not applicable	Not applicable	30 days

3.8.2. Public Access Restrictions

Public access must be restricted following the application of septage. You must post and maintain signs limiting access to the site during the time when site access is restricted, in accordance with the requirements in Table S2.

Table S2: Site Posting Requirements for Septage Application Sites

Where	Notice Content	How Long
All significant points of access to the site. Every ½ mile (805 meters) around the perimeter of the site.	The name and address or phone number of the generator and, if different, the person who applies. The names, addresses, and phone numbers of the regulatory and permitting authorities. The material that is being applied. Notice that access is restricted and, if desired, the date after which access is no longer restricted. If applicable, a notice on limitations regarding the harvesting of edible plants from the site.	Sites with a high potential for public exposure: 1 year Sites with a low potential for public exposure" 30 days

3.8.3. Buffers

You must meet the additional site management restrictions in Table S3 below when septage is applied to the land. For information on interpreting buffers, please refer to Ecology's Biosolids Management Guidelines, WDOE 93-80[41].

Table S3: Additional Site Management Restrictions for Septage

Feature	Restriction
Surface waters	No application within 100 feet (30.5 meters)*
Wells	No application within 100 feet (30.5 meters)*
Wetlands	No application allowed*
Public contact sites, lawns, or gardens	No application allowed
Flooded, frozen, or snow-covered sites	No application allowed

*** Unless otherwise approved by Ecology**

4. Permit Section: Active Biosolids Management

Facilities covered in this section have active biosolids management programs. You have an active biosolids management program, if you are:

- Treating sewage sludge and/or septage to produce biosolids.
- Treating sewage sludge and/or septage to produce biosolids, and directly applying biosolids to the land, or have a legal arrangement to have your biosolids applied to the land where you remain directly responsible for all compliance aspects.
- Sending your biosolids to a BUF that applies them to the land under a separate permit (this does not relieve you of responsibility for proper management of your biosolids).
- Applying biosolids to the land as a permitted BUF.
- Producing exceptional quality biosolids to sell or give away. This includes wastewater treatment plants, composters, and other treatment facilities.

If you also apply septage to the land, you are subject to the requirements in section (3) of this permit.

If you only transfer your biosolids to another facility for further treatment, or you operate a surface impoundment and do not plan to remove solids during the life of this permit, you are subject *only* to section (2) of this permit.

4.1. Obtaining and Maintaining Coverage

You must apply for coverage, obtain coverage, and maintain coverage under this permit. Refer to section (2) for details on the permit process.

4.2. Public Notice Required

Facilities must obtain approval from Ecology prior to issuing public notice of permit actions.

Notices required to be published or posted under this permit, must meet Ecology standards as to content, overall dimension, font size, and placement.

4.2.1. Who Must Provide Public Notice

You must conduct public notice according to WAC 173-308-310(13)[77] if you have an active biosolids management program and you land apply non-exceptional quality biosolids, or you propose or are required to modify the terms of your coverage under this permit, or you are a new facility beginning operations, and when otherwise required by Ecology. Modifications include but are not limited to the addition of new land application plans and significant changes to existing management practices. You do not have to conduct public notice if:

- You have been permitted to produce exceptional quality biosolids unless you rely on your own land application site for biosolids that do not meet exceptional quality standards.
- You rely on a BUF for land application of non-exceptional quality biosolids you produce, or you transfer non-exceptional quality biosolids to another facility for further treatment.

Please note this list does not excuse new active biosolids management facilities from conducting initial public notice to gain coverage under the general permit.

4.2.2. State Environmental Policy Act

You must comply with applicable SEPA requirements. Applicants may combine the public notice required under SEPA with notice required for the biosolids program in WAC 173-308-310[7], with the approval of the SEPA Responsible Official. See 2.14 and 2.18.

When conducting separate notice under the State Environmental Policy Act, approval for the purpose of compliance with SEPA rests with SEPA Lead Agency.

4.2.3. Identification and Notice to Interested Parties

All facilities must maintain a list of interested parties during the life of the permit, and must maintain a record of attempts to notify each interested party on the list, whenever public notification is required, including when notification is undeliverable to the interested party. Should notice return to the facility as undeliverable via mail, email, or some other means, and all methods to reach the interested party are exhausted, the facility must document the attempts and the interested party in question may be removed from the facility's interested party list. Ecology may assist with interested party notification, but it is the permit holder's responsibility to ensure notification to interested parties.

All facilities must provide their interested parties list to Ecology on request.

A person is an interested party, if:

- They request a facility to place them on their interested parties list.
- They attend a public meeting or hearing offered by Ecology's state biosolids program and provide an email or physical mailing address. *Persons do not have to comment or testify during a meeting or hearing in order to be interested parties. Persons who attend without signing in, or who do not provide contact information, do not qualify as interested parties.*
- They notify Ecology of their interest in a specific facility. Ecology will share this information with the facility.

If an interested party provides both an email and physical mailing address, the facility must notify using both addresses, or confirm receipt of notification by one.

For the purposes of notifying organizations that may be interested, notification to the president (or other officer if specified by the organization) constitutes notice to all members of the organization, *except* where members have made individual requests for separate notification.

4.3. Removing Manufactured Inerts

Prior to land application, biosolids must meet the requirements for removal of manufactured inerts in WAC 173-308-205[28].

Materials removed by screening are solid waste and must be contained on site in a manner that does not present a threat to human health or the environment, consistent with the requirements of WAC 173-350-040[29] until lawfully disposed of in the municipal solid waste handling system.

4.4. Requirements for Sampling, Analysis, and Process Monitoring

This section contains the *minimum* requirements for sampling and analysis of biosolids and soils, and process monitoring that are applicable when you prepare biosolids for beneficial use.

4.4.1. Representative Sampling

You must collect samples that are representative of the biosolids or soils you are characterizing. Samples must represent the quality of biosolids at the time they are transferred, used, disposed, sold, or given away.

You must collect samples at times and locations that will capture biosolids representative of the stage of treatment.

You must collect a sufficient number of samples to meet requirements for characterization of pathogen reduction, vector attraction reduction, pollutant limits, nitrogen, and any other required macro or micronutrients.

4.4.2. Sampling and Analysis Plans

You must submit a sampling and analysis plan for all biosolids and soil sampling activities.

Soil sampling and analysis plans must conform to cooperative extension guidelines or generally accepted guidance, or be prepared by a soil scientist, agronomist, crop adviser, or other certified or licensed professional. A list of approved analysis methods is maintained on

[28] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-205
[29] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-040

Ecology's webpage. Making it available outside the permit document allows for more efficient maintenance, as analytical methods change, or are updated from time to time.

At a minimum, plans must address:

- When you will collect samples, including calendar timing and with respect to treatment processes as appropriate.
- Where you will collect samples (i.e. the physical point in the process, or location).
- The number of samples you will collect for each analyte, and how you will determine the location for sample collection.
- How you will collect samples including a description of the supplies and equipment needed, and onsite manipulation such as compositing or subsampling.
- How you will handle and care for samples from the time of collection to the time of analysis or delivery to an accredited laboratory for analysis, including sample preservation, chain of custody, and compliance with holding time requirements.

All samples, including soil samples and surface or groundwater samples, must be analyzed by a lab properly accredited by Ecology if accreditation is available. Note that accreditation must be specified for the appropriate matrix – solid and chemical materials for biosolids, drinking water for drinking water, and nonpotable water for influent or effluent.

You may identify a lab appropriate for your needs by searching Ecology's web[30].

4.4.3. Frequency of Process Monitoring

You must monitor the pathogen reduction processes (WAC 173-308-170[31]) and vector attraction reduction processes (WAC 173-308-180[32]), at a frequency and duration that will ensure the process and biosolids meet applicable requirements.

4.4.4. Frequency of Biosolids Analysis

At a minimum, you must analyze your biosolids at the frequency listed in Table B1 below.

The dry weight tonnage of biosolids applied to the land or prepared for sale/give away per 365-day period determines the minimum frequency of biosolids analysis (Table B1 below).

For facilities that compost or mix Class B quality biosolids with other materials, the frequency of analysis is based on the dry weight tonnage of the total amount of material, not just the biosolids.

[30] https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Laboratory-Accreditation/How-to-choose-an-analytical-laboratory
[31] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-170
[32] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-180

For facilities with surface impoundments preparing to remove solids, frequency of sampling is converted to a number of samples based on the amount of solids that will be removed.

For facilities with surface impoundments characterizing biosolids under section 2.5.1, the number of samples is determined based on the estimated quantity of solids in the impoundment at the time of sampling, or as otherwise approved by Ecology.

Table B1 applies to the pollutants in WAC 173-308-160[33], the pathogen density requirements in WAC 173-308-170[34], the vector attraction reduction standards in WAC 173-308-180[35], and the nitrogen concentrations and percent solids data needed to support agronomic rate determinations. It does not apply to process monitoring

Table B1: Minimum Frequency of Biosolids Analysis (adapted from WAC 173-308-150[36])

Dry Metric tons per Year	Frequency*
>0 <290 (>0 <320 U.S. tons)	once per year (1X per year)
290 - 1,500 (320 - 1,653 U.S. tons)	once per quarter (4X per year)
1,500 - 15,000 (1,653 - 16,535 U.S. tons)	once per 60 days (6X per year)
>15,000 (>16,535 U.S. tons)	once per month (12X per year)

*** after 2 years of analyzing at this frequency, analysis for the pollutant concentrations may be reduced with approval of Ecology, but it must not be less than once per year. The frequency of sampling for compliance with pathogen and vector attraction reduction cannot be reduced.**

4.4.5.Point of Compliance

The point of compliance for a sample is the date on which the sample is taken, not the date on which results are subsequently reported. It is a violation of this permit to use or distribute biosolids that fail to meet applicable standards.

4.4.6.Analytical Methods and Holding Times

You must use approved analytical methods, and conform to sample preservation and holding time requirements for each analyte in accordance with the specifications of the analytical method used.

The appropriate methods specified in 40 CFR 503.8[8], 40 CFR 136[37], and WAC 173-308[2] are approved unless otherwise specified in an Ecology final sampling and analysis plan or final approval of coverage.

[33] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-160
[34] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-170
[35] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-180
[36] http://app.leg.wa.gov/WAC/default.aspx?cite=173-308-150
[37] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-D/part-136?toc=1

4.5. Requirements for Non-Exceptional Quality Biosolids to the Applied the Land

These requirements apply to non-exceptional quality biosolids that are applied to:

- Agricultural Land,
- Forest Land,
- Public Contact Sites, or
- Land Reclamation Sites

Non-exceptional quality biosolids are not commercial fertilizers unless properly registered. Generators cannot make, nor can users rely on, any guarantee of nutrient value.

4.5.1. Site Specific Land Application Plans

You must submit a site specific land application plan (SSLAP) meeting the content requirements in Appendix B, for every site where non-exceptional quality biosolids will be applied to the land. You are not required to submit a SSLAP for biosolids sent to a BUF, if the conditions in WAC 173-308-310(8)(g)[7] have been met.

You are not required to submit a SSLAP for the management of exceptional quality biosolids unless Ecology requires a plan in accordance with WAC 173-308-310(8)(a)(ii) or (iii).[7]

A generator is not required to submit a SSLAP if they send non-exceptional quality biosolids to a BUF, and the conditions in WAC 173-308-310(8)(g)[7] have been met.

4.5.2. General Land Application Plans

Submit a General Land Application Plan (GLAP) meeting the content requirements of Appendix A if you intend to develop other land application sites during the life of your permit coverage.

4.5.3. Soil Testing Required

You must test all new land application sites for the pollutants in Table 1 of WAC 173-308-160[33], including nitrate and other nutrients if specified.

Testing of soils for pollutants and nutrients must be consistent with an approved sampling and analysis plan.

4.5.4. Agronomic Rate

Biosolids must be applied at an agronomic rate in accordance with WAC 173-308-190[38], except as allowed for certain land reclamation sites or research projects approved in accordance with WAC 173-308-190(1) - (3)[38] and WAC 173-308-192[39], respectively.

The person who prepares the biosolids is responsible for providing information necessary to determine an agronomic rate to the person who receives the biosolids.

4.5.5. Pollutants

When beneficially used, concentrations of pollutants in biosolids must not exceed the ceiling concentration limits in WAC 173-308-160[33] Table 1. If biosolids exceed the pollutant concentration limits in WAC 173-308-160[33] Table 3, they must be applied at a rate that will not exceed the cumulative pollutant loading rates in WAC 173-308-160[33] Table 2, over the lifetime of the site.

If the biosolids are subject to the cumulative pollutant loading rates in WAC 173-308-160[30] Table 2, the person who proposes to apply the biosolids must obtain approval from Ecology in accordance with the process prescribed in WAC 173-308-160(2)[33] prior to application.

Table B2 below provides a summary of WAC 173-308-160 Tables 1, 2, and 3.

Table B2: Allowable Biosolids Pollutants and Loading Rates

Pollutant	WAC 173-308-160 Table 1 (173-308-160) Ceiling Concentration Limits	WAC 173-308-160 Table 2 (173-308-160) Cumulative Loading Rates	WAC 173-308-160 Table 3 (173-308-160) Pollutant Concentration Limits
Arsenic	75 mg/kg	41 kg/ha	41 mg/kg
Cadmium	85 mg/kg	39 kg/ha	39 mg/kg
Copper	4300 mg/kg	1500 kg/ha	1500 mg/kg
Lead	840 mg/kg	300 kg/ha	300 mg/kg
Mercury	57 mg/kg	17 kg/ha	17 mg/kg
Molybdenum	75 mg/kg	Not applicable	Not applicable
Nickel	420 mg/kg	420 kg/ha	420 mg/kg
Selenium	100 mg/kg	100 kg/ha	100 mg/kg
Zinc	7500 mg/kg	2800 kg/ha	2800 mg/kg

4.5.6. Pathogen Reduction

Biosolids must meet one of the Class A processes in WAC 173-308-170(1)-(4)[34] or one of the Class B processes in WAC 173-308-170(5)-(7)[34].

[38] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-190
[39] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-192

4.5.7. Vector Attraction Reduction

Biosolids must meet one of the vector attraction reduction processes in WAC 173-308-180[35], or be managed to reduce vector attraction in the field as described in WAC 173-308-210(4)(a) and (b)[40].

4.5.8. Landowner Consent

You must obtain written consent of all landowners prior to applying non-exceptional quality biosolids to the land for the first time on any parcel. The landowner must consent to allow access for Ecology inspections, and agree to comply with requirements for site management and access in Chapter 173-308 WAC[2].

4.5.9. Site Management and Public Access Restrictions for Class B Biosolids

Whenever Class B biosolids are applied to the land, the site management and public access restrictions in this subsection apply.

4.5.9.1. Crop Harvest Waiting Periods

The time between the last application of Class B biosolids and crop harvesting must adhere to the waiting periods in Table B3.

[40] https://app.leg.wa.gov/WAC/default.aspx?cite=173-308-210

Table B3: Crop Harvesting Restrictions for Class B Biosolids

Crop Type	Examples	Does the harvested part of plant contact biosolids?	Length of time the biosolids remain on soil surface	Waiting period until harvest is allowed
Above ground food crops where the edible portion does not contact the biosolids/soil mixture	Cherries, wheat	No	Not applicable	30 days
Above ground food crops where the edible portion may contact the biosolids/soil mixture	Lettuce, cucumbers, strawberries	Yes	Not applicable	14 months
Root food crops	Onions, potatoes	Yes	≥4 months	20 months
Root food crops	Onions, potatoes	Yes	<4 months	38 months
Feed crops	Range land, pasture	Not applicable	Not applicable	30 days
Fiber crops	Trees, cotton	Not applicable	Not applicable	30 days
Turf	Lawn grass	Not applicable	Not applicable	1 year*

**** Unless a different waiting period is approved by Ecology***

4.5.9.2. Public Access Restrictions

Public access must be restricted following the application of Class B biosolids. Minimally, you must maintain posted informational signs during the time site access is restricted, in accordance with the requirements in Table B4. Exceptions to these requirements must be approved in writing by Ecology.

Table B4: Site Posting Requirements for Class B Biosolids

Where	Notice Content*	How Long
All significant points of access to the site. Every ½ mile (805 meters) around the perimeter of the site.	The name and address or phone number of the generator and, if different, the person who applies the biosolids. The names, addresses, and phone numbers of the regulatory and permitting authorities. The material that is being applied Notice that access is restricted and, if desired, the date after which access is no longer restricted. If applicable, a notice on limitations regarding the harvesting of edible plants from the site.	Sites with a "high" potential for public exposure: 1 year Sites with a "low" potential for public exposure: 30 days

4.5.9.3. Buffers

The additional restrictions in Table B5 are in effect for sites where Class B biosolids are applied. For information on interpreting buffers, please refer to Ecology's Biosolids Management Guidelines, WDOE 93-80[41].

Table B5: Additional Site Management Restrictions for Class B Biosolids

Feature	Restriction
Surface waters	No application within 33 feet*
Wells	No application within 100 feet *
Wetlands	No application allowed*
Waters of the state	No application allowed*
Flooded, frozen, or snow-covered sites	No application allowed*
Adjacent Properties	As specified by Ecology

*** Unless otherwise approved by Ecology**

4.6. Exceptional Quality Biosolids

Exceptional quality (EQ) biosolids have been treated to the highest regulatory standards. Examples of EQ biosolids processes include thermal drying, lime pasteurization, temperature-phased (including thermophilic) anaerobic digestion, and auto-thermal aerobic digestion. Process controls and biosolids quality must be documented.

All first-generation exceptional quality biosolids products must comply with the labeling and information sheet requirements of 4.6.2. If you guarantee a nutrient content, or represent your product as a commercial fertilizer, in addition to the requirements of this permit you are subject to regulations implemented by the Washington State Department of Agriculture under chapter 15.54 RCW**Error! Bookmark not defined.** and chapter 16-200 WAC**Error! Bookmark not defined.**.

Biosolids generated from EQ treatment processes may in some cases be made into second-generation products such as manufactured soil and compost. The state biosolids program does not regulate second-generation products, but we do require specific documentation for generators of them, see 4-6.1 – Plan Required.

4.6.1. Plan Required for Second-Generation Products

Publicly-owned or private facilities that manufacture second-generation exceptional quality biosolids products must ensure separation of those products from first-generation exceptional quality biosolids. The separation between first and second-generation EQ biosolids products must be physically distinct, and ensure no possibility of mingling. Operators must be able to identify each product at all times.

[41] https://apps.ecology.wa.gov/publications/SummaryPages/9380.html

All generators of EQ products that manufacture second-generation EQ products must submit a basic operational plan describing the products they manufacture, and how those products are managed on site to ensure compliance with the requirements of this subsection. Generators producing second-generation products must submit a plan with their permit application. Other generators of EQ products must submit a plan prior to manufacturing second-generation products. Facilities must notify their regional biosolids coordinator prior to making any changes to this plan.

4.6.2. Labeling Requirements for Exceptional Quality Biosolids

Whenever first-generation exceptional quality biosolids products are sold or given away, you must label the container or provide an information sheet with the following information:

- The name, address, and phone number of the person who prepared the biosolids.
- A statement or information indicating that the product complies with applicable regulations for biosolids, or that the product has been prepared to meet standards that make it safe for its intended use when used in accordance with the directions provided by the manufacturer.
- A statement or information that encourages proper use of the product and protection of public health and the environment. This may include information on product storage, hygiene, and protection of surface or ground water resources.
- Agronomic rates for typical applications or guidance on how to determine the agronomic rate of application.
- A statement or information indicating that the product contains or is derived from biosolids.
- Unless registered as a fertilizer by the Washington State Department of Agriculture, a disclaimer stating that the product is not a commercial fertilizer and that all nutrient claims are estimates or averages and not guaranteed.

Appendices

Appendix A - Minimum content for a General Land Application Plan (GLAP)

(1) Describes the geographical area covered by the plan, including the names of all counties and water resource inventory areas where biosolids may be applied.

(2) Identifies site selection criteria.

(3) Describes how sites will be managed.

(4) Provides for not less than thirty days advance notice to the department of new or expanded land application sites, including those subject to provisional approval under WAC **173-308-310**(18)[7], to allow time for the department to object prior to the biosolids application.

(5) Provides for advance public notice as required in WAC **173-308-310**(13)[7], and that is reasonably calculated to reach potentially interested adjacent and abutting property owners.

Appendix B - Minimum Content for a Site Specific Land Application Plan

(1) Whether or not it is known or can be determined that biosolids containing pollutants in excess of the values WAC 173-308-160[16] Table 3 have ever been applied to the site, and if so:

(a) The date(s) when the biosolids were applied (if known).

(b) The amount of biosolids applied (if known).

(c) The concentrations of the pollutants in the biosolids (if known).

(d) The area(s) of the site to which the biosolids were applied (if known).

(2) A discussion of the types of crops grown or expected to be grown, their intended end use (e.g., pasture grass for a feed crop, corn as a food crop), and the current distribution of crops on the site.

(3) An explanation of how agronomic rates will be determined during the life of the site, along with any currently available calculations. Whenever agronomic rates or the method used to determine agronomic rates change, an update of the agronomic rate calculations must be filed with the department.

(4) Method(s) of application.

(5) Seasonal and daily timing of biosolids applications.

(6) Provisions for conducting any sampling of soils, surface waters, or groundwater and any available data collected from the site within the last two years.

(7) The name of the county and water resource inventory area where biosolids will be applied.

(8) A description of how biosolids will be staged or stored at the site that also addresses related offsite storage.

(9) Maps. The purpose of a site map is to provide a clear understanding of the features that both encourage *and* limit or condition the appropriate beneficial use of biosolids. *Several maps are typically required for each site*.

Maps must be submitted at minimum scales as follows:

Maps of individual land application sites must be at a minimum scale of 1:7920 (8 inches per mile). Larger scales (i.e. showing less area and providing more detail) are acceptable, but all maps must fit on a standard 8-1/2 x 11-inch page when printed at scale unless a different size is approved in advance by Ecology. Facilities should reach out to their biosolids coordinator for prior approval.

Maps intended to show the general area around a facility or a group of specific land application sites must be presented at a minimum scale of 1:24,000 (also known as the 7.5 minute scale ~ 2.6 inches per mile). Larger scales are acceptable, but all maps must fit on a standard 8-1/2 x 11-inch page when printed at scale unless a different size is approved in advance by Ecology. Facilities should reach out to their biosolids coordinator for prior approval.

Legends and all other notations must be rendered in a location and size, and be of such contrast as to easily distinguish them from the base map and other information on the map.

Graphically rendered notations are preferred. Handwritten notations are acceptable *only* if they are neat, legible, and meet the criteria above.

Minimally, maps must provide the following information

(a) A legend.

(b) The location and means of access.

(c) Specific areas of the site where biosolids may be applied. If there is more than one site or more than one application unit within a site, delineate the specific area and include a site or unit ID number.

(d) The number of acres in the site or in any distinct application unit within a site.

(e) Location and extent of any wetlands on the site.

(f) A topographic relief of the application site and surrounding area.

(g) Adjacent properties and uses and their zoning classification.

(h) Any seasonal surface water bodies located on the site.

(i) Any perennial surface water bodies located on or within one-quarter mile (402 meters) of the site.

(j) The location of any wells located on or within one-quarter mile (402 meters) of the site that are listed in public records or otherwise known to the applicant, whether for domestic, irrigation, or other purposes.

(k) Buffer zones to features such as surface waters, wells, property boundaries, and roadways and the width of the buffer zones.

(l) The presence and extent of any threatened or endangered species or related critical habitat.

(m) The location of any critical areas on site, as required to be identified under chapter 36.70Ab RCW in the county's growth management plan.

(n) The location and size of any areas that will be used to store biosolids.

(10) If the seasonal groundwater is three feet (0.91 meters) or less below the surface, a management plan describing how you will protect groundwater. For example, you may propose to limit applications to the time of year when groundwater has receded to more than three feet (0.91 meters) below the surface.

(11) A description of how access to the site will be restricted (e.g., signs posted around the site or other approved method of access restriction).

(12) A copy of the landowner agreement required under WAC 173-308-120(6)[42].

(13) Any additional information requested by the department that is needed to evaluate the appropriateness of the site for biosolids application.

[42] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-120

Appendix C - Glossary of Terms

See also the definitions in WAC 173-308_080[9].

Active biosolids management facility: Facilities that sell, give away or apply biosolids to the land. Facilities that only store or treat biosolids in surface impoundments, only send biosolids to another facility for further treatment, or that only dispose of biosolids, do not have active management programs.

Active septage management facility: Facilities that treat and/or apply ONLY septage to the land. Businesses that only deliver septage to an active septage management facility, and that only service onsite wastewater systems and similar devices, do not have active programs.

Beneficial use facility: A receiving-only facility consisting of a site or sites where biosolids from other treatment works treating domestic sewage are applied to the land for beneficial use, which has been permitted as a treatment works treating domestic sewage in accordance with the provisions of WAC 173-308-310[7], and that has been designated as a beneficial use facility through the permitting process.

First-generation exceptional quality biosolids: Exceptional quality biosolids produced from the treatment of non-exceptional quality biosolids, and meeting all standards for Class A pathogen reduction, vector attraction reduction, and pollutant concentration. Standards must be met at the time EQ biosolids are distributed or made into a second-generation product.

Public contact site: Land with a high potential for contact by the public. This includes, but is not limited to, public parks, ball fields, cemeteries, plant nurseries, turf farms, and golf courses.

Second-generation exceptional quality biosolids products: Products that blend first-generation EQ biosolids with other materials to make products like manufactured soil or compost. Further monitoring and testing of second-generation products against biosolids standards is not required. **Septage or domestic septage:** Liquid or solid material removed from septic tanks, cess pools, portable toilets, type III marine sanitation devices, vault toilets, pit toilets, RV holding tanks, or similar systems that receive only domestic sewage. Septage may also include commercial or industrial septage mixed with domestic septage if approved in accordance with the provisions in WAC 173-308-020(3)(g)[43].

Septage managed as biosolids originating from sewage sludge: Septage treated and managed as biosolids originating from a wastewater treatment plant.

Septage management facility: A facility that treats and/or applies septage to the land.

Sewage Sludge: Solid, semisolid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes, but is not limited to, domestic septage;

[43] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308-020

scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and a material derived from sewage sludge. Sewage sludge does not include ash generated during the firing of sewage sludge in a sewage sludge incinerator or grit and screenings generated during preliminary treatment of domestic sewage in a treatment works.

Staging: Short-term storage of biosolids at a land application site, in preparation for land application.

Storage: Placing biosolids or sewage sludge on land or in surface impoundments or other containment devices in which the biosolids or sewage sludge remain for two years or less, except where a greater time period has been approved by the department. This does not include the placing of biosolids or sewage sludge on land or in surface impoundments or other containment devices for treatment or disposal.

Temporary, small-scale storage: The storage of biosolids or sewage sludge for no more than thirty days in a tank holding no more than 10,000 gallons with a total on-site maximum volume of no more than 20,000 gallons.

Treatment Works Treating Domestic Sewage: A publicly owned treatment works or any other sewage sludge or wastewater treatment devices or systems, regardless of ownership, used in the storage, treatment, recycling, and reclamation of municipal or domestic sewage or sewage sludge, including land dedicated for the disposal of sewage sludge. Treatment works treating domestic sewage also includes beneficial use facilities and septage management facilities as defined in this section, and a person, site, or facility designated as a treatment works treating domestic sewage in accordance with WAC 173-308-310(1)(b)[7]. This definition does not include septic tanks or similar devices or temporary, small-scale storage as defined in this section.

Washington State
Department of Ecology

By: Laurie H. Davies 6/15/22

Laurie Davies
Solid Waste Management
Program Manager

Date

EXHIBIT B

SEPA ENVIRONMENTAL CHECKLIST

Purpose of checklist:

Governmental agencies use this checklist to help determine whether the environmental impacts of your proposal are significant. This information is also helpful to determine if available avoidance, minimization or compensatory mitigation measures will address the probable significant impacts or if an environmental impact statement will be prepared to further analyze the proposal.

Instructions for applicants:

This environmental checklist asks you to describe some basic information about your proposal. Please answer each question accurately and carefully, to the best of your knowledge. You may need to consult with an agency specialist or private consultant for some questions. You may use "not applicable" or "does not apply" only when you can explain why it does not apply and not when the answer is unknown. You may also attach or incorporate by reference additional studies reports. Complete and accurate answers to these questions often avoid delays with the SEPA process as well as later in the decision-making process.

The checklist questions apply to all parts of your proposal, even if you plan to do them over a period of time or on different parcels of land. Attach any additional information that will help describe your proposal or its environmental effects. The agency to which you submit this checklist may ask you to explain your answers or provide additional information reasonably related to determining if there may be significant adverse impact.

Instructions for Lead Agencies:

Please adjust the format of this template as needed. Additional information may be necessary to evaluate the existing environment, all interrelated aspects of the proposal and an analysis of adverse impacts. The checklist is considered the first but not necessarily the only source of information needed to make an adequate threshold determination. Once a threshold determination is made, the lead agency is responsible for the completeness and accuracy of the checklist and other supporting documents.

Use of checklist for nonproject proposals:

For nonproject proposals (such as ordinances, regulations, plans and programs), complete the applicable parts of sections A and B plus the SUPPLEMENTAL SHEET FOR NONPROJECT ACTIONS (part D). Please completely answer all questions that apply and note that the words "project," "applicant," and "property or site" should be read as "proposal," "proponent," and "affected geographic area," respectively. The lead agency may exclude (for non-projects) questions in Part B - Environmental Elements –that do not contribute meaningfully to the analysis of the proposal.

A. Background [HELP]

1. Name of proposed project, if applicable:

   Issue a General Permit for Biosolids Management (general permit) with statewide applicability. A draft can be found in Ecology[1]'s publications database or on Ecology's biosolids web[2].

2. Name of applicant:

   Washington State Department of Ecology

3. Address and phone number of applicant and contact person:

   Emily Kijowski
   Biosolids Technical Specialist
   Washington State Department of Ecology
   Solid Waste Management
   PO Box 47600
   Olympia, WA 98504-7600
   Emily.kijowski@ecy.wa.gov
   360-789-6592

4. Date checklist prepared:

   May 4, 2021

5. Agency requesting checklist:

   Washington State Department of Ecology

6. Proposed timing or schedule (including phasing, if applicable):

   Ecology will issue a SEPA threshold determination with public notice concurrent with public notice for the draft general permit. Following hearings on the draft permit, Ecology will make a decision on whether to issue the permit, and if so, any appropriate revisions. If issued, the final general permit will become effective 30 days after notice is published in the State Register, and will remain in effect for 5 years after the effective date. Ecology anticipates a decision by August 4, 2021.

7. Do you have any plans for future additions, expansion, or further activity related to or connected with this proposal? If yes, explain.

[1] https://fortress.wa.gov/ecy/publications/summarypages/2107006.html
[2] https://ecology.wa.gov/Biosolids-permit-actions

Ecology could mofidfy, rescind, or replace the permit during its five year life if underlying rules change or new information requires changes that cannot be properly addressed by conditioning individual facility approvals.

There are currently 375 facilities subject to the general permit. The permit breaks these facilities into two primary groups: those *without* active biosolids management programs, and those *with* active biosolids management programs.

Facilities *without* active biosolids management programs do not engage in beneficial use. This group includes facilities where biosolids are held in a surface impoundments with no expectation of removal during the life of the permit, and facilities where biosolids are removed and sent only to another permitted facility for further treatment, or disposal. Facilities that do not have active biosolids management programs will have final approval of coverage on the effective date of the permit.

Facilities with active biosolids management programs must submit a permit application, and are subject to further review that may include additional public notice, additional review under SEPA, and incorporation of additional or more stringent requirements as a condition of final approval of coverage.

8. List any environmental information you know about that has been prepared, or will be prepared, directly related to this proposal.

This SEPA checklist and accompanying Determination of Nonsignificance.

Ecology uses numerous guidance documents and other authoritative sources as the basis for developing and implementing the general permit, including but not limited to"

Chapter 173-308 WAC[3] – These are the rules that govern implementation of the state biosolids program.

Biosolids Management Guidelines[4] – This guidance document helps biosolids managers and agency staff make appropriate decisions when evaluating site and facility proposals.

Managing Nitrogen from Biosolids[5] – Nitrogen is a critical plant nutrient. This guidance document helps biosolids managers and staff understand how to evaluate nitrogen in biosolids.

Control of Pathogens and Vector Attraction Reduction in Sewage Sludge[6] – This federal guidance document helps managers and staff understand the basis for

[3] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308
[4] https://apps.ecology.wa.gov/publications/SummaryPages/9380.html
[5] https://apps.ecology.wa.gov/publications/SummaryPages/99508.html
[6] https://www.epa.gov/biosolids/control-pathogens-and-vector-attraction-sewage-sludge

pathogen reduction and controlling attraction to vectors in biosolids. This is the best guidance available for the purpose, and there is no state equivalent.

40 CFR Part 503 - Standards for the Use or Disposal of Sewage Sludge[7] –the state program is based on this federal rule.

A Plain English Guide to the EPA Part 503 Biosolids Rule[8] – EPA wrote this guidance document to help interested persons interpret requirements of the federal program. Washington's program is based on the federal program.

Fertilizing with Biosolids[9] - A product of the joint efforts of Washington State and Oregon State Universities, by Oregon State Extension.

Other authoritative sources can inform decision-making. In particular, crop-specific nutrient management and soil sampling guidelines, typically produced by university cooperative extension services.

9. Do you know whether applications are pending for governmental approvals of other proposals directly affecting the property covered by your proposal? If yes, explain.

NOTE: This proposal is not project specific. All facilities subject to the general permit are potentially subject to other rules or local ordinances, and must comply at the proper time.

10. List any government approvals or permits that will be needed for your proposal, if known.

No other approvals are need to issue this permit, but approvals are required for new facilities that apply for coverage, and for existing facilities with active biosolids management programs.

11. Give brief, complete description of your proposal, including the proposed uses and the size of the project and site. There are several questions later in this checklist that ask you to describe certain aspects of your proposal. You do not need to repeat those answers on this page. (Lead agencies may modify this form to include additional specific information on project description.)

This proposal is to issue a new statewide general permit for biosolids management with a term of 5 years. If issued, the general permit, along with Chapter 173-308 of the Washington Administrative Code (WAC) will be used to regulate all forms of biosolids produced, treated, stored, transferred from one facility to another, sold or given away, applied to the land for beneficial use, and disposed through incineration or landfilling within the jurisdiction of the State of Washington.

The proposed general permit differs structurally from the previous general permit by eliminating the administrative burden of applying for coverage for some

[7] https://www.govinfo.gov/content/pkg/CFR-2018-title40-vol32/xml/CFR-2018-title40-vol32-part503.xml
[8] https://www.epa.gov/biosolids/plain-english-guide-epa-part-503-biosolids-rule
[9] https://catalog.extension.oregonstate.edu/pnw508

facilities that do not have active biosolids management programs, and thereby prioritizing permit review for facilities with active management programs. It organizes the permit into three distinct sections: Baseline, Active Septage Management, and Active Biosolids Management.

The Baseline section of the permit establishes requirements that apply to all existing and new facilities. Existing facilities without active biosolids management programs that have previously submitted applications, undergone SEPA review, and submitted Notices of Intent to continue coverage under the new general permit are subject only to the Baseline section of the permit if they make no major changes to their operations. These facilities will receive final coverage when the general permit becomes effective. Existing facilities that fall only under the Baseline and have major changes in operations must submit a permit application, and are subject to additional public notice and SEPA review.

New facilities must submit a comjplete permit applictioin. Based on information in the application, Ecology will determine whether they are subject to requirements of the permit beyond the Baseline.

The Active Septage and Biosolids Management sections of the general permit cover *new* and *existing* facilities with active management programs (such as land application). These facilities must submit a complete permit application package with plans that include specific information about biosolids treatment, analysis, and uses, including detailed information about proposed land application sites or programs that will sell or give biosolids away without further regulation (if applicable). These facilities are subject to public notice and review under SEPA, as applicable, prior to receiving final coverage. All facilities with active biosolids management programs are subject to additional or more stringent requirements as a condition of final approval of coverage. Ecology makes a decision about the need for additional requirements based on the content of an application, a review of facility operations, and public input, as applicable.

12. Location of the proposal. Give sufficient information for a person to understand the precise location of your proposed project, including a street address, if any, and section, township, and range, if known. If a proposal would occur over a range of area, provide the range or boundaries of the site(s). Provide a legal description, site plan, vicinity map, and topographic map, if reasonably available. While you should submit any plans required by the agency, you are not required to duplicate maps or detailed plans submitted with any permit applications related to this checklist.

The general permit will be applicable within the boundaries of the State of Washington for all facilities and lands under the jurisdiction of the State of Washington. The permit will not apply to federal lands, lands within the boundaries of Washington Tribal Reservations, or lands outside of Washington

Tribal Reservations that are held in trust by the federal government for the Tribe. Certain conditions of state program rules and the general permit may apply when biosolids are exported from areas outside the jurisdiction of the state, into the jurisdiction of the state.

B. Environmental Elements [HELP]

Note: This is not a site-specific project proposal. A programmatic review has been prepared for this proposal. The agency responses are found in Part D of the checklist. Specific facility and project proposals will receive further environmental review as required.

1. *Earth* [help]

a. General description of the site:

(circle one): Flat, rolling, hilly, steep slopes, mountainous, other _____

b. What is the steepest slope on the site (approximate percent slope)?

c. What general types of soils are found on the site (for example, clay, sand, gravel, peat, muck)? If you know the classification of agricultural soils, specify them and note any agricultural land of long-term commercial significance and whether the proposal results in removing any of these soils.

d. Are there surface indications or history of unstable soils in the immediate vicinity? If so, describe.

e. Describe the purpose, type, total area, and approximate quantities and total affected area of any filling, excavation, and grading proposed. Indicate source of fill.

f. Could erosion occur as a result of clearing, construction, or use? If so, generally describe.

g. About what percent of the site will be covered with impervious surfaces after project construction (for example, asphalt or buildings)?

h. Proposed measures to reduce or control erosion, or other impacts to the earth, if any:

2. Air [help]

a. What types of emissions to the air would result from the proposal during construction, operation, and maintenance when the project is completed? If any, generally describe and give approximate quantities if known.

b. Are there any off-site sources of emissions or odor that may affect your proposal? If so, generally describe.

c. Proposed measures to reduce or control emissions or other impacts to air, if any:

3. Water [help]

a. Surface Water: [help]

1) Is there any surface water body on or in the immediate vicinity of the site (including year-round and seasonal streams, saltwater, lakes, ponds, wetlands)? If yes, describe type and provide names. If appropriate, state what stream or river it flows into.

2) Will the project require any work over, in, or adjacent to (within 200 feet) the described waters? If yes, please describe and attach available plans.

3) Estimate the amount of fill and dredge material that would be placed in or removed from surface water or wetlands and indicate the area of the site that would be affected. Indicate the source of fill material.

4) Will the proposal require surface water withdrawals or diversions? Give general description, purpose, and approximate quantities if known.

5) Does the proposal lie within a 100-year floodplain? If so, note location on the site plan.

6) Does the proposal involve any discharges of waste materials to surface waters? If so, describe the type of waste and anticipated volume of discharge.

b. Ground Water: [help]

1) Will groundwater be withdrawn from a well for drinking water or other purposes? If so, give a general description of the well, proposed uses and approximate quantities withdrawn from the well. Will water be discharged to groundwater? Give general description, purpose, and approximate quantities if known.

2) Describe waste material that will be discharged into the ground from septic tanks or other sources, if any (for example: Domestic sewage; industrial, containing the following chemicals. . . ; agricultural; etc.). Describe the general size of the system, the number of such systems, the number of houses to be served (if applicable), or the number of animals or humans the system(s) are expected to serve.

c. Water runoff (including stormwater):

1) Describe the source of runoff (including storm water) and method of collection and disposal, if any (include quantities, if known). Where will this water flow? Will this water flow into other waters? If so, describe.

2) Could waste materials enter ground or surface waters? If so, generally describe.

3) Does the proposal alter or otherwise affect drainage patterns in the vicinity of the site? If so, describe.

d. Proposed measures to reduce or control surface, ground, and runoff water, and drainage pattern impacts, if any:

4. Plants [help]

a. Check the types of vegetation found on the site:

____deciduous tree: alder, maple, aspen, other
____evergreen tree: fir, cedar, pine, other
____shrubs
____grass
____pasture
____crop or grain
____ Orchards, vineyards or other permanent crops.
____ wet soil plants: cattail, buttercup, bullrush, skunk cabbage, other
____water plants: water lily, eelgrass, milfoil, other
____other types of vegetation

b. What kind and amount of vegetation will be removed or altered?

c. List threatened and endangered species known to be on or near the site.

d. Proposed landscaping, use of native plants, or other measures to preserve or enhance vegetation on the site, if any:

e. List all noxious weeds and invasive species known to be on or near the site.

5. Animals [help]

a. List any birds and other animals which have been observed on or near the site or are known to be on or near the site.

Examples include:

birds: hawk, heron, eagle, songbirds, other:
mammals: deer, bear, elk, beaver, other:
fish: bass, salmon, trout, herring, shellfish, other _____

b. List any threatened and endangered species known to be on or near the site.

c. Is the site part of a migration route? If so, explain.

d. Proposed measures to preserve or enhance wildlife, if any:

e. List any invasive animal species known to be on or near the site.

6. Energy and Natural Resources [help]

a. What kinds of energy (electric, natural gas, oil, wood stove, solar) will be used to meet the completed project's energy needs? Describe whether it will be used for heating, manufacturing, etc.

b. Would your project affect the potential use of solar energy by adjacent properties? If so, generally describe.

c. What kinds of energy conservation features are included in the plans of this proposal? List other proposed measures to reduce or control energy impacts, if any:

7. Environmental Health [help]

a. Are there any environmental health hazards, including exposure to toxic chemicals, risk of fire and explosion, spill, or hazardous waste, that could occur as a result of this proposal? If so, describe.

1) Describe any known or possible contamination at the site from present or past uses.

2) Describe existing hazardous chemicals/conditions that might affect project development and design. This includes underground hazardous liquid and gas transmission pipelines located within the project area and in the vicinity.

3) Describe any toxic or hazardous chemicals that might be stored, used, or produced during the project's development or construction, or at any time during the operating life of the project.

4) Describe special emergency services that might be required.

5) Proposed measures to reduce or control environmental health hazards, if any:

b. Noise

1) What types of noise exist in the area which may affect your project (for example: traffic, equipment, operation, other)?

2) What types and levels of noise would be created by or associated with the project on a short-term or a long-term basis (for example: traffic, construction, operation, other)? Indicate what hours noise would come from the site.

3) Proposed measures to reduce or control noise impacts, if any:

8. Land and Shoreline Use [help]

a. What is the current use of the site and adjacent properties? Will the proposal affect current land uses on nearby or adjacent properties? If so, describe.

b. Has the project site been used as working farmlands or working forest lands? If so, describe. How much agricultural or forest land of long-term commercial significance will be converted to other uses as a result of the proposal, if any? If resource lands have not been designated, how many acres in farmland or forest land tax status will be converted to nonfarm or nonforest use?

1) Will the proposal affect or be affected by surrounding working farm or forest land normal business operations, such as oversize equipment access, the application of pesticides, tilling, and harvesting? If so, how:

c. Describe any structures on the site.

d. Will any structures be demolished? If so, what?

e. What is the current zoning classification of the site?

f. What is the current comprehensive plan designation of the site?

g. If applicable, what is the current shoreline master program designation of the site?

h. Has any part of the site been classified as a critical area by the city or county? If so, specify.

i. Approximately how many people would reside or work in the completed project?

j. Approximately how many people would the completed project displace?

k. Proposed measures to avoid or reduce displacement impacts, if any:

L. Proposed measures to ensure the proposal is compatible with existing and projected land uses and plans, if any:

m. Proposed measures to reduce or control impacts to agricultural and forest lands of long-term commercial significance, if any:

9. Housing [help]

a. Approximately how many units would be provided, if any? Indicate whether high, middle, or low-income housing.

b. Approximately how many units, if any, would be eliminated? Indicate whether high, middle, or low-income housing.

c. Proposed measures to reduce or control housing impacts, if any:

10. Aesthetics [help]

a. What is the tallest height of any proposed structure(s), not including antennas; what is the principal exterior building material(s) proposed?

b. What views in the immediate vicinity would be altered or obstructed?

b. Proposed measures to reduce or control aesthetic impacts, if any:

11. Light and Glare [help]

a. What type of light or glare will the proposal produce? What time of day would it mainly occur?

b. Could light or glare from the finished project be a safety hazard or interfere with views?

c. What existing off-site sources of light or glare may affect your proposal?

d. Proposed measures to reduce or control light and glare impacts, if any:

12. Recreation [help]

a. What designated and informal recreational opportunities are in the immediate vicinity?

b. Would the proposed project displace any existing recreational uses? If so, describe.

c. Proposed measures to reduce or control impacts on recreation, including recreation opportunities to be provided by the project or applicant, if any:

13. Historic and cultural preservation [help]

a. Are there any buildings, structures, or sites, located on or near the site that are over 45 years old listed in or eligible for listing in national, state, or local preservation registers ? If so, specifically describe.

b. Are there any landmarks, features, or other evidence of Indian or historic use or occupation? This may include human burials or old cemeteries. Are there any material evidence, artifacts, or areas of cultural importance on or near the site? Please list any professional studies conducted at the site to identify such resources.

c. Describe the methods used to assess the potential impacts to cultural and historic resources on or near the project site. Examples include consultation with tribes and the department of archeology and historic preservation, archaeological surveys, historic maps, GIS data, etc.

d. Proposed measures to avoid, minimize, or compensate for loss, changes to, and disturbance to resources. Please include plans for the above and any permits that may be required.

14. Transportation [help]

a. Identify public streets and highways serving the site or affected geographic area and describe proposed access to the existing street system. Show on site plans, if any.

b. Is the site or affected geographic area currently served by public transit? If so, generally describe. If not, what is the approximate distance to the nearest transit stop?

c. How many additional parking spaces would the completed project or non-project proposal have? How many would the project or proposal eliminate?

d. Will the proposal require any new or improvements to existing roads, streets, pedestrian, bicycle or state transportation facilities, not including driveways? If so, generally describe (indicate whether public or private).

e. Will the project or proposal use (or occur in the immediate vicinity of) water, rail, or air transportation? If so, generally describe.

f. How many vehicular trips per day would be generated by the completed project or proposal? If known, indicate when peak volumes would occur and what percentage of the volume would be trucks (such as commercial and nonpassenger vehicles). What data or transportation models were used to make these estimates?

g. Will the proposal interfere with, affect or be affected by the movement of agricultural and forest products on roads or streets in the area? If so, generally describe.

h. Proposed measures to reduce or control transportation impacts, if any:

15. Public Services [help]

a. Would the project result in an increased need for public services (for example: fire protection, police protection, public transit, health care, schools, other)? If so, generally describe.

b. Proposed measures to reduce or control direct impacts on public services, if any.

16. Utilities [help]

a. Circle utilities currently available at the site:
electricity, natural gas, water, refuse service, telephone, sanitary sewer, septic system, other _____

b. Describe the utilities that are proposed for the project, the utility providing the service, and the general construction activities on the site or in the immediate vicinity which might be needed.

C. Signature [HELP]

The above answers are true and complete to the best of my knowledge. I understand that the lead agency is relying on them to make its decision.

Signature: _____

Name of signee Kyle Dorsey

Position and Agency/Organization State Biosolids Program Coordinator; Ecology Solid Waste Management Program

Date Submitted: May 4, 2021

D. Supplemental sheet for nonproject actions [HELP]

(**IT IS NOT NECESSARY** to use this sheet for project actions)

Because these questions are very general, it may be helpful to read them in conjunction with the list of the elements of the environment.

When answering these questions, be aware of the extent the proposal, or the types of activities likely to result from the proposal, would affect the item at a greater intensity or at a faster rate than if the proposal were not implemented. Respond briefly and in general terms.

1.How would the proposal be likely to increase discharge to water; emissions to air; production, storage, or release of toxic or hazardous substances; or production of noise?

Excepting the impact of population growth, from the standpoint of current practices, the proposed general permit is not expected to increase the discharge of pollutants to water; emissions to air; production, storage or release of toxic or hazardous substances; or production of noise. Beneficial use of biosolids has been the *primary* method of management in Washington since at least 1992 and is known to have occurred as early as the 1970s. This general permit will be the fifth since program inception. In 2019, about 65% of all biosolids produced were applied to the land directly, and 17% were sold or given away to individuals (including in the form of biosolids compost and soil products) . About 18% of biosolids were disposed, the majority of which is attributed to five treatment works in the state that operate incinerators. These conditions have not changed in many years.

The proposed permit is written to ensure protection of human health and the environment while beneficially using biosolids to the greatest extent possible as mandated in chapter 70A.226 RCW. Biosolids contain pollutants that are subject to regulation under the federal and state biosolids programs. Those are arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. Some of those are also essential nutrients for plants and animals. There are also pollutants in biosolids that are not regulated. In that sense, the permit will authorize the release of pollutants, but within the limits of established regulations.

Generally, pollutants in biosolids occur in very low concentrations, below the level where an adverse effect is expected. Pollutants in biosolids originate from the activities of businesses and individuals. We are often much more highly exposed to them during the course of routine daily activities than would be possible from the use of biosolids. Some pollutants, although present in very small amounts, are known to persist or bioaccumulate. Those are of most concern, and research and investigation by U.S. EPA, Ecology, and universities on the fate and transport of pollutants in biosolids is contnuing.

The state biosolids program is based on the standards established by the U.S. Environmental Protection Agency (EPA) in 40 CFR Part 503. The federal

program is based on a nationwide survey of biosolids quality, and a comprehensive risk assessment using data and information available for pollutants that can occur in biosolids. EPA performs biennial reviews of the national biosolids program requirments and has published eight reports since 2005. Treatment works that generate biosolids are required to monitor for, and keep records of, regulated pollutants in the biosolids they produce. The permit itself, and approvals of individual facilities under the permit, can both be modified to include additional pollutants if new information becomes available.

Proposed measures to avoid or reduce such increases are:

Even though this proposal is not expected to result in increased release of pollutants, beneficial use activities of individual facilities subject to the general permit are evaluated and regulated based on specific proposals in permit applications required under the general permit.

Varying buffers to property boundaries and sensitive areas (such as surface waters and wetlands) are required at land application sites. Seasonality of application may also be restricted to avoid high rainfall or flood events, and some sites require checking for the presence of shallow groundwater prior to beginning application. Biosolids are applied to the land at agronomic rates designed to protect groundwater from excess nitrate, and soils are monitored to validate application rates.

WAC 173-308-280(3) prohibits storage of biosolids in a manner that would be likely to result in the contamination of groundwater, surface water, air, or land under current conditions or in the case of fire or flood.

The minimum buffer to surface water is ten meters under federal and state rules (WAC 173-308-210(b)). In practice, actual buffers are typically wider. Ecology's Biosolids Management Guidelines (WDOE 93-80) address agricultural site suitability in chapter 4. Depending on slope, soil type, amount cover, and method of application, buffer widths range up to 200 feet and could be increased if appropriate.

If groundwater is less than three feet from the surface of the land at any time, a groundwater protection plan is required per WAC 173-308-90003.

Washington implements a pretreatment program that reduces or alters discharges of pollutants of concern from significant industrial dischargers. In some cases, program authority is delegated to local government. When pollutants are reduced before they enter the sewer system, water quality and biosolids quality are protected.

EPA's current top priority for the national biosolids program is development of a new risk-screening tool that can be used to further evaluate risks from pollutants.

The screening tool will help EPA determine whether additional research or regulatory standards are needed to be adequately protective. Ecology is monitoring this activity and expects to continue participating with EPA in national program development.

Ecology has the ability to modify the permit or specific conditions for individual facilities subject to the permit. If the regulation of other pollutants becomes necessary during the course of the permit cycle, that is sufficient cause for Ecology to open the permit for modification.

2.How would the proposal be likely to affect plants, animals, fish, or marine life?

The proposed general permit is not expected to have an adverse effect on plants, animals, fish, or marine wildlife. To the contrary, decades of scientific research have shown that biosolids provide needed nutrients and organic matter to soils for healthy crop and forest production. The use of biosolids reduces the need for synthetic fertilizer, increases soil organic matter content and water retention, and reduces erosion. Biosolids have been shown to improve habitat, which in turn has a positive impact on wildlife.

Proposed measures to protect or conserve plants, animals, fish, or marine life are:

Site-specific permit conditions include buffers to surface waters, restrictions on seasonality of application to avoid high rainfall and flood events, and checking for the presence of shallow groundwater. Biosolids are applied to the land at an agronomic rate. Along with required buffers, this protects our ground and surface water resources and associated wildlife.

Biosolids application is mostly associated with conventional farming practices. Land application could affect plants on forested sites by favoring the growth of some species over others. Sites where Class B biosolids are applied to the land are subject to SEPA review which facilitates identification of sensitive plant or animal populations and allows for the addition of adddtional or more stringent requirments as needed.

3.How would the proposal be likely to deplete energy or natural resources?

We do not expect the biosolids general permit to deplete energy or natural resources.

Proposed measures to protect or conserve energy and natural resources are:

The beneficial use of biosolids helps build and replenish soils depleted by farming and other activies. Studies have shown biosolids to be an equal and sometimes superior substitute for commercial fertilizers, thus reducing the demand for synthetic fertilizer products.

4.How would the proposal be likely to use or affect environmentally sensitive areas or areas designated (or eligible or under study) for governmental protection; such as parks,

wilderness, wild and scenic rivers, threatened or endangered species habitat, historic or cultural sites, wetlands, floodplains, or prime farmlands?

We do not expect any adverse affect. Parks, wilderness areas, and wild and scenic rivers are likely too remote to be desirable for the land application of non-EQ biosolids. It is possible that EQ biosolids might be used to develop a public site such as a park.

Proposed measures to protect such resources or to avoid or reduce impacts are:

The amount of biosolids produced is small in comparison to demand, and there is a large demand for application to agricultural and forested lands. Some sites may contain or be adjacent to critical habitat, historic or cultural sites, wetlands, or floodplains. Wherever Class B (non-exceptional quality biosolids) are applied to the land, a site specific SEPA review is required. Review of a permit application and associated SEPA checklist will identify these types of resources and allow for addition of permt condtions to ensure protections are in place.

The general permit implements the rules in chapter 173-308 WAC. The use of non-exceptional quality biosolids is prohibited, generally, wherever it might adversely affect a threatened or endangered species or its critical habitat (WAC 173-308-191), identification of which is a required component of site specific land application plans (WAC 173-308-90003).

WAC 173-308-210(b) prohibits application to wetlands unless authorized by permit. In practice, the agency does not allow application of biosolids to functioning wetlands. Some farmland contains areas of hydric soils – where the water table fluctuates. Even though crops are grown in those areas, when they are identified during permit review, application may be restricted or limited to times when groundwater is not near the surface.

5.How would the proposal be likely to affect land and shoreline use, including whether it would allow or encourage land or shoreline uses incompatible with existing plans?

Exceptional quality biosolids are not regulated once distributed. Less than 20% of biosolids meet EQ criteria. A primary use of EQ products is on lawns and home gardens, and as components of topsoil and compost products. When Class B (non EQ) biosolids are applied to the land, public access may be restricted for up to a year, and harvest of some crops may be restricted for up to thirty-eight months after application.

Proposed measures to avoid or reduce shoreline and land use impacts are:

Compatibility with project plans and land use would be addressed during the application process that includes site specific review, SEPA review, and public notice. The general permit requires buffers to protect surface waters, and any proposal for application of biosolids in a shoreline area would require site evaluation, SEPA review, and public notice.

6.How would the proposal be likely to increase demands on transportation or public services and utilities?

Increased population will result in increased production of biosolids. The permit itself will not increase demands on transportation or public services and utilities. Biosolids must be periodically removed from all facilities because they are an integral product of the wastewater treatment process.

Proposed measures to reduce or respond to such demand(s) are:

No measures are proposed, but consideration may be appropriate for individual projects. For example, preferred routes for truck traffic based on traffic impacts, or seasonal limitations related to freeze/thaw cycles.

7. Identify, if possible, whether the proposal may conflict with local, state, or federal laws or requirements for the protection of the environment.

We do not anticipate conflicts with other laws. The general permit is written in accordance with chapter 173-308 WAC, as authorized by chapter 70A.226 RCW. The state program is designed to meet the standards of federal rules in 40 CFR 503, as authorized by the Clean Water Act. WAC 173-308-030 identifies compliance with other federal, state, and local laws.

EXHIBIT C

(Use Agency Letterhead)

STATE ENVIRONMENTAL POLICY ACT

Determination of NonSignificance

May 4, 2021

Lead agency: Washington State Department of Ecology

Agency Contact: Kyle Dorsey, kyle.dorsey@ecy.wa.gov, 360-407-6559

Agency File Number: NA

Description of proposal: – Issue a new statewide general permit for biosolids management with a term of 5 years. If issued, Ecology will use the general permit and Chapter 173-308 of the Washington Administrative Code (WAC) to regulate all forms of biosolids produced, treated, stored, transferred from one facility to another, sold or given away, applied to the land for beneficial use, and disposed through incineration or landfilling within the jurisdiction of the State of Washington.

Location of proposal –The permit is applicable statewide in all areas subject to the jurisdiction of the State of Washington

Applicant/proponent: Washington State Department of Ecology, Solid Waste Management Program, PO Box 7600, Olympia, WA 98504-7600. Program reception phone: 360-407-6900

The Washington State Department of Ecology has determined that this proposal will not have a probable significant adverse impact on the environment. An environmental impact statement (EIS) is not required under RCW 43.21C.030(2)(c). We have reviewed the attached Environmental Checklist with consideration of the proposed general permit and biosolids permit program implemented under Chapter 173-308 of the Washington Administrative Code. This information is available at: https://ecology.wa.gov/Biosolids-permit-actions

This determination is based on the following findings and conclusions:

> The state biosolids program is based on, and meets or exceeds the requirements of the federal biosolids management program implemented by U.S. EPA under 40 CFR Part 503. Beneficial use is the primary means of management in Washington, and nationwide. Biosolids that meet appropriate standards for beneficial use do not pose a significant risk to human health or the environment when used in accordance with applicable rules, guidelines and permit requirements. The permit authorizes landfilling and incineration when biosolids do not meet applicable standards. The permit program implemented by Ecology allows the agency to impose additional or more stringent requirements for individual facilities and sites, as required, following review of a permit application, additional environmental review, and public hearings if required.

This DNS is issued under WAC 197-11-340(2) and the comment period will end on July 1, 2021.

Responsible Official:

Laurie G. Davies, Manager
Washington State Department of Ecology Solid Waste Program
PO Box 47600, Olympia, WA 98504-7600
Laurie.davies@ecy.wa.gov or 360-407-6103:

Signature Laurie G. Davies Date May 5, 2021

EXHIBIT D

Response to Comments

General Permit for Biosolids Management

Solid Waste Management Program

Washington State Department of Ecology
Olympia, Washington

June 2022, Publication 22-07-015

Publication Information

This document is available on the Department of Ecology's searchable publication collection.

Contact Information

Solid Waste Management Program

P.O. Box 46700
Olympia, WA 98504-7600
Phone: 360-407-6900
Website: Washington State Department of Ecology[1]

ADA Accessibility

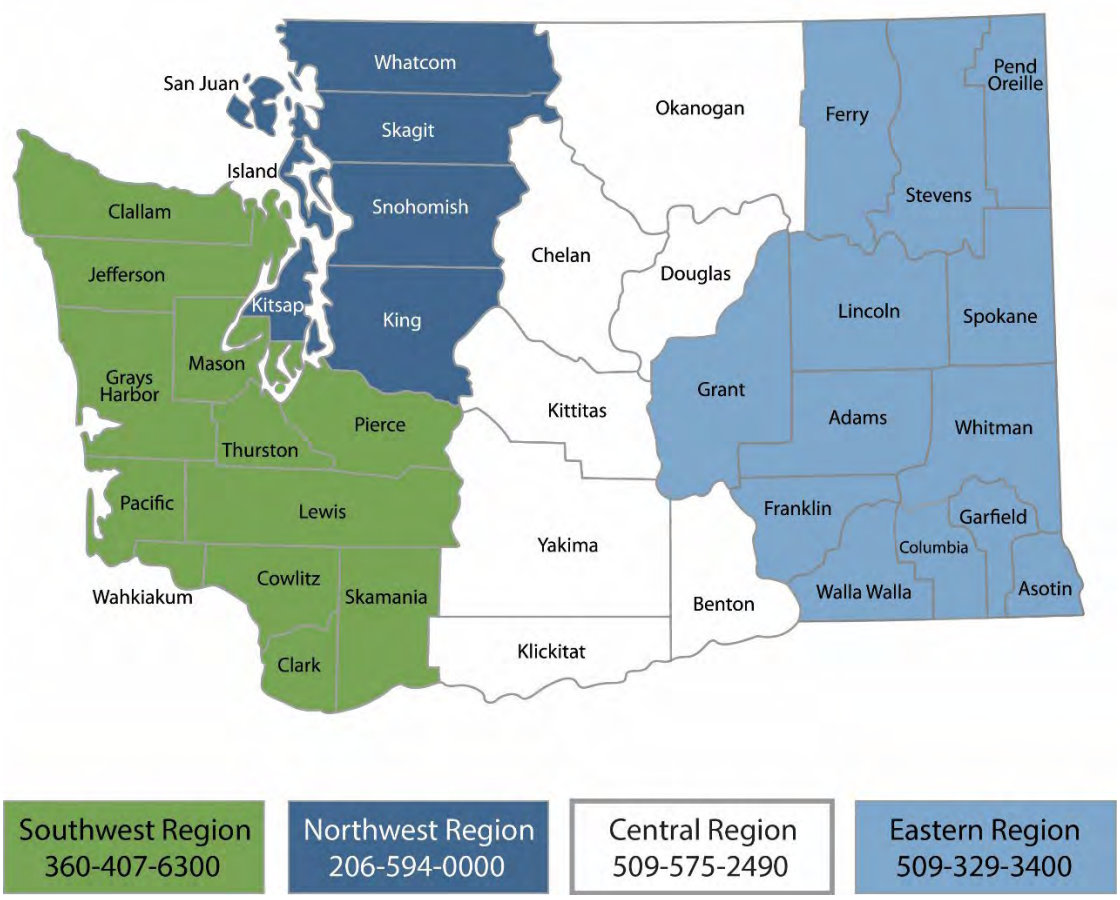
The Department of Ecology is committed to providing people with disabilities access to information and services by meeting or exceeding the requirements of the Americans with Disabilities Act (ADA), Section 504 and 508 of the Rehabilitation Act, and Washington State Policy #188.

To request an ADA accommodation, contact Ecology by phone at 360-407-6900 or email at swmpublications@ecy.wa.gov. For Washington Relay Service or TTY call 711 or 877-833-6341. Visit Ecology's website for more information.

[1] www.ecology.wa.gov/contact

Department of Ecology's Regional Offices

Map of Counties Served



Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	P.O. Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	P.O. Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 West Alder Street Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 North Monroe Spokane, WA 99205	509-329-3400
Headquarters	Statewide	P.O. Box 46700 Olympia, WA 98504	360-407-6000

Response to Comments

General Permit for Biosolids Management

Solid Waste Management Program
Washington State Department of Ecology
Olympia, WA

June 2022 | Publication 22-07-015

DEPARTMENT OF
ECOLOGY
State of Washington

Table of Contents

1. List of Figures and Tables

Figures

Tables

Response to Comments submitted on the Draft General Permit for Biosolids Management

Introduction

Summary of Permit Development

The Washington Department of Ecology (Ecology) issues this Response to Comments (Response) for input received on the Draft General Permit for Biosolids Management.

The purpose of the Biosolids General Permit is to implement the biosolids management rules in chapter 173-308 WAC.

Ecology's public process included:

December 2019: Ecology filed a notice of preliminatory determination in the State Register to issue a new general permit for biosolids management. We solicited comments on the appropriateness of issuing a new general permit for biosolids management to replace the one that would expire September 4, 2020. We received 24 comments between December 3, 2019 and January 24, 2020.

January 2020: Ecology reviewed all responses and determined that a general permit was the best approach to implementing chapter 173-308-WAC.

March 2020: Notices of Intent to continue permit coverage under the next general permit for biosolids management were due. Ecology received NOIs from all permitted facilities on time.

June 2020: Ecology responded to the 24 comments received on the preliminary determination to issue a new general permit for biosolids management, which can be found on our Publications Page[2].

September 2020: The previous general permit for biosolids management expired on September 4, 2020. The requirements of the expired permit remain in effect for all facilities who successfully submitted a Notice of Intent.

May 2021: Ecology filed a notice in the State Register of the draft general permit for biosolids management. We held a two-month public comment period and two virtual public hearings so as to solicit comments safely during the COVID-19 pandemic. We received 146 comments between May 19, 2021 and July 12, 2021, which can be read in full on our Public Comment Page[3]. This document responds to those comments.

May 2022: After reviewing all responses, and making changes to the draft general permit based on input received, Ecology made the determination to issue the final general permit for biosolids management to replace the expired one.

Summary of Changes

Ecology made changes to the permit and associated documents to improve clarity and readability. The following list outlines the more significant changes made between the draft version and final permit:

- Included a visual in section 1.2, *Structure of this General Permit,* of the final permit document to aid facilities in determining what sections of the permit their operations are subject to, as requested by several commenters.

[2] https://apps.ecology.wa.gov/publications/documents/2007017.pdf
[3] https://swm.ecology.commentinput.com/?id=SpmPs

- Revised section 2.1.2, *Automatic Coverage for Some Facilities*, of the final permit document to consistently represent automatic issuance of permit coverage for Baseline facilities. Facilities that do not have active management programs will be automatically covered on the effective date of this permit. Previous language was not clear.
- Updated section 2.3, *Maintaining Contact Information,* of the final permit document to specify that facilities must notify their biosolids coordinators of any changes in contact information, in order to increase effectiveness of communication. In the draft permit, this section simply required updated contact information to be communicated with Ecology.
- Updated sections 3.4.2 and 4.4.2, *Sampling and Analysis Plans*, of the final permit document to include reference to a list of approved analysis methods that Ecology will post and maintain our webpage, as several commenters requested. Previously this was included within the permit document. Making it available outside the permit document allows for more efficient maintenance, as analytical methods change, or are updated from time to time.
- Updated Table S3 in section 3.8.3, *Buffers*, of the final permit document to accurately show that land application of septage is not permitted on public contact sites, lawns, gardens, flooded, frozen, or snow-covered sites. In previous permit iterations, the table included asterisks next to these features which read as if application could be allowed if Ecology gave approval. However, Ecology never approved application to such sites previously and will not going forward, so this revision makes that clear.
- Revised the language in sections 3.2.2 and 4.3.2, *Identification and Notice to Interested Parties*, of the final permit document to include a process for appropriately removing interested parties if all attempts to notify fail to be delivered. Adopting this process encourages more efficient maintenance of interested parties' lists.
- Revised the language in sections 3.2.2 and 4.3.2, *Identification and Notice to Interested Parties*, of the final permit document to specify interested parties are persons who attend public meetings or hearings offered by Ecology's state biosolids program, not any public meetings or hearings. This clarifies who an interested party is.
- Ecology revised parts of section 4.6, *EQ Biosolids,* of the final permit document to better distinguish between first and second generation EQ biosolids, as requested by many commenters.
- Ecology added Section 4.6.1, *Plan Required for Second-Generation Products,* to the final permit document as well as correlating requirements in the new permit applications to identify when a plan is needed. This Plan for second-generation EQ products is a new requirement implemented based on EPA's recent updated interpretation of their regulations[4]. All generators of EQ products that manufacture second-generation EQ products will be required to submit a basic operational plan describing the products they manufacture, and how those products are managed on site. This plan will provide Ecology with information necessary to regulate facilities that produce second generation products.
- Included verbiage in Appendix B, *Minimum Content for a Site Specific Land Application Plan*, of the final permit document that allows facilities to request approval from Ecology to submit maps in size different from those previously stipulated. This was requested by at least one commenter, and will allow permittees to submit appropriate and professional maps.
- Removed Appendix C, *Delegation of Signature Authority*, from the permit document entirely. This document is available on Ecology's webpages, including it in the permit document is unnecessary.

[4] https://www.epa.gov/sites/default/files/2020-11/documents/land-application-classa-memo-2020.pdf

Including it in the permit could also restrict Ecology's ability to update it in the future.

- Updated the final active management permit applications to ensure compliance with any additional or more stringent requirements during the period of provisional approval, that were included as conditions for final approval under a previous permit. Although this was implied and practiced during previous permit iterations, including this verbiage in the active permit applications makes it more obvious to permittees.

Organization of the Response to Comments

Ecology thanks everyone who took the time to review the draft general permit for biosolids management and submit comments. We received 146 comments from individuals, organizations, local and state government, tribes, and businesses. We did our best to address each comment fully and appropriately. In order to achieve this, we split many comments up based on the topic(s) they focused on. We made a separate category for each topic we received comments on, and organized the Response based on those categories. This way, readers can find responses to topics of interest to them more easily.

In the event we received the same or similar remarks from multiple commenters, we combined them and responded to the collection of comments, rather than duplicating the response to each similar comment. We made note of any combinations so as not to lose sight of all who shared the same remarks.

We made no changes to the comments received, simply included them as they were submitted, including any references or citations to other literature. All comments received can also be read in full on our Public Comment Page[3].

Instead of including commenter names next to their submitted remarks, we compiled their names in a list and gave each a unique identifier to ensure each commenter will be able to easily locate their remarks. Identifiers are in the following format: "Letter-number-number". The letter corresponds to the type of commenter, (see Table 1 for an explanation of each commenter type), and the first number refers to the sequence in which that type of comment was received. The third number refers to the different parts of the comment that we split it into. For example, identifier I-200-4 represents the 200th *individual* who submitted a comment, and we are referencing the *4th* part of their comment.

Table 1

Comment Identifier	Commenter Type
I	Individual
O	Organization
LG	Local Government
SG	State Government
T	Washington Tribe
B	Businesses

Key Topic Discussions

During our review of comments on the Draft General Permit for Biosolids Management, we identified recurring topics and compiled key topic discussions below. This allowed us to provide background information and detail to illustrate complex subjects, while reducing the length of the response, instead of duplicating answers to individual comments. Many commenters will find we refer them to one or more of these discussions when applicable. Review of the key topic discussions would improve all readers' understanding of the biosolids program and our responses to individual comments in this document.

Drinking water standards inappropriate for biosolids

Some commenters argued that concentrations of pollutants in biosolids should meet standards for drinking water. Using the same arguement, we would also test other soil amendment materials such as commercial fertilizers, pesticides, compost, animal manures, and manufactured topsoil products against drinking water standards. They would all fail in some respect because we do not drink those substances. Drinking water standards are not meant to apply to them. Regulatory standards are specific to the material(s) they regulate. For example, standards for hazardous wastes are different from those for cleaning up sites impacted by the release of hazardous substances, just as standards for surface water are different from those for drinking water.

The U.S. EPA is working on a risk-screening tool for biosolids that will allow them to assess the risk of pollutants in biosolids following different pathway and exposure scenarios. The drinking water pathway is a standard consideration when analyzing the fate and transport of pollutants in many materials, including biosolids. The result of screening will help EPA determine if more investigation of a particular pollutant is needed for a specific pathway and management scenario. When the risk-screening tool is complete, EPA will have to prioritize contaminants for analysis. Those applicable to drinking water would be worth considering.

Groundwater protection and biosolids

Commenters expressed concern for potential impacts to groundwater. Ecology agrees that groundwater is a vital resource and should be protected.

EPA has and will again consider the potential for contamination of ground water in future risk analyses for pollutants in biosolids. Ecology's biosolids rules and permit program includes provisions to protect groundwater. Biosolids must be applied at an agronomic rate (unless it is a remediation site) supported by an authoritative source such as university cooperative extension guidance, or a professional soil scientist. Soil sampling for nitrogen is included in all site-specific land application plans for non-exceptional quality biosolids. Depending on the type of site and climate, sampling may be required post-harvest or pre-application. Soil sampling allows for experience-based adjustments to the rate of application and prevents long-term over applications that can lead to groundwater impacts. A plan to protect seasonally shallow groundwater (if present) is also required.

As part of the application process for approval of a specific land application site, applicants are required to identify surface and groundwater resources on or adjacent to the site. Specifically:

- The location and extent of any wetlands on the site.
- Any seasonal surface water bodies located on the site.

- Any perennial surface water bodies located on or within one-quarter mile (402 meters) of the site.
- The location of any wells located on or within one-quarter mile (402 meters) of the site that are listed in public records or otherwise known to the applicant, whether for domestic, irrigation, or other purposes.
- Buffer zones to features such as surface waters, wells, property boundaries, and roadways and the width of the buffer zones.
- Ecology considers the site-specific information provided above (and more) in making decisions about permit applications and site proposals. Ecology can impose additional or more stringent requirements where needed.

The presence of a pollutant in biosolids, however, does not mean that it will reach groundwater. There are different mechanisms at work in the soil that affect how the pollutants move through and interact with soil.

Soil generally carries a negative electrical charge because of the chemical structure of both the clay content of the soil and the organic matter component. Remember that opposites attract, and like charges repel each other. The nine regulated pollutants in biosolids occur in various forms, but generally with a positive charge. The negatively charged soil attracts the positively charged pollutant and holds on, making it less likely to end up in groundwater, or for that matter to be taken up by plants. In addition, the regulated pollutants generally occur in forms that are not highly soluble, meaning they do not dissolve easily, and are not available to plants under typical farming conditions.

Conversely, nitrate - a major plant nutrient - has a negative charge and is very soluble. It is the main nutrient in virtually every primary fertilizer product or substitute (e.g. manure). Nitrate dissolves in water readily, instead of binding to the soil. This means that nitrate can be leached out of the soil profile and downward toward drinking water. To avoid nitrate ending up in groundwater, biosolids are applied at agronomic rates. Applicators also conduct post-harvest or pre-application soil sampling, and the results allow year-to-year adjustments in application rates.

Per- and Polyfluoroalkyl Substances (PFAS)[5] are presently of great interest to many and are found in biosolids. PFAS are manufactured chemicals that are commonly used in many of the items we come into contact with every day. For example, they help keep food from sticking to its packaging, coat carpets and fabrics as stain-repellants, and are found in cleaning products and firefighting foam.

Contamination of groundwater with PFAS compounds has been documented, primarily in association with the use of firefighting foams (especially near firefighting training facilities), and facilities that manufacture PFAS (none in Washington state). PFAS compounds are complex molecules and generalizations are risky. That being said, some forms of PFAS are more soluble than others, some at least are toxic to varying degrees, they tend to be persistent (they do not break down completely), and can accumulate through the food chain.

Two types of PFAS that were historically used in large quantities are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS)[6]. PFOS was phased out of use in the United States starting in 2002, and PFOA was phased out by 2015. As a result, we have seen decreased levels of both compounds in biosolids,

[5] https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos
[6] https://www.epa.gov/ground-water-and-drinking-water/supporting-documents-drinking-water-health-advisories-pfoa-and-pfos

showing that source control is an appropriate and effective action to minimize exposure.

A few states have set very low regulatory levels for PFAS in biosolids, but most states have not taken action yet. Both EPA and Ecology are targeting PFAS for further investigation and scrutiny. Ecology is implementing a Chemical Action Plan[7] - a non-regulatory strategy to address PFAS, which includes additional commitments regarding biosolids, and from programs across the agency.

Ecology is awaiting the results of an Ecology study of PFAS in wastewater treatment plant influent, effluent, and biosolids that the commenter referenced. This study is far too small (only three wastewater treatment plants included) to stipulate any regulatory action, especially because there is no established regulatory standard with which to compare these results. However, it allows us a small glimpse into what is happening with respect to PFAS at those wastewater treatment plants specifically. Ecology plans to work with U.S. EPA to perform soil sampling on some existing biosolids land application sites. EPA will conduct additional risk analysis using a new risk-screening tool (draft expected to the EPA Science Advisory Board in 2022). Ecology has relatively new authority to ban the use of PFAS in manifacturing[7] if they are considered to pose unacceptable risks and there are other compounds that can be used in their place. Ecology has established a cleanup level under the state Model Toxic Control Act, and our State Department of Health has adopted standards for drinking water.

Heavy metals and biosolids

Commenters expressed concern about the presence of *heavy metals* in biosolids. While there is no consistent definition of the term, it carries a connotation of toxicity that is not necessarily correct and is frequently used when referring to regulated pollutants in biosolids. But in reality, it has not been defined in any meaningful way, and over the years because of its prolific use in a variety of ways has essentially lost any true meaning[8].

The nine pollutants currently regulated in biosolids include:

- Selenium – an mineral essential for plant and human health, and not a metal.
- Arsenic – a metalloid
- Copper – a metal and essential mineral for plant and human health
- Zinc – a metal and essential mineral for plant and human health
- Cadmium – a metal
- Lead – a metal
- Mercury - a metal
- Molybdenum – a metal
- Nickel – a metal

Overall, the concentration of regulated pollutants in Washington biosolids is low enough that it would require centuries or even millennia, to reach the level where the accumulated pollutant would become a concern.

It's also important to note that concentrations of lead and other pollutants in biosolids have declined

[7] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals/PFAS
[8] https://doi.org/10.1351/pac200274050793

significantly over the years. Various factors have contributed to their decline, including the implementation of pretreatment requirements for industries and businesses that discharge significant amounts of pollutants, other regulatory limits impacting manufacturer uses, and consumer pressures and purchasing habits. Ecology expects that will continue to be the case. The bottom line is that the land application of biosolids does not create a significant risk to human health or the environment due to the presence of "heavy metals."

Understanding regulated pollutants in biosolids

Commenters remarked about large numbers of pollutants in biosolids. We have heard concerned parties' comments that there are 60,000 to 80,000 pollutants in biosolids, up to even a nearly infinite number. Let's examine the world of chemicals.

Materials that can be dumped, poured, or swept into a drain, can end up in a sewer system. However, we want the reader to understand there are many barriers and processes that work to remove, dilute, or alter materials during the process between entrance to the sewer system and the production of biosolids suitable for land application.

The definitive source for chemical substances is the Chemical Abstracts Service (CAS) Registry maintained by the American Chemistry Society. You can learn more at the CAS website[9]. There are some 250,000,000 chemicals identified in CAS, including innocuous but necessary things like proteins and nucleic acids, which make up our very DNA. So while there are in fact millions and millions of chemical substances, they are not all toxic and not all used in manufacturing.

Ecology believes the references to sixty to eighty thousand chemicals in biosolids comes from a list maintained by U.S. EPA under the Toxic Substances Control Act (TSCA). Substances on the list are those that have been introduced in commerce. Contrary to the implications of the program title, they are not necessarily toxic. Being informed about their presence in commerce allows us a chance to consider downsides like toxicity. EPA says there are currently 86,607 chemicals on the list, but only 41,953 are in use. You can learn more on EPA's web[10]. For a well-written article on why knowing the number of chemicals in commerce can be difficult, this article posted to the International Council of Chemical Associations[11]is helpful.

If there are some 40,000-plus chemicals circulating in commerce, it is unlikely they will all end up in our biosolids. Many large industries engaged in manufacturing have their own wastewater treatment systems, separate from the public sewer system. Remember too that not all of those substances are toxic, and many do not survive the wastewater treatment process.

When considering risk, a pathway of exposure is critical. Many of the substances about which commenters are concerned are used in manufacturing products intended for everyday use, such as non-stick cooking pans and utensils, water resistant and waterproof fabrics and coatings, cosmetics and food packaging. Everyone is exposed to those substances during everyday activities; usually the closer you are to the product of concern or source, the greater your exposure. Pathways of exposure could include eating and drinking, touching, and breathing (due to particulates-house dust) gasses volatilized from those things. Some of those substances

[9] https://www.cas.org/cas-data/cas-registry
[10] https://www.epa.gov/tsca-inventory/how-access-tsca-inventory
[11] https://icca-chem.org/news/how-do-we-calculate-the-number-of-chemicals-in-use-around-the-globe/

enter the wastewater treatment system as well, from your home to the public sewer, or from the septage or effluent of your onsite wastewater treatment system.

Ecology acknowledges that there are chemicals in biosolids that are not regulated. We agree that research and adjustment to regulations as we learn more is necessary to continue protecting human health and the environment.

In 2018, the Office of the Inspector General released a report titled, "EPA Unable to Assess the Impact of Hundreds of Unregulated Pollutants in Land-Applied Biosolids on Human Health and the Environment."[12] As noted in response to other comments, Ecology has taken issue with the (lack of) objectivity in preparing that report. You can read more about Ecology's opinion on the OIG report on page 10 of these key topic discussions.

The OIG report said that EPA, "...lacked the data or risk assessment tools needed to make a determination on the safety of 352 pollutants found in biosolids."

It is important to understand the OIG did not do any original work to develop a list of pollutants requiring regulation in biosolids. Rather, they simply went to the information EPA had already developed around the national biosolids program. They go on to say, "The EPA identified these pollutants in a variety of studies from 1989 through 2015."

The Clean Water Act, which is the national law that directs EPA to do some of its most important work, requires the agency to review their biosolids regulations every two years and identify any additional pollutants that may occur in biosolids. EPA is authorized to regulate any pollutant *if sufficient scientific evidence* shows it may harm human health or the environment. This is where the OIG got their list of 352 pollutants.

So clearly, EPA has been at work identifying pollutants. In fact, through national sewage sludge surveys and periodic analysis of available information, EPA has identified more than 700 potential pollutants in biosolids.

This list is comprised of substances that have been reported to the EPA or identified by the EPA in biosolids. Their simple presence in biosolids does not mean there is a significant risk to human health or the environment. At this time, there is either insufficient evidence to justify regulating substances on the list, or EPA does not have the right tool - the right technical method - to assess the risk from the presence of the substance in biosolids. *It is essentially a watch list* – and at this point a very active one. The fact that EPA has been tracking potential pollutants in biosolids, and that the list has grown in the last few years, is clear evidence that the agency is not ignoring its duty.

But how can there be so many pollutants, even if only some hundreds as opposed to thousands, in biosolids, and EPA not know whether they should regulate them or not? It is very difficult to establish pollutant thresholds. It is one thing to know whether something is toxic to some degree, in some circumstance. It is another thing to link the release of a pollutant to an adverse impact. EPA did that in 1993 when they released the original federal biosolids rules in 40 CFR Part 503[13]. In support of their decision to regulate the nine pollutants currently regulated in federal rules, EPA described 14 pathways of exposure. They built

[12] https://www.epa.gov/sites/default/files/2018-11/documents/_epaoig_20181115-19-p-0002.pdf
[13] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-O/part-503

assumptions about the amount of exposure into each pathway, then assessed the potential for adverse impacts at that endpoint of each pathway. The result was a decision to regulate nine specific pollutants (see our discussion on heavy metals and biosolids on page 4) that EPA knew occurred in biosolids, and at times in excess of thresholds that were safe in the environment.

To conduct assessments of the current list of substances, EPA needs a better understanding of their presence in biosolids, their fate and transportation in the environment, and their toxicity. Some of this is known for a number of these substances, but not all of them. The EPA also needs to establish appropriate scenarios for exposure because not all contaminants harm people or the environment in the same way.

As some commenters have pointed out, EPA did their work in support of the federal biosolids rules, many years ago. Some methods of analysis have changed, and our knowledge of chemical behaviors is much improved. But EPA needs a better tool to evaluate substances of concern in biosolids. EPA has revised pathways of exposure from their early work - refined them so that they will be more discerning. That is one piece of the puzzle. EPA plans to submit a new biosolids risk-screening tool to their Science Advisory Board, in the near future. The tool will help EPA set aside potential pollutants that simply do not appear likely to pose a threat, and allow EPA to focus resources where they will do the most good. The draft tool will be announced to the public and reviewed by EPA's Science Advisory Board[14] (SAB). The SAB is comprised of a core group of advisors, and then various committees that may be expanded to meet the needs of specific review. Members are appointed to committees following a public nomination and vetting process.

Biosolids beneficial use has a positive impact on our environment. Some commenters advocate for processes like incineration, or simply landfilling biosolids, however both of those options present risks themselves. Neither destroys all of the pollutants in biosolids, and both release pollutants to the environment that have adverse impacts. They also encourage complacency: out of sight, out of mind. We have known for many years that in the long term, practices that depend on disposal are not sustainable. By addressing substances in biosolids that concern us, we can ultimately change manufacturing practices and purchasing habits. In turn, we can expect to see reductions in those substances in not only biosolids, but also wastewater effluent. Implementing a better biosolids program becomes an index of our success, long-term, at protecting the environment.

Getting well water tested

At least one commenter remarked about the potential for pollutants in biosolids to impact drinking water supplies, and that the government had not tested their well. It occurred to us then that others might have the same concern, or in general not understand how to check the quality of individual supply wells.

Public and private water supplies that supply community groups are required to perform testing for certain criteria. We want to emphasize that there are no requirements for sampling and analysis of *individual* supply wells for any drinking water standard. That is left to the responsibility of the homeowner.

Homeowners can get an indication of water quality by sampling for two common pollutants of concern: nitrate and coliform bacteria. Nitrate is a major plant nutrient and component of fertilizers (it also occurs naturally in soils). Because of its negative charge, it doesn't bind well in the predominantly negatively charged

[14] https://www.epa.gov/aboutepa/about-science-advisory-board-sab-and-sab-staff-office

soil matrix (remember opposites attract) and any excess can migrate to groundwater.

The presence of coliform bacteria in a drinking water supply indicates environmental contamination. If fecal coliform (a subgroup of coliform bacteria) are found, that indicates contamination by waste from people or animals. Bacteria can enter a drinking water supply around poorly sealed wells, especially where animals are allowed to congregate near the wellhead. The cost for analyzing nitrate and coliform is relatively low - generally less than a hundred dollars for both - and homeowners can collect their own samples. At the time a house is sold, it is typical to have the onsite sewage system pumped. Pumpers may be able to collect and submit water samples for analysis on request. A homeowner could expand on the list of analytes to include any number of pollutants, but costs rise sharply for some analytes.

We believe that homeowners checking the quality of water in their individual supply well is a good practice in general. Start by reaching out to your local health jurisdiction[15] as they may have an established well water-testing program. Follow their sampling instructions and submit samples to an accredited lab[16].

If your health jurisdiction does not have an established program, find an accredited lab near you to inquire about well water sampling. In addition to the link for a list of accredited drinking water labs above, you can also search on Ecology's web[17] for accredited labs.

Below are some links that may be helpful.

Unites States Environmental Protection Agency

This Water Testing Guide,[18] designed for the general public, can help homeowners understand what to look for in their water supply, and how to protect it.

"Drinking Water From Household Wells"[19] is a seventeen-page document written to help homeowners understand and protect their individual supply well.

"Quick Guide To Drinking Water Sample Collection"[20], is a twenty-page document describing how to collect samples.

Washington State Department of Ecology

Ecology's private well guide[21] has information for homeowners with private wells.

Washington State Department of Health

Testing Your Water[22] from the State Department of Health on how to test your water.

[15] https://doh.wa.gov/about-us/washingtons-public-health-system/washington-state-local-health-jurisdictions
[16] https://apps.ecology.wa.gov/laboratorysearch/appfiles/DWLabs_WAByCounty.pdf
[17] https://apps.ecology.wa.gov/laboratorysearch/
[18] https://www.epa.gov/privatewells/protect-your-homes-water#welltestanchor
[19] https://nepis.epa.gov/Exe/ZyPDF.cgi/200024OD.PDF?Dockey=200024OD.PDF
[20] https://www.epa.gov/sites/default/files/2015-11/documents/drinking_water_sample_collection.pdf
[21] https://apps.ecology.wa.gov/publications/documents/0611021.pdf
[22] https://www.doh.wa.gov/CommunityandEnvironment/DrinkingWater/Contaminants/TestingYourWater

Monetary incentive

Some commenters expressed the belief that beneficial use occurs (perhaps only) because there is an inappropriate monetary incentive from which Ecology and/or others benefit. Commenters did not support this view except to say that some Ecology staff get paid to implement the program, and therefore have a stake in seeing it not fail. Ecology does not support this view. Staff implement a program required by law. Most importantly, staff live in Washington and share the consequences of their decisions with others. Ecology supports the beneficial use of biosolids because it is the best approach to managing an unavoidable product of wastewater treatment, and because it has clearly demonstrable benefits.

Ecology's biosolids program is supported by permit fees paid by all applicable facilities. Permittees/fee payers include publicly owned wastewater treatment plants, special utility districts, and small businesses such as land application service providers, biosolids composters, and onsite wastewater treatment (septic) system service providers (if they land apply). Ecology is not compensated and does not benefit from contractual arrangements between permit holders and service providers, and is generally not privy to financial details of contracts.

Understanding the 2018 Office of the Inspector General (OIG) report

Commenters point to a report issued by the U.S. Office of the Inspector General (OIG) in December 2018[12] as support for the idea that biosolids are toxic. The Inspector General is a separate federal agency and not part of the EPA. They function similarly to our State Auditor's Office. The OIG evaluates many federal programs. In so doing they help ensure that programs and agencies are operating consistent with their charges, and in compliance with a wide variety of laws, rules, and policies. Exactly what prompted the OIG to audit the federal biosolids program - whether it was the result of a complaint, some long-planned follow-up, or just a random audit, is unknown.

Ecology reviewed the OIG's draft report. We were in fact in agreement with some findings and recommendations critical of EPA's implementation of the federal biosolids program. We have been a critic of EPA's past decision to disinvest from the national biosolids program. EPA made that decision, allowing attrition of critical staff and shifting funds and resources to other activities because the agency identified biosolids management as a low-risk activity and elected to focus resources on more critical priorities. Ecology did not disagree with EPA's characterization of the program, nor with the agency's determination of relative priorities, which was their prerogative. But EPA's original commitment of staff and resources was modest (at very best) for a national program. Ecology was concerned about EPA's disinvestment because it meant a loss of technical support to states, and it meant EPA would not help the national program to improve over time. Ultimately, it meant the loss of critical institutional memory. We were also concerned because while EPA did not identify the program as even a modest risk, that feeling was clearly not shared by members of the public such as those who have commented here in opposition to the draft permit.

Although we certainly could agree with some findings of the OIG, we were shocked to see evident bias in the writing of the report, beginning with a title clearly designed to inflame, if not outright frighten readers before they can even consider the information presented in context. We identified other aspects of the report that reflected a lack of understanding on the part of the authors. Some incorrect inferences easily drawn from the report would include the idea that EPA has not taken steps to help ensure that beneficial use is safe, that all substances identified present risks to public health and/or the environment, and that the standards and

classifications of substances by other programs is directly relevant to biosolids management. EPA staff attempted to work with the OIG to produce a final product that fairly framed program shortcomings and contained recommendations to which the agency could respond. National stakeholder groups reached out to the OIG to try and understand. The OIG declined to meet with stakeholders. When routine discussions failed, EPA took the rare (as we understand) step of formally disputing the report, forcing the OIG to engage in a resolution process. The final report contained more than a dozen recommendations, nearly all of which EPA has addressed (quite some time ago).

In summary, Ecology agrees with some of the criticisms in the OIG report, and we agree that EPA needed to move the program forward by addressing some key issues, including in some cases further assessment of substances of concern. We were sorely disappointed with the less than objective and cooperative approach taken by the OIG. We also want to commend EPA for having re-engaged the national program before the OIG began its audit, and for the agency's clear commitment to program improvement and bolstering outreach and technical support to states. EPA's national program is moving in the right direction, including recent awards of nearly six million dollars to further study biosolids. To the extent the OIG report helped that along, we support it.

Consequences of ceasing all biosolids land application

Ecology understands that some commenters wish for land application of biosolids to cease. Ecology does not believe such action is consistent with, or necessary to comply with, our statutory directives in chapter RCW 70A.226[23]. It is also contrary to the provisions of the national program established by EPA. Commenters did not discuss the impacts of ceasing land application.

Ecology's considerations for program development include in some measure, elements of science, economics, and social impacts. For the sake of discussion, we can consider the consequence of withdrawing the draft permit and ordering all treatment works to begin disposing of biosolids by incineration or landfilling.

About half the treatment works in the state:

- Directly apply their own biosolids to the land.
- Send their biosolids to a second party who applies them to the land.
- Treat their biosolids so that they can be sold or given away directly to individuals as a soil amendment, substitute for commercial fertilizer, compost product, or as part of a soil product.

Some small businesses (service providers) have developed around beneficial uses, and are referred to as having "active" programs. These include:

- Privately owned compost facilities,
- Beneficial use facilities that perform land application services,
- Facilities that specialize in treating or land applying septage.

Onsite wastewater treatment system (septic) service providers who do not land apply biosolids themselves, still depend on the services of a publicly owned treatment works or another small business that does.

[23] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.226&full=true

At least 184 facilities do not have active biosolids management programs. These are facilities that:

- Hold biosolids for long terms (years) in surface impoundments
- Only send their biosolids to another facility for further treatment before beneficial use
- Dispose of their biosolids through incineration or to landfills

Among the facilities immediately above, are more than a hundred that operate surface impoundments (lagoons). All lagoon owners are expected to eventually remove biosolids for beneficial use under the current program. So, while most would not be immediately impacted, ending land application practices would eventually impact those facilities, and thus, the strong majority of facilities across the state.

Some of the 184 facilities above - primarily smaller treatment works, depend on the services of another facility for further treatment of their biosolids. As smaller treatment works grow with their populations, it may become less practical for them to rely on the services of another facility. They may want develop their own active beneficial use programs. If Ecology were to end beneficial use programs, some of those treatment works would look to deliver their biosolids to another facility prior to disposal (to save transportation costs, or to obtain necessary dewatering). Even under present circumstances, some treatment works accepting biosolids from others must cease doing so, often due to limitations on capacity. Disallowing beneficial uses would at a minimum impact the cost charged to generators by their receiving partners.

Fifteen facilities disposed of some biosolids, either by landfilling or incineration in 2020. For most, disposal was a short-term management need, and they would be impacted by the cessation of a beneficial use program. Those that rely on disposal as a long-term management solution (less than ten facilities) would not be impacted.

With beneficial use prohibited, facilities with active programs would have to begin diverting their biosolids to incinerators or landfills. The capacity for incineration (which does have environmental impacts) is not adequate to handle statewide production as there are only five incinerators in the entire state. Transportation logistics would make the option impractical for many. Landfill disposal (which also has environmental impacts) would be possible for some. Disposal would also result in much higher transportation costs for some facilities. We also need to consider impacts to owners of onsite (septic) treatment systems. Statewide capacity to manage septage is strained, and without land application as an option, extreme increases in costs for pumping could be expected. Whatever the case, the overall cost of management would escalate, resulting in higher costs to ratepayers - both individuals and businesses.

Note, above we said that *some* facilities would be able to dispose of biosolids in landfills. Setting aside questions of logistics and cost, landfills cannot accept liquids for disposal. For those facilities that do not have dewatering capability, there would be an added expense to either install dewatering equipment or send their biosolids to a facility that has this technology and capacity. In many cases, wastewater treatment plants have limited capacity for accepting materials outside of their typical operations.

Some commenters implied that if all biosolids were incinerated or landfilled, then no pollutants would be returned to the environment from biosolids beneficial use activities. However, this is not the case; incineration and landfills each have environmental impacts. Neither option would completely eliminate the release of pollutants to the environment, address the actual source of pollutants, or result in zero risk, and neither is a sustainable management option. Additionally, if all biosolids were disposed of, then the nutrient

value, organic matter, and carbon sequestration benefits of beneficial use would be lost. In 2020, about 103,000 dry tons of biosolids were beneficially used; we expect beneficial use for 2021 to be similar in quantity. If land application practices were ceased, all of this material would need to be disposed of via incineration or landfilling. Some commenters mention or allude to other technologies, like pyrolysis. Washington and the United States in general, has little experience with other technologies. Ecology does not have the resources to examine those alternatives unless they are proposed by a permittee.

Ecology received 147 comments on the draft general permit from individuals, organizations, businesses, tribes, state and local governments. While some represent organizations with large membership, there are about 7.7 million people in Washington overall. So we must weigh the merit of all comments, and the potential impact on residents of the state as a whole. Especially considering that the public and regulated community tend to comment when they object to something, rather than when they feel neutral or see something as a positive. Ecology cannot make decisions based on opinions alone.

As a regulatory agency it is our responsibility to make science-based decisions. It would be irresponsible to impose regulations, or bans on biosolids operations simply based on commenter opposition. In addition to considering public comments received, Ecology must base regulatory decisions on peer-reviewed research and years of practical experience. Since its inception, the Washington State biosolids program has been the subject of ongoing research in a variety of topic areas focused on the safety and efficacy of the beneficial use of biosolids. The science-based review of the biosolids program continues to demonstrate safety with regard to human health and the environment.

If Ecology prohibited beneficial use programs statewide, we would anticipate an immediate backlash from treatment works, small businesses, farmers, and the general public (i.e. ratepayers) statewide. As explained above, solid waste management costs would escalate sharply, contracts would be compromised or invalidated, and treatment works and small businesses would face exorbitant cost increases (and debt). Ecology would almost certainly face appeals of the decision, and would be asked to defend the decision with science – which we could not do. Despite some recent high-profile media coverage (around per- and polyfluoroalkyl substances in particular), the majority of beneficial use activities in the United States have proceeded without incident for decades. It is too early to speculate if new evidence of PFAS will result in changes to the program, and what those changes might be. At this point, Ecology does not see a scientific basis for ceasing beneficial use, and can easily see very large environmental, human health and financial consequences of doing so.

General vs. individual permits and expediting coverage

Commenters argued that a general permit is not adequate because only individual permits can address circumstances specific to individual facilities or sites.

Ecology established a general permit approach with the original adoption of state rules in 1997. The permit system in chapter 173-308 WAC[24] allows Ecology to use a general permit to establish an overarching framework of conditions and requirements for all applicable facilities. The general permit structure also allows Ecology to impose additional or more stringent requirements for individual facilities as a condition of

[24] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308&full=true

their final approval of coverage. Ecology must, however, have a defensible reason for the requirements.

Under the state program, facilities begin the general permit process by submitting a Notice of Intent (NOI) to obtain coverage, or to continue coverage if they were permitted under the previous general permit for biosolids management. Upon issuance of the general permit, facilities enter into a state of "provisional" approval, which allows them to operate in accordance with the rules, applicable general permit requirements, and the conditions of their permit application submitted to Ecology. Permittees are expected to understand their obligations and to seek technical assistance when needed. A permittee cannot justify non-compliance by arguing that their current or proposed operations supersede the requirements of the rule or general permit, or because Ecology has not reviewed their operations.

Under past general permits, the requirement to submit a permit application extended to all facilities. For the first time in the nearly twenty-five-year history of the biosolids permit program, Ecology intends to approve final coverage for existing facilities without active programs on the effective date of the permit. A permit application will not be required from those facilities. This comprises about half of the nearly 380 regulated facilities in the state. Ecology maintains records of these facilities, including all previous permit applications and Notices of Intent, ensuring they will not be overlooked.

Commenters expressed dismay at the idea of expediting permit coverage at all. Ecology considers it a major step forward in good business practices. None of the automatically covered facilities has active biosolids management programs. Many are lagoons where biosolids may sit for years (even decades) before they are removed. The bulk of the rest rely on sending biosolids they produce to other treatment works that further treat them before use or disposal. The facilities that benefit from the reduction in administrative burden are in many cases located in small communities with limited resources. The automatic coverage approach eliminates uncertainty for a group of facilities that are not directly carrying out any beneficial use of their biosolids. Making the permit process more efficient for some facilities avoids an administrative permit application process that creates a burden for the facilities and Ecology. In addition, the administrative burden created by the current permit process adds little to no value, as the information required in the application is already well documented. The information was collected in previous permit applications, a facility's notice of intent, and their annual reports. If a facility without an active program changes management practices, they will be required to submit a permit application at that time, also making the application more reflective of current conditions. Also importantly, the remaining group of facilities that must submit applications constitute a clear target upon which Ecology staff can focus attention. This is actually to the advantage of commenters who want Ecology to better focus its resources on beneficial use activities.

The process for approval under the general permit is robust. When facilities go through review for final approval of coverage, they must comply with State Environmental Policy Act requirements and notify interested parties. They also will be required to publish a notice in an area newspaper and post information at sites where biosolids are proposed to be applied. Ecology may require a public hearing, and interested parties can also request a public hearing.

Finally, Ecology has provided a means for interested parties to Register for Notifications[25] so they can be informed of any significant biosolids permit activity in a specific county), counties, or even statewide. We

[25] https://apps.ecology.wa.gov/solidwastefacilities/Subscriptions/Subscribe

have called this out in our permit process and on our website. Thus, the opportunity for individuals to be further informed and comment on concerns specific to a particular proposal is preserved, along with Ecology's ability to address those issues.

In summary, Ecology cannot support the argument that the general permit does not provide for an adequate overview of an applicant's proposal, or that utilizing individual permits would accomplish this more effectively.

Wastewater treatment process and biosolids

Commenters express the belief that pollutants discharged to a sewer system are extracted into biosolids during the wastewater treatment process. Therefore, biosolids contain every pollutant and contaminant that passes through a wastewater treatment process. That is not correct.

Many pollutants are broken down during treatment, and substances in the treatment process undergo *partitioning*. Partitioning means that pollutants can end up in the effluent (the final water discharge from the treatment process), in the air (volatilization), or in the solids (which can be treated to become biosolids) - or some combination. Pollutants may be dissolved and found in the effluent, or they can be associated with solids that settle or remain suspended.

To understand why contaminants end up where they do, it is helpful to understand a little more about wastewater operations. There are many ways to treat wastewater, and many different possible configurations for wastewater treatment plants. The explanation that follows is a general one.

Wastewater treatment plants operate under permits that specify criteria for the effluent they discharge. In order to meet those permit limits, solids must be removed from the wastewater. Whether a substance ends up in the effluent, in the air, or in the solids (which can be treated to become biosolids), depends on each pollutant's individual characteristics and the treatment process.

One of the criteria for discharges to surface water is the amount of Suspended Solids. Those are small particles that do not settle out during treatment. Biological Oxygen Demand is another criterion. It is a measure of oxygen consumed by microorganisms when they break down solids in the wastewater. Removal of solids from the wastewater is essential to meeting both criteria.

Primary treatment removes solids - what most people think of as actual sewage solids, although they may not appear as such. Removal of solids in this phase of treatment is accomplished in various ways. Trash is removed or reduced by grinding and or screening at the headworks (and sometimes before). Heavier materials - like rocks or pieces of glass are also removed at the start of the process. Additional solids are then removed in settling basins or clarifiers. The removed solids end up in a digester. Think of a digester as a composter for liquids. Conditions in the digester - including time and temperature - are monitored to ensure proper performance. Pollutants that partition to the solids fraction tend to end up in the digester, where they may be further broken down. Digestion stabilizes solids - breaks down the most easily decomposable elements, and reduces pathogens. In some systems, this is the final step to producing biosolids. Other systems employ additional treatment and processing technologies.

Wastewater treatment is a complex process and there are many things happening around the solids separation phase. Wastewater treatment involves processes that actually nurture microorganisms that consume solids in the wastewater. Treatment plant operators monitor the microorganisms in their treatment

process to ensure good performance and solve problems that arise with treatment. To be clear, wastewater treatment plants deliberately grow microorganisms to accomplish treatment. Those microorganisms were not present in the sewage that came into the plant. When those microorganisms have done their job, they need to be removed because they would contribute to the effluent's suspended solids and biological oxygen demand. So those microorganisms become part of the biosolids. The solids separated during primary and secondary processes are different in their nature, but the qualitative criteria for biosolids remain the same. After digestion, neither form of solids is the same as before digestion. You can liken this to a pile of lawn clippings that have been allowed to sit for a period of time. They start out looking like grass. If you mix them and encourage decomposition - composting - the end-product does not look like the original lawn clippings and becomes useful for other purposes.

Some processes do "extract" selected pollutants. One example of an advanced treatment process involves nurturing microorganisms that remove phosphorous from wastewater - biological phosphorous removal. Phosphorous is a major plant nutrient, but it causes problems in our surface waters. Removing the organisms that have collected the phosphorous, creates more biosolids with more phosphorous in them, but means better effluent discharged to our surface waters.

So, in general, wastewater treatment does not extract regulated pollutants into the solids portion. Rather, the solids are removed. Pollutants are captured with the solids depending on how they partition in the treatment process. Pollutants may or may not be changed in the treatment process, and if they tend to associate with the solids fraction in the wastewater treatment process, they can be found in the biosolids. When pollutants are not degraded during treatment and interfere with the operation of the treatment process or impair the quality of the solids or effluent, the solution to the problem is to look back up the pipe to the source. That is where the requirements of Ecology's pretreatment program kick in, and where manufacturing practices and consumer purchasing preferences can make a difference toward more sustainable wastewater management.

Food chain crops and biosolids

Commenters worry that much of our food is grown on soils amended with biosolids, and therefore the magnitude of potential impacts to health and the environment is just that much greater. As can be seen from the data below, that is incorrect. Well less than two-tenths of one percent of food chain crops in the state of Washington receive biosolids application annually.

Ecology requires an annual report from all permitted biosolids facilities in the state. Some data from the 2020 annual reports are provided below. They are similar and consistent with previous historical summaries, and no overall significant departures from past practices are expected looking forward to 2021 data.

2020 Biosolids Production and Use - Summary data in dry tons (rounded)

Total amount of biosolids used beneficially: 102,632.99 dry tons

Beneficial use of biosolids in Washington is approximately 86% of total production, with the rest disposed of or in storage. The percentage of biosolids beneficially used cannot increase much more unless one or more of the five communities that operate incinerators shift from disposal to beneficial use. Note that storage refers to biosolids that are generated and have become an obligation for use or disposal. Biosolids held in lagoons or drying beds are considered to be undergoing treatment. They become part of total production when they are removed.

In 2020, non-exceptional quality biosolids were applied to about 28,000 acres of land in Washington.

According to the American Farmland Trust[26] there are 43,279,500 acres of land in Washington, including 15,398,200 acres of agricultural land. Data from the U.S. census[27] puts Washington's land area at 66,466 square miles, or about 42,531,533 acres, including 16,469,678 acres of agricultural land (per the USDA Natural Agricultural Statistics Service[28]). Other sources show similar results.

Using the lower figure of available agricultural land of 15,398,200 acres, and the conservative (high-end) value of 30,000 acres receiving biosolids annually, we find that just about 0.2%, or two tenths of one percent of farmland receives biosolids each year. Keep in mind that not all biosolids are applied to farmlands, and not all land characterized as agricultural is used to grow food chain crops. So we can objectively say that well less than 0.2%, or two-tenths of one percent of food chain crops receive biosolids annually.

For the purposes of the national rule, EPA assumed that 2% of agricultural land would receive biosolids in a year – about ten times as much as in Washington. When characterizing risk, exposure is a key criterion. From this data, we can see that the amount of food crops receiving biosolids is quite small, and the potential for a typical individual to obtain a significant amount of their diet from crops grown on biosolids is very small.

Finally, it is worth noting that uptake of pollutants by crops is variable, and certainly not 100%. While data are still being collected on per- and polyfluoroalkyl substances (and ultimately wanted on other substances), many studies have documented the lack of mobility - including through crop uptake - of currently regulated pollutants (AKA heavy metals) in biosolids. Available data suggest that concentrations of PFAS in biosolids are about 1,000 times *less* than concentrations of currently regulated pollutants. We do want to point out that the concentration of a pollutant in biosolids is just one consideration of many in evaluating risk.

[26] https://farmlandinfo.org/statistics/washington-statistics/
[27] https://www.census.gov/quickfacts/WA
[28] https://www.nass.usda.gov/Statistics_by_State/Washington/index.php

Comment Categories

The comments received were reviewed and evaluated by Washington State Department of Ecology. Comments were categorized into 35 areas for response, though many comments touched on aspects of more than one comment category. The comment categories include:

1 Contaminants in biosolids

2 Public Notice

3 Monetary incentives

4 Ceasing land app

5 OIG Report

6 Food chain crops

7 Permit Process

8 Sampling

9 Environmental Justice

10 Buffers

11 EQ Products

12 Alternative Management Methods

13 Transportation

14 Jurisdiction

15 Labeling

16 Liability

17 Acknowledgement

18 Posting of Sites

19 Enforcement

20 Climate Change

21 Site Specific Comment

22 Beneficial Use

23 Protecting Water Resources

24 Terms/Definitions

25 Program Authority

26 SEPA

27 T and E Species

28 Manures

29 Rules

30 Right to Farm

31 Clarifications

32 EPA Federal Program

33 CAP

34 Fertilizer Registration

35. Forestland Application

List of Commenters

A total of 146 persons provided comments regarding the draft documents. In the comment table, each commenter is referenced by an assigned commenter number.

- Steve Reinhart , Commenter: I-1
- Olivia Stone , Commenter: I-2
- Janet Migaki , Commenter: I-3
- Paula Atti , Commenter: I-4
- Judy Golden , Commenter: I-5
- Linda Braune , Commenter: I-6
- Lou Stone , Commenter: I-7
- Sally Duffy , Commenter: I-8
- Diane Emerson , Commenter: I-9
- Kate Ryan , Commenter: I-10
- Shawn Holmes , Commenter: I-11
- Nance Van Winckel , Commenter: I-12
- Bonnie Mager , Commenter: I-13
- Caesare Assad , Commenter: I-14
- Karen Rhodes , Commenter: I-15
- Terri Thomas , Commenter: I-16
- Ann Keane , Commenter: I-17
- Carrie Anderson , Commenter: I-18
- Julie Summers , Commenter: I-19
- Kathleen Johnson , Commenter: I-20
- Mark Kreilkamp , Commenter: I-21
- Judy Avery , Commenter: I-22
- Mary and Brian Jokela , Commenter: I-23
- Rose Fanger , Commenter: I-24
- Jody Thorsen Grage , Commenter: I-25
- Annette Cottrell , Commenter: I-26
- Kathleen Allen , Commenter: I-27
- Aileen Kane , Commenter: I-28
- Jason , Commenter: I-29
- Linda Carroll , Commenter: I-30
- Sheryl Krohne , Commenter: I-31
- Lupito Flores , Commenter: I-32
- David Losie , Commenter: I-33
- Kari Mueller , Commenter: I-34
- Devlan Pool , Commenter: I-35
- Annie Herrera , Commenter: I-36
- Linda Knowlton , Commenter: I-37
- D Robinson , Commenter: I-38
- Annonymous, Commenter: I-39
- Kyle Hartmeier , Commenter: I-40
- Anonymous, Commenter: I-41
- Trevor Dodge , Commenter: I-42
- Norman Baker , Commenter: I-43
- Brenda Yates , Commenter: I-44
- Caelan Angell , Commenter: I-45
- Anna Pymander , Commenter: I-46
- Doris Cellarius , Commenter: I-47
- Chrys Ostrander , Commenter: I-48
- Morton Alexander , Commenter: I-49
- Jor Piver , Commenter: I-50
- Nancy Foll , Commenter: I-51
- Jo Bohna , Commenter: I-52
- Denise Trabbic-Pointer , Commenter: I-53
- Harry Branch , Commenter: I-54
- JJ Lindsey , Commenter: I-55
- Glen Anderson , Commenter: I-56
- Chris Eaton , Commenter: I-57
- Rebecca Deardorff , Commenter: I-58
- Paula Shafransky , Commenter: I-59
- Laura Harris , Commenter: I-60
- Sandra King , Commenter: I-61
- Larry McCarter , Commenter: I-62
- Debbie Stanley , Commenter: I-63
- P Ellerby , Commenter: I-64
- Dennis , Commenter: I-65
- Phyllis Silver , Commenter: I-66
- Paige Kenney , Commenter: I-67
- Annonymous Commenter: I-68
- Kraig Schwartz , Commenter: I-69
- Annonymous, Commenter: I-70
- Monica Aebly , Commenter: I-71
- Matt Wright , Commenter: I-72
- Richard Taylor , Commenter: I-73
- Eleanor Mattice , Commenter: I-74

- Sarah Monaco , Commenter: I-75
- Rachel Hultengren , Commenter: I-76
- Marah Hulse , Commenter: I-77
- David Houle , Commenter: I-78
- Josette Gates , Commenter: I-79
- Alex Smith , Commenter: I-80
- Linda Myriah Pazereckas Roy , Commenter: I-81
- Marguerite Winkel , Commenter: I-82
- Janet Glenn , Commenter: I-83
- Hilary Ohm , Commenter: I-84
- David Green , Commenter: I-85
- Margaret Drumm , Commenter: I-86
- Rebecca Stiles , Commenter: I-87
- Andrea Johns , Commenter: I-88
- Mark Walker , Commenter: I-89
- Marisa Hendron , Commenter: I-90
- Susan Kyle , Commenter: I-91
- Crystal Olmo , Commenter: I-92
- Olivia Ramon , Commenter: I-93
- Natia Tucker , Commenter: I-94
- Nichole Woolsey , Commenter: I-95
- Jennifer Spiegelberg , Commenter: I-96
- Lisa Peterson , Commenter: I-97
- Michael Hagar , Commenter: I-98
- Amber Wright , Commenter: I-99
- Amy Martin , Commenter: I-100
- Porter Andrea , Commenter: I-101
- Debra Conklin , Commenter: I-102
- Aubrey Steedman , Commenter: I-103
- J Merryman , Commenter: I-104
- Denise Trabbic-Pointer , Commenter: I-105
- Gwen Innes , Commenter: I-106
- Nils Johnson , Commenter: I-107
- Jacob McLellan , Commenter: I-108
- Wyatt Golding , Commenter: I-109
- Wyatt Golding , Commenter: I-110
- Suzanne G. Builta , Commenter: I-111
- *Comment I-112 omitted. Duplicate comment and commenter*
- Monica Lowney , Commenter: I-113
- Jean Jarecki , Commenter: I-114
- Robert and Linda Capps , Commenter: I-115
- Michael Pilarski , Commenter: I-116
- Michelle and James Brigham , Commenter: I-117
- Constance Ibsen , Commenter: I-118
- Leigh Ost , Commenter: I-119
- Stanley Jackowski , Commenter: I-120
- David Losie , Commenter: I-121
- Deanne Burdine , Commenter: I-122
- Heather Trim, Commenter: I-123
- Allen R. Guenther, Commenter: I-124

- Earth Ministry/Washington Interfaith Power & Light (LeeAnne Beres) , Commenter: O-1
- Friends of Toppenish Creek (Jean Mendoza) , Commenter: O-2
- Northwest Biosolids (Liz Truong) , Commenter: O-3
- Far West Agribusiness Associaiton (Margaret Bahns-Jensen) , Commenter: O-4
- RE Sources (Kirsten McDade) , Commenter: O-5
- City of Wenatchee (Jessica Shaw) , Commenter: O-6
- WA State Sierra Club Chapter ( ) , Commenter: O-7
- Sierra Club/Toxic Free Future (Laurie Valeriano) , Commenter: O-8
- Zero Waste Washington (Heather Trim) , Commenter: O-9
- Pierce County Planning and Public Works (Karla Guevarra) , Commenter: LG-1
- LOTT Clean Water Alliance (Wendy Steffensen) , Commenter: LG-2
- King County Wastewater Treatment Division (Kamuron Gurol) , Commenter: LG-3
- City of Tacoma (Dan Thompson) , Commenter: LG-4
- Discovery Clean Water Alliance (Robin Krause) , Commenter: LG-5
- City of Vancouver (Frank Dick) , Commenter: LG-6
- Three Rivers Regional Wastewater Authority (Duane Leaf) , Commenter: LG-7
- Wa Dept of Ecology - SWM Program, SWRO (William Harris) , Commenter: SG-1
- Department of Health (Washington State Department of Health) , Commenter: SG-2
- Washington State Department of Agriculture (Kelle Davis) , Commenter: SG-3
- FIRE MOUNTAIN FARMS (Ryan Thode) , Commenter: B-1
- The Oasis (James Schierman) , Commenter: B-2
- Bio Recycling Corporation (Bio Recycling Corporation) , Commenter: B-3
- Nisqually Indian Tribe - Natural Resources (David Troutt) , Commenter: T-1

Comments and Responses

1. Contaminants in biosolids

Comment	Response
I-1-1 Having a Waste Water Treatment Plant operator's license, I know a little about the high loads of toxics in processed sewage coming out of residuals wastewater treatment plants. I would like to know how you are planning to assess and then remove the toxic loads of lead, mercury, cadmium, copper PCBs household cleaners and everything else people flush down their toilets that end up in the waste water "bio solids"? In the "processed bio-waste you are planning to spread all over the place, before spreading it all over the place how are you planning to remove all of the toxics? Sure human poop & pee is great compost but the collective load from runoff that comes from the streets and that's flushed down peoples toilets is a serious problem. I know of no system presently available that can remove toxic trace elements on an industrial scale like the one you are proposing here. Yes, please publicly present these comments and also please explain to me how you plan to remove the toxic trace elements from the "processed bio-waste. Thank You. I'm looking forward to hearing from you and hearing your insights on how you plan on resolving this old and well known toxic trace elements problem.	I-1-1 Beneficial use of biosolids is an established practice. It has been happening in the U.S. for about a hundred years, and in Washington for more than forty years. About half the facilities in the state have active beneficial use programs. Nearly all of those that do not, rely on another treatment works that does. It is important to recognize that the presence of a contaminant does not necessarily mean there is a risk to human health and the environment. Although Ecology recognizes the presence of trace contaminants in biosolids, many factors determine risk, including but not limited to concentration, toxicity, and pathway of exposure to the contaminants. EPA performed an extensive risk analysis in support of the original federal rule. They have periodically evaluated various contaminants in the years since, and are preparing to implement a new risk-screening tool. In general, we have seen the presence of contaminants decrease significantly over the last two decades, brought about due to shifts in manufacturing practices, consumer habits, and environmental regulations. Concentrations of regulated pollutants in biosolids in Washington are typically far below the lower threshold set by EPA. Science-based review continues to demonstrate that beneficial use is safe when rules and permit requirements are followed. In addition to the response above, Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "The wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", and "Heavy metals and biosolids".

Comment	Response
I-3-2, I-21-2 Toxic contaminants found in biosolids can be taken up by plants (eaten by humans) and animals (eaten by humans).	I-3-2 A large amount of research has been conducted, and will continue on both regulated and unregulated pollutants with respect to plant uptake and food chain impacts Regulated pollutants are not in a form that plants can uptake under normal application and growing conditions. In some cases, plant uptake has been seen in non-edible portions of a plant. For example, pollutant concentrations could be detected in wheat roots, but not in the grain. Since we harvest and eat the grain, not the wheat roots, this does not constitute a risk to the consumer. However, the crop greatly benefits from the additional macro and micronutrients provided by the biosolids that are often leached from soils by farming. Many biosolids studies looking at pollutant uptake by plants use worst-case scenarios that are not seen in actual practice. For example, studies often use highly contaminated biosolids, biosolids spiked with contaminants, rates of excessive application, or a combination thereof. To our knowledge there are no definitive studies showing pollutants in edible portions of plants resulting from biosolids application rates typical of actual practices. It is helpful to keep in mind that biosolids are applied to only a small amount of agricultural land, and an even smaller amount of the land base overall. Because most contaminants are found only at very low levels, the exposure potential is also very small. Ecology supports the idea of reducing contaminants in the environment, and will continue to work in that direction. Please see the key topics discussion titled “Food chain crops and biosolids” at the start of this response to comments for more information.

Comment	Response
I-4-1 Biosolids need to be dealt with, but not by reintroducing these toxic materials back into our soils and water ways. Our vegetables and fruits are only as good as the soils that we grow them in. We should be rebuilding soils, not contaminating them. There is NO evidence that biosolids are safe. Period. It's time that we interrupt the legacy of doing what's convenient and easy in the moment while blindly ignoring its future ramifications.	I-4-1 We all contribute to the production of biosolids. Wastewater treatment is essential to maintain public health. A large part of biosolids consists of beneficial microorganisms that are grown and nurtured during the wastewater treatment process. Without those organisms, we cannot treat wastewater. Disposing of all biosolids by landfill or incineration is not feasible for many reasons. Refer to the key discussion titled "Consequences of ceasing all biosolids land application" for additional information. In Washington, we prioritize the beneficial use of biosolids over disposal. The state biosolids program is based on federal regulations that are designed to be protective of human health and the environment. It is important to recognize that the presence of a contaminant does not necessarily mean there is a risk to human health and the environment. Although Ecology recognizes the presence of trace contaminants in biosolids, there are many other factors that determine whether a practice is safe, including concentration, toxicity, and pathway of exposure to the contaminants. A 2015 combined publication from Oregon State University, University of Idaho, and Washington State University[29] provides the following information: • Biosolids are an effective replacement for commercial Nitrogen; • The combination of increased soil organic matter, increased soil nutrients, and improved soil physical properties following biosolids application can produce higher crop yields. • Biosolids increase soil organic matter; • Biosolids application enriches the supply of immobile nutrients such as P and Zinc; • Soil salinity (can cause problems in certain climates) remains low after repeated applications

[29] https://catalog.extension.oregonstate.edu/pnw508

Comment	Response
	of biosolids; Biosolids applications are also limited to locations that have been reviewed and deemed appropriate for use. Many factors are taken into account when evaluating a site for biosolids land application including the agricultural practices in use, the environmental characteristics like proximity to surface and ground water, and wildlife living in the area. Within these evaluated sites, buffers are established to limit application and protect the environment including our state waterways.
I-7-3, I-13-3,I- 23-3, I-25-1, I-32-1, I-49-3 My main concern with a five-year re-authorization of how the Department of Ecology manages the program of land application of sewage sludge is that the material is host to an unknown amount of contaminants which constantly go down the drain in municipalities. They only test for nine heavy metals, nitrogen and selected pathogens. Unexamined are the many chemicals, micro-plastics, pharmaceuticals, and the infamous alphabet soup of ubiquitous super toxins now headed by PFAS (Per- and PolyFluoroAlkyl Substances).	I-7-3 EPA conducted an extensive risk assessment prior to developing the federal biosolids rule. EPA later performed a risk assessment on dioxins, furans, and coplanar PCBs in biosolids. Three targeted national sewage sludge surveys have been conducted since the original to assess contaminants in biosolids thought to pose risks to human health and the environment. EPA also reviews information available on pollutants in biosolids every two years. Contaminants in biosolids are generally present in small amounts, but the presence of a contaminant does not mean there is a risk to human health and the environment. There are many other factors that determine whether a practice is safe, including concentration, toxicity, and pathway of exposure to the contaminants. Decades of research and practical experience support that the beneficial use of biosolids is safe when applicable rules and proper management practices are followed. Ecology is currently involved with the EPA's Office of Research and Development (ORD) to assess Per- and polyfluoroalkyl Substances (PFAS) in Washington's biosolids. ORD is one of the leading research institutions in the world regarding analysis of PFAS in complex organic compounds such as biosolids. Setting regulatory standards often results in large economic impacts on public and private wastewater treatment plants that serve Washington communities.

Comment	Response
	Increased costs are passed along to the communities they serve, meaning an increased water or sewer bill. EPA has conducted expanded sampling in the past, and we expect will continue to do so. To date, that expanded testing, has not identified the need to regulate additional pollutants. If additional pollutants requiring regulation are identified, Ecology can modify the general permit and or rules, and implement additional sampling requirements. In addition to the response above, Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "The wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", and "Heavy metals and biosolids".
I-9-1 Having worked in the specialty chemical industry for 17 years, many of those years in production and research, I know what industrial companies put down the drain. I see how it is less costly to pay the fines than dispose of these toxic chemicals correctly. The mix of toxic chemicals found in sewage sludge changes daily, depending on who is dumping what that day. It cannot be adequately tested, nor can the companies doing the dumping be adequately policed or enforced in our current system. ...Finally, the state need to work on separating the human waste and food waste from the industrial waste. I don't put drain cleaner on my breakfast cereal. What goes into my body is far far safer than what industry dumps down the drain.	I-9-1 All treatment works in Washington operate under a discharge permit issued by Ecology's Water Quality Program. The discharge permit establishes pollutant limits for effluent (treated water) leaving the plant, and requires proper operation and maintenance of the facility. Some businesses and industries that discharge to the public sewer system are further regulated under Washington's pretreatment program. This program requires additional treatment and monitoring of industrial discharges to restrict the release of pollutants to the public sewer system. The additional treatment ensures pollutants do not exceed concentrations the public sewer system can handle. Not all treatment works discharge to the public sewer system, some businesses and industries have their own wastewater treatment facilities. The sludge that originates from these systems is regulated differently and not incorporated into biosolids that are land applied as a soil amendment On any given day, there may be periodic or temporary

Comment	Response
	increases in a particular discharge to the sewage system due to people's and businesses' changing activities. However, the impact from these varying discharges is generally not expected to be significant as most of what is discharged to the sewer is water, natural organic material, and silt or sand. So a significant effect on the quality of biosolids is also unlikely. Additionally, biosolids are not the product of a single day's activities. Biosolids accumulate over time and are treated in the aggregate - so they represent a sort of overall average of what comes into a treatment works over a period of time (which can range from a few weeks to several years, depending on the system). Please also see the key topics discussion titled "Food chain crops and biosolids" at the start of this response to comments for more information.
I-10-1 It's unconscionable to allow the spreading of sewage sludge on any land, let alone our forests and farmland. If it were a matter of being nothing but poop and pee from healthy people not taking any medications, etc. I could probably go along with it. But I cannot since it is acknowledged that there are an almost infinite number of chemical/rX/biological contaminants coming not only from people pooping, but from all the myriad businesses that have access to a sewer connection. Would love to believe that everyone complies with only putting what's allowed down the drain, but once again, it's universally acknowledged that is not the case. If you cannot guarantee that every cubic yard of sewage sludge is completely safe of any contamination, regardless how small, it cannot be considered safe to apply to the landscape.	I-10-1 Pleases see the response to comment I-7-3. In addition, Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "The wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", and "Heavy metals and biosolids".

Comment	Response
I-11-1 The use of this is a health and safety concern for the public, wildlife and ecosystems of the region among other unknown impacts bio solids will have when used in these ways.	I-11-1 Please see the response to comment I-7-3.
I-13-2 The application of these substances is the same as playing Russian Roulette with our health and the health of generations to come. These harmful substances contaminate the ground and make our food host to an unknown amount of contaminants as well as run off and constantly go down the drain in municipalities... It is the government's job to protect "We the People" from harmful chemicals indiscriminately flushed into our sewers. If we can't prove it is safe, we shouldn't be doing it. First, do no harm should be our motto.	I-13-2 The regulated biosolids program is based on significant risk assessments conducted over many years. In addition, we have improved the permitting process as it has matured over the last 23 years it has been in place. Please see the response to comment I-7-3. In addition, Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "Groundwater protection and biosolids", "Wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", "Heavy metals and biosolids", and "Food chain crops and biosolids".
I-17-1 I feels so primative to contaminate our water source of all well being to fertilize with our waste that includes bio pharmisudical. the current drugs taint our pristine eco system and this reflects the increase in immune system breakdown miss carriqages, autism one in 6 now. All are enviornmentally influenced.	I-17-1 The regulated biosolids program is based on significant risk assessments conducted over many years. In addition, we have improved the permitting process as it has matured over the last 23 years it has been in place. Please see the response to comment I-7-3. In addition, Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "Groundwater protection and biosolids". "Wastewater treatment process and biosolids",

Comment	Response
	"Understanding regulated pollutants in biosolids", "Heavy metals and biosolids", and "Food chain crops and biosolids".
I-23-1 Garbage out of the effluent, and garbage back in to our crops. Biosolids (the marketing name for sewage sludge) levels have been confirmed to be impossible to manage and contain toxic and hazardous elements.	I-23-1 The term biosolids was selected as a better descriptor for treated sewage sludge because there are many different kinds of sludges. The term is also established in state law. Biosolids are defined in state law and rules as municipal sewage sludge that is a primarily organic, semisolid product resulting from the wastewater treatment process, that can be beneficially recycled and meets all applicable requirements (Chapter 173-308 WAC[24], RCW 70A.226[23]). Biosolids includes a material derived from biosolids, and septic tank sludge, also known as septage, that can be beneficially recycled and meets all applicable requirements under 173-308 WAC. In addition to the response above, see the response to comment I-4-1. Ecology also prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "The wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", and "Food chain crops and biosolids".
I-24-1 Just because you spread sewage out and it seems to disappear doesn't mean it goes away. In fact its poison spreads a greater distance through uptake by air, plants and water.	I-24-1 The biosolids program is based on risk assessment, continuing research, and the application of best management practices that support the safety of beneficial use. Nutrients and trace contaminants in biosolids are regulated specifically for ensuring land application at appropriate rates and locations. Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more

Comment	Response
	information, in particular the following discussions touch on the commenter's inquiry: "The wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", "Heavy metals and biosolids", and "Food chain crops and biosolids".
I-28-2 It's common sense not to use such a toxic substance in our food and lands. The lack of a deeper study on what the biosolids contain is very concerning. We need to quit making our environment, food and water toxic. Please do not pass this.	I-28-2 Large amounts of research have been done on biosolids over several decades. The work done by U.S. EPA in support of the current biosolids program considered food chain and other pathways of exposure when biosolids are applied to the land. The overarching conclusion of the bulk of reliable research is that the beneficial use of biosolids is safe when regulations and good management practices are followed. Please also see the response to comment I-4-1. In addition, Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "The wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", and "Food chain crops and biosolids".
I-30-1 As an environmentally motivated voter and the daughter of a chemist who worked first in the food industry and then as a high school teacher, I am horrified and disgusted at the proposal to put biological waste on the plants that will become our food. The kinds of deleterious effects on our health that could be generated boggle the mind, not to mention the ways in which the contents of this waste could poison our water and soil and all kinds of living creatures.	I-30-1 Please see the response to comments I-3-2, and I-4-1. In addition, Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "Wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", "Groundwater protection and biosolids", "Consequences of ceasing all biosolids land

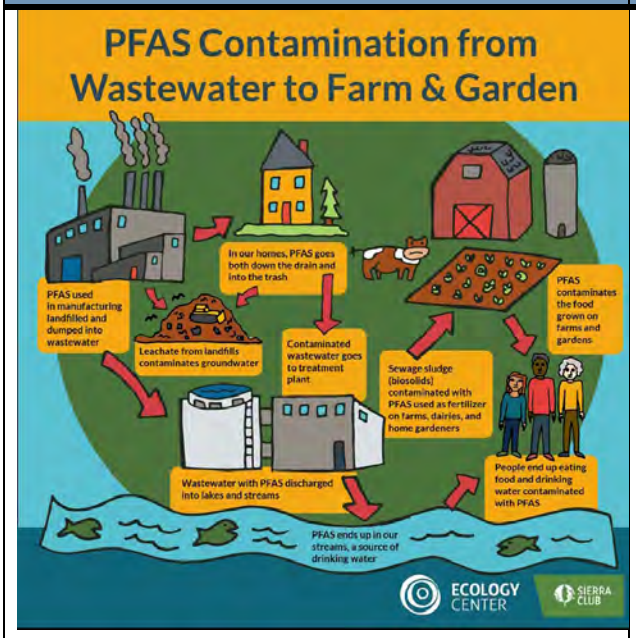
Comment	Response
	application", and "Food chain crops and biosolids".
I-33-2 The risks to the health to humans and all life that ingests and comes into contact with is extreme. Please read list below from a study done by the North Carolina department of health. All toxic substances ever found in must be tested for each time and 100% removed before dumped anywhere, esp. on farmland.	I-33-2 Note: Commenter submitted on line and by mail, also as I-121. The commenter submitted a 2005 report by the North Carolina State Department of Health that identified certain concerns associated with the land application of biosolids and other materials. The commenter asked Ecology to give special attention to a list of contaminants in the report. Ecology is generally familiar with the list of substances. It appears the commenter may be equating hazard with risk. The presence of something that may be hazardous in some circumstances does not constitute a significant risk. If that were true, many of the products in our garages and shops could never be used. Rather, the nature of the substance and the means and amount of exposure must be considered. Many of the substances on the list have previously been evaluated by EPA and are either regulated in some way or have been determined, thus far, to not pose a threat based on concentration typically found in biosolids. Ecology also recognizes some for which additional information is wanted. EPA is presently working on an improved risk-screening tool that they expect to submit to the EPA Science Advisory Board early next year. The final tool will allow EPA to refine the risk evaluation process they have used to date,

Comment	Response
	and help them identify substances that may need more regulation now as well as those for which a need for more information is clearly indicated. The commenter argues that 100 percent of any contaminant ever found must be removed before biosolids are applied to the land. Complete removal is not possible in many cases. That is why it is important to recognize hazardous substances before they enter the wastewater system. We want to point out that many of the substances to which the commenter may object are found in common products we use every day, and to which we are exposed at a much higher level by daily and socially acceptable activities.
I-36-2 It is now in the air we breathe, the food we eat, the water we use to recreate, and potentially our drinking water.	I-36-2 Please see the response to comment I-4-1. In addition, Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "Wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", and "Food chain crops and biosolids".
I-41-1 Sewage sludge (biosolids) is not a beneficial by-product of waste, and does not belong in agriculture settings. There are simply too many contaminants...	I-41-1 Biosolids are by law a commodity that can be used beneficially. For more information see the response to comment I-43-2.

Comment	Response
I-43-2 There are too many pharmaceuticals, chemical pollutants, heavy metals, and inappropriate nutrients for plants.	I-43-2 Ecology agrees that there are substances in biosolids that require regulation or further investigation. The bulk of evidence including extensive research over many years and practical experience supports that the beneficial use of biosolids is safe when applicable rules and permit conditions are followed. Research has shown biosolids to be an equal or even superior substitute for commercial fertilizers. In addition to the response above, please see the response to comment I-3-2. Ecology also prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "The wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", and "Heavy metals and biosolids", and "Understanding the 2018 Office of Inspector General report".
I-45-1 Spewing biosolids onto our crops is exposing us and our children to hundreds of toxic chemicals.	I-45-1 A large amount of research has been done in support of beneficial use activities. More research is being conducted as questions about safety or best practices arise, but the bulk of research and practical experience support that the beneficial use of biosolids is safe when rules and permit requirements are followed. Biosolids are land applied at agronomic rates in the same way other fertilizers are. Land appliers of biosolids must comply with specific site management requirements and harvest restrictions, depending on the crop being grown. In addition to the response above, please see the response to comment I-4-1. Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more

Comment	Response
	information, in particular the following discussions touch on the commenter's inquiry: "The wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", and "Heavy metals and biosolids", and "Understanding the 2018 Office of Inspector General report".
I-47-1 *NOTE that the commenter also submitted by email on 6/23.* Ecology's mission is to "protect, preserve and enhance Washington's environment and promote the wise management of air, land and water for the benefit of current residents and future generations."	I-47-1 Ecology does not disagree that the PFAS issue merits attention, and we are in fact devoting significant resources to it. The study cited by the commenter, "Nationwide occurrence of PFASs in U.S. biosolids," was based on an evaluation of archived samples collected in 2001. Two forms of PFAS of greatest concern (so far), PFOA and PFOS, were phased out of use starting in 2003. According to EPA Drinking Water Advisories[30], the levels of PFAS in blood serum have been decreasing. According to an analysis of a 2019 CDC report by several stakeholder groups[31] blood levels for PFOA and PFOS decreased by 70% and 84% respectively, between 1999 and 2014. We disagree with the commenter's statement that land application of biosolids is a serious cause of PFAS pollution. Biosolids are applied to less than one tenth of one percent of the land in Washington each year.

[30] https://www.epa.gov/sites/default/files/2016-06/documents/drinkingwaterhealthadvisories_pfoa_pfos_updated_5.31.16.pdf
[31] https://www.cambridgema.gov/-/media/Files/waterdepartment/labfiles/pfasfactsheet.pdf

Comment	Response
 PFAS IN BIOSOLIDS CONTAMINATE FARMLAND AND THREATEN DRINKING WATER SOURCES A nationwide survey "Nationwide occurrence of PFASs in U.S. biosolids" https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3776589/ found PFAS - per-and poly-fluoroalkyl substances - in Washington state biosolids. The only Oregon facility tested was in Redmond, Washington, but because PFAS are now found widely in US biosolids, it is likely that if other Oregon facilities were tested PFAS would be found there too. "Ten out of thirteen PFASs analyzed were consistently detected in all composite biosolids samples except for PFBA, PFHpA, and PFBS (Table 2). The most abundant PFAS in biosolids was PFOS, detected at a concentration of 403 ¬± 127 ng/g dw, followed by PFOA (34 ¬± 22 ng/g dw). The remaining	The amount of biosolids applied to the land is positively dwarfed by the amount of commercial fertilizers and manures, as well as the amounts of compost and topsoil. PFAS are found in many common products in everyday use[32]. According to a study published by the American Chemical Society[33], PFAS are found in nearly half of North American cosmetics. Our argument is not that cosmetics are the largest problem, but we point this out to give some context to arguments that land application of biosolids is somehow a concern above all others. Numerous studies have documented the presence of PFAS in dust and air samples collected from homes and workplaces. A study by Pepper et al published in Science of the Total Environment[34] found that long-term application of biosolids resulted in a low incidence of soil PFAS analytes. Thus, the cause of PFAS in biosolids - and its release to the environment, is their widespread use in many different products for the last several decades. Individuals are exposed to PFAS and other substances of concern from a variety of sources each day, by common and socially acceptable practices and activities. We are aware of work done by the State of Michigan and have been in touch with staff there. We think the approach taken in Michigan has merit and is worth considering for Washington. At present, Ecology has three initiatives underway that may impact PFAS. Ecology has committed to further analysis of PFAS in biosolids, and appropriate steps to follow, in a Chemical Action Plan (CAP)[35]. We are also evaluating alternatives for PFAS under Safer Products Washington[36]. We are awaiting the results of an Ecology study of PFAS in wastewater treatment plant influent, effluent,

[32] https://saferchemicals.org/get-the-facts/toxic-chemicals/pfas-per-and-polyfluoroalkyl-substances/#section1
[33] https://pubs.acs.org/doi/10.1021/acs.estlett.1c00240
[34] https://www.sciencedirect.com/science/article/abs/pii/S004896972103521X
[35] https://apps.ecology.wa.gov/publications/summarypages/2004035.html
[36] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Safer-products

Comment	Response
eleven PFASs ranged between 2 and 26 ng/g (Table 2) and the mean total concentration of PFASs (œÉPFAS) detected in the five composite samples was 539 ¬± 224 ng/g dw. The levels detected in U.S. biosolids are more than an order of magnitude higher than levels detected in sewage sludge samples collected from Spain and Germany." Many kinds of Industries in Washington state use and may release PFAS compounds to sewage plants. Washington's Biosolids Program should require sewage treatment plants producing biosolids to test for PFAS because this family of thousands of synthetic, persistent, bioaccumulative, and toxic chemicals has been linked to adverse effects on human health, wildlife and ecosystems. Many PFAS found in consumer products are released to sewers from homes, a situation hard to prevent except by urging consumers to stop these uses. The good news is that some states are finding ways to reduce these discharges from the many kinds of facilities are known to use, release or dispose of PFAS: waste and sewage management; aerospace; automotive; aviation; building and construction; cable and wiring; cookware; electronics; energy; food processing; inks; paints; polishes; stain and water repellant coatings for paper, packaging, textiles, footwear, furniture and carpeting; and firefighting products. Land application of biosolids and biosolids-based soil amendments is a serious cause of PFAS pollution: https://www.sierraclub.org/toxics/pfas/pfas-sludge Washington can clean up its biosolids by regulating PFAS discharges from Washington's industries that discharge to sewers. States	and biosolids. This study is far too small (only three wastewater treatment plants included) to stipulate any regulatory action especially because there is no established regulatory standard with wich to compare these results with. However, it allows us a small glimpse into what is happening with respect to PFAS at those wastewater treatment plants specifically. Funding may be a barrier for further work on PFAS in biosolids, but we are keeping an eye open for ways to support further work. Ecology remains open to new information on PFAS including better data on the presence of PFAS in biosolids. We should not lose track of the best solutions to problems. With the foregoing in mind, it seems that biosolids being applied to perhaps 0.2% of agricultural land in Washington is a questionable focus for elevated concern. Indeed, since phasing out of PFOA and PFOS resulted in observable decreases in blood levels[30], it seems there is a productive pathway forward that can preserve biosolids beneficial use. Ecology believes that biosolids can become an index of our success at protecting the environment. If biosolids become cleaner, then we will know we are making headway.

Comment	Response
such as Michigan and others are now testing for PFAS and if levels exceed the regulatory levels they have set -- action must be taken. Actions vary across states but Michigan is a leader. Michigan Issues Interim Strategy for Land Application "Land Application of Biosolids Containing PFAS Interim Strategy. michigan.gov "The Michigan Department of Environment, Great Lakes, and Energy (EGLE) has released its "Interim Strategy for Land Application of Biosolids Containing PFAS," published in late March, to formalize EGLE's guidance for recycling biosolids in light of concerns about per- and polyfluoroalkyl substances (PFAS). The strategy document has been expected for a while now following the work EGLE put into studying the issue of PFAS in land applied biosolids. EGLE reports issued to date include: SUMMARY REPORT: Initiatives to Evaluate the Presence of PFAS in Municipal Wastewater and Associated Residuals (Sludge/Biosolids) in Michigan and Evaluation of PFAS in Influent, Effluent, and Residuals of Wastewater Treatment Plants (WWTPs) in Michigan. The interim strategy will be effective for land application occurring after July 1st but EGLE is recommending that biosolids producers consider following the guidelines starting this Spring. Testing of biosolids for PFAS prior to land application is required. Based on previous work by EGLE to understand the concentrations and impacts of PFAS in land-applied biosolids, the Department has established the following guidelines for perfluorooctane sulfonate (PFOS): • Biosolids with concentrations at or above 150 µ/kg (equivalent to parts per billion, ppb) are considered industrially-impacted	

Comment	Response
and cannot be land applied. Water resource recovery facility (WRRF) biosolids managers much immediately notify EGLE of these test results and begin effluent sampling and an investigation into potential sources of PFOS in their sewershed. Of course, they will also have to make other arrangements for treatment or disposal of the industrially-impacted biosolids. • If PFOS concentrations are less than 150 ppb but greater than 50 ppb, the generators must again notify EGLE immediately and initiate effluent testing and investigations into the sources of PFOS to develop a source reduction program. Materials in this concentration range can be land-applied but in order to reduce the overall PFOS loading to the site, EGLE is restricting application rates to 1.5 dry tons per acre. Biosolids with PFOS concentrations below 50 ppb, which was the case for the majority of WRRFs that EGLE studied, can continue to be land applied. EGLE recommends for PFOS concentrations above 20 ppb, the WRRF consider investigating possible sources and conducting additional sampling." ...If PFAS contamination is found, biosolids should not be applied.	

Comment	Response
I-48-4 Recently, per- and polyfluoroalkyl substances (PFAS) chemicals are being found in increasing concentrations in sewage sludge. These are the man-made fire-retardant and non-stick chemicals that are now found all over the globe-- even in rain drops! PFAS have already caused havoc on farms all over the country where sludge has been used for fertilizer. Some farms have had to close because of the PFAS from sewage sludge fertilizer getting from the field into their food. Government agencies like the Dept. of Ecology are reluctant to test farms extensively, fearing perhaps an iceberg-like food safety crisis if the problem on farms is confirmed to be widespread. I believe our regulatory agencies including the EPA and the Dept. of Ecology are so fearful of an avalanche of lawsuits from food producers and consumers alike (since these agencies have not only allowed but promoted the unquestionably wrong-headed practice of the land-application of sewage sludge for decades now) that they will drag their feet and obstruct any changes in the status quo. And that is exactly what is happening. These agencies know how vulnerable they have made themselves having jumped on the land application band wagon so long ago. They are going to cling to that wagon. It's up to the people to push them off. PFAS is one only family of chemicals that contaminates sewage sludge. There are hundreds more. Honestly, just the idea of letting sludge anywhere near our food seems crazy. And it is crazy. Why can't Ecology grow a pair and acknowledge that fact too?	I-48-4 Ecology is acutely aware of concerns about PFAS in general, one facet being the presence of PFAS in biosolids. The commenter did not provide support for their remarks about biosolids causing havoc on farms all over the country. Ecology hasn't seen any indication that appropriate use of biosolids in agricultural settings has led to farm closures due to PFAS contamination. Ecology is currently engaged in discussions with the EPA's Office of Research and Development (ORD) to assess Per- and polyfluoroalkyl Substances (PFAS) in Washington's biosolids. ORD is one of the leading research institutions in the world regarding analysis of PFAS in complex organic compounds such as biosolids. Ecology plans to analyze biosolids from a variety of WWTPs across the state and the soils upon which they have been land applied. As noted by the commenter, PFAS are ubiquitous, Because analytical results are often reported in parts per trillion, obtaining reliable samples is more difficult than those required to characterize biosolids for other contaminants. On top of that, methods for the analysis of PFAS in soils and biosolids have yet to be fully validated, although Ecology has determined to press ahead regardless In addition to the comment above, please also see our response to comment I-7-3, and I-47-1. Please also see the key topics discussion titled "Food chain crops and biosolids" at the start of this response to comments for more information.
I-48-6 Ecology's foot-dragging when it comes to	I-48-6 Two risk assessments by EPA determined the

Comment	Response
launching a major effort to conduct broadscale groundwater testing, conduct broadscale soil testing or conduct broadscale crop tissue analysis of areas where sewage sludge has been applied or to conduct broadscale blood sampling of farmers and others in proximity to areas where sewage sludge has been applied, is entirely unjustified, especially when it comes to testing for PFAS. There are PLENTY of data on PFAS and many accepted testing methodologies despite Ecology's claims otherwise. The following is just a sampling of articles and studies about PFAS from the Interstate Technology and Regulatory Council, a project of the Environmental Council of the States (ECOS) which works to improve the capability of state environmental agencies and their leaders to protect and improve human health and the environment of the United States of America. ECOS is the national nonprofit, nonpartisan association of state and territorial environmental agency leaders. The Washington State Department of Ecology is an official member of ECOS! To claim ignorance or lack of a mandate in the face of this avalanche of data is utterly disingenuous. Ecology claims they "are tracking information regarding biosolids work happening elsewhere" (such as what is referred to below) and yet they seem prepared to ignore what they find instead. In Ecology's call for comments on the statewide general permit for biosolids management they shamefully ask the public to provide documentation along with their public comments to back up assertions that biosolids are too dangerous to be allowed to be land-applied. No, Ecology only has to study and respond appropriately to the available evidence already in their possession and leave the politics behind and blinders. Ecology will suffer a reckoning someday for its	substances in biosolids that did or did not require further regulation. EPA will submit a new risk-screening tool to its Science Advisory Board this spring. It is their number one priority for biosolids, and will help the agency assess or reassess the potential risk of substances of concern in biosolids. To date, the body of research and practical experience support the safety and efficacy of biosolids management. Ecology bases its program decisions on peer-reviewed research, evidence, and, experience, and overall best public policy. We encouraged commenters to include supporting documentation that substantiates their comments; otherwise, we would in many cases be left with only an opinion. The biosolids program does not purport to ignore concerns about PFAS. We recognize there is substantial research to support that some forms (at least) of PFAS are a concern. We do not see evidence that the relatively small amounts of PFAS typically found in biosolids, combined with the methods of use and potential impacts, support establishing a standard for PFAS in biosolids, and certainly do not support banning beneficial use. But that question continues to be evaluated. We are directing resources from five programs toward PFAS research. Ecology is currently involved with the EPA's Office of Research and Development (ORD) to assess PFAS in Washington's biosolids. ORD is one of the leading research institutions in the world regarding analysis of PFAS in complex organic compounds such as biosolids. Ecology plans to analyze biosolids from a variety of WWTPs across the state and the soils upon which they have been land applied. Ecology will continue to evaluate PFAS and other chemicals of concern, and we will make measured decisions in the advancement of regulation or development of policies.

Comment	Response
malfeasance on this issue unless it abandons its goose-stepping conformity to an obviously unjustifiable legislative mandate to promote biosolid's "beneficial use." Ecology must put its mission above sewage sludge conformity. PFAS - Per- and Polyfluoroalkyl Substances https://pfas-1.itrcweb.org It is the intention of ITRC to periodically update the document as significant new information and regulatory approaches for PFAS develop. The guidance document ... Fact Sheets - -PFAS - Per- and Polyfluoroalkyl Substances https://pfas-1.itrcweb.org/fact-sheets PFAS Fact Sheets. This page includes links for the ITRC PFAS fact sheets. The fact sheets are available as PDF files. Several tables of supporting information ... 2.2 Chemistry, Terminology, and Acronyms- PFAS - Per- and ... https://pfas-1.itrcweb.org/2-2-chemistry-terminology-and-acronyms PFAS are characterized by carbon atoms that are linked together with fluorine atoms attached to the carbons. A more specific and technical definition of PFAS ... 1 Introduction- PFAS -- Per- and Polyfluoroalkyl Substances https://pfas-1.itrcweb.org/1-introduction Per- and polyfluoroalkyl substances (PFAS) are a very large family of thousands of chemicals that vary widely in their chemical and physical properties, as well ... 2 PFAS Chemistry and Naming Conventions, History and Use of ... https://pfas-1.itrcweb.org/2-pfas-chemistry-and-naming-conventions-history-an...	

Comment	Response
The PFAS Team developed two training module videos with content related to ... and chemical properties of PFAS impart oil, water, stain, and soil repellency, ... 5 Environmental Fate and Transport Processes -- PFAS -- Per- and ... https://pfas-1.itrcweb.org/5-environmental-fate-and-transport-processes PFAS fate and transport describes the behavior of these compounds following their release to the environment. This includes the physical, chemical, and biological ... Naming Conventions and Physical and Chemical Properties of Per ... https://pfas-1.itrcweb.org/PFAS_Fact_Sheet_Naming_Conventions_April2020 1 Introduction. The following topics are covered in this fact sheet: ● Polymer vs. Nonpolymer PFAS. ●Perfluoroalkyl substances. ● Polyfluoroalkyl substances. 11 Sampling and Analytical Methods -- PFAS -- Per- and ... https://pfas-1.itrcweb.org/11-sampling-and-analytical-methods Sampling conducted to determine PFAS concentrations in water, soil, sediment, air, biota, and other media is similar to that for other chemical compounds, but with ... 12 Treatment Technologies -- PFAS - Per- and Polyfluoroalkyl ... https://pfas-1.itrcweb.org/12-treatment-technologies State of Development: GAC is an established water treatment technology proven to effectively treat long-chain PFAS (such as PFOS, PFOA, and PFNA). The ... 6 Media-Specific Occurrence -- PFAS -- Per-	

Comment	Response
and Polyfluoroalkyl ... https://pfas-1.itrcweb.org/6-media-specific-occurrence This section focuses on occurrence in air, soil and sediment, groundwater, surface water, and biota. PFAS occurrence in several media types is an active area of ... 14 Risk Communication -- PFAS - Per- and Polyfluoroalkyl ... https://pfas-1.itrcweb.org/14-risk-communication Additional human health and exposure factors that heighten risk perception for PFAS are summarized in Section 14.2, Risk Communication Challenges. This ... 3 Firefighting Foams -- PFAS -- Per- and Polyfluoroalkyl Substances https://pfas-1.itrcweb.org/3-firefighting-foams AFFF is a highly effective type of Class B foam that is especially effective on large liquid fuel fires. AFFF is of particular concern because it contains PFAS. As ... History and Use of Per- and Polyfluoroalkyl Substances (PFAS) https://pfas-1.itrcweb.org/PFAS_Fact_Sheet_History_and_Use_April2020 Certain PFAS, most notably some of the perfluoroalkyl acids (PFAAs), such as perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS), are mobile, ... 2.5 PFAS Uses -- PFAS - Per- and Polyfluoroalkyl Substances https://pfas-1.itrcweb.org/2-5-pfas-uses The unique physical and chemical properties of PFAS impart oil, water, stain, and soil repellency, chemical and temperature resistance, friction reduction, and ... 13 Stakeholder Perspectives -- PFAS - Per- and	

Comment	Response
Polyfluoroalkyl ... https://pfas-1.itrcweb.org/13-stakeholder-perspectives PFAS - Per- and Polyfluoroalkyl Substances ... PFAS, including PFOA and PFOS, have been detected in biosolids produced at a wastewater treatment plant ... 2.6 PFAS Releases to the Environment -- PFAS -- Per- and ... https://pfas-1.itrcweb.org/2-6-pfas-releases-to-the-environment industrial facilities that produce PFAS or process PFAS, or facilities that use PFAS chemicals or products in manufacturing or other activities (Section 2.6.1); areas ... 2.3 Emerging Health and Environmental Concerns -- PFAS -- Per ... https://pfas-1.itrcweb.org/2-3-emerging-health-and-environmental-concerns PFAS -Per- and Polyfluoroalkyl Substances. HOME ... Like other emerging contaminants, knowledge and concern about PFAS in the environment has evolved ... Remediation Technologies and Methods for Per- and Polyfluoroalkyl ... https://pfas-1.itrcweb.org/pfas_fact_sheet_remediation_3_15_18 Certain PFAS have recently been the subject of regulatory actions and attempted soil, sediment, and water remediation. These compounds have unique chemical ... 4 Physical and Chemical Properties -- PFAS -- Per- and ... https://pfas-1.itrcweb.org/4-physical-and-chemical-properties Apr 14, 2020 ... For an individual PFAS	

Comment	Response
compound (or mixture of PFAS) that exists as a liquid at ambient temperatures, density can influence its behavior in the ... Per- and Polyfluoroalkyl Substances (PFAS) https://pfas-1.itrcweb.org/uploads/2020/04/ITRC_PFAS_TechReg_April2020 Apr 1, 2020 ... Substances (PFAS). Technical/Regulatory Guidance. April 2020. Prepared by. The Interstate Technology & Regulatory Council (ITRC). 2.4 PFAS Reductions and Alternative PFAS Formulations - PFAS ... https://pfas-1.itrcweb.org/2-4-pfas-reductions-and-alternative-pfas-formulations 1 3M Voluntary Phaseout of Certain Long-Chain PFAS. In early 2000, 3M was the principal worldwide manufacturer of PFOA and POSF-derived PFAS (for ... 10 Site Characterization -- PFAS -- Per- and Polyfluoroalkyl ... https://pfas-1.itrcweb.org/10-site-characterization There are also "secondary sources," such as PFAS concentrating into one portion of a plume (for example, groundwater into surface water) that then acts as a ... 7 Human and Ecological Health Effects of select PFAS -- PFAS ... https://pfas-1.itrcweb.org/7-human-and-ecological-health-effects-of-select-pfas The best studied PFAAs are PFOS and PFOA, although considerable information is available for some other PFAS, including PFNA, PFHxS, PFBA, PFBS, and the ... 9 Site Risk Assessment -- PFAS -Per- and Polyfluoroalkyl ... https://pfas-1.itrcweb.org/9-site-risk-	

Comment	Response
assessment For PFAS chemicals as of September 2019: Tier 1 values are peer-reviewed toxicity values published on the USEPA's Integrated Risk Information System (IRIS). 8 Basis of Regulations -- PFAS - Per- and Polyfluoroalkyl Substances https://pfas-1.itrcweb.org/8-basis-of-regulations Providing blood testing for PFAS for all DOD firefighters during their annual physical exam; Ensuring that no water contaminated with PFOA or PFOS above ... Acronyms -- PFAS - Per- and Polyfluoroalkyl Substances https://pfas-1.itrcweb.org/acronyms PFA, perfluoroalkoxy polymer. PFAA, perfluoroalkyl acid. PFAI, perfluoroalkyl iodides. PFAS, per- and polyfluoroalkyl substances. PFBA, perfluorobutanoate ... 17 Additional Information -- PFAS - Per- and Polyfluoroalkyl ... https://pfas-1.itrcweb.org/17-additional-information Data presented include PFAS concentrations in water and particle phases. Water maximum: PFHxS: 281; PFOS: 2,920; PFHxA: 757; PFHpA: 277; PFOA: 767 ... 15 Case Studies -- PFAS - Per- and Polyfluoroalkyl Substances https://pfas-1.itrcweb.org/15-case-studies presented a detailed characterization of a subset of PFAS soil and groundwater concentrations, focused on PFAAs in the vicinity of a former unlined burn pit where ... and Polyfluoroalkyl Substances (PFAS)	

Comment	Response
https://pfas-1.itrcweb.org/PFAS_Fact_Sheet_Regulations_April2020 1. Regulations, Guidance, and Advisories for Per- and Polyfluoroalkyl Substances (PFAS). ITRC has developed a series of fact sheets to summarize the latest ... Acknowledgments -- PFAS - Per- and Polyfluoroalkyl Substances https://pfas-1.itrcweb.org/acknowledgements	
I-48-8 A 2009 U.S. Environmental Protection Agency study concluded that all sewage sludge contains toxic elements. Official estimates of the numbers of toxic contaminants that could be present in any given batch of sludge range into the thousands. One only needs to consider the hundreds of industrial, pharmaceutical and organic pollutant contaminants that our chemical-dependent society flushes down the drain every day. Antibiotic resistant bacteria and mobile antibiotic resistance genes are present in sewage sludge. Micro-plastic is an increasingly common component of sewage sludge and is no good for the soil it's spread on, the creatures that live in that soil or the wildlife that depend on it. Disease-causing bacteria, viruses, protozoa and parasites are never entirely killed off when sewage sludge is treated to be used as fertilizer and can grow back in the nutrient-rich sludge especially in the warm and moist conditions on a farm. Current interpretations of sewage sludge regulations shockingly allow sewage sludge in consumer fertilizer and compost products for home gardens-- the gardens that	I-48-8 The commenter did not provide a citation or title for the referenced 2009 study by EPA. There are two reports on biosolids by EPA dating from 2009. One is a biennial review[37], the other is a Targeted National Sewage Sludge Survey[38]. Every two years, the EPA evaluates available information on known contaminants in order to identify additional substances of concern. They can then decide whether there is sufficient cause for regulation. The 2009 biennial report[37] was just one in a series of similar reports. EPA has identified an additional 700 substances for continued consideration, but for which data have not thus far supported the need for additional regulation. Ecology recognizes the presence of trace contaminants in biosolids, as does the EPA, but the presence of a contaminant does not mean there is a risk to human health and the environment. Many other factors must be considered, including the contaminant's concentration, toxicity, and pathway of exposure. So the issue becomes not whether a substance can be found in biosolids, but whether the actual hazard presented by the substance, combined with expectations for exposure is cause to merit regulation in biosolids. Implementing regulatory requirements can have large

[37] https://www.epa.gov/sites/default/files/2015-03/documents/br2009_summary_final.pdf
[38] https://www.epa.gov/sites/default/files/2018-11/documents/tnsss-sampling-anaylsis-tech-report.pdf

Comment	Response
Washingtonians want your children to play in.	monetary impacts for wastewater treatment facilities (that are passed down to every citizen of the state). It is critical for state and federal agencies to be confident in their analysis before imposing new regulatory requirements. If the EPA's review indicates that additional regulatory standards are needed to ensure the safety of public health and the environment, Ecology is prepared to revise state regulations and the general permit to include them. Ecology is hopeful that a new risk-screening tool EPA will present to its Science Advisory Board this year, will help to either allay concerns or provide needed impetus to take appropriate regulatory steps. The commenter remarks specifically about microplastics, which are fragments of plastic substances generally less than 0.5 millimeters in size. Ecology understands the commenter's concern, but much more study is needed for this particular issue. The commenter also notes that disease-causing organisms, or pathogens, are never entirely killed when sewage sludge is treated, and can regrow. Pathogens in Class B biosolids are estimated to have been reduced by 99%, and to below detectable limits in Class A processes. Regrowth has rarely been observed in either case. It is important to keep in mind that pathogens are abundant in our normal environment. They exist in the air, soil, and water, around us. The bulk of research and practical experience support that beneficial use is safe for human health and the environment when done so in accordance with state and federal regulations, and permit requirements. Ecology applies the same logic in supporting the use of other soil amendments. Animal manures for example are more widely used on crops with fewer regulatory requirements. Although they have on rare occasions been positively linked with outbreaks of illnesses, it is commonly understood that their benefits on crop growth and soil maintenance

Comment	Response
	outweighs this drawback.”
I-49-4 As you well know: A 2009 U.S. Environmental Protection Agency study concluded that all sewage sludge contains toxic and hazardous elements.	I-49-4 Please see response to comment I-48-8.
I-51-1 Applying septage to the ground where crops are growing should not be allowed	I-51-1 Biosolids, including septage, contains nitrogen and other plant nutrients. Septage is the material removed from onsite wastewater treatment systems and similar devices. It is a form of biosolids, but subject to somewhat different regulatory standards. Prohibitions on the harvest of crops following land application of septage range up to thirty-eight months, which makes septage application to many crops impractical. Land application of septage is protective of human health and the environment when managed in accordance with state and federal regulations and permit requirements. Proper site management includes human and livestock site access restrictions, appropriate application rates, and crop harvesting restrictions. Septage cannot be applied to lawns, gardens, or areas with high public contact like parks. Septage applications to land where crops like wheat is grown is permitted because the grain develops after the time of application, and does not come into contact with the soil.

Comment	Response
I-52-1 Our body collective is stressed already by back ground radiation from 10 years and counting of Fukushima nuclear meltdown.	I-52-1 Thank you for your comment. Please see the response to comments I-1-1, I-3-2, and I-4-1 for more information about biosolids land application in the state of Washington. The commenter may also be interested in information provided by our State Department of Health on Biosolid Land Application[39].
I-53-2 The rest of my comments are focused on the urgent need for the Washington Department of Ecology [Ecology] to include provisions for and in consideration of PFAS in WWTP discharge and biosolids and to respond to the numerous erroneous, inaccurate, and misleading statements made in the Per- and Polyfluoroalkyl Substances [PFAS] Draft Chemical Action Plan. 2. In response to Ecology's stance that they will not require sampling for biosolids because there "is no validated method for the analysis of PFAS in biosolid". • Other states require that WWTPs use an isotope dilution method like Method 537.1, ASTMD7979-19M, or CWA Method 1600 for PFAS analysis of biosolids in the interim and until EPA completes its work. As with drinking water guidelines, states cannot afford to sit and wait for EPA to determine and put protections in place. The environment and people's health are in significant risk by waiting when there are perfectly acceptable methods for analyzing for PFAS out there that are used globally. EPA's website for current research and validation information is at this link . Such methods are reliable for biosolids because they use an isotope-dilution method to	I-53-2 We understand that some labs have developed techniques for the analysis of PFAS in biosolids, and we have never argued to the contrary. Before developing this response, we had said that there was no method validated by U.S. EPA for analysis of PFAS in biosolids, which was correct. We see that other states have performed analysis, but most either have not, or are not sharing the information very visibly. Our concern was and remains that when EPA finally validates and eventually approves one or more methods, differences in the methodologies may call into question the results obtained by previous (and perhaps no longer approved methods). We remind readers here that we are dealing in some cases with parts per trillion, which is an extremely small unit. Therefore, the established efficacy of sample collection, preparation, and analysis is of the utmost importance. To provide a little insight, if we think about parts per trillion in terms of seconds, one part per trillion is equal to one second in about 31,000 years. Although cost seems to have declined over time, sampling and analysis for PFAS in biosolids is still rather costly by comparison with other analytes. Given the evolving science, work underway by U.S. EPA, our State Department of Health, and staff in other programs here at Ecology, we thought it was appropriate to wait for a validated method, which always seemed just around the corner.

[39] https://www.doh.wa.gov/CommunityandEnvironment/Radiation/FukushimaUpdate/FukushimaFAQs

Comment	Response
measure sample extraction recoveries and correct for matrix suppression effects in the LCMSMS. Ecology should allow the use of these methods as do other states. Another approach would be to use language such as Massachusetts permit language in the interim. "If EPA's multi-lab validated method is not available by ___ months after the effective date of this Final Permit, the Permittee shall contact _____ for guidance on an appropriate analytical method." Or, better "If EPA's multi-lab validated method is not available by ___ months after the effective date of this Final Permit, continue to use the interim CWA Method 1600 or other Method generally accepted by EPA."	Following the release of our draft permit, EPA provided guidance that encouraged states to work with a selected laboratory to obtain meaningful analytical results on PFAS in biosolids. On September 2, 2021, EPA announced the first single-lab validated method for PFAS in eight different matrices, including biosolids[40]. Ecology was content to move forward with the guidance and encouragement of EPA. The more recent single-lab validated method further bolsters prospects for obtaining meaningful results of sampling efforts. However, the gold standard remains to be multi-lab validation. Ecology is currently engaged in discussions with the EPA's Office of Research and Development (ORD) to assess Per- and polyfluoroalkyl Substances (PFAS) in Washington's biosolids. ORD is one of the leading research institutions in the world regarding analysis of PFAS in complex organic compounds such as biosolids. Ecology plans to analyze biosolids from a variety of WWTPs across the state and the soils upon which they have been land applied. We will need to identify funding to conduct more sampling at wastewater treatment plants, or require it under Administrative Order or by permit.
I-54-1 Sewage biosolids contain all kinds of nasty, persistent, biologically damaging chemicals and do not belong in our food.	I-54-1 Ecology agrees that harmful chemicals do not belong in our food chain. We do not agree that biosolids are a significant source of those substances in our food chain. Levels of regulated pollutants – things like lead and mercury - in Washington biosolids are generally far below limits established by U.S. EPA. Additionally, those substances tend to be in forms with a reduced bioavailability. See response to comment I-3-2 for more information. The commenter did not mention any specific chemicals, however many commenter's shared their concern for PFAS. Per- and poly-fluoroalkyl substances

[40] https://www.epa.gov/newsreleases/epa-announces-first-validated-laboratory-method-test-pfas-wastewater-surface-water

Comment	Response
	(PFAS) are currently receiving close scrutiny across the board including their presence in biosolids. PFAS are substances that make things flame-resistant, stain-resistant, water-resistant, and non-stick. From a chemical perspective, they are remarkable substances. They make your shirts and carpet easier to clean, help your outdoor wear repel water, make your car shine, and make your food not stick to the package or frying pan. Their common use makes these substances ubiquitous in our lives today, and unfortunately, that means they can end up in biosolids. Some PFAS compound also have known health concerns. The amount of PFAS in biosolids, however, is estimated to be quite low as compared with something like a bag of microwaved popcorn[41]. Right now Ecology staff are working on issues related to PFAS and are in communications with other state and federal agencies as well. We will ultimately put the pieces together to help us better understand and appropriately respond to the level of threat posed by PFAS and any other contaminants of concern. Please also see the key topics discussion titled "Food chain crops and biosolids" at the start of this response to comments for more information.

[41] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7255411/

Comment	Response
I-55-1 I have become very aware of the dangers of PFAS and related chemicals in our environment....how we ALL carry these highly toxic chemicals around in our bodies. We are existing through epidemics of chronic and acute disease....cancers which cost not only the very lives of our loved ones, but also create gargantuan costs to our health care systems. Our state Ecology agency can be a leader in removing these dangers to our citizens. Please stop business as usual. Be bold, take steps to actually protect---the true mission of your agency… …Thank you for acting in meaningful ways to protect us all. PLEASE don't fail us.	I-55-1 Ecology is concerned about PFAS and other persistent, bioaccumulative, or toxic substances in our environment, and are directing resources to this emerging contaminant of concern. A great deal of research has been done on the beneficial use of biosolids, and the bulk of that work taken with practical experience supports that beneficial use is safe when rules and permit requirements are followed. That being said, we recognize there are substances in biosolids that remain concerning like PFAS. Ecology was critical of U.S. EPA for many years as they disinvested from the national biosolids program. They have now "reinvested" with new staff, starting about four years ago, and recently awarded nearly six million dollars in grants to conduct further research. Please also see the response to comment I-47-1 and I -70-1.
I-55-8, I-56-2, I-57-1, I-58-1, I-59-1, I-61-1, I-64-1 Please update the three-decades-old regulations on which it bases permits to reflect current science: Testing must be done for PFAS, PCBs, pharmaceuticals, endocrine disruptors, and antibiotic resistant bacteria before spreading it on land and selling it as compost. O-7-63 The biosolids regulations are old. They should be updated based on current science to reflect what is known to be contained in the processed waste, including pathogens and emerging chemicals of concern.	I-55-8 State rules were first adopted in 1998, and last updated in 2008. If the commenter is referring to the federal rules in 40 CFR Part 503[13], there have been some revisions since adoption in 1993, although Ecology cannot chronicle them at the moment. It appears however that the commenter's concern is for analysis of specific pollutants, and desire for an expanded list of monitoring requirements. U.S. EPA is currently developing a risk-screening tool that it will submit for review to its Science Advisory Board early next year. EPA has already updated the potential pathways of exposure that were used for modeling the rules adopted by the agency in 1993. EPA staff will be able to enter information about specific pollutants of concern into the new model and get an indication as to whether a particular pollutant might pose a risk in some scenario. That will enable EPA to eliminate substances that are likely to pose a problem and prioritize those that remain for further evaluation. The outcome of that effort can then drive

Comment	Response
	requirements for further analysis and, if appropriate, additional regulatory standards.
I-60-1 I am writing to express my disapproval of further permitting for agricultural use of biosolids as they exist now. The mixing of human waste with toxic waste produces an unknowable mixture, each one different, with no way to trace what is going where. Food is being grown in toxic waste and that is abhorrent and evil and wrong. People who work around this toxic sludge are at extreme risk of being contaminated, as are the people who eat the food grown in it... …The current distributing of toxic sludge as fertilizer by the Department of "Ecology" is a sign of the total corruption of the word Ecology. With a government agency so sold out to corporate interests that you deceive farmers into using waste that is sure to be their ruin… …For now, I say no more use of biosolids in agriculture.	I-60-1 Please refer to the key topic discussions Ecology has provided regarding "Ceasing Land Application", "Monetary Incentive", and "Food chain crops and biosolids".
I-62-1 Washington State's new law, Pollution Prevention for Our Future Act (SB 5135) prohibits producing products with certain pollutants, all of which can be found in Biosolids. How can Ecology legally allow biosolids to be produced with this law in place? Biosolids most certainly do have pollutants, and spreading them on the surface in trace amounts today, amounts to poisoning our children's children's future enjoyment of a	I-62-1 SSB 5135, the Pollution Prevention for Healthy People and Puget Sound Act, passed in 2019 (legislative history of SB 5135[42]). The new law, RCW 70A.350[43], does not prohibit the production of products with certain pollutants, as stated in this comment. Instead, the law sets up a 4-step process that requires Ecology to identify priority chemicals, identify consumer products that are a significant source or use of a priority chemical, determine whether regulatory actions are needed and

[42] https://app.leg.wa.gov/billsummary?BillNumber=5135&Chamber=Senate&Year=2019
[43] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.350&full=true

Comment	Response
pollution free world.	if so adopt those determinations in rule. Steps 1-3 require reporting to the Legislature on a timeline specified in the law. Ecology is currently in Step 3 of the process, implementing the law through the Safer Products for Washington program[44]. Lastly, landfilling is not a sustainable practice and results in the loss of the valuable attributes of the biosolids, as well as the production of leachate and greenhouse gasses. Ecology is committed to beneficial use of biosolids.
I-66-1 Geo solids should not be used on land because of their inherent toxicity.	I-66-1 Please see the response to comment I-48-8.We also prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "Consequences of ceasing all biosolids land application".
I-67-4 The current practices are not safe. They should not be renewed. They are poisoning the soil with PFAS, PCB's and other chemicals. They are not consistent with current science. The EPA acknowledged the toxins in sludge as early as 2009.	I-67-4 Many responses to other comments that will address the commenter's concern here. Please see the responses to comment I-48-8, for example. We also suggest reviewing our discussion titled "Heavy metals and biosolids".
I-70-1 Testing for PFAS is not a "new" thing for the Department of Ecology Their PBT Monitoring Program has been using AXYS Ltd. lab for testing a range of materials for PFAS. They published information showing that wastewater treatment plant effluent is a major source of PFAS pollution in Washington state. Our state's lakes, fish, even bird eggs are	I-70-1 Ecology is aware that analysis of PFAS in water and wastewater has been done. There are validated methods for the analysis of PFAS in water and wastewater. At the time the draft permit was issued for comment, there was no validated method for analysis of PFAS in biosolids (or soils). There is presently only a single-lab validated method, and EPA has not formally approved this methodology for the

[44] https://www.ezview.wa.gov/site/alias__1962/37555/safer_products_for_washington.aspx

Comment	Response
contaminated. "Survey of Per- and Poly-fluoroalkyl Substances (PFAS) in Rivers and Lakes -- 2016." To back up the Department of Ecology claims that domestic discharges from homes -- not industries - are the major sources of PFAS released to wastewater plants the Biosolids Program require industries to test their wastewater right now using the AXYS Ltd. lab, their test methods and protocols. Their biosolids should be tested also. AXYS testing is reliable for biosolids because it uses an isotope-dilution method to measure sample extraction recoveries. Similarly Ecology itself could require that WWTPs that receive industrial wastewaters to sample their effluent for PFAS	analysis of PFAS in biosolids. Levels of PFAS in biosolids must be measured in the parts per billion down to parts per trillion range. For perspective, if we think about parts per trillion in terms of seconds, one part per trillion is equal to one second in about 31,000 years. Those extremely small concentrations require extraordinary measures to collect and analyze samples that will yield results that can be depended upon - particularly in a matrix like biosolids where interference can be significant. Following the release of the draft permit, EPA provided guidance that encouraged states to work with a selected laboratory to obtain meaningful analytical results on PFAS in biosolids. On September 2, 2021, EPA announced the first single-lab validated method for PFAS in eight different matrices, including biosolids[45]. Ecology was content to move forward with the guidance and encouragement of EPA. The more recent single-lab validated method further bolsters prospects for obtaining meaningful results of sampling efforts. However, the gold standard remains to be multi-lab validation. Ecology has not claimed that domestic discharges from homes are the primary source of PFAS in biosolids. We shared some information about the many household items that people regularly interact with that contain PFAS, as it is used for stain and water repellant, to keep food from sticking to containers and pots and pans, etc. Discharges from homes to the sewer system, and septage from onsite wastewater treatment systems delivered to sewage treatment plants undoubtedly contribute to the occurrence of PFAS in biosolids. The point we have consistently made is that people have objected to relatively low concentrations of PFAS in biosolids, applied to an extremely small amount of land in Washington, but at the same time have not acknowledged that they are exposed on a daily basis

[45] https://www.epa.gov/newsreleases/epa-announces-first-validated-laboratory-method-test-pfas-wastewater-surface-water

Comment	Response
	through routine and socially acceptable activities to a range of pollutants, including PFAS, and at much higher levels than will ever be connected to biosolids. If the issue is PFAS, then the solution is to quit using it in the manufacture of products that are ubiquitous in our daily living. That will eliminate the concern for biosolids. Research has documented the decline of two forms of PFAS - PFOA and PFOS - in various sampling events since their use was phased out over the last ten to twenty years[30]. We expect levels of those two PFAS forms to continue declining, and others would follow suit if they were no longer used in the manufacturing process. Lastly, the commenter remarks about Ecology using its authority to require dischargers to sample effluent for PFAS. We are not certain if the commenter meant to refer to effluent specifically, or intended to say biosolids. Effluent is the treated wastewater exiting a wastewater treatment facility, and is not regulated by the biosolids program. Ecology does have the authority to require sampling. Determining the best approach to PFAS requires an understanding of partitioning within the treatment process. EPA expects to forward a draft risk-screening tool for biosolids to its science advisory committee next year. We believe the tool will be helpful in prioritizing pollutants in biosolids for further attention. In the meantime, Ecology expects the results of our blind study to be helpful, and work is continuing on our Chemical Action Plan and through our Safer Products for Washington program. Lastly, we want to point out some realities of program implementation. First, the ability to require sampling notwithstanding, Ecology also has an obligation to consider impacts on the regulated community for the things it requires. Consequently, an economic analysis accompanied the draft general permit. Sampling and analysis for PFAS is very costly. Moreover, there are no standards on which to base possible regulatory limits (standards are being developed). While some

Comment	Response
	commenters may think to the contrary, it is not a proper approach for a regulatory agency to demand sampling without examining the impact of that requirement on the regulated community, and balancing that impact against the need. Ecology could do that by modifying our general permit at some point in the future, or by updating our regulations as suggested by some commenters. The latter approach would be preferable and most likely to stand up to legal scrutiny. Ecology can obtain samples for analysis at its own expense, but the agency is not funded to do so (for PFAS in biosolids) in the current biennium.
I-73-1 We know that sewer sludge has chemicals that can't be filtered out or otherwise removed. We don't want this spread on ground that we grow our food in. Put it on the lawns in Seattle.	I-73-1 Some forms of biosolids are suitable for use on lawns and in home gardens, and some facilities have invested in developing programs around those end uses. The technology required, and the regulations are quite different from biosolids that are applied to farmland. Ecology does not mandate where beneficial use occurs. Use of the term "sewer sludge", is a misrepresentation of biosolids. Biosolids are a further treated residual that results from the initial treatment of wastewater. Good portions of biosolids are actually beneficial microorganisms grown in a wastewater treatment plant to treat the wastewater. It may help to think of the difference between fresh grass clippings and finished compost. Please also see the response to comments I-7-3 and I-13-2, and the key topics discussion titled "Food chain crops and biosolids" at the start of this response to comments for more information.
I-79-2 Heavy metals, pathogens or pharmaceuticals could be allowed to contaminate vast areas.	I-79-2 Please see the response to comment I-43-2.
I-80-1 The use of unprocessed human feces as fertilizer is a risky practice as it may contain	I-80-1 The commenter did not identify any particular facilities that recommend limitations on use of their

Comment	Response
disease-causing pathogens. ... The safe reduction of human excreta into compost is possible. Some municipalities create compost from the sewage sludge, but then recommend that it only be used on flower beds, not vegetable gardens. **NOT SURE WHY THIS IS EVEN A QUESTION IF THESE FACTS HAVE ALREADY BEEN DETERMINED***	biosolids, but they are free to do so. Ecology generally does not control the marketing recommendations of biosolids producers. Exceptional quality biosolids can be applied as desired by the end-user. Biosolids are not the equivalent of unprocessed human feces. Biosolids are a treated residual that results from the treatment of wastewater. A good portion of biosolids are actually the beneficial microorganisms grown in a wastewater treatment plant to treat the wastewater. Before biosolids can be used for any purpose, they must go through a process to reduce pathogens. There are two levels of treatment. The first, called Class B, is expected to reduce pathogens by ninety-nine percent. Class B biosolids are safe for use, but because pathogen reduction is not complete they require additional site-specific management practices, including significant limits on the harvesting of crops grown for human consumption. They are not available to the public, and are used only in situations with site-specific permit requirements. The second level of treatment, Class A, results in a further reduction of pathogens to below detectable limits. Class A biosolids can be used on lawns and gardens if they meet other qualitative criteria as well. There are different ways to achieve reductions in pathogens. Some examples include composting, lime stabilization, heat drying, and digestion. We refer the commenter to two documents for more information: Control of Pathogen and Vector Attraction Reduction in Sewage Sludge[46], for technical details, or alternatively to the A Plain English Guide to the EPA Part 503 Biosolids Rule[47].

[46] https://www.epa.gov/biosolids/control-pathogens-and-vector-attraction-sewage-sludge
[47] https://www.epa.gov/biosolids/plain-english-guide-epa-part-503-biosolids-rule

Comment	Response
I-82-2 There are many unknown toxins and other dangerous substances in sewage sludge that do not belong in our soil to be consumed by its microbial population and passed on to whoever consumes it or contacts it in any manner, human or otherwise...through food, drink or other forms of contact. Washington state needs to charge the sources of sewage sludge for the proper and safe disposal of sewage, sludge and other hazardous waste in ways that do not do further harm to citizens and our future health and well being. Thank you.	I-82-2 In adopting federal regulations, EPA evaluated several hundred pollutants across fourteen pathways of exposure. That is what led to the list of currently regulated pollutants in federal and state rules. Over the years since EPA did that work, analytical methods have improved, and we have learned more about substances that may be found in biosolids. EPA is currently working on a risk-screening tool that will help them identify substances in biosolids that should have more investigation. They have already updated the original pathways of exposure. The risk screening tool will allow them to set aside things that pose little to no risk and focus on the ones that deserve more attention. The draft permit addresses only biosolids that meet standards for beneficial use. The permit does not address other kinds of sludge, or any hazardous waste at all. Ecology has an entirely separate program devoted to managing hazardous waste. By law, biosolids are considered a valuable commodity - they are not a waste at all. Additionally, the simple presence of a hazardous or potentially hazardous substance in something does not make it a waste. If that were true, many things we purchase and use on a regular basis would be considered hazardous waste. The commenter says, "Washington state needs to charge the sources of sewage sludge for the proper and safe disposal of sewage, sludge and other hazardous waste..." The commenter may misunderstand the relationships and costs involved. Biosolids are an unavoidable product of wastewater treatment. Most biosolids come from publicly owned wastewater treatment plants. A few privately owned treatment works treat only domestic sewage and produce biosolids (a resort would be an example). About a third of the state's population is served by on-site sewage disposal (septic) systems. Septage removed from those and similar systems is also regulated as biosolids.

Comment	Response
	Treatment works and septage pumpers provide a service for which they charge their customers - including the commenter. The commenter and every other person in the state of Washington makes use of the services provided by wastewater treatment systems. The cost of managing biosolids is ultimately passed on to customers, which includes the commenter and every citizen of the state. The generators are us, and the people who pay are us. Please also see the key topics discussion titled "Food chain crops and biosolids" at the start of this response to comments for more information.
I-83-1 Stop using proven toxic biosolids to grow our food.	I-83-1 Ecology notes the commenter's opposition to land application of biosolids. Please also see the key topics discussion titled "Food chain crops and biosolids" at the start of this response to comments for more information.
I-83-2 Figure out another way of getting rid of biosolids that doesn't include toxic food!!!	I-83-2 Ecology notes the commenter's opposition to land application of biosolids. Please also see the key topics discussion titled "Food chain crops and biosolids" at the start of this response to comments for more information.
I-90-2 It is unjust and irresponsible to apply poorly studied, poorly tested for chemicals such as PFAS and pharmaceutical metabolites on our state's precious lands. Particularly given that the EPA has documented toxicity in similar sewage by-products, this is a regressive and short-sighted plan to deal with Washington's sewage waste.	I-90-2 Biosolids have been studied extensively and there are ongoing studies. Research to date supports that beneficial use is safe when rules and permit requirements are followed. We are not certain what the commenter means in referring to "similar" sewage by-products. This general permit addresses only biosolids land application. Please also see the response to comment I-70-1.

Comment	Response
I-96-2 The people are sick with cancers and other illnesses, and it's no wonder. Chemicals of every kind go down the drain. Washington state is poisoning it's land by this practice.	I-96-2 Ecology notes the commenter's opposition to the land application of biosolids. Businesses and industries that have significant discharges to the sewer are regulated by pre-treatment permits. Those permits limit the discharge of contaminants that might have an adverse impact on the treatment process. Some manufacturers have separate wastewater treatment systems. The solids produced from those systems is not considered biosolids. Individuals can help by making environmentally friendly purchasing decisions. That includes both those connected to public sewars and those served by onsite wastewater treatment systems.
I-102-2 This is the sludge created in the attempt to remove a cornucopia of toxic contaminants from our sewage before we dump it into our rivers. If it is TOO TOXIC FOR OUR RIVERS it is certainly TOO TOXIC FOR OUR HOMES AND GARDENS (and any place that grows food)!!	I-102-2 Biosolids are not created for the purpose of removing contaminants. A large amount of biosolids consists of the microorganisms cultured in our wastewater treatment plants for the purpose of treating wastewater. Ecology notes the commenter's opposition to land application of biosolids. Other commenters expressed a similar concern, so we prepared a response on that topic. Please see the key topics discussions titled "Understanding regulated pollutants in biosolids" and "Food chain crops and biosolids" at the start of this response to comments.
I-104-1 I know you won't listen to the people. So I'm not going to waste too much of my breath. Unless you put microorganisms that are indigenous to the area that you're going to be spreading this stuff in with it then it won't be broken down and it's just going to poison the earth. I'm sure that you can also grow hemp in those soils and pull the heavy metals out of the sludge and then turn around and process it into CBD and sell it in our i-502 market where we can't test for those heavy metals and we	I-104-1 Ecology notes the commenter's opposition to the land application of biosolids. The use of septic systems wouldn't eliminate the production of biosolids. Septic systems must be pumped periodically to ensure proper performance. The solids removed are a form of biosolids and must be managed.

Comment	Response
can poison our citizens. Either way I know you don't care about the people because if you did everyone would have a septic system and we wouldn't have sludge like this to be spread.	
I-105-2 Note that this is my 2nd public comment submittal on this draft permit. The following are new comments. Review of the 2007, 2015 and draft version of the General Biosolids Permit [Permit] indicates that there is and never has been allowances in the Permit for the use of biosolids that contain discharges from industrial activities. However, this requirement is not clearly spelled out. Categorical discharges in particular, as defined in 40 CFR 403, should not be allowed in biosolids that are received, stored, treated, or applied to land under this Permit. The following are examples of how this lack of clarity can confuse those having to meet the Permit and can lead to unintended consequences. • The case of Emerald Kalama Chemical, Inc [Emerald]. and Fire Mountain Farms (FMF) is illustrative of what can and did happen when permits are not clear in what is and is not allowed. In this case, FMF received categorical industrial biosolids from Emerald for nearly 19 years, treated and blended it with other materials, and then stored and land applied it. That FMF was	I-105-2 We acknowledge this second set of comments, thank you for including this clarification. Regarding the commenter's recommendation about wastewater treatment plants receiving discharges from industrial facilities, the state program is implemented consistent with the federal program. Sludge produced from these facilities can be treated to meet standards for biosolids and be beneficially used. Industrial discharges are allowed in municipal biosolids when the proper pre-treatment management practices are implemented. Ecology cannot change this fact through a general permit update. Washington state is delegated by EPA to implement pretreatment requirements for industrial discharges to publicly operated wastewater treatment plants. Federal rules identify fifty-nine categories of industrial activities that may require specified effluent limits, monitoring, and other permit conditions. In addition, Ecology typically applies state-specific developed conditions and conditions from municipal ordinances, as appropriate. These conditions ensure that wastewater treatment plant operations are protected, and that permit limits can be met. Pretreatment has shown itself to be an effective means of reducing contaminants in the sewerage

Comment	Response
receiving industrial sludge from Emerald Kalama should have been made clear to Ecology by a 2009 Fact Sheet submitted by Emerald where they state: "The sludge is registered as a fertilizer with the Department of Agriculture. Emerald loads the sludge into the trucks and sends it to Fire Mountain Farms in Lewis County for land farming." As outlined in the Department of Ecology, State of Washington document "Fact Sheet: 2021 General Permit for Biosolids Management", FMF is defined and permitted as a beneficial use facility (BUF). According to the Draft Permit, a beneficial use facility is defined as: "A receiving-only facility consisting of a site or sites where biosolids from other treatment works treating domestic sewage are applied to the land for beneficial use, which has been permitted as a treatment works treating domestic sewage in accordance with the provisions of WAC 173-308-3107, and that has been designated as a beneficial use facility through the permitting process." • The 2021 draft General Biosolids Permit Fact Sheet states that "This permit does not apply to sludge generated by the treatment of industrial wastewater." The Fact Sheet then goes on to enumerate the status of 375 facility types and to list all subject facilities. I make note that one facility listed as subject to the General Biosolids Permit is the Tacoma Central WWTP. The Tacoma Central WWTP clearly receives industrial discharges as evidenced by their 2015 renewal application and the fact that they are on the list of facilities that are subject to the Permit is in conflict with the Fact Sheet statement that the Permit does not apply to sludge generated by the treatment of industrial wastewater. The same is true of	system and in biosolids. EPA and Ecology are both proactively working on source control and waste management strategies for controlling PFAS discharges from industrial users to publically owned treatment works. With respect to the comments about specific facilities, please see comment B-2-1. Please also see the response to comment O-8-12, and I-7-4.

Comment	Response
the Spokane City Adv Wastewater Treatment Plant and I am sure there are others on the list. Recommendation: Ecology must clearly state that biosolids derived from industrial discharges are not allowed in biosolids that are received, stored, treated or land applied by facilities that are subject to the draft General Biosolids Permit. State NPDES permits must also clearly state the same prohibition.	
I-108-1 My interest in soil and water quality is vested coming from the perspective of raising my family near fields treated with biosolids. What heavy metals and toxins are tested for when the compost is released to the field? Is every load tested? Where are the records? Are heavy metals, contraceptives, household and industrial detergents, and pharmaceutical and non-pharmaceutical drugs tested for? I don't have any issue with manure that is properly composted, but why put mercury, lead, and waste pharmaceuticals on our food, soil, and water?	I-108-1 Wastewater treatment is a necessity for the more than 7.7 million people living in Washington; therefore, we need a way to make use of, or dispose of biosolids, as we all contribute to their production. Even those served by onsite wastewater treatment systems, including those who live organic lifestyles, contribute to the generation of wastewater and biosolids. The permitted entity is responsible for maintaining a complete record relating to compliance and biosolids management activities for a period of five years. Analytical data may also be held at the laboratory that performed the analysis. All facilities are required to submit annual reports to Ecology, and certain data is required with those submittals. The commenter is comfortable with properly composted animal manure. We want to note that most animal manure is not composted prior to land application. Animal manures and commercial fertilizer for example are more widely used on crops with fewer regulatory requirements. Although manure on rare occasions has been positively linked with outbreaks of illnesses, it is commonly understood that

Comment	Response
	the benefits on crop growth and soil maintenance it has outweighs this drawback. Therefore, Ecology applies the same logic in supporting their use to that of biosolids, because the bulk of research and practical experience show when used in accordance with state and federal rules and permit requirements biosolids are a safe and effective soil amendment. We have addressed the commenter's questions about contaminants in biosolids and sampling methods in our responses to others and in our key topics discussions. Please see comments I-3-2, I-7-3, O-7-27, and O-7-39, and refer to the following key topic discussions at the front of this response to comments: “Heavy metals and biosolids”, “Understanding regulated pollutants in biosolids”, and “Food chain crops and biosolids”.
I-109-3 C. The General Permit Fails to Protect Against Dangerous Chemicals The fundamental failing of the general permit is that, even though Ecology knows and recognizes that biosolids contain dangerous contaminants of emerging concern and microplastics, Ecology requires no testing or control for these substances whatsoever. This is a very significant concern given the capacity of these substances to penetrate to groundwater and enter drinking water and surface waters. There is also concern that biosolids directly applied or in compost will expose farmworkers. Lack of adequate regulation of contaminants is a systemic concern which poses cumulative effects. The issues referenced in this letter should be dealt with at the programmatic general permit level and not deferred until site specific review. Because the areas that produce the most biosolids tend to be the most populated and affluent urban areas in Washington, and the	I-109-3 Ecology concurs that some things should be dealt with at a programmatic level - ideally even at the rule level, above the permit. Several commenters have argued that every site is unique and that only individual permits can be adequately protective (we note, however, in their submittal the commenter did not advance that particular argument). Ecology has pointed out that it has the ability to impose additional or more stringent requirements on an individual facility basis because we do in fact have that authority. That does not mean that approach is optimal or that we intend to apply overarching standards one at a time in individual permit reviews. In fact, we very much want to avoid that. We have also repeatedly observed that we have the ability to modify a general permit before it expires, based on new information that would have overarching applicability statewide. The commenter's argument that biosolids contain dangerous contaminants appeals to the commenter's position that biosolids are then dangerous, or are inadequately regulated to mitigate potential dangers. That biosolids contain substances that might pose

Comment	Response
areas that receive biosolids tend to be less affluent, rural areas, the general permit raises serious environmental justice issues that Ecology has not evaluated.	some risk gives us some perspective on how to improve the program over the long term. Ecology would like to see no substances of concern in biosolids, at all. We expect the commenter would readily agree with us. But the simple presence of something that has properties of concern (i.e. is dangerous in some respect in some circumstances) is not the question that drives an informed regulatory approach. The question that most appropriately drives regulation, in this case, is one of risk, and this underscores a huge shortcoming in the commenter's reasoning. Risk is a function of hazard and exposure. Ecology acknowledges that there are unregulated pollutants in biosolids. It is our assessment at this time that those contaminants are not present in biosolids at a level that would pose a sufficient risk to human health or the environment to warrant either a determination of significance under SEPA, or establishing a regulatory standard. That position is consistent with the position of the U.S. EPA and to the best of our knowledge, the majority of states in the union. Ecology's present position in this matter does not mean the agency is uninterested in any particular substance, including microplastics. The best solution to any particular contaminant in the environment may not be one that is attained through changes in the biosolids program (or perhaps changes will prove warranted and efficacious). EPA is preparing a risk screening tool that will allow them to assess the likelihood of significant risk from pollutants in biosolids, based on appropriate pathways of exposure and available information about the substance of concern. The tool will use pathways of exposure that are updated from those used in support of the original federal rules, and can take advantage of more recent analytical results and updated information on hazardous properties of substances. We also recognize a current significant concern about PFAS in particular. Most states have not acted to

Comment	Response
	regulate PFAS in biosolids Biosolids are applied to a very small amount of land in Washington each year. Data collected around the country argue that in most cases concentrations of PFAS in biosolids will be relatively low. Ecology agrees that reducing the release of PFAS (and other contaminants) to the environment is an appropriate goal. Exposure of individuals to PFAS and other contaminants in biosolids is undoubtedly far lower than what occurs through product use and activities in which people engage on a regular and socially acceptable basis. The agency does not argue that those exposures are acceptable, but we believe an effective strategy will more likely focus on improved source control and pretreatment programs. Finally, a critical obstacle for the commenter's argument is the lack of standards for the substances of concern. Simply analyzing for a substance does not achieve anything productive if we don't have a regulatory threshold against which to compare results Instead, it would lead to communities spending significant resources to produce results that have little to no benefit.This is precisely the problem that is presentely EPA's number one priority, and of which Ecology has maintained a consistent awareness and contact.

Comment	Response
I-109-6 One contaminant of particular concern is PFAS. According to the Department of Health, Per- and polyfluoroalkyl substances (PFAS) are a family of chemicals used since the 1950s to manufacture stain-resistant, water-resistant, and non-stick products. PFAS are widely used as coatings in common consumer products such as food packaging, outdoor clothing, carpets, leather goods, ski and snowboard waxes, and more. Ecology has recognized the risks posed by these chemicals, and has prioritized regulating them through a chemical action plan (CAP). Federal and State agencies increasingly recognize PFAS as widespread and a serious health risk. On February 22, 2021, the United States Environmental Protection Agency (EPA) made final determinations to regulate PFOS and PFOA in drinking water. On April 27, 2021, Administrator Regan called for the creation of a new "EPA Council on PFAS" that is charged with building on the agency's ongoing work to better understand and ultimately reduce the potential risks caused by these chemicals. EPA has recognized that PFAS pose serious health risks that can no longer simply be ignored. Likewise, the State has acknowledged that PFAS are chemicals of serious public health concern that is likely present in biosolids and wastewater, highly mobile in water and soil, do not degrade, bioaccumulate in humans and other animals, and cause likely human health effects. Ecology's website provides a fact sheet for PFAS, reading in part that: PFAS have become a serious public health concern across our country and state. Over time, some PFAS released from manufacturing sites, landfills, firefighting foam, and other	I-109-6 The commenter points to PFAS as a contaminant of concern. We received many similar comments that we address throughout this response that the commenter may wish to review in addition to the response below. Ecology also notes the additional supporting documents submitted by the commenter on the topic of PFAS. We want to clarify that a Chemical Action Plan is a non-regulatory strategy to address a substance of concern. The CAP can be looked at as more of a scientific investigative tool. A “substance of concern” is a substance that appears to be hazardous. The CAP is the method Ecology will use to investigate the risk associated with this substance through the various possible routes of human and environmental exposure. With this risk assessment, the agency can determine what, if any, regulatory action should be taken. An outcome of a CAP might in fact be a regulation of some sort, but the CAP itself is not a rule and is not an enforceable document. The commenter notes some of the common, everyday products wherein PFAS are encountered, such as food packaging, outdoor clothing, carpets, etc. This supports our point that the source of PFAS is not biosolids, and eliminating PFAS associated with biosolids beneficial use, will do little (if anything) to minimize public exposure. Ecology’s stance remains that the best approach to reducing public and environmental exposure to PFAS is to reduce or eliminate their use in manufacturing-their true source. The commenter argues that Ecology has extensive knowledge of threats posed by PFAS compounds, but has not established specific requirements for PFAS in biosolids. The commenter states that PFAS in biosolids pose a significant threat to human health or the environment, but this has not been demonstrated. Ecology is putting significant effort into evaluating PFAS - on multiple fronts - in a way that will allow the

Comment	Response
products seep into surface soils. From there, PFAS leaches into groundwater and can contaminate drinking water. PFAS have also been found in rivers, lakes, fish, and wildlife ... PFAS do not break down easily and stay in the environment for a long time. As a result, PFAS are widely detected in air, soil, water, and food. Exposure can occur when someone uses certain products that contain PFAS, eats PFAS-contaminated food, or drinks PFAS-contaminated water. When ingested, some PFAS can build up in the body and, over time, these PFAS may increase to a level where health effects could occur. Studies in animals show that exposure to some PFAS can affect liver function, reproductive hormones, development of offspring, and mortality. Although nearly all of us are exposed to PFAS, their toxicity in humans is not completely understood. Experts investigating the effects on people have found probable links to immune system toxicity, high cholesterol, reproductive and developmental issues, endocrine system disruption, ulcerative colitis, thyroid issues, certain cancers, and pregnancy-induced hypertension.[10] Media accounts and increasing science support these conclusions.[11] The Ecology fact sheet for PFAS similarly acknowledges that Ecology is "concerned" because Certain PFAS are highly mobile in the environment, meaning they can contaminate groundwater. Some PFAS transform into highly persistent perfluorinated chemicals-no natural processes can break these substances down.	agency to set additional regulatory requirements if necessary. Ecology made specific commitments in the PFAS CAP for biosolids. We intend to follow through and in fact determined that we should not wait for EPA to approve a method for PFAS analysis in biosolids - although it would be best - but in doing so we removed one barrier. The commenter notes that Ecology's PFAS CAP[35] recognizes biosolids as a potential pathway of PFAS contamination to waters of the State, and calls for Ecology to, inter alia, "[e]stablish biosolids and soil sample collection and handling methods for PFAS analysis," "[a]ccredit Washington labs for EPA-validated analysis methods," "[i]nvestigate land application sites where procedures mimic rates and practices under current state rule (Chapter 173-308 WAC)," "[e]valuate realistic exposure pathways," and "[e]valuate risk modeling using realistic input values." We understand what the CAP commits Ecology to in regards to biosolids. Biosolids staff authored that section of the CAP. Accreditation is an expectation for compliance sampling when there is an approved method. Our Manchester lab will address accreditation for PFAS according to available resources and with respect to other work. Following the release of the draft permit, EPA provided guidance that encouraged states to work with a selected laboratory to obtain meaningful analytical results on PFAS in biosolids. On September 2, 2021, EPA announced the first single-lab validated method for PFAS in eight different matrices, including biosolids[48]. Ecology was content to move forward with the guidance and encouragement of EPA. The more recent single-lab validated method further bolsters prospects for obtaining meaningful results of sampling efforts. However, the gold standard remains to be multi-lab validation. Ecology is currently engaged in discussions with the

[48] https://www.epa.gov/newsreleases/epa-announces-first-validated-laboratory-method-test-pfas-wastewater-surface-water

Comment	Response
Once in the environment, PFAS can contaminate water and bioaccumulate in wildlife. The drinking water supplies in several parts of Washington are contaminated with PFAS above Environmental Protection Agency's health advisory level. They are costly to filter out. Accordingly, the draft chemical action plan recognizes biosolids as potential sources of PFAS contamination to waters of the State, and calls for Ecology to, inter alia , "[e]stablish biosolids and soil sample collection and handling methods for PFAS analysis," "[a]ccredit Washington labs for EPA-validated analysis methods," "[i]nvestigate land application sites where procedures mimic rates and practices under current state rule (Chapter 173-308 WAC15)," "[e]valuate realistic exposure pathways," and "[e]valuate risk modeling using realistic input values." For wastewater, the draft CAP recommends that "Ecology should evaluate PFAS in WWTP influent and effluent to better understand PFAS discharges in Washington state," "Ecology should develop a study design to sample PFAS in three different types of plants," "Ecology should consider additional monitoring requirements for WWTP dischargers...Based on this evaluation Ecology should require possible PFAS monitoring for some or all domestic and industrial WWTPs." According to the draft CAP, the Legislature provided Ecology "$235,000 to conduct a WWTP sampling study by June 30, 2021. This includes costs for sample analysis, which can range from $1,000 to $1,500 per sample as well as project staff salaries." Footnotes [8] Seattle Times, Puget Sound salmon do drugs, which may hurt their survival (April 16, 2018).	EPA's Office of Research and Development (ORD) to assess Per- and polyfluoroalkyl Substances (PFAS) in Washington's biosolids. ORD is one of the leading research institutions in the world regarding analysis of PFAS in complex organic compounds such as biosolids. Ecology plans to analyze biosolids from a variety of WWTPs across the state and the soils upon which they have been land applied. We will continue to participate in the federal work by evaluating EPA's risk screening tool, and also any individual assumptions and analytics for specific pollutants of concern. To date, other states have moved forward with establishing their own regulatory standards (as evidenced by some of the commenter's supporting documents), and Ecology is pivoting in this direction as well. However, this kind of work is outside the biosolids program operations, and funding – one of the reasons we were hopeful for an EPA validated method. To summarize, we understand PFAS are a concern and will continue to monitor them as mentioned above. As a regulatory agency it is our responsibility to make science-based decisions. It would be irresponsible to impose regulations, or bans on biosolids operations without peer-reviewed research that defend our actions. Without an established regulatory standard for PFAS, sampling for it in biosolids will not improve the quality of biosolids. It may in fact lead us to the wrong conclusions if we do not first understand its behavior in biosolids, soils, plant-uptake and routes of exposure. The purpose of this general permit is to communicate how we will regulate biosolids now. It does not cover the research and investigation that the agency will also be conducting related to PFAS and other possible contaminants.

Comment	Response
Available at: https ://www. sea ttletimes.com/seattle-news/puget-sound-salmon-do-drugs-which-may-hurt-their-survival/ [9] Fact Sheet for NPDES Permit WA0029181 West Point Wastewater Treatment Plant (WWTP) and Combined Sewer Overflow (CSO) System December 19, 2014. [10] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals/PFAS [11] See, e.g. , https ://www. ny times.c o m/2020/09/23/parenting/pregnancy/pfas-toxins- chemicals.html?searchResultPosition=1 "These Everyday Toxins May Be Hurting Pregnant Women and Their Babies" Despite a long record of Ecology recognizing the risks of PFAS, including those risks specific to wastewater treatment and biosolids land application, the draft general permit has no protections in place for PFAS which Ecology recognizes as a priority-toxic chemical. The same is true for pharmaceuticals and other contaminants of emerging concern. Lastly, pathogens deemed dead may actually be dormant. When applied to land in sewage wastes, dormant pathogens can regenerate when spread on the soil, especially wet soil. There is also no meaningful discussion of contaminants beyond those specified in regulation in the draft general permit or associated documents, no disclosure of risk, and no indication that Ecology has seriously considered how to address PFAS, PBDE, and other contaminants.	

Comment	Response
I-109-7 In public meetings and comments on prior applications, the public has rightfully raised concerns regarding lack of testing and monitoring for PBDEs, PFAS and other chemicals in biosolids. In general, Ecology has responded that it is not financially or technically feasible to test for PFAS because there is not a validated testing methodology, and that the more efficient method of regulating PFAS is "upstream" in consumer products. As an initial matter, many chemicals, such as PBDEs, phthalates, illegal drugs, and pharmaceuticals, are readily tested. To fulfill its statutory mandates and duties to protect the public and environment, Ecology must sample biosolids for these contaminants. Furthermore, as noted, Ecology has received funding to complete testing for PFAS associated with wastewater. This testing effort should be incorporated into permit review. Ecology should also draw from ongoing testing and information gathering from drinking water regulation to inform environmental review of the biosolids program, in consultation with the Department of Health.[12] Mr. Kenney notes that other states require that WWTPs use an isotope dilution method like Method 537.1, ASTMD7979-19M, or CWA Method 1600 for PFAS analysis of biosolids in the interim and until EPA completes its work. Such methods are reliable for biosolids because they use an isotope-dilution method to measure sample extraction recoveries and correct for matrix suppression effects in the LCMSMS. Ecology should allow the use of these methods as do other states. Footnotes [12] https ://www.	I-109-7 The commenter remarks about certain substances PBDEs, phthalates, etc. being readily tested, and argues that Ecology is obligated to require or perform analysis for a wide range of potential pollutants in biosolids. This does happen now, to a limited extent, in association with pretreatment program requirements implemented by Ecology's Water Quality Program. If resources were unlimited, we would be happy to accommodate the commenter's wishes. Since resources are not limitless, Ecology questions the wisdom behind sampling for substances where there are no established standards in biosolids or similar matrices, and moreover, where biosolids are unlikely to be a significant source of the substance in question. Presence by itself does not determine exposure or establish risk. At no point in their submittal did the commenter identify a regulatory standard against which the results of such analysis could be properly evaluated. EPA has performed these analyses, and evaluated available data for many years and has not concluded that further regulation is necessary. As mentioned elsewhere in our response, EPA will submit a new risk-screening tool to its Science Advisory Board early next year. Ecology believes it is likely that EPA will identify some substances for further study or regulation. The commenter argues that it is entirely possible for Ecology to test groundwater and surface water for a wide range of contaminants, but ignores the fact that biosolids sites, and in fact sites where manures and commercial fertilizers are applied, in general, do not require groundwater monitoring to begin with. There are no resource protection wells to monitor on these sites, and the apparent presumption that domestic supply or other wells will be properly positioned or even available is highly questionable. The commenter ignores measures in place such as buffers and seasonal restrictions on application that are designed to protect water resources. The commenter in fact

Comment	Response
doh.wa.gov/CommunityandEnvironment/DrinkingWater/RegulationandCompliance/RuleMaking. Mr. Kenney also notes that PFAS is a nationally recognized concern on and around lands used for training by the Department of Defense. In these locations, the DOD regularly tests water using EPA-approved methods for PFAS. For example, testing has been underway for PFAS on Whidbey Island associated with the Naval training area since 2016.13 Water sampling at Joint Base Lewis McChord revealed elevated levels of PFAS in 2018, which required cessation of drinking water use to protect public safety.14 As such it is entirely possible for Ecology to test groundwater and surface water associated with biosolids applications sites. With respect to consumer product regulation, Mr. Kenney welcomes those efforts. However, even if implemented immediately the benefits would be limited and long-term, given the prevalence of PFAS in widespread consumer products and the global nature of commerce.	has remarked upon unexplained contamination with some of these substances in the Nisqually River that is not linked to biosolids or a treatment plant discharge.
I-109-8, I-110-1 D. The General Permit Fails to Protect Against Microplastics WAC 173-308-205(1) requires that "all biosolids...must be treated by a process such as physical screening or another method to significantly remove manufactured inerts prior to final disposition." Additionally, "biosolids (including septage) that are land applied...must contain less than one percent by volume recognizable manufactured inerts." WAC 173-308-205(4). Biosolids generally contain large volumes of small plastics, referred to as microplastics and nanoplastics. A recent synthesis of literature	I-109-8 The standard for removing manufactured inerts was established in rule at a time when Ecology (and we think most others) were not aware of issues related to microplastics. This is clearly evidenced by the cited standard of a bar screen with a 3/8" aperture (whereas microplastics are generally 5 millimeters or less). The threshold by percent is 1% recognizable inerts by volume. In this case, Ecology adopted the standard with ocular recognition in mind, literally what might be seen in a field. Ecology notes the additional supporting documents submitted by the commenter on the topic of microplastics. We understand microplastics are a concern and will continue to monitor their occurrence and impose regulations if peer-reviewed research and

Comment	Response
focused on microplastics in biosolids, titled "An overview of microplastic and nanoplastic pollution in agroecosystems" (Ng et al. 2018),[15] states that "polyethylene, plastic fibres, and polystyrene foam occupied up to 5% w/w in compost from mixed municipal solid waste for all size fractions between 420 Œºm and 25 mm; with around 0.5 to 0.6% having sizes b2 mm." Prevailing agronomic rates in the United States suggest maximum potential rate of microplastic inputs from biosolid in the order of 0.5 to 3.2 t·ha-1·yr-1. This unit measurement equates to 0.2 to 1.3 metric tons per acre per year of plastics present in biosolids (one hectare equals 2.471 acres). Plastics are "manufactured inerts." Extensive study, widespread publicity dedicated to microplastic contamination in soils and waters, and the ability to eliminate microplastics if desired indicates that microplastics are "recognizable." WAC 173-308-205(4). The general permit would authorize approximately 430,000 tons of biosolids land application over a five-year period. Even a conservative estimate under which microplastics compose 2.5% of those biosolids would mean that 10,7050 tons of microplastics will be land applied under the general permit. Plastics take hundreds of years to break down: "projections indicate that the lifetime of polyolefins on land is in the vicinity of hundreds of years."[16] This means that microplastics not dispersed into surface or groundwaters (with resulting harm to aquatic species), or ingested and adsorbed by grazing cattle, will bioaccumulate on site and quickly add up. The plastics are harmful in their own right, and also can transport and degrade into a variety of contaminants. The health effects of microplastics are believed to be detrimental	practical experience determine it necessary, as with other contaminants of concern.

Comment	Response
but are still poorly understood. According to Ng et al.: Classical soil ecotoxicological approaches use isolated organisms and standard substrates, with measures taken for survival, growth, reproduction and avoidance behaviour over a period of days and weeks. Such approaches may not capture the full impact of chemical additives in plastics that act as endocrine disruptors in addition to those which bioaccumulate, where long-term exposure at low doses may alter cell functions or cause DNA damage. Such damage manifests later in life or across generations as the damage accumulates.[17] The most recent studies of microplastics suggest that they are highly mobile in water. Crossman et al. (2020) measured microplastics biosolids at various application sites, found high levels of contamination, and determined that 99 percent of the microplastics appeared to be transported by water over time.[18] In short, the proposed application would put cumulatively significant amounts of plastic onto application sites, that would likely enter surrounding waters and organisms and cause uncertain long-term impacts to the native ecosystem and human health. Despite these risks, the general permit does not specify any means by which to comply with the requirement to remove manufactured inerts. As a result the general permit is deficient and must be conditioned to require rigorous screening for microplastics and nanoplastics. Accordingly, Mr. Kenney requests that Ecology make the following changes to the general permit documentation and SEPA review to better protect the environment and public	

Comment	Response
health: • Identify and discuss all other jurisdictions that monitor, test, and/or regulate microplastics in biosolids. Explain the implications for this information on the Washington regulatory program. • Identify mechanisms to remove microplastics from biosolids, and the viability of these methods. • In the SEPA analysis, identify information gaps and obtain information to fill those gaps to the maximum extent feasible. To the extent information truly cannot be obtained, "indicate in the appropriate environmental documents its worst-case analysis and the likelihood of occurrence." WAC 197-11-080(3)(b). • Require as a condition of the general permit that WWTP operators remove microplastics from biosolids in accordance with WAC 173-308-205. • Ecology should test runoff and groundwater associated with select recent biosolids application sites after rain and report the results. As with PFAS, PBDEs, and contaminants of emerging concern, Ecology cannot fulfill its public statutory obligations by simply ignoring microplastics. Mr. Kenney requests that Ecology take reasonable, affirmative steps to address this serious issue and comply with its statutory mandate to protect waters of the state. Footnotes [13] https ://www. nav fac.navy.mil/navfac_worldwide/pacific/fecs/northwest/about_us/northwest_documents/environme ntal-restoration/pfas-groundwater-and-drinking-water-investigation/nswi_pfas.html ; see also https	

Comment	Response
://www. nav fac.navy.mil/niris/SOUTHWEST/FALLON_NAS/N60495_000011.PDF (Naval Air Station Fallon); [14] https://home.army.mil/lewis-mcchord/application/files/2015/6106/2504/CCR_2018_Lewis_DIGI_FINAL.pdf [15] Ng et al., 2018, An overview of microplastic and nanoplastic pollution in agroecosystems. Science of the Total Environment, Vol. 627, pp. 1377-88. [16] Ng et al., 2018, An overview of microplastic and nanoplastic pollution in agroecosystems. Science of the Total Environment, Vol. 627, p. 1380. [17] Id. at 1385. [18] Crossman, Rachel R. Hurley, Martyn Futter, Luca Nizzetto, Transfer and transport of microplastics from biosolids to agricultural soils and the wider environment, Science of The Total Environment, Volume 724, 2020, 138334, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.138334 (https ://www. s cien ce direct.com/science/article/pii/S0048969720318477)	
I-111-2 You are poisoning the very soil and water you are supposed to protect. Just like allowing a landfill in Pierce county over our main aquifer. Protect our soil and water!	I-111-2 Large amounts of research and practical experience demonstrate the safety and efficacy of the beneficial use of biosolids. Soils benefit, crops benefit, and wildlife benefit. We cannot respond to arguments about individual facilities or separate permit processes. Solid waste permits are issued by local jurisdictional health departments.
I-113-1 I am submitting this written response as a public comment pertaining to Ecology's permit application process for sewage sludge, aka; bio	I-113-1 Ecology notes the commenter's support for the Sierra Club submittals. We refer you to our responses to the entirety of Sierra Club comments, commenter O-7), as

Comment	Response
solids. I concur with everything Darlene Schanfeld has stated in the two Sierra Club letters she submitted dated July 10th and July 11th 2021. I agree with the current positions Sierra Club holds. I am also a member of the Toxics Committee with Sierra Club. We have been studying the negative impacts on both human and environmental health for quite some time in relation to sewage sludge. Many studies already exist. In light of not repeating what Darlene has already shared, I will touch on a few other areas of concern and make suggestions. I have been a community advocate for the environment for 30 years. I have grave concerns with the long term environmental and health impacts due to the spread of sewage sludge which has been proven to contain many hazardous chemicals. The exposure limits on children are far greater than adults. The contamination of our ground water in addition to the foods we consume from farmland contaminated with sewage sludge is immeasurable.	well as to our various topical discussions at the start of this document. Risk assessments consider a target individual - the person to be protected - which may be a child or an adult exposed for a lifetime. EPA's original risk assessment evaluated fourteen pathways of exposure, including adults and one specifically involving a child. We expect that future evaluations will take an appropriate approach to model risk around appropriate susceptible individuals.
I-113-5 I would like to see your toxicology department monitor the cumulative impacts on humans, children and the environment, including our rivers and ground water. This study should be funded through the legislature... …If DOE would classify this as a hazardous waste, opposed to a bio solid, we could better inform the farmers and the public and prevent future contamination of land, water and food sources. Not to mention avoid numerous health related issues including cancer.	I-113-5 By law, biosolids are not a waste - they are a commodity. Biosolids also do not have the characteristics of hazardous waste and therefore are not classified as such. Regardless, the presence of a hazardous substance in biosolids does not mean there is a significant risk from the beneficial use of biosolids. If that were true, then many products we use on a daily basis would be unsafe as used. Ecology does not think the suggested monitoring program is practical or warranted. It is not something for which we would request funding from the Legislature. Please also see the key topics discussion titled “Understanding regulated pollutants in biosolids”, and

Comment	Response
	"Food chain crops and biosolids" at the start of this response to comments for more information.
I-114-2 Why in Gods name would you even consider poisoning what little clean Earth we have. You know besides human waste, there are pesticides, heavy metals, fire retardants, medical waste, nitrates, and pharmaceuticals.	I-114-2 Ecology notes the commenter's opposition to the land application of biosolids.
I-115-2 I don't care that it is supposedly found tolerably safe, there are drugs, heavy metals & a whole assortment of contaminants that don't need to be used as a "bio-solid", your agency can't guarantee it's completely safe, would you be will to have a child of yours plan in a area that has been spread on? Can you with all good conscience gamble with the health and well being of children, and the elderly? Would you yourself eat something grown in that muck?	I-115-2 Ecology notes the commenter's opposition to the land application of biosolids land application.

Comment	Response
I-116-2 I have been an organic farmer since 1972. I do a lot of research and there is no doubt that sewage sludge has lots of harmful contaminants in it. If you go forwad with this I hope that there will be successful litigation to force you to stop and that some of your bureaucrats will lose their jobs or go to jail.	I-116-2 We commend the commenter for being a pioneer in organic farming. As discussed throughout this response, we do not share the commenter's perspective on biosolids. Please read the response to comment I-117-2 for more information.
I-117-2 We do NOT support this at all and are aware that many in the US have been negatively impacted by this long and dangerous practice. We believe the number of chemicals contained in this toxic material, no matter how one might argue that sludge is properly "treated" before dispersal, is unknowable. Why? Because chemicals react to form new chemicals and the DOE has no way of testing that unknown number... We are supposed to be moving toward a green new deal, per the current Biden/Harris administration. How can we then ignore the fact that spreading human and industrial waste on the land is NOT green and is poisoning not only our fish as toxins make their way into rivers and oceans, but ourselves. Could there not be a link between what is going into the soil as toxic waste (regardless of whether Class "A" or "B") where our food is then produced and ever increasing rates in cancer?	I-117-2 The commenters say that many in the U.S. have been negatively affected by the beneficial use of biosolids. We recognize that people object for one reason or another, but there are also many people who support beneficial use and who benefit from it. Ecology cannot make decisions based on opinions alone. As a regulatory agency it is our responsibility to make science-based decisions. It would be irresponsible to impose regulations, or bans on biosolids operations simply based on commenter opposition. There are volumes of research and decades of practical experience that show benefits to soils, plants, and wildlife, and which have not detected negative impacts. Biosolids management practices are intended to protect both surface and groundwater. Permit applicants are required to identify wells and surface water bodies within a quarter-mile of an application site, the presence of seasonally shallow groundwater, and to provide data on site topography and soils. That information is taken into account when establishing buffers and seasonal restrictions on application. Biosolids are applied to less than 0.2 percent of agricultural land in Washington in any given year. It seems unreasonable to link escalating rates of any form of cancer to a practice that impacts such a small amount of land base. Please see the key topics discussion titled "Food chain crops and biosolids" at the start of this response to comments for more

Comment	Response
	information.
I-119-1 As a resident of Lincoln County with a rental property in Spokane County, I offer the following. As a citizen, I am very concerned that the quality of waste treatment in these two counties is currently below that necessary to capture and prevent heavy metals, pathogens, and such everyday products as sunscreen and cosmetics from polluting water and land areas within these two counties. Evidence points to treatment plants nationally lacking the technology and facilities to prevent microfibers from entering surface waters after treatment, and I believe the same can be said of heavy metals, pathogens, and everyday products. The technology is too old-school to cope with these heightened threats to public health, not only in Washington, but in the United States, and certainly world wide.	I-119-1 The commenter begins by identifying a concern for the quality of treatment plant effluent discharged to surface waters. This permit does not address effluent quality and we cannot address that subject here in our response to comments. We can say that all wastewater treatment plants in the state are required to meet specific limits for their effluent discharges, and those discharges are monitored to ensure compliance. EPA performed a risk assessment in support of their original rule and has reviewed information on contaminants multiple times since. Thus far, the agency has not chosen to regulate other substances in biosolids. EPA will release a draft screening tool next year that is intended to help them identify pollutants that might be a concern and so focus more resources on the need for additional regulation. The commenter asks about heavy metals, pathogens, and advanced cosmetics. There are limits on heavy metals and pathogens in biosolids. Pathogens are reduced by 99% in Class B biosolids, and site management and access restrictions are in place to protect against exposure to any residual pathogens. Those pathogens are then attenuated by natural processes. Pathogens are reduced to below detectable limits in Class A biosolids. The commenter's remark about cosmetics is insightful. We know that cosmetics contain, for example, PFAS compounds, which Ecology, the State Department of Health, and others are currently devoting a great deal of resources in investigating and preparing to regulate. But the commenter is asking us what we are doing to protect the environment against substances that are sold over the counter and which people apply liberally to their bodies. If there is a threat from such substances, then it is much greater from our personal use than will ever be the case for

Comment	Response
	biosolids.
I-119-2 Rather than concentrating on defining who can apply sludge to land, which can then migrate to aquifers, I believe the Department of Ecology could better work to identify and define methodology to assist treatment plants in the entire state to prevent the above pollutants from entering the food-producing chain. Very unsuitable sludge products are currently being applied on agricultural land which produces food and feed for livestock for consumption by the public. What are the safeguards in place to prevent over-exposure of the public's food supply to heavy metals, pathogens, and advanced cosmetics? Are oversight procedures in place to ensure applicators have sludge products that are safe? Is there enough knowledgeable manpower available to judge the suitability of particular batches of sludge? Do applicators adhere rigorously to the regulations to ensure safety, or do they just apply the product as fast as possible to get on with the next application? I suspect what the answers are, what with budget constraints always in the picture. AND, who from DOE is watching applicators for compliance? Are they watching enough of the time? As I'm sure most at the Department are aware, heavy metals are long-term threats to public health. Pathogens of all types are swift killers, yet these are present and available to food	I-119-2 We agree with the idea the commenter is advancing about reducing pollutants in biosolids. The quality of biosolids is in fact an index to our overall success as a society at taking steps to protect our environment. So we agree with the commenter's idea of preventing pollutants from entering the food chain. The best way to do that is to not use them to begin with. Ecology is working on initiatives like Safer Products for Washington that can have a significant impact on pollutants that enter our environment and food chain. Consumers can have an impact by making their preferences known, and by purchasing products that are environmentally friendly, from start to finish. The second-best approach is to implement cost-effective solutions to treating contaminants when they do enter the wastewater system. Ecology and others are working to better understand the impacts of different forms of treatment on PFAS. That being noted, at least as regards biosolids, Ecology is not charged nor funded to do the kind of research the commenter is wanting. EPA has recently awarded 6,000,000 dollars in grant funds to support further research[49]. The commenter refers to the presence of heavy metals and “pathogens of all types being available to food plants grown where sludge is applied”. Ecology will be pleased to see concentrations of any substance of concern in biosolids decline further (they have declined substantially over the years). Heavy metals occur naturally in soils. Biosolids regulations are intended to ensure that they do not accumulate

[49] https://www.epa.gov/newsreleases/epa-awards-nearly-6-million-research-potential-risks-pollutants-found-biosolids

Comment	Response
plants grown where sludge is applied. Are current safeguards enough? I suspect not.... Rather, please investigate ways to empower treatment plants to mitigate the damage to health caused by heavy metals, pathogens, and advanced cosmetic products. Maybe much better filters are the answer. I think this should be the thrust of the Department of Ecology's efforts for the environment and the people who have to live in it.	to unacceptable levels as a result of beneficial use. As regards pathogens, the commenter says that pathogens of all kinds are killers, and that pathogens are available to food plants grown where sludge is applied. This is really not correct. Biosolids are treated to reduce pathogens to either below detectable limits (Class A), or by about 99% (Class B). Most land-applied biosolids are Class B. Because pathogen reduction is not complete for Class B biosolids, there are additional restrictions for site access and management that include waiting periods before people are allowed to access a site, before animals are allowed to graze a site, and before crops are allowed to be harvested. The primary threat of transfer from food chain crops would be from pathogens adhered to the edible portion of the crop, such as a carrot, or potentially a strawberry where the fruit might touch the soil surface and contact biosolids. The restrictions on harvest for those kinds of crops range from 14 to 38 months after the last application - *before* a crop can be harvested. In other words, regulations largely discourage the application of Class B biosolids except to crops where the edible portion develops above ground after biosolids are applied (wheat and corn, for example). Internalization of pathogens by crops is possible - but certainly not widely known. This seems to be an emerging area of science and the potential for impacts from land-applied biosolids seem quite low due to treatment requirements, restrictions on methods of application, and waiting periods for harvest. For more information, the commenter may wish to review *What are pathogens, and what have they done to and for us?*[50].

[50] https://bmcbiol.biomedcentral.com/articles/10.1186/s12915-017-0433-z

Comment	Response
I-120-2 We don't know what may be in those bio-solids. We test for only 9 heavy metals. All sewage bio-solids may contain toxic and hazardous materials. It is a dangerous program. Again, please do not renew!	I-120-2 Regarding pollutants in biosolids, please see the response to comment I-7-3. In addition, Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "Consequences of ceasing all biosolids land application".
I-121-1 Please read, esp. list of toxins in later pages. Commenting on renewal of permit for putting biosolids on farmland in Wash state.	I-121-1 Please see the response to I-33-2.
I-123-2 *This comment was submitted verbally during the June 22, 2021 Public Hearing.* Anyway, my comment technically on the permit renewal is a very deep concern as you've heard from many of the questions about perfluorinated chemicals, and actually, other toxic chemicals. Washington State can go beyond EPA and the national standards in terms of addressing perfluorinated chemicals, and this is a very serious issue. Yes, maybe, me sitting in my home, you know, somewhere in an urban area is not being directly impacted by biosolids. But people who are around those communities where the material is being, land applied and in the forest, and the fact that it's running potentially running out in- or is running out into the surface waters, going down into groundwater and impacting potentially, the air and plants. So this is a major major issue. There's a ton of litigation and other very serious regulations	I-123-2 Ecology is acutely aware of concerns about PFAS in general, one facet being the presence of PFAS in biosolids. We are also aware of the response by states in the New England area, as well as Colorado. Most states have not taken those steps. That does not mean Washington should not, or will not, but we do believe a thoughtful approach is important. Ecology made specific commitments in the PFAS CAP[35] for biosolids. We intend to follow through and in fact determined that we should not wait for EPA to approve a method for PFAS analysis in biosolids - although it would be best - but, in doing so, we removed one barrier. However, we disagree about implementing testing requirements for PFAS in this permit for several reasons, foremost because it would be premature to impose such requirements without a multi-lab validated method, or an established regulatory standard with which to compare results. Please also see the response to comments I-7-3, I-47-1, I-48-4, LG-2-2, and O-1-1 for additional information.

Comment	Response
and environmental attention being paid to this in other states. And I really do think that this permit should be, including this in the permit and you do have the ability to also require testing, not only testing you yourself could do as Ecology, which I think you have funding to do, but also to require testing by the permittees. So I'll end there and thank you so much.	
LG-2-2 LOTT acknowledges that there has been much talk and concern around the potential levels of PFAS and other contaminants of emerging concern in biosolids. We agree with Ecology's approach and think it most prudent to wait for an EPA approved and validated method prior to sampling for these chemicals in biosolids.	LG-2-2 Ecology's initial position was as suggested by the commenter at the time the comment was submitted. After a time it became clear that EPA was stalled on identifying a multi-lab validated method that they could formally approve. To date they have a single-lab validated method. EPA eventually encouraged states to work directly with experienced labs and move ahead with analysis as needed. Ecology has been discussing a possible research effort with U.S. EPA. At this time, Ecology does not have funds to implement research on its own. We would like to see other work evolve before considering permit requirements to monitor for PFAS.
O-1-1 Earth Ministry/Washington Interfaith Power & Light (WAIPL) represents people of faith and spiritual communities across our state. Our membership of over 5,500 Washingtonians cares deeply about environmental justice and public health as moral issues and for years have been advocating for stronger protections against toxic PFAS chemicals. We are grateful that our state is a leader in protecting communities from PFAS. Thank you for Ecology's current work to limit and prevent Washingtonians' exposure to these chemicals through Safer Products for Washington, the PFAS Chemical Action Plan, rulemaking with the Department of Health on a standard for	O-1-1 We see that the commenter is aware of other work Ecology is doing on PFAS. We expect there are small amounts of PFAS in biosolids. Biosolids are applied to an extremely small amount of land in Washington – around 0.2% of farmland each year. Since PFAS are found in the breast milk of 100% of females, who on average are exposed to an *extremely* small amount of food grown on biosolids amended soils (and we expect in most cases not at all), we cannot reasonably attribute the presence of PFAS in breast milk (or blood serum) to the use of biosolids. It is possible that EPA and/or Ecology will require analysis for PFAS in biosolids at some point in the future, and it is possible that regulatory criteria will be established for PFAS in biosolids. We want to point

Comment	Response
PFAS in drinking water, and implementation of the 2018 ban of PFAS in food packaging. In line with this important work, we ask that your scope action on PFAS be expanded to include biosolids. Earth Ministry/WAIPL is concerned about the presence of PFAS in biosolids sludge used on farmland in our state. PFAS is found in the blood of nearly every American, and it is alarming that a recent peer-reviewed study showed it in the breast milk of 100% of women tested. In order to live into our faith values of justice and stewardship, we must stop continued contamination of our food and communities. One actionable step is to test for PFAS in biosolids sludge before it is spread on land used for food production. Based on scientific testing of sludge from municipal water treatment plants, there is good reason to believe that PFAS is present in sludge used in our state. Washington already bans the use of PFAS-containing fire-fighting foam (the major source of PFAS contamination in drinking water in our state) and Ecology is implementing a ban on PFAS in food packaging with the goal of reducing exposure of PFAS from food. To truly remove PFAS from our food and water we must also stop spreading sludge on farmland. Thank you for taking strong action to protect our communities and ecosystems from toxic PFAS.	out, however, that those steps would not be a solution to concerns about PFAS. We are much more exposed to PFAS from products we willingly use on a daily basis than we are from PFAS in biosolids. If PFAS or other contaminants are of concern in biosolids, the solution is to look back up the pipe and eliminate or at least reduce them at the source.

Comment	Response
O-2-5, O-7-29 Sections 3.4.5 and 4.4.5 Point of Compliance say: *The point of compliance for a sample is the date on which the sample is taken, not the date on which results are subsequently reported. It is a violation of this permit to use or distribute biosolids that fail to meet applicable standards.* This is not a correct definition of Point of Compliance. Point of Compliance is not a date. A correct definition would read something like: *Point of compliance means the geographic location at which the concentration of the chemical of concern is to be at or below the risk-based corrective action standard determined to be protective of public health and the environment.*	O-2-5 The definition in the draft permit, in this case, *a point in time*, is correct. The intent is to prohibit the sale, use, or distribution of biosolids before the results of applicable laboratory analysis are known.
O-2-14, O-2-68, O-7-74 How does Ecology know that manufactured inerts, including plastics, will not impact soil health and/or end up in crops?	O-2-14 The program requires screening to remove trash, but of course pieces smaller than the screening aperture can get through the process. If we are talking about larger pieces of debris – say those that are visible to the naked eye – they are simply too large to be taken up by plants (as is the case even for many particles too small to be seen with the naked eye). If we are talking about microscopic pieces, then there is some possibility of uptake. Research on microplastics is building and Ecology is paying close attention. As for soil health, there is abundant evidence from decades of research that shows healthy crops and soils following biosolids land application.

Comment	Response
O-2-15, O-2-69, O-7-75 Ecology has been aware of per- and polyfluoroalkyl substances (PFAS) in biosolids since at least 2008. Why has Ecology failed to require testing for PFAS in biosolids that are land applied? Wouldn 't it be prudent to stop application of biosolids to cropland until there are clear safety limits? Who will compensate farmers if biosolid applications leave PFAS in the soil that renders it useless for growing crops?	O-2-15 The commenter questions why Ecology has not required sampling for PFAS in biosolids since at least 2008. We must speculate here to an extent, but use of two forms of PFAS of greatest concern (PFOS and PFOA) was phased out starting in the early 2000s[3031]. As discussed in comment I-70-1, EPA has only recently provided a single-lab validated method for analysis of PFAS in biosolids[45] – there was no validated method previously, and there is no regulatory standard now. Ecology has released a chemical action plan on PFAS that shows the steps we plan to take. In the meantime, biosolids are applied to a very small amount of cropland in Washington each year. We are far more exposed to PFAS in other ways. Ecology does not agree that it would be prudent to cease the application of biosolids. In addition to the loss of benefits from land application of biosolids, there would be significant economic impacts that in Ecology's expectation would far outweigh the benefit of any moratorium. We cannot engage in speculation about the outcomes of litigation. Such questions of are the province of the courts.
O-2-17, O-7-58 How does Ecology address the presence of pharmaceuticals, pesticides and other chemicals that likely change the biota on land where biosolids are applied?	O-2-17 We suppose that anything applied to the land can have an impact on soil biota – even a soft drink spilled on a spot of land probably has some temporary influence on microorganisms in the soils. There is no evidence that soil biota are compromised by the land application of biosolids. In fact, some studies show very healthy biota. Research clearly shows that plants and soils benefit from the land application of biosolids.

Comment	Response
O-5-2 ...We have concerns that this permit is not protective of human health and the environment because of the potential for sewage-derived biosolids to contain and spread toxic chemicals into the environment... …Thousands of unregulated toxics in sewage-derived biosolids: Research shows that thousands of chemical contaminants have been identified in sewage sludge including: 27 metals, PFAS (per- and polyfluoroalkyl substance), microplastics, flame retardants, pesticides, personal care products, pharmaceuticals, and hormones.[1,2,3] ... …Biosolids Permit is not protective of human health and the environment: Of the thousands of toxic chemicals found in biosolids only 9 metals are regulated at the Federal and State levels, and therefore with this permit.	O-5-2 We acknowledge the commenters concern that the permit is not adequately protective. The commenter says that research shows there are thousands of unregulated toxics in sewage-derived biosolids, and provides three cited articles in support. Ecology reviewed each of the cited articles. One article speculates that there are more compounds than reported by analysis, but none refers to thousands of unregulated toxics in biosolids. EPA has confirmed over 700 substances of interest in biosolids[51]. Presence by itself does not establish a hazard.
O-5-3 Many of the chemicals found in sewage sludge are defined in Ecology's terms as being persistent, bioaccumulative, and toxic (PBT). They transfer throughout the food web,[4,5,6,7] exist in all trophic levels, and are found in organisms that are far from the source of contamination.[8]. Exposure to even small amounts of these toxics can, over time, be dangerous to human health and the environment. Studies show that these toxics can lead to respiratory and cardiovascular disease, cancer, reproductive effects, nerve and neurodevelopmental effects, endocrine disruption or immune	O-5-3 The commenter expresses concern that many of the chemicals found in biosolids are persistent, bioaccumulative, and toxic, but only a couple are regulated in biosolids. Ecology acknowledges that there are trace amounts of PBTs in biosolids (but not thousands). They are in biosolids and in the environment in general because they are persistent. However, biosolids are not the source, as they do not originate within wastewater treatment plants. In many cases, exposure derives from commonly used products and activities in our day-to-day lives. The commenter identifies six PBTs for which Ecology has created Chemical Action Plans (CAPs) : Mercury,

[51] https://comptox.epa.gov/dashboard/chemical-lists/BIOSOLIDS

Comment	Response
system dysfunction, and organ damage in humans and animals.[3,9]... …The Department of Ecology recognizes that PBTs are a serious health and environmental problem and has created Chemical Action Plans (CAPs) for 6 PBTs: Mercury, polybrominated diphenyl ethers (PBDE), lead, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs), and per- and poly-fluorinated alkyl substances (PFAS). The two metals (mercury and lead) are currently being regulated under the Biosolids Permit but PBDEs, PAHs, PCBs, and PFAS are not. The PBDE CAP explains the hazardous nature of PBDEs and reports that "PBDE's have been detected in biosolids and sewage sludge in the U.S. and Europe" but that "Washington State does not monitor PBDEs in biosolids."[10] The PCB CAP reports that even though PCBs are found in biosolids "there are no requirements to monitor PCBs in biosolids, nor a regulated level of PCBs in biosolids."[11] Most recently the PFAS CAP states that "Biosolids have been identified as a significant source of PFAS emissions"[12] but are also not regulated in the Biosolids Permit. The Chemical Action Plan process is the mechanism that Ecology uses to reduce or eliminate the use of PBTs in Washington State but is not as effective as it could be. While these CAPs recognize that PBDEs, PCBs, and PFAS are all hazardous substances that are ubiquitous in biosolids, they do not require biosolids to be tested or regulated for these substances. The CAP documents claim that data gaps, lack of standardized tests, and absence of safety levels for these toxics are the reasons amongst others for inaction. Given the overwhelming evidence that biosolids are a source of toxic contamination in Ecology's	polybrominated diphenyl ethers (PBDE), lead, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs), and per- and poly-fluorinated alkyl substances (PFAS). The commenter also notes Ecology's work with the Safer Products for Washington Program. The commenter is concerned that despite the chemical action plans and focus on PBTs under Safer Products for Washington, only two are currently being regulated in biosolids. The presence of a substance, though it may not be desirable, does not mean there is a risk that requires the regulation of biosolids as a solution. The fundamental determinant is mathematical: risk is equal to hazard - how dangerous something is, multiplied by exposure - how much you eat, breathe, or contact on your skin. Many substances have some degree of hazard associated with them. It can be quite complex to determine how much exposure occurs to target individuals in certain circumstances. Biosolids are applied to a very small percentage of land in Washington in any year, not all of which is used to grow food crops. Also, the existence of a CAP does not mean that the best solution for a particular pollutant is to increase regulation in biosolids (although that is one possible element of a solution). Ecology has reviewed a great many analytical reports for PCBs in biosolids, for example, and did not find them at levels that would trigger a regulatory response. That does not mean we would not like to see fewer PCBs in the environment. Given the work being done on PFAS at the moment, and additional work by EPA on risk screening of pollutants in biosolids, Ecology thinks that it is appropriate to examine all of the CAPs we have prepared, and evaluate them in the context of the biosolids program. Ecology is presently developing an AP for phthalates and will consider biosolids in the agency strategy. At this time, Ecology cannot make any commitment regarding microplastics. The commenter argues that the production and use of

Comment	Response
own documents and many others, the assumption should be that they are unsafe until proven otherwise - not the other way around. [1]EPA. 2009. Targeted National Sewage Sludge Survey Sampling and Analysis Technical Report. EPA-822-R-08-016. Retrieved from: https://www.epa.gov/sites/production/files/2018-11/documents/tnsss-sampling-anaylsis-tech-report.pdf [2]Chad, A. et al. 2006. Survey of Organic Wastewater Contaminants in Biosolids Destined for Land Application. *Environmental Science & Technology* 2006 *40* (23), 7207-7215. DOI: 10.1021/es0603406 [3]EPA. 2018. EPA Unable to Assess the Impact of Hundreds of Unregulated Pollutants in Land-Applied Biosolids on Human Health and the Environment. Report No. 19-P-0002. Retrieved from: https://www.epa.gov/sites/production/files/2018-11/documents/_epaoig_20181115-19-p-0002.pdf [4]Wu, C. et al. 2010. Uptake of Pharmaceutical and Personal Care Products by Soybean Plants from Soils Applied with Biosolids and Irrigated with Contaminated Water. Environmental Science & Technology 2010 *44* (16), 6157-6161. DOI: 10.1021/es1011115 [5]Kirkham, M.B. 2020. *Water Relations and*	biosolids will disproportionately affect people who work in wastewater treatment plants, biosolids processing facilities, and farm workers (who are often immigrants) because those groups of people are generally less well educated and have less access to health care. The commenter did not provide any documentation to support the argument that workers at wastewater treatment plants are less educated, have less access to health care, or even have an overall unaddressed concern about working with biosolids (let alone raw sewage). We can more easily understand the commenter's concern for immigrant farmworkers as a group that might not have a voice, but the commenter did not provide information or speculate as to how many farmworkers are employed or exposed to biosolids where they are used. We believe the vast majority are not exposed to biosolids (though they may be exposed to chemicals, animal manures, dust and other hazards). The commenter argues that the permit will disproportionately affect people who cannot afford to eat certified organic produce — per the commenter, the only food guaranteed to be grown without biosolids. Ecology observes that organic produce - no matter how desirable - is not available to many people, and that the vast majority of produce is grown without the use of biosolids. Ecology agrees it will be a good thing to reduce the presence of substances of concern in biosolids. Ecology does not agree that biosolids are a source of toxic contamination. The amount of various contaminants in biosolids is quite small, and biosolids are applied to only a very small fraction of land in Washington. The reason CAPs did not recommend additional analysis of these substances in biosolids is that a review of available information did not support the need to do so. In particular, the commenter requests that Ecology begin monitoring biosolids for the following contaminants: 1. Per- and Polyfluoroalkyl Substances (PFAS) 2. Polybrominated diphenyl ethers (PBDE) -

Comment	Response
Cadmium Uptake of Wheat Grown in Soil with Particulate Plastics. Particulate Plastics in Terrestrial and Aquatic Environments. CRC Press. 442 p. [6]Kinney, C.A. et al. 2008, Bioaccumulation of pharmaceuticals and other anthropogenic waste indicators in earthworms from agricultural soil amended with biosolid or swine manure: Environmental Science and Technology, v. 42, no. 6, p. 1863-1870, doi:10.1021/es702304c. [7]Jessica J. et al. 2016. Occurrence of Triclocarban and Triclosan in an Agro-ecosystem Following Application of Biosolids. *Environmental Science & Technology* 2016 *50* (24), 13206- 1321. DOI: 10.1021/acs.est.6b01834 [8]Ahrens, L., & Bundschuh, M. (2014). Fate and effects of poly- and perfluoroalkyl substances in the aquatic environment: A review. Environmental Toxicology and Chemistry, 33, 1921– 1929. https://doi.org/10.1002/etc.2663 [9]Yu, M. et al. 2011. Environmental Toxicology: Biological and Health Effects of Pollutants, Third Edition. CRC Press. 397 p. [10]Ecology et. al. 2006. Washington State Polybrominated Diphenyl Ether (PBDE)	flame retardants 3. Polychlorinated biphenyls (PCB), dioxins, and furans 4. Polycyclic Aromatic Hydrocarbons (PAHs) 5. Phthalates 6. Microplastics

Comment	Response
Chemical Action Plan: Final Plan. Publication number: 05-07-048. Retrieved from: https://apps.ecology.wa.gov/publications/summarypages/0507048.html [11]Davies, H. et al. 2015. PCB Chemical Action Plan. Publication number: 15-07-002. Retrieved from: https://apps.ecology.wa.gov/publications/SummaryPages/1507002.html [12]Ecology. 2020. Focus on: PFAS Chemical Action Plan. Publication number: 20-04-048. Retrieved from: https://apps.ecology.wa.gov/publications/SummaryPages/2004048.html	
O-5-4 Safer Products for Washington, also known as Substitute Senate Bill 5135, is another mechanism that Washington State is using to identify, reduce, and eliminate hazardous chemicals. The program identified 5 priority chemicals: PFAS, PCBs, phthalates, phenols, and flame retardants (PBDEs)[13]. All of these chemicals are found in biosolids yet none of them are being regulated in the Biosolids Permit. [13]Ecology. 2020. Priority Consumer Products Report to the Legislature: Safer Products for Washington Implementation Phase 2. In sum, the Chemical Action Plans and the Safer Products for Washington program both recognize that reducing exposure to chemicals is a priority for the state and they both acknowledge that hazardous chemicals are found in biosolids and that biosolids are a method of toxic chemical transmission. Yet,	O-5-4 There are several reasons why Ecology is not regulating all of the substances identified in our various CAPs. First, the EPA is better positioned to assess the risk from contaminants in biosolids. They will be releasing an updated risk-screening tool for assessment by their Scientific Advisory Board, in 2022. It makes better sense for Ecology to provide input on that process, than to attempt to assess the risk independent from the EPA. Secondly, we do not regulate based on the simple presence of a substance. We regulate based on risk, which is a function of hazard and exposure. Ecology has seen many results for PCB analysis in biosolids and did not observe them to ever approach a regulatory threshold. As a result, we discontinued looking for them under the biosolids program, although facilities with pretreatment programs still check for them. PBDEs are found in biosolids, but at the time the CAP was produced, biosolids were not observed to be a significant source of PBDEs released to the

Comment	Response
none of these toxic contaminants are regulated in the Biosolids Permit. *Please explain this contradiction.*	environment. The foregoing discussion does not mean Ecology will not regulate all of the items in our CAPs at some point in the future, but if establishing a regulatory threshold had made the best sense, we would have recommended it at the time the CAP was developed. We are currently assessing some forms of PFAS and other PBTs under Safer Products for Washington. Safer Products is a powerful tool because it can allow Ecology to get at the actual source of contaminants of concern.
O-5-6 Requested changes to the Biosolids Permit: Ideally, land application of biosolids should be phased out in Washington State until we are able to control the source of or remove all toxic contaminants. Until then, the Biosolids Permit needs to include additional testing that goes beyond the current, inadequate federal regulations. We request that the General Biosolids Permit include biosolids testing for, at minimum: 1. Per- and Polyfluoroalkyl Substances (PFAS) 2. Polybrominated diphenyl ethers (PBDE) - flame retardants 3. Polychlorinated biphenyls (PCB), dioxins, and furans 4. Polycyclic Aromatic Hydrocarbons (PAHs) 5. Phthalates 6. Microplastics	O-5-6 Ecology (and many others including EPA) are currently assessing PFAS for potential regulation in biosolids. EPA evaluated dioxins and coplanar PCBs (certain PCBs that have dioxin-like structures) and concluded that regulation in biosolids was not necessary. We have looked at PBDEs and PCBs in biosolids in the past and have not found them in significant amounts in biosolids.
O-5-9 In Conclusion: We live in an industrialized nation that uses and depends on thousands of toxic chemicals that have not been adequately tested for safety yet are ubiquitous in our environment. These chemicals are having serious consequences on our health and the	O-5-9 We agree with the commenter as far as the idea of removing chemicals from the environment. We disagree that the permit is not protective of human health and the environment, but we do hear the concerns of commenters. We believe we should continue to evaluate pollutants in biosolids, and we should act in any case where research shows a pollutant presents a significant risk to human health

Comment	Response
environment. Because of better wastewater treatment technologies, our wastewater is getting cleaner which results in our sewage sludge becoming increasingly concentrated with toxic chemicals. We have a unique opportunity here to remove these chemicals from our environment forever instead of allowing, even encouraging, them to be redistributed into the environment. The Department of Ecology needs to make major changes on how it manages and regulates sewage solids in Washington state, modifying this permit is a good place to start. As written, the Biosolids Permit is clearly not protective of human health and the environment.	or the environment. We are disappointed that the commenter did not remark on the merit of removing contaminants at the source in order to have a better biosolids management problem. The total contaminants in biosolids are insignificant as compared to other sources.
O-7-3 We were pleased to see the July 2021 Report, CECs and Wastewater Treatment, Publication 20- 10-06. The Department of Ecology admitted to the existence and wide breadth of Chemicals of Emerging Concerns (CECs) in wastewater plants. And though Ecology only analyzed four contaminants in the waste and compared their potential removal levels from newer treatment technologies, we are glad to see Ecology invested in this work. This information on CEC's should be incorporated into the Draft Biosolids Permits.	O-7-3 We acknowledge the commenter's support for further investigation of CECs in wastewater and biosolids.

Comment	Response
O-7-4 We strongly recommend the following regarding the Draft General Statewide Permit:… …Expand the list of contaminants to be analyzed… …Based on a 2009 USEPA report measuring dozens of contaminants, including hazardous wastes, in sewage sludge, including from a Washington State Wastewater Treatment Plant, Ecology should expand the list of contaminants that municipalities and haulers must analyze to include those analyzed by EPA.	O-7-4 The commenter is referring to a targeted national sewage sludge survey conducted by EPA in 2009. Ecology has remarked about the 2009 report in the response to comments O-7-14 and O-7-16. EPA does not require the scope of analysis in the 2009 report or related reports for biosolids. EPA and Ecology have complimentary programs. Ecology requires analysis for pollutants in biosolids exactly as EPA has specified. As a point of clarification, biosolids are not listed and do not meet criteria to be classified as a hazardous waste.
O-7-5 One CEC that should be on the list is PFAS. PFAS is now a primary chemical of concern with Congress, EPA and Ecology. Ecology staff is well along in its PFAS work and should supply permit language measuring influent, sewage sludge/solids and effluent for this "forever chemical." A recent Sierra Club study, "Sludge in the Garden" tested nine commercial compost products used by home gardeners, including one produced in Washington State. These commercial composts are made with sewage sludge. All nine, marketed as "eco" or natural, contained PFAS. Eight of the nine products contained PFAS at a level higher than that allowed by the states of Maine, which currently have the strictest safeguards for PFAS contamination of agricultural lands.	O-7-5 Ecology is currently addressing PFAS on multiple fronts, including our Safer Products for Washington work. A group of stakeholders provided this analysis of the Sierra Club report[52].

[52] https://casaweb.org/wp-content/uploads/2022/01/Cover-Letter-to-Sierra-Club-010422.pdf

Comment	Response
O-7-10 Finally, we would like to see the Draft Permit require newer technologies be employed by Waste Water Treatment Plants that will detect viral levels in the influent, the solids and the effluent to ensure that pathogens are dead, not dormant, and will not be spread on land or passed to surface water bodies via the effluent. We recommend that you review "*Capacity of existing wastewater treatment plants to treat SARS-CoV-2. A review*."	O-7-10 The biosolids permit only covers the management of biosolids. It is beyond the scope of the permit to specify analysis in wastewater influent and effluent. Ecology does not see evidence that additional analysis or measures are necessary to protect against Covid-19 (or other pathogens) in biosolids. Class B treatment is expected to reduce pathogens in biosolids by ninety-nine percent, but relies also on additional site management practices including restricting access and harvesting of crops, thus allowing the natural environment to complete the pathogen reduction process. Class A treatment processes reduce pathogens to below detectable limits. At the request of the commenter, we reviewed, Capacity of existing wastewater treatment plants to treat SARS-CoV-2. A review[53]. The article is a review of more than 100 papers related to wastewater treatment and the reduction of pathogens. We have previously read articles relating to the presence of COVID 19 in wastewater, and we reviewed some additional articles as a consequence of reading the one referenced by the author. The article presents a global view - including "low sanitation countries," and is not focused on wastewater and biosolids management in the United States. Overall, the focus of the authors is on the potential for the spread of COVID in wastewater effluent (not biosolids). The review identifies the concentration of pathogens in sludge as one means of reducing their presence in the effluent, which has been understood for decades. That is why pathogen reduction is required for sludge to be classified as biosolids. Nowhere in the article do the authors link biosolids management as practiced in the United States to the spread of COVID-19. The authors did not say treatment under federal or state rules is inadequate - just that it is necessary.

[53] https://pubmed.ncbi.nlm.nih.gov/34179735/

Comment	Response
O-7-13 Ecology is aware of the presence of PFAS/PFOS and related chemicals in sludge. Some Ecology staff members are working with the Department of Health to finalize guidance for handling these 2 chemicals. Because of their use in non-leaking food containers, cooking surfaces, outdoor wear, fire-fighting foam, and flame-retardant materials, PFAS chemicals has been found in most Washingtonians that have been tested for it, and is eliminated via toilets to the wastewater processing plants. Industry also sends its PFAS-laden wastes to municipal processing plants. This "forever-chemical" class is now found not only in Class B and "Exceptional Quality" sludge, but in commercial composts and fertilizers. https://www.sierraclub.org/toxics/pfas/pfas-sludge Continuation of this waste for land spreading will allow continue permeation of this chemical into soils, air, ground and surface water bodies, grazing animals and edible crops. PFAS can ruin a farmer's land, resulting in lost economics for the farmer and the community. A case in point is the citizens' class action lawsuit against paper mills that polluted their properties with PFAS-laden waste, devaluing their land, exposing them to harm, and costing them to remediate the soils on their properties. https://www.natlawreview.com/article/pfas-paper-mill-lawsuit-adds-additionalcompanies At some point we can expect that insurance companies will refuse to ensure farmers who take sewage wastes, particularly untested for PFAS or found in PFAS. In the published article of February 8, 2021, by Gregory Capps and Robert Walsh on insurance coverage, their concluding statement is Consistent with its	O-7-13 The commenter points out only some of the products where PFAS have been or continue to be used. Biosolids are neither the source of PFAS, nor the source of most immediate exposure. Moreover, biosolids are unlikely to rank amongst significant sources of exposure for the population overall. Ecology does not believe the amount of PFAS in biosolids poses a threat to human health or the environment, but does agree that further study is needed, and also agrees that we should be taking steps to reduce the presence of PFAS in wastewater systems, and therefore in biosolids. The commenter remarks about litigation around the land application of paper mill sludge. Paper mill sludge is not biosolids and is not regulated under biosolids laws or rules at either the federal or state level. Ecology does not control what insurers may or may not address or require.

Comment	Response
nickname, the "forever chemical" is posed to become a source of claims for years to come. Insurers should prepare now by developing a plan for dealing with these claims under multiple lines of coverage. http://www.jdsupra.com/legalnews/the-abcs-of-pfas-what-youneed-to-know-8584037.	
O-7-14 The foundation for our position also rests on the following: 1. EPA states that the report identified 18 pier-reviewed articles referencing 116 new chemicals that occurred in biosolids. The study, *Survey of organic wastewater contaminants in biosolids ["biosolids" is an EPA designation for "treated sewage sludge"] destined for land application examined* nine different biosolid products, produced by municipal wastewater processing plants in seven different states, finding 87 different chemicals, with fifty-five chemicals found in one product alone. https://www.jdsupra.com/legalnews/u-s-environmental-protection-agency-1383484/ 2. In 2009, EPA published the Targeted National Sewage Sludge Survey. The survey focused on 74 processing plants in 35 states that treated more one million gallons per day. It concluded that all sewage sludge contains toxic and hazardous materials. https://www.epa.gov/sites/production/files/2018-11/documents/tnsss-sampling-anaylsis-techreport.pdf. 3. In 2018, EPA's Office of Inspector General (OIG) published its audit of the agency's	O-7-14 Ecology reviewed or attempted to review documents cited by the commenter. Point (1) cites a biennial review from EPA[54]. The purpose of the biennial review is to identify substances of possible concern in biosolids. EPA can then choose whether to investigate further or develop regulations as appropriate. EPA did not act to regulate any additional substances of concern as a result of the survey. EPA's top priority is the development of a screening tool that will assist them in narrow the list of contaminants in biosolids to hose that warrants further study or regulation. Ecology will follow EPAs work carefully. Point (2) mentions another work by EPA from 2009[38] to collect data. The authors say in the report that it is not appropriate to speculate on the results until proper analysis has been completed. EPA did not elect to impose additional regulations following the 2009 report. As noted above, we expect EPA will revisit acquired data once their new screering tool is finished. Point (3): Ecology has remarked about the OIG report[12] in a separate discussion readers can find in the key topics section at the front of this response to comments titled "Understanding the 2018 Office of the Inspector General report". We did not agree with the presentation of information by the OIG. As a point of clarification, the OIG is not a part of EPA. OIG is a

[54] https://www.epa.gov/biosolids/biennial-report-no-8-reporting-period-2018-2019

Comment	Response
"Biosolids" Program and found that *the EPA was unable to assess the impact of hundreds of unregulated pollutants in land-applied "biosolids" on human health and the environment*. To date, the EPA has identified 352 pollutants in biosolids, out of an unknown and incalculable total that frustrates any meaningful risk assessments; 61 of these pollutants have been categorized as hazardous by other federal program. These pollutants currently are not considered for further regulation because the agency lacks the data and tools necessary to assess the health and environmental risks. https://www.epa.gov/sites/production/files/201811/documents/_epaoig_20181115- 19-p-0002.pdf 4. On April 8, 2019, the OIG issued a management alert informing the US EPA that its Toxic Release Inventory data pertaining to releases of hazardous substances from publicly owned wastewater processing plants are inaccurate. As a result, the public and researchers are not receiving complete and timely information about environmental conditions affecting human health. https://www.epa.gov/office-inspector-general/report-management-alert-certain-toxic-releaseinventory-data-disclosed 5. Studies report the uptake of sewage contaminants in edible plants. Microplastics accumulate on pores in seed capsule and delay germination and root growth. https://www.sciencedirect.com/science/article/pii/S0045653519306095 6. The ubiquity of anthropogenic toxic marine	separate agency. Point (4): Ecology briefly reviewed this article which identifies a reporting error by EPA[55]. It is beyond the scope of this response to further evaluate the OIG findings or EPA's performance related to TSCA. Point (5): Ecology does not have resources to focus on microplastics at this time. We cannot tell if study conditions reflect likely real world scenarios. The authors stated the observed effects were short-term and transient. Point (6): The study looked at ingestion of anthropenic debris by marine animals. We do not have data or information linking biosolids land application to ingestion of anthropomorphic debris by fish and shellfish. Buffers to surface waters are required for biosolids land application sites. Point (7): The news article[56] reports on events in the state of Florida which has an environment entirely different from that of Washington. As a point of clarification WA does not identify a Class AA biosolids. Point (8): The article is behind a paywall, but appears to be an opinion piece, again from the State of Florida. The link does not provide any indication that the article pertains to biosolids or biosolids alone. Point (9): State of the Salish Sea[57] is an impressive and handsome work that is beyond our ability to thoroughly review. We searched for references to both biosolids and sludge and found none. There were a few references to discharges from sewage treatment plants. The authors identify sources of pollutants other than biosolids as being of greater concern – we would agree. Overall, the work reflects the complexity of the environment and a myriad of impacts worthy of consideration and attention.

[55] https://www.epa.gov/sites/default/files/2019-04/documents/_epaoig_20190408-19-n-0115.pdf
[56] https://www.wlrn.org/news/2021-06-02/state-tightens-rules-for-sewage-sludge-used-as-fertilizer-but-leaves-a-loophole-in-place
[57] https://cedar.wwu.edu/salish_pubs/1/

Comment	Response
pollution raises concerns about how the ingestion of anthropogenic debris by marine animals may impact human health. https://www.nature.com/articles/srep14340#ref38 7. There is runoff effecting algae blooms, even from "Class AA" biosolids. http://www.alrn.org/news/2021-06-02/state-tightens-rules-for-sewage-sludge 8. Material that is spread on land becomes non point pollution into water bodies. https://www.miamiherald.com/opinion/op-ed/article236381288.html 9. The June 2021 report, *State of the Salish Sea* states: "Part of that loading comes from sewage treatment plants, shipyards, municipalities, and a multitude of commercial/industrial operations that have the legal right to discharge waste into the Salish Sea through permitting processes like the NPDES program (National Pollutant Discharge Elimination System) that was established by the Clean Water Act in the United States. Added to these permitted discharges is the massive load of chemicals and bacterial pollutants that enter the Salish Sea with stormwater runoff from roadways, lawns, farms, and parking lots. Under the *Contaminants* Section, the author spells out the legacy and contaminants of emerging concern and recommends other forms of treatment be developed to better handle the wastes and runoff. https://cedar.wwu.edu/cgi/viewcontent.cgi%3Farticle=1000%26context=salish_pubs	

Comment	Response
O-7-16 1.1.6 Role of EPA: Though you work cooperatively with the USEPA, that agency has not updated its list of contaminants since the program was initiated in 1992, even after its own research report in 2009, *Targeted National Sewage Sludge Survey*. (See above)	O-7-16 The 2009 survey[38] was not intended to compel an expansion of analytes required for analysis under 40 CFR Part 503[13] or related state programs. The purpose of the 2009 survey was to obtain additional information on a small number of contaminants previously identified for further analysis. EPA expanded the scope of the survey to gather information on a broader range of contaminants. That information has informed the current list of confirmed contaminants in biosolids - presently more than 700[51]. That list will form the basis for selecting contaminants to be further evaluated using EPAs new risk screening tool. The screening tool will be submitted to EPA's Science Advisory Board early in 2022, following which we expect the SAB to publish it for comments. Yes, Ecology works cooperatively with EPA. When EPA asks for input from states about the national biosolids program or hosts an informational event, Ecology responds or participates. We do our best to provide information and insight that will help EPA guide the federal program along in a way that serves all states. Washington is not alone in our efforts, as many other states work cooperatively with EPA. In turn, when we have questions relating to the national program, we reach out to EPA staff in their headquarters or regional office for help (as well as to contacts in other states). We are all working toward making a better biosolids management program, nationally and locally. The commenters remarks about EPA not having expanded its list of contaminants since the federal program started in 1993 (the current state program started in 1992) is correct, and frustrating on more than one level. Ecology has remarked many times over the years, and elsewhere in this response to comments, about our dismay at EPA's decision to disinvest from the national biosolids program beginning in the late 90s as we recall. We don't recall if the Sierra Club challenged EPA's resource allocation or not, but Ecology certainly

Comment	Response
	did. Had EPA stayed invested, the national and state programs would be farther along with a much better focus on many current issues, if not resolution. In the last four to five years EPA has reinvested, solidly, and Ecology has frequently commended them for doing so. It appears to us that EPA will likely maintain the current level of investment. Many commenters disregard the need to connect hazards with exposures to define risk, and from there to allow risk to determine the appropriate regulatory steps. It should be noted, biosolids are a very small piece of the things that are applied to our soils, and a very small contributor to crops grown for human consumption overall. Ecology does not object to the regulation of additional substances in biosolids if it overall makes sense, but that is only one mechanism. The mechanism will also not help to address the actual source of the problem.
O-7-34 **3.6.5 Pollutants and 4.5** "Requirement for Non-Exceptional Quality Biosolids Applied to the Land: There does not seem to be any requirement yet in this draft permit to test for PFAS compounds (despite the insistence from top Ecology officials that such testing is not feasible, other states like Michigan perform it), pesticides, herbicides, PBDE's, PCB's, PAH's, pharmaceuticals, microplastics or any of the other hundreds of toxic substances found in almost every load of sewage sludge. This lack of a testing requirement before septage, sludge or biosolids are spread on the land alone makes this draft plan unacceptable.	O-7-34 Testing beyond what is required for biosolids occurs for facilities with pretreatment permits. Ecology does not have an applicable standard for the substances referenced by the commenter in biosolids. They generally occur at very low concentrations. Ecology is giving close attention to EPA's progress on development of a risk-screening tool, as discussed elsewhere in our response.

Comment	Response
O-7-50, We strongly recommend the following regarding the Draft General Statewide Permit: ... ...The permit should include regulations pertaining to PFAS Sampling for PFAS must precede allowing the waste to change hands.	O-7-50 Correctly, regulations would be developed under our rules in Chapter 173-308 WAC[24]. Requirements for PFAS could be included under the permit. At this time, there is not an adequate basis for regulating PFAS in biosolids. Most states have not taken that step. EPA has not taken that step. We are working on PFAS from different approaches within Ecology, as discussed elsewhere in our response. Ecology can pursue revisions to the rules if necessary, or could address PFAS with a permit modification during the permit cycle if information supports.
O-7-67 All processed sewage wastes should be tested for PFAS, a range of endocrine disruptors, microplastics, and other potentially hazardous contaminants.	O-7-67 For the purposes of the biosolids program, requirements for testing are established in state rules and reflect those at the federal level. Some biosolids are tested more extensively as part of the Pretreatment Program implemented by Ecology's Water Quality Program. Some testing also occurs for investigational purposes, and for the purposes of research (more on the national level). Sampling for substances that do not have regulatory thresholds, while not pointless, has limited value. This is why Ecology is very interested in the new risk-screening tool being developed by EPA (and remarked upon elsewhere in this response). If EPA prioritizes substances for further investigation, that step could provide sufficient cause for Ecology to further investigate information that might exist within our Water Quality Program or local data sets. It could also support meaningful work between EPA, states, and all stakeholders to assess the need for further regulations (within or without the biosolids program).
O-8-2 In 2018 EPA's Office of the Investigator General raised serious concerns about the presence of harmful, poorly regulated chemicals in sewage sludge and biosolids (USEPA 2018). We see major opportunities for	O-8-2 Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to the discussion titled "Understanding the 2018 Office of the Inspector

Comment	Response
Washington to address these pollutants, specifically PFAS, in the draft permit.	General report". We have addressed issues around contaminants of concern such as PFAS in section 1 of this response; please see comments I-47-1, I-48-6, and I-53-2. Ecology will not require sampling for a substance when there is no applicable standard unless the sampling is done to support the development of a standard. In that latter case, Ecology is currently engaged in discussions with the EPA's Office of Research and Development (ORD) to assess Per- and polyfluoroalkyl Substances (PFAS) in Washington's biosolids. ORD is one of the leading research institutions in the world regarding analysis of PFAS in complex organic compounds such as biosolids. Ecology plans to analyze biosolids from a variety of WWTPs across the state and the soils upon which they have been land applied. Ecology also is awaiting the results of an Ecology study of PFAS in wastewater treatment plant influent, effluent, and biosolids that the commenter referenced. This study is far too small (only three wastewater treatment plants included) to stipulate any regulatory action, especially because there is no established regulatory standard with which to compare these results. However, it allows us a small glimpse into what is happening with respect to PFAS at those wastewater treatment plants specifically.

Comment	Response
O-8-3 The state of Washington has prioritized action on PFAS in the state's Chemical Action Plan. PFAS are highly persistent and mobile and many are bioaccumulative. PFAS are widely used in industrial and consumer products with little regard to their lifecycle impacts to air, water, and land resources. More than 99 percent of Americans have measurable amounts of PFAS chemicals in their bloodstream. A recent peer reviewed study by the University of Washington, Toxic-Free Future and Indiana University found 100% of breast milk samples of 50 women in Washington state testing positive for PFAS. The study also found that detections of PFAS currently used in food packaging, textiles and other products are doubling every 4 years. This study is an urgent call for action on PFAS in all media, including biosolids.	O-8-3 Ecology acknowledges these observations about PFAS. As described elsewhere in our response to comments, Ecology is actively investigating PFAS for potential regulation and is monitoring activities undertaken by U.S. EPA. This comment clearly illustrates why addressing PFAS in biosolids may not be the best approach to the problem. We expect that exposure to PFAS from beneficial use of biosolids is quite small, and far, far less than from the use of common everyday products. Please see also the response to comment O-1-1.
O-8-4 There is growing concern that unregulated discharges of PFAS into the wastewater system could pose a hazard to the food supply when biosolids are applied to land, as is common practice in Washington. Case studies demonstrate that highly contaminated biosolids can permanently contaminate agricultural fields and dairies.	O-8-4 The commenter remarks about case studies demonstrating that highly contaminated biosolids can permanently contaminate agriculture fields and dairies, but does not provide any sources. Ecology is aware of one instance that has received a great deal of media attention, and where commenters have generally ignored inputs of paper sludge (not biosolids) as the most likely cause. Please see also the response to O-1-1. Please also see the key topics discussion titled “Food chain crops and biosolids” at the start of this response to comments for more information.

Comment	Response
O-8-5 A number of states, including Maine, Michigan and Colorado are moving to investigate PFAS levels in biosolids, and Maine tests foods cultivated from treated soils. With the current draft permit, Washington state is missing an important opportunity to reduce the amount of PFAS entering wastewater systems, while it is leading the nation in action to prevent its use in food packaging, firefighting foam, as well as carpet, rugs, upholstered furniture and aftermarket treatments.	O-8-5 Ecology is currently investigating PFAS on a number of fronts, and that includes activities related to wastewater and biosolids. We maintain that source reduction is the best approach. If we reduce the number of sources from which people encounter PFAS at much higher levels on a daily basis, the amount of PFAS in biosolids will decline. This reduction is evidenced by the decline of two forms of PFAS - PFOA and PFOS - in various sampling events since their use was phased out over the last ten to twenty years[58].
O-8-6 The state of Washington is one of the most committed to land application of biosolids, with 85-90% of the state's biosolids waste on agricultural fields, forest lands, undisturbed lands, and lawns or home gardens as well as public spaces. There is little data characterizing the PFAS levels in Washington state biosolids, but results from a recent Sierra Club and Ecology Center study of commercial biosolids-derived fertilizers and soil amendments, included Tagro Mix, made from biosolids produced that the Tacoma Central Wastewater Treatment Plant, indicated the presence of PFAS. Our tests of Tagro and 8 other products found significant levels of total inorganic fluorine and of individual PFAS, including PFOA and PFOS, in products marketed directly to home gardeners for use on lawns, ornamental plants and home gardens. PFOS and PFOA measurements exceeded the state of Maine screening guideline of 2.5 ppb for PFOA, 5.2 ppb for PFOS, at 7.5 and 7.9 ppb respectively. The sum of 33 individual PFAS	O-8-6 Ecology agrees that the question of PFAS in biosolids warrants investigation. If it becomes apparent that additional regulatory standards are needed to ensure the safety of public health and the environment, for PFAS or any other pollutant, Ecology is prepared to take action. The general permit allows for adjustments like this to be made whenever necessary, not just every 5 years upon issuance. Stakeholder supporting biosolids beneficial use published a response to the Sierra Club report[52] that readers may wish to evaluate.

[58] https://www.atsdr.cdc.gov/pfas/health-effects/us-population.html

Comment	Response
chemicals was 87 ppb, and those concentrations increased 5.25-fold after the samples were oxidized in the TOP Assay, reflecting one measure of the amount of these PFAS that could be formed in the environment due to "weathering" of longer PFAS precursors into stable end products. The total amount of unknown organic fluorine chemicals in the Tagro Mix sample was roughly 150 times greater than the sum of specific, identifiable PFAS - in line generally with the magnitude of difference in the other products - indicating a major quantity of unknown or mystery PFAS in these products. **PFOS** / **PFOA** / **Sum of 24 measureable PFAS** / **SUM Post-TOP analysis** / **Total fluorine** / **Total inorganic fluorine** Tagro Mix: 7.9 / 7.5 / 87 / 457 / 13,000 / <1 Range in all products: <1 – 22.1 / <1 – 23.8 / 38 – 223 / 235 – 457 / 13,000 – 321,000 / <1 – 1000 All units parts per billion More details in the Sierra Club/Ecology Center report: PFAS in the Garden (2021) Based on these findings, we are concerned that the concentrations of PFAS in fertilizers and compost made from sludge-biosolids could lead to accumulation in food plants grown in fertilized beds in home gardens. The land application of biosolids generally could pose similar hazards to foods and dairy products produced on treated fields. Applications to forest and undisturbed lands still increase the global cycling of PFAS as the chemicals still wash off of soils into surface and groundwater.	
O-8-7 Nationally the EPA is investigating the threat posed by PFAS in biosolids, and data coming from these studies confirm that land application spreads PFAS through the food chain (USEPA 2020). PFAS from highly contaminated sludges from industrial sites have been determined to contaminate local water supplies and agricultural products. The FDA has identified several other PFAS hot	O-8-7 The commenter is supposing that the problems at these farms are due to the use of biosolids. Paper mill sludge, which is well known to contain PFAS was land applied to the Stoneridge Farm. The Tozier farm was permitted to receive other types of sludge, not only biosolids. Because the levels of PFAS found at Tozier farm were so high, it is less likely they could be attributed to biosolids.

Comment	Response
spots where water contaminated by biosolids application or industrial sources tainted dairy products or produce (FDA undated). Maine farmer Fred Stone's milk had similar levels of PFOS and PFOA, concentrations that exceeded the state's limit for milk, which is 210 parts per trillion (ppt). Tozier Dairy Farm in Fairfield, Maine, had similar problems, with concentrations of PFAS ranging from 12,000 to 32,000 ppt found in its milk. The remainder of milk sampled in Maine had undetectable levels of PFAS (less than 50 ppt).	
O-8-8 In general, newer generation-or "shorter-chain"-PFAS are more mobile in water, less removed by water filtration systems, and more readily taken up by plants than longer-chain PFAS compounds. One study of vegetables that included celery, peas, radishes, and tomatoes grown in PFAS-tainted water found that different PFAS chemicals accumulated in different parts of the plant (Blaine 2014). Another study measured high levels of one chemical, PFDA, in tomatoes and potatoes (Li 2021). While these studies have focused on highly contaminated biosolids, there are reasons to be concerned about the PFAS in biosolids with lesser levels of contamination. While concentrations of PFAS measured in commercially sold vegetables and dairy products are generally much lower than those from polluted sites, even small amounts still pose a health concern, as they add to the overall burden of exposure to multiple sources.	O-8-8 Ecology reviewed the abstracts of both cited articles. We agree that the articles help establish a broader understanding of PFAS in the environment. We do not agree that they demonstrate a significant threat to food crops from biosolids (which the commenter did not specifically allege here). The first article from Li concerns contaminated groundwater used for irrigating crops. The second article used the term biosolids to include industrial sludges, which is an unfortunately incorrect use of the term. We note that the abstract says, "PFAA levels measured in lettuce and tomato grown in field soil amended with only a single application of biosolids (at an agronomic rate for nitrogen) were predominantly below the limit of quantitation (LOQ). In addition, corn (Zea mays) stover, corn grains, and soil were collected from several full-scale biosolids-amended farm fields. At these fields, all PFAAs were below the LOQ in the corn grains and only trace amounts of PFBA and PFPeA were detected in the corn stover." While we can use articles like these to help inform ourselves, it is important not to let them steer us to the wrong conclusions. Please also see the key topics discussion titled “Food chain crops and biosolids” at the start of this response to comments for more information.

Comment	Response
O-8-9 In general, people are estimated to ingest far more PFAS from their diets than from their drinking water, unless their water has high levels of PFAS. Since the chemicals do not break down in the environment, levels in farm fields will slowly increase every time more biosolids are applied to a piece of land. The fertilizer products we tested are marketed for multiple applications per year to home gardens. The EPA reports that some farm fields have had biosolids continuously applied for up to 20 years. While the general draft permit appears to meet the requirements of EPA's Rule 503, this is not acceptable for Washington state, which has been a leader on PFAS. The state should use its ability to impose greater requirements for monitoring and management of PFAS and other chemical contaminants. EPA has identified a number of industries that discharge PFAS into wastewater systems, but not yet acted to restrict these emissions. In the absence of federal regulation, Washington must move quickly to identify and avert discharges from industries like metal plating, chemical manufacturing, plastics, paper and textile mills, printing, petroleum extraction, mining, paint manufacturing, car washes and industrial laundries. Ecology must fully assess the hazard posed by PFAS in biosolids by requiring periodic testing Testing is essential to identify and control point sources into the wastewater system. While Ecology has done an initial sampling of PFAS levels in surface water and WWTP plant effluent, it hasn't done a systematic study of biosolids, as is happening in other progressive states.	O-8-9 We expect that exposure to PFAS is from a range of sources, with some sources contributing more than others in different cases. We also expect that the contribution from biosolids use on food chain crops is extremely small when contrasted with others. That does not mean we are ignoring the issue of PFAS in our food chain, as can be clearly seen from many other responses in this document. Please also see the key topics discussion titled “Food chain crops and biosolids” at the start of this response to comments for more information. We think this comment has merit as a potential strategy for addressing PFAS in influent (and therefore biosolids and effluent as well). We are awaiting the results of an Ecology study of PFAS in wastewater treatment plant influent, effluent, and biosolids. This study is far too small (only three wastewater treatment plants included) to stipulate any regulatory action especially because there is no established regulatory standard with which to compare these results with. However, it allows us a small glimpse into what is happening with respect to PFAS at those wastewater treatment plants specifically. Funding may be a barrier for further work on PFAS in biosolids, but we are keeping an eye open for ways to support further work. While Ecology would prefer to wait for fully validated methods for PFAS in biosolids, as noted in responses to other comments, we concluded that is not practical. Funding for a broader analysis of PFAS in biosolids is a barrier at present; the agency will examine ways to fund an expanded effort as data from other work indicates. In particular, we think the identification of potential sources of PFAS to the sewer system has merit and would combine well with analysis of PFAS in biosolids. We are aware of the response by states in the New England area, as well as Colorado. Most states have not taken those steps. That does not mean

Comment	Response
One barrier Ecology identified in its 2019 Chemical Action Plan and 2021 update, is the lack of validated methods to measure the compounds in sludges. This shouldn't be an excuse to stall testing. Other states require an isotope dilution method like Method 537.1, ASTM D7968-17, or CWA Method 1600 for PFAS analysis of biosolids until EPA completes its validated method for biosolids and soil. Massachusetts' permit language addresses the use of interim monitoring methods with the following language: "If EPA's multi-lab validated method is not available by [date] months after the effective date of this Final Permit, the Permittee shall contact [person] for guidance on an appropriate analytical method." Washington should take action to limit PFAS discharges to wastewater Other states are acting with urgency to identify and abate WWTP polluted with high levels of PFAS chemicals. Washington should be doing the same given its Chemical Action Plan and commitment to addressing these chemicals. Maine - After discovering high levels of PFAS in milk produced from dairy cattle feeding on contaminated fields, Maine is measuring the amount of PFAS in biosolids and ensuring that the materials do not contaminate agricultural lands. Maine's testing of one contaminated dairy found that the PFOS and PFOA levels in milk exceeded the concentrations it measured in the soils themselves. When biosolids exceed screening levels, the state requires modeling or testing to ensure the repeat application has not pushed agricultural fields over the screening level of 2.5 ppb for PFOA and 5.2 ppb for PFOS (Maine 2021). Unfortunately, Maine still allows contaminated biosolids to be	Washington should not, or will not, but we do believe a thoughtful approach is important. The commenter is aware of the strategy and commitments in our PFAS Chemical Action Plan[35]. For now, we believe the steps and commitments described in our CAP remain as the best approach.

Comment	Response
spread on other agricultural lands. Michigan - The state has taken the most aggressive efforts to prevent PFOS and PFOA in WWTP effluent waters, driven by protective surface water standards. The state has identified a number of wastewater treatment plants receiving high levels of PFOS and PFOA, and requires some upstream industries to change practices or filter wastewater to remove PFAS (Michigan 2021). This is a slow and data-intensive process, yet it is highly effective in removing PFAS from wastewaters and sludge. Interventions at seven highly contaminated wastewater systems reduced PFOS levels in biosolids by 90 to 99 percent. The state didn't study or report the impact these measures had on other PFAS chemicals. Unfortunately Michigan's newly proposed screening levels for PFOS and PFOA in sludge are much higher than Maine's limits, and will be less protective of agricultural fields in the state. Colorado - The state adopted new "narrative" standards for five categories of PFAS chemicals in 2020 and has surveyed PFAS levels in state surface waters. These standards will allow the state to require wastewater testing in key industries and will ultimately lead to permit restrictions on industrial sources (Colorado 2020). Colorado's recent draft CWA permit for large metropolitan wastewater districts will require monthly sampling for PFAS in effluent water as well as a "source identification study" to be completed by 2024 to identify key dischargers of PFAS into the system. This important step lays the groundwork for cost-effective and permanent reductions of PFAS into wastewater systems and biosolids. Massachusetts, Vermont, and New Hampshire are testing PFAS levels in biosolids.	

Comment	Response
Massachusetts has the long-term goal of "virtually eliminating" PFAS in biosolids but has not set a screening limit or management plan to achieve this goal (Massachusetts 2021). Vermont will require annual testing of soil, ground water, and plant tissue (Vermont 2020). New Hampshire instructs wastewater systems to test for PFAS using guidelines developed by the industry group the North East Biosolids & Residuals 5 Association, and not apply sludge with high concentrations to land, but it doesn't clarify the numeric screening level online (New Hampshire 2021).	
O-8-12 Washington must clearly state that biosolids derived from industrial discharges are not allowed in soil amendments that are land applied by facilities that are subject to the draft General Biosolids Permit. Washington Ecology must prevent industrial wastewater discharges from being mixed into soil amendments and land applied. The current draft general permit doesn't explicitly do this, nor do prior versions of the permit. Categorical discharges from industrial sites, in particular, as defined in 40 CFR 403, should not be allowed in biosolids that are received, stored, treated, or applied to land in Washington. The case between Emerald Kalama Chemical, Inc (Emerald) and Fire Mountain Farms (FMF) illustrates the problem. For nearly two decades Emerald sent its industrial biosolids to FMF, who treated and blended it with other materials, and land applied the waste. FMF is also a licensed contractor for wastewater treatment lagoon dredging operations in Washington, Oregon, Idaho and Montana and it is possible that they also receive industrial solids from these sources.	O-8-12 We have noted the commenter's recommendation; however, Ecology does not have the jurisdiction to implement this recommendation outside of a rule update. It is allowable to mix industrial waste with biosolids as long as the proper permitting process is conducted, which generally involves demonstrating that contaminants found in the industrial waste do not pose a threat to the quality of biosolids being produced. Fire Mountain Farms did not go through the proper permitting channels to use EKC waste. Biosolids cannot be produced from the treatment of **only** industrial wastewater. The solids resulting from industrial wastewater treatment plants are by law a solid waste. However, publicly owned wastewater treatment plants may receive discharges from industrial sources via the sewerage system. When it arrives at the treatment works as an influent, it is not an industrial discharge. Rather, it is sewage influent. Ecology does not prohibit businesses from discharging to the sewer, but may require them to have pretreatment permits in order to limit substances that might compromise plant performance or result in a violation of effluent discharge limits. The commenter asks that we prevent industrial wastewater discharges from being mixed into soil amendments and land applied. If the commenter is

Comment	Response
To prevent this from happening again Washington Ecology must review all industrial individual NPDES permits to assure it is clear that that their sludge is not going to land application. Staff should also review NPDES permits and compliance documents for WWTPs that receive industrial sludge to 1) assure it is clear that sludge containing industrial discharges cannot be land applied and to 2) require these WWTPs maintain a list of their industrial users and a list of where/how their (the WWTP) sludge is being managed (i.e. landfilled, incinerated, land applied). Both the NPDES permits and the General Permits should clearly spell out the prohibition of industrial sludge ending up being land applied. While the FMF/Emerald example should have been easily identified by the state permit staff, there are likely other cases where WWTP receiving industrial waste send their solids to beneficial use or compost facilities. Michigan's NPDES permits require facilities to enact a Residuals Management Plan and report annually how and where their biosolids were handled. Ecology should also review all Beneficial Use Facilities to make sure they aren't receiving industrial wastes.	addressing discharges from the treatment of industrial wastewater, those are not managed through the biosolids program. If, for example, an industrial facility produced a sludge and mixed it with a soil amendment, that would either be managed through our Water Quality Program, or through a local jurisdictional health department (as a solid waste activity). The commenter argues that categorical discharges should not be allowed in biosolids that are received, stored, treated, or applied to the land. There are 59 categorical discharges identified by U.S EPA[59]. Compliance with the discharge standards allows a discharge to the public sewer system, assuming the receiving treatment works accepts the discharge. Ecology does not prohibit the co-application of different materials on one site. A land applier could, for example, apply biosolids to a site, and then under a separate permit apply a solid waste (such as an industrial sludge), and then apply manure. Each permit or nutrient source would have to account for the impact of the other materials being land applied. The rules governing the application of industrial source sludges differ from those governing biosolids. An industrial sludge might be land applied under an Ecology Water Quality permit and/or a permit from the local jurisdictional health authority. It is possible after extensive review for an industrial sludge to receive a beneficial use determination under solid waste regulations. In that case the material would not require a solid waste permit if its use was limited to the scope of the beneficial use determination. An industrial sludge might also be classified as a waste-derived fertilizer through a joint process with the State Department of Agriculture and Ecology. Biosolids staff discussed the idea of a prohibition as suggested by the commenter – that if biosolids are land applied then no other nutrient source could be

[59] https://www.epa.gov/eg

Comment	Response
	added to the site (at least while a biosolids permit was in place). Staff concluded that a prohibition was not feasible at this time.
O-8-14 Washington should aggressively ban PFAS from all products. The primary way that PFAS enters these systems is through the products where PFAS is used. Washington has identified certain products for action including carpet, rugs, upholstery textiles and aftermarket treatments which is an excellent start. We urge the agency to identify phase PFAS out of these products and identify new priority products for Washington to phase out on a swift timeline.	O-8-14 Ecology is investigating several substances (including some PFAS) under Safer Products for Washington. Ecology has the authority to ban the use of certain substances from use in manufacturing if there are economically feasible substitutions available. We support the idea of solutions that result in curtailing the release of substances of concern before they enter the wastewater treatment system.
O-9-1 Zero Waste Washington appreciates the opportunity to comment on the *Washington 2021 General Permit for Biosolids Management*, made public on May 18, 2021. Zero Waste Washington is a nonprofit organization that represents the public on recycling and zero waste issues. We work to drive policy change for a healthy and waste-free world. We envision a just, equitable, and sustainable future where we all produce, consume, and reuse responsibly. Regarding the land application of biosolids on agricultural fields, forest lands, and other locations, we are strongly concerned about per- and poly-fluoroalkyl substances (PFAS) and microplastics. Both of these contaminants tend to prefer the solids and thus are likely present in significant amounts in Washington's biosolids, based on evidence from elsewhere. They have the potential to adversely impact	O-9-1 Evaluating PFAS in biosolids is worth agency attention. Research around microplastics is building, and Ecology will be mindful, but cannot make any commitments at this time. Ecology is not convinced that either PFAS or microplastics pose a threat to surface waters or air quality as the result of biosolids management practices, but we do respect the commenter's concerns. Ecology's Biosolids Management Guidelines[60] provide a means to assess sites and determine buffer requirements. We believe buffers established during permitting/site approval processes are protective. Please see also the response to comment I-55-5. We tried to obtain funding in the last biennium to support work at WSU on the development of a method for isolating and quantifying microplastics in biosolids. Funds in our permit fee account were not sufficient, and the Office of Financial Management

[60] https://apps.ecology.wa.gov/publications/SummaryPages/9380.html

Comment	Response
local waters and also impact air quality (traveling in dust and particulate). We would like Ecology to take steps to reduce these contamination problems, both within this general permit and in other actions. Specifically, we would like to see monitoring requirements included in the permit for both contaminants. At a minimum, at least once every five years, and ideally more frequently. The monitoring should occur both in the material before application and also at the application sites. In addition, steps should be taken to begin to limit these contaminants in the material. Washington should be a national leader in helping reduce these two toxic contaminants.	eliminated that part of our request. More information is needed on PFAS in biosolids. Ecology has committed in our PFAS Chemical Action Plan[35] to analysis in biosolids. We have been waiting on U.S. EPA to validate and ideally, approve an analytical methodology. An agreed-upon methodology would provide a uniform footing for evaluation and further discussions about the need for additional regulation. Unfortunately, we have recently concluded that we cannot wait for EPA to accomplish that work. We have begun the process of identifying prospective laboratories, but progress will depend on funding. The commenter recommends analysis at least once every five years - preferably more frequently, and would like to see Ecology take a leadership role in setting limits and reducing these contaminants. We believe the question of PFAS in biosolids will be resolved during the coming permit life cycle. If regulatory limits and/or monitoring are necessary, Ecology could accomplish them by modifying the general permit. It would likely be more desirable, to modify state rules. We are less hopeful for a resolution of concerns about microplastics. We do not have a strategy at this time.
SG-1-1 The current SGP, at Section 9.3, requires that "[a]ll new land application sites, where nonexceptional quality biosolids will be applied, must be tested for the pollutants listed in WAC 173-308-160 Table 3 to determine background levels." However, the current SGP does not identify a meaning of "background" as a regulatory term in this context, nor does it describe how the background levels established through this testing requirement are to be used in decision-making about land applications of biosolids. It appears that the 308 rule is also silent on these points.	SG-1-1 The purpose of this sampling requirement is to avoid a circumstance where a land applier or generator applies biosolids to a site with elevated concentrations of pollutants. We think "background" is an apt term here, but it can also be thought of as existing levels of regulated pollutants. This particular requirement grew out of an incident where significantly elevated levels of lead and arsenic were identified on an old orchard site, prior to biosolids land application. In that case, the proponent opted to remove the site from consideration. The incremental addition of pollutants from biosolids land application is actually very small. The concern was less for the burden of the site than for the scrutiny that might be

Comment	Response
The Draft SGP includes similar language in Section 4.5.3, requiring that permittees "must test all new land application sites for the pollutants in Table 1 of WAC 173-308-160, including nitrate and other nutrients if specified." There is no mention of determining background levels as a rationale for this required testing. Is the draft SGP's omission of the clause "to determine background levels" intentional?	attracted if sampling was conducted at a later date without knowledge of preexisting levels of regulated pollutants. Nothing actually prohibits the land application of biosolids to a site with elevated levels of pollutants, other than the discretion of the generator, land applier, and Ecology staff in assessing site suitability. In fact, biosolids have been used successfully to restore sites with very high levels of pollutants from past activities. That is not the aim of most proponents, however, so Ecology wants to ensure that all parties enter into a project well informed.
T-1-4 We also request that Ecology provide additional protections to water quality and environmental health and equity in the general permit by requiring: …2. Enhanced testing of the source materials and proposed product application to include know issues like PBDE's and 6PPD Quinone.	T-1-4 As a matter of regulation, Ecology can require sampling for pollutants that have established limits. Ecology is very interested in the new risk-screening tool that EPA will release to its Science Advisory Board this year. We are not sure of the process EPA will use to prioritize substances for analysis. We encourage the Nisqually Tribe and others to participate in the process. Ecology looked at PBDEs in biosolids when we prepared a chemical action plan some years ago. We did not see that biosolids were a significant source of releasing PBDEs to the environment. Ecology notes the interest in 6PPD Quinone related to impacts on salmon. We do not have information on that substance in biosolids.

2. Public Notice

Comment	Response
O-7-19 RCW 173-308-310(11) PUBLIC ACCESS TO INFORMATION. Ecology can withhold, but EPA can release information (11(b). Is this correct?	O-7-19 The Washington Public Records Act, Chapter 42.56 RCW[61], requires us to make identifiable public records available for inspection and provide records upon request. There is a similar process at the federal level under the Freedom of Information Act. We cannot speak to what EPA will or must disclose, or may withhold. Ecology may withhold some information. In particular, information related to ongoing litigation and attorney-client privilege may be withheld. The agency may also withhold information that has been determined to be proprietary. The provisions regarding confidentiality of proprietary information in WAC 173-308-310(11)[62] apply only when the proprietary nature has been established under separate rules. The provision in (11)(b) only says that even if the information is proprietary, Ecology must provide it to EPA on request.

[61] https://apps.leg.wa.gov/rcw/default.aspx?cite=42.56&full=true
[62] https://app.leg.wa.gov/WAC/default.aspx?cite=173-308-310

Comment	Response
O-7-42 **4.5.9.2** Site Posting Requirements for Class B Biosolids: Table B4 If there is a public comment opportunity, include it on the posting with all the pertinent information.	O-7-42 Content requirements for advisory posting of site access restrictions is specified in WAC 173-308-310(13)[62] and (14), and sections 3.8.2 (septage) and 4.5.2 (biosolids) of the general permit. Table B-4 only addresses public notice as regards restrictions on site access. Those signs are intended to be in place throughout the life of a site, and consequently are not appropriate for the purposes of notice regarding opportunities for public input. Notice for public comment opportunities is addressed in WAC 173-308-310(13)[62] and section 2.1.8 of the general permit. The information requested by the commenter is required in those notifications. In addition to the response above, please see the response to comment O-7-36.

3. Monetary incentives

Comment	Response
I-4-2 It's past time that profit and greed are valued over the health and well being of future generations. I say NO!	I-4-2 Other commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Monetary Incentives”.
I-11-2 This decision does not seem to be backed by science or health and safety and that is major concern for me that the individuals proposing this only have a monetary incentive to do so.	I-11-2 Several commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Monetary Incentives”.
I-30-2 Please do not implement this cynical and greedy proposal.	I-30-2 Several commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Monetary Incentives”.
I-67-2 The practice of promoting the spreading of biosolids has a corrupting effect on the DOE because of the partnership the DOE has had with for-profit purveyors of sludge who have been proven to be unscrupulous. I'd like to see the DOE partner with communities to find alternatives.	I-67-2 Several commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Monetary Incentives”. The 1992 state Legislature directed Ecology to establish a program to manage municipal sewage sludge. The Legislature also declared that the program should, to the maximum extent possible, ensure that municipal sewage sludge is reused as a beneficial commodity and is managed in a manner that minimizes risk to public health and the environment. Ecology regulates a legal activity, which is not the same as promoting the activity itself. We emphasize partnering with the regulated community, farmers, and others who beneficially

Comment	Response
	use biosolids, as opposed to adversarial relationships because we can accomplish more with the resources we have. That partnership does not impede our ability to take the necessary steps to correct problems when we discover them. Regardless of the management practice chosen, there will always be a monetary component to the program. The permit fees assessed by Ecology are apportioned fairly amongst regulated entities, and Ecology does not specifically benefit from its relationship with one generator or user over another. Ecology welcomes your idea of community partnerships and encourages you to reach out to your local biosolids coordinator to discuss in futher detail.
I-69-3 Moreover, corporate pressure to proceed without further testing is not acceptable.	I-69-3 The commenter suggests Ecology is being pressured not to expand testing of biosolids, and that by doing so we may be benefitting monetarily. This is not true. Ecology is carrying out a responsibility we were charged with by the Washington State Legislature to establish a biosolids program that prioritizes public health and the environment. Most of the regulated community is comprised of publicly owned wastewater treatment plants. They are very cooperative when it comes to testing their materials. Testing, however, is costly and treatment works are responsible to their customers for the bottom line costs as they affect rates. Ecology has generally not encountered reluctance to test biosolids. What we do encounter is treatment work's desire to understand why samples are needed, how samples need to be collected, and how analysis needs to be performed to assure useful results, and for an understanding of the standards against

Comment	Response
	which sampling results are compared. Efforts to study potential contaminants of concern are ongoing at multiple levels across the country. If it becomes apparent that additional regulatory standards are needed to ensure the safety of public health and the environment, Ecology is prepared to revise state regulations and the general permit to include them. In addition to the response above, please see response to I-7-3. We also prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Monetary Incentives”.

4. Ceasing land application

Comment	Response
I-14-1, I-15-1, I-16-1, I-19-1, I-21-3, I-27-1, I-32-2, I-44-1, I-48-1, I-71-1, I-72-1, I-76-1, I-77-1, I-79-1, I-81-1, I-82-1, I-85-1, I-88-1, I-91-1, I-92-1, I-93-1, I-94-1, I-95-1, I-96-1, I-97-1, I-98-1, I-99-1, I-100-1, I-101-1, I-102-1 "The State of Washington must cease issuing any permit that allows the disposal of sewage sludge in any form on homes, farmland, forestland or parkland."	I-14-1 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled "Consequences of ceasing all biosolids land application".
I-7-1 Should we continue to issue permits to businesses and agencies that give them permission to spread sewage sludge on farmland and forest land? NO! ... ...END permits and revoke existing permits to businesses and agencies that give them permission to spread sewage sludge on farmland and forest land!	I-7-1 Many commenters submitted a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled "Consequences of ceasing all biosolids land application".
I-8-1 The use of sludge in farming and domestic growing represents a threat to our environment and soil. Please stop the spread of this dangerous practice.	I-8-1 Ecology notes the commenter's opposition to the land application of biosolids. Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Consequences of ceasing all biosolids land application".

Comment	Response
I-10-2 I have no interest in subjecting our forest and farmlands to a grand experiment with the repeated application of these products and their unknown contaminates. We simply do not know enough about what is in the stuff and what the long-and short-term effects might be. Please do NOT allow this practice to continue. The health of future generations is likely at stake!	I-10-2 Beneficial use of biosolids has been practiced in the United States for a hundred years and in Washington since the 1970s. Large amounts of research have been done on biosolids over several decades. The work done by U.S. EPA in support of the current biosolids program considered food chain and other pathways of exposure when biosolids are applied to the land. The overarching conclusion of the bulk of reliable research is that the beneficial use of biosolids is safe when regulations and good management practices are followed. Efforts to study contaminants of concern are ongoing at multiple levels across the country. If it becomes apparent that additional regulatory standards are needed to ensure the safety of public health and the environment, Ecology is prepared to revise state regulations and the general permit to include them. Please also see the key topics discussion titled "Consequences of ceasing all biosolids land application" and "Food chain crops and biosolids" at the start of this response to comments for more information.
I-13-1 We strenuously oppose land application of sewage.	I-13-1 We want to clarify that the general permit does not authorize the land application of sewage. Biosolids are a treated residual that results from the treatment of municipal sewage sludge. When used properly, the word biosolids tells you the origin of the material and confirms that it has met standards that make it safe for beneficial use. (somewhat analogous to fresh grass clippings and finished compost). Please also see the key topics discussion titled "Consequences of ceasing all biosolids land application" at the start of this response to

Comment	Response
	comments for more information.
I-18-1 PLEASE stop the disposal of chemically infused toxic sewage sludge on the land upon which we farm and play and work.	I-18-1 Ecology notes the commenter's opposition to the land application of biosolids. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Consequences of ceasing all biosolids land application".
I-21-1, I-49-8, Almost weekly, new studies come out around the world criticizing the practice of conditioning soil with sewage sludge as dangerous folly. How long do you intend to ignore these and resist growing public disgust with this barbaric model?	I-21-1 The national and state biosolids programs are informed by peer-reviewed research, reports, guidance, and analysis of risk to human health and the environment, all developed by knowledgeable individuals and institutions. Biosolids staff are expected to remain informed on current research, and develop helpful relationships with EPA and other state biosolids programs. Since its inception, the Washington biosolids program has been the subject of ongoing research in a variety of topic areas including emerging contaminants, pathways of exposure, and field production studies comparing biosolids to conventional commercial agriculture practices. The science-based review of the biosolids program continues to demonstrate safety with regard to human health and the environment. We understand that some articles question the wisdom of beneficial use of biosolids, but Ecology continually re-evaluates new and emerging concerns regarding biosolids. We believe the bulk of competent peer-reviewed research and practical experience demonstrate that beneficial use is both safe and effective when applicable rules and permit requirements are followed.

Comment	Response
I-22-1 I am opposed to the use of bio-sludge, an end product of sewage sludge to be used to fertilize soil.	I-22-1 "Bio-sludge" is not a term used or defined in state or federal programs. The term biosolids was selected to differentiate because there are many kinds of sludges from different processes. When used properly, the word biosolids tells you the origin of the material and confirms that it has met standards that make it safe for beneficial use. Ecology notes the commenter's opposition to the land application of biosolids. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Consequences of ceasing all biosolids land application".
I-23-4 Accordingly, we urge denial of any permit for biosolids on agricultural land.	I-23-4 Many commenters submitted the same or a similar comment. Ecology does not believe denying permits is the best course of action. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Consequences of ceasing all biosolids land application".
I-24-2 The only way to get rid of it is to quit making it. I don't know how to do that, but spreading it over the land is NOT a good idea. Don't do it	I-24-2 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Consequences of ceasing all biosolids land application".

Comment	Response
I-28-1 I am completely opposed to using biosolids in agriculture and offering it for fertilizer to the public. It is a disaster waiting to happen, for our crops, for our rivers, wildlife and ground water when the rains come.	I-28-1 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”. Please also see the response to comments I-1-1, I-3-2, and I-4-1.
I-31-2 Sludge should not be used as a fertilizer. It is not stored safely before use in many cases, and can contaminate food production.	I-31-2 Staging is short-term stockpiling of biosolids that occurs at some active land application sites. It is done ahead of the growing season, or when biosolids are being applied - in which case the goal is to keep enough biosolids on hand to busy application equipment before the next load arrives. Staging areas are identified in the process of approving plans for specific sites. Winter storage is also subject to site-specific approval. In all cases, the intent is to avoid areas that will be wet or subject to runoff Please also see the key topics discussion titled “Consequences of ceasing all biosolids land application” at the start of this response to comments for more information.
I-33-1 Bio-solids do not belong on any soil, esp. farmland soil.	I-33-1 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.

Comment	Response
I-34-1 When is the disposal of sewage sludge in any form on homes, farmland, forestland or parkland ever a good idea? Please stop the insanity!	I-34-1 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.
I-36-1 This practice of spreading human waste and all it contains must end. ... Just stop!!	I-36-1 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.
I-38-1 I have just one word: NO! No bio solids on ag lands It's time to stop spreading sewage sludge on our farms.	I-38-1 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.
I-39-1 Sewage sludge, Biosolids class A, and Biosolids Class B should not be allowed to be spread across a community's watershed, land.	I-39-1 Ecology notes the commenter’s opposition to the land application of biosolids. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.

Comment	Response
I-41-2 Please do not approve its use. Once approved, it would be difficult to reverse and remedy the harm it will cause.	I-41-2 Beneficial use of biosolids has been practiced in Washington state since the 1970s at least, and for a hundred years in the United States. The draft permit proposes some changes to the existing permit program but is otherwise simply carrying on a longstanding activity. Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.
I-42-1 Please don't allow this to go through. Think of the ecology on the downhill slope from this property.	I-42-1 Ecology requested comments on the whole of the draft general permit for biosolids management. This comment seems to pertain to a particular site and therefore is beyond the scope of this comment period and response. Please see the response to comment B-2-1 for more information about how to inquire about specific land application sites and becoming an interested party. The commenter may also be interested in separate discussion we prepared that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.

Comment	Response
I-43-1 Applying biosolids to the land for any purpose is simply wrong...Biosolids ought to go to a landfill.	I-43-1 Ecology notes the commenter's opposition to land application of biosolids. Landfilling is not a sustainable activity. There are well-documented benefits to soils, crops, and wildlife from the land application of biosolids. Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Consequences of ceasing all biosolids land application".
I-45-2 The damage these chemicals can inflict on our bodies and ecosystems is vast and to continue this practice would be ignorant and violent. I oppose permits.	I-45-2 Ecology notes the commenter's opposition to land application of biosolids. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Consequences of ceasing all biosolids land application".
I-62-2 "Loading" is another world for cheap disposal. Please stop this cheap, outdated disposal and use landfills like all other wastes. Biosolids by weight have 5% nutrient value which means its is a low grade product anyway.	I-62-2 We are unclear about the commenter's use of the term, "loading." Biosolids are not wastes, by law. In addition to nitrogen, biosolids contain all the macro- and micro-nutrients necessary for plant growth, as well as organic matter that helps improve soil. Ecology does not see disposing of materials in landfills as part of a sustainable future. We will continue to support beneficial use, and of course, adjust regulations as necessary. Please also see the key topics discussion titled "Consequences of ceasing all biosolids land application" at the start of this response to comments for more information.

Comment	Response
I-67-1 I am writing to oppose the permit renewal... ...Please do not renew the permit. Instead implement a moratorium and then go on to investigate and promote better systems for destroying what is toxic in these wastes and using what is valuable in a safer, more carefully managed, more discriminating way.	I-67-1 Ecology notes the commenter's opposition to the land application of biosolids, and we appreciate their recognition of the valuable resources contained in biosolids. Please see the response to comment I-119-3.
I-69-2 Until it can be determined that sludge has no contaminants whatsoever, it should not be used.	I-69-2 Many commenters submitted the same or a similar comment regarding ending land application of biosolids. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application.” Please also see the response to comment I-1-1, and I-74-1 for more information.
I-74-1 Do not spread sewer sludge on the ground. Sludge is more than urine and feces. It has every chemical that is used to clean or taken medicenely. Sewer sludge must not be spread on the ground where food is going to be grown.	I-74-1 Use of the term "sewer sludge”, is a misrepresentation of biosolids. Biosolids are a further treated residual that results from the initial treatment of wastewater. A good portion of biosolids are actually the beneficial microorganisms grown in a wastewater treatment plant to treat the wastewater. Please see also the response to comment I-1-1 for more information. In addition, we prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.
I-75-1 Please stop spreading "biosolids" sewer sludge on our farms and public lands. This is polluting our Earth with pharmaceuticals and other	I-75-1 Use of the term "sewer sludge”, is a misrepresentation of biosolids. Biosolids are a further treated residual that results from the initial treatment of wastewater. A good portion of

Comment	Response
contaminants.	biosolids are actually the beneficial microorganisms grown in a wastewater treatment plant to treat the wastewater. Please see also the response to comment I-1-1 and I-26-1 for more information. In addition we prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”
I-78-1 Stop spreading dubious quality sewage sludge solids on agricultural land both food and flower. It's doing more harm than good for all but a very select few	I-78-1 Many commenters submitted the same or a similar comment regarding ending land application of biosolids. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.
I-84-1 I am a Washington State citizen and I am very opposed to the permitting of sewage sludge on our lands, be it homes, farmland, parks or forests. …Please reconsider permitting biosolids.	I-84-1 Many commenters submitted the same or a similar comment. Ecology does not believe denying permits is the best course of action. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.
I-87-1 I do not support the use of bio-solids on any agriculture lands in the state of Washington.	I-87-1 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.

Comment	Response
I-89-1 With all the toxins and potentially radioactive substances in this sludge we should stop doing this immediately. No other advanced country puts this on their farm lands or public areas.	I-89-1 Beneficial use programs are in effect across the globe, including Canada and in many parts of Europe. Frankly, citizens in many countries do not enjoy the high degree of sanitation and wastewater treatment from which we benefit in the United States, and would be very glad to have access to those services at all. Many commenters submitted the same or a similar comment regarding ending land application of biosolids. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.
I-107-1 I am opposed to the application of biosolids to residential land and agricultural land. I implore the WSDOE to cease issuing permits for that allow this practice.	I-107-1 Many commenters submitted the same or a similar comment. Ecology does not believe denying permits is the best course of action. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.
I-111-1 It is wrong to use Biosolids on any land, public or private.	I-111-1 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.

Comment	Response
I-114-1 I am strongly against the all in for Biosoilds without consent or consideration of the toxicity to our land, wells, rivers, fish and wildlife.	I-114-1 Many commenters submitted the same or a similar comment. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Consequences of ceasing all biosolids land application".
I-115-1 My comment is NO, don't do it... On top of that, the companies that run these outfits have not been the most reliable with safety protocols. So my answer is just a plain and simple NO!!!	I-115-1 Ecology notes the commenter's opposition to the land application of biosolids. If the commenter has issues with a specific site or operator, they should reach out to the appropriate Regional Biosolids Coordinator[63] with their concerns. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Consequences of ceasing all biosolids land application".
I-117-1 We do not believe that the spreading of sludge, aka biosolids, on the land or in landfills is a viable solution to this significant waste disposal problem... We implore you and your agency to do what is right. Not what appears to be the cheapest route and mistakenly convenient. Our children, our future, and all of nature deserves better.	I-117-1 Ecology notes the commenter's opposition to biosolids beneficial use and disposal in landfills. We agree that future generations deserve a better environmental legacy, and we are working in that direction. The commenter asks Ecology to do what is right, not what is simply convenient or the least costly. Providing sanitary services is complicated and overall very expensive. Biosolids are an end result of wastewater treatment systems. Wastewater treatment is a necessity for the more than 7.7 million people living in Washington. So we need a way to make use of, or dispose of biosolids, as we all contribute to their production. As explored in our discussions, disposing of all biosolids via landfilling or incineration is not feasible for many

[63] https://ecology.wa.gov/Waste-Toxics/Reducing-recycling-waste/Biosolids/Program-contacts

Comment	Response
	reasons. Please refer to the key topic discussions titled “Monetary incentive”, and “Consequences of ceasing all biosolids land application” for additional information.
I-119-3 Therefore, I would be in favor of a moratorium to granting new powers to applicators until new technologies can make sludge safer. The actively managed septage and biosolids applicators, who are in the business for profit, need many more controls on the products they disburse than I see being required by the Department. Please understand that I am vitally concerned with applications to food-producing land and water.	I-119-3 Ecology notes the commenter's opposition to the land application of biosolids and appreciate their concern for lands and waters used to grow food crops. To date, science-based review continues to demonstrate safety for human health and the environment when land applied under our state rules and permit. A moratorium is impractical. Biosolids are an end result of wastewater treatment systems. Wastewater treatment is a necessity for the more than 7.7 million people living in Washington. So we need a way to make use of, or dispose of biosolids, as we all contribute to their production. As explored in our discussions, disposing of all biosolids via landfilling or incineration is not feasible for many reasons. Refer to the key topic discussion titled “Consequences of ceasing all biosolids land application” for additional information. The amount of land that receives biosolids application overall is a very small fraction of land in Washington state (about 30,000 acres out of

Comment	Response
	more than 43,000,000). Rerouting all sludge produced via wastewater treatment to landfills or incinerators for disposal has environmental impacts and is not a sustainable. The commenter says that more controls are needed on companies that profit from beneficial use, but does not address the fact that most biosolids are produced by publicly owned treatment works that are not motivated by profit. If the commenter is thinking about contaminants in general, Ecology is continuing to monitor developments in the assessment of substances like PFAS. The state permit program has the flexibility to allow for modification of requirements, or we can modify the underlying rules if new information emerges that warrants changes. If the commenter is remarking about operational limitations or requirements for documentation, those are already substantial although we could certainly consider recommendations.
I-120-1 I am commenting on "Statewide General Permit for Biosolids Management". Please do not renew.	I-120-1 Many commenters submitted the same or a similar comment. Ecology does not believe denying permits is the best course of action. We prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Consequences of ceasing all biosolids land application”.

5. OIG Report

Comment	Response
I-23-2, I-49-5 In 2018, the EPA's Office of Inspector General concluded that they haven't the means to prove "biosolids" safe.	I-23-2 Other commenters submitted the same or a similar comment. Please see the response to comment I-48-3. We also prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: “Understanding the 2018 Office of the Inspector General report”.
I-48-3 According to the U.S. Environmental Protection Agency's Office of Inspector General, the EPA knows of 352 "pollutants" that can be found in municipal sewage sludge (the EPA regulations that govern this practice nationwide only require testing for nine). The Inspector General compared those 352 pollutants to three federally maintained lists of hazardous substances and found this: Of those 61 pollutants, 32 are hazardous wastes under the Resource Conservation and Recovery Act, including four described as acutely hazardous; 35 are EPA priority pollutants; 16 are on the National Institute for Occupational Safety and Health's list of hazardous drugs. Washingtonians' food is grown in this filth! "The EPA's controls over the land application of sewage sludge (biosolids) were incomplete or had weaknesses and may not fully protect human health and the environment." - U.S. Environmental Protection Agency's Office of Inspector General, November 15, 2018.	I-48-3 Ecology takes issue with the report prepared by the U.S. Office of the Inspector General (a separate agency with an office located within EPA) for several reasons. The report highlighted a number of pollutants that may be found in biosolids, but provided inadequate context for readers to properly evaluate what that means. Section 405(d)(2)(C) of the CWA requires EPA to review the regulations at least every two years, to identify additional toxic pollutants and then implement new regulations if necessary. EPA reviews information on pollutants, or potential pollutants to assess their safety. If data do not indicate a risk then no regulation is required. They periodically review available information as our ability to detect pollutants and our knowledge about their impacts grows with time. Ecology does not take issue with the OIG's finding that certain substances occur in biosolids. Contaminants or pollutants in biosolids are generally present in small amounts, but the mere presence of a pollutant does not mean there is a risk to human health and the environment. The amount and means of exposure combined with toxicity determine a pollutant’s risk. Finding one of the pollutants the EPA highlighted in biosolids does not mean the biosolids are dangerous, nor did the report conclude this. However, because

Comment	Response
	those substances can be of concern in other contexts, they merit attention in biosolids. Ecology agrees that certain pollutants do require additional attention. Ecology is currently involved with the EPA's Office of Research and Development (ORD) to assess per- and polyfluoroalkyl Substances (PFAS) in Washington's biosolids. ORD is one of the leading research institutions in the world regarding analysis of PFAS in complex organic compounds such as biosolids. If it becomes apparent that additional regulatory standards are needed to ensure the safety of public health and the environment, for PFAS or any other pollutant, Ecology is prepared to take action. The general permit allows for adjustments like this to be made whenever necessary, not just every 5 years upon issuance. Ecology prepared separate discussions that readers can find in the key topics section at the front of this response to comments. Please refer to these for additional information, in particular the following discussions touch on the commenter's inquiry: "Understanding the 2018 Office of the Inspector General report", "Wastewater treatment process and biosolids", and "Understanding regulated pollutants in biosolids".
I-118-3 November 15, 2018 Findings by the USEPA Unable to Assess the Impact of hundreds of Unregulated Pollutants in Land-applied Biosolids on Human Health and the Environment	I-118-3 Several commenters submitted the same or a similar comment. Please see the response to comment I-48-3. We also prepared a separate discussion that readers can find in the key topics section at the front of this response to comments titled: "Understanding the 2018 Office of the Inspector General report".

6. Food chain crops

Comment	Response
I-26-1 Please don't use or process biosolids on or near food sources. There are many ornamental applications it can be rerouted to. There is too much opportunity for cross contamination or mishandling or misprocessing and too many people with weakened immune systems.	I-26-1 In Washington, biosolids are applied to ornamental crops, non-food-chain crops, forestlands and pastureland as well as feed and food crops. There are specific biosolids quality and site management requirements for biosolids used on food crops. Biosolids must meet pollutant limits, achieve a 99% reduction in pathogens (at a minimum) during the treatment process, and comply with restrictions on application and crop harvest timing. These application and harvest restrictions are designed to allow for the remainder of pathogens to be destroyed before the crop is harvested, and to ensure that the actual edible portion of the crop is protected. When used on food crops, biosolids are generally applied before planting, or before the edible portion of the crop develops (e.g. applied to the soil before the wheat is sown). That means the edible portion of the crop develops above the ground level, and after the biosolids are applied to the land. The federal program, upon which Washington bases its program, considered risks from the application of biosolids to food chain crops in its analysis. Standards for regulated pollutant limits and pathogen reduction were studied and designed specifically to protect food and feed crops and consumers. Overall, biosolids are applied to a very small fraction of agricultural lands in Washington. The bulk of research and practical experience support that beneficial use is safe for human health and the environment when done so in accordance with state and federal regulations, and permit requirements. Ecology applies the same logic in supporting the use of other soil amendments.

Comment	Response
	Animal manures for example are more widely used on crops with fewer regulatory requirements. Although they have on rare occasions been positively linked with outbreaks of illnesses, it is commonly understood that their benefits on crop growth and soil maintenance outweighs this drawback. In addition to the response above, please also see the response to comment I-3-2, and the key topic discussion titled: “Food chain crops and biosolids” that readers can find at the front of this response to comments.
I-69-1 In particular, as a city dweller I need to know that the food I eat is free from any and all harmful substances. Sewer sludge is a harmful substance, and the science to this date regarding sludge is underdeveloped and inconclusive.	I-69-1 Use of the term "sewer sludge”, is a misrepresentation of biosolids. Biosolids are a further treated residual that results from the initial treatment of wastewater. A good portion of biosolids are actually the beneficial microorganisms grown in a wastewater treatment plant to treat the wastewater. It may help to think of the difference between fresh grass clippings and finished compost. Please also see the response to comments I-3-2, I-26-1, and the key topic discussion titled: “Food chain crops and biosolids” that readers can find at the front of this response to comments.
I-103-1 Please do not allow biosolids from human waste to be disposed of in any area that is used to produce food. This can lead to serious health issues.	I-103-1 Ecology notes the commenter’s opposition to the land application of biosolids. Since its inception, the Washington State biosolids program has been the subject of ongoing research in a variety of topic areas focused on the safety and efficacy of the beneficial use of biosolids. The science-based review of the biosolids program continues to demonstrate safety with regard to human health and the environment. Please also see the response to comments I-3-2, I-26-1 and the key topic discussion titled: “Food

Comment	Response
	chain crops and biosolids" that readers can find at the front of this response to comments.
I-106-1 Please do not allow this sludge on our food. It is outrageous that this is even being considered.	I-106-1 Biosolids are a treated residual that results from the treatment of wastewater. A good portion of biosolids are actually the beneficial microorganisms grown in a wastewater treatment plant to treat the wastewater. Please also see the response to comments I-3-2, I-26-1, and the key topic discussion titled: "Food chain crops and biosolids" that readers can find at the front of this response to comments.
I-116-1 I am writing to comment on the Statewide General Permit for Biosolids Management. I strongly object to using biosolids for food production or on fields which will be used for crop production in subsequent years.	I-116-1 Biosolids have been beneficially used in Washington since the 1970s and in the United States for about a hundred years. Some biosolids are used on forest lands. The decision of how to beneficially use biosolids rests with the producer. The commenter may wish to review specific restrictions related to food crops in 4.5.9.1 of the permit. Please also see response to comments I-3-2, I-26-1, and the key topic discussion titled: "Food chain crops and biosolids" that readers can find at the front of this response to comments.
O-7-35 **3.8.1** Crop Harvest Waiting Periods. Table S1: Restrictions How are harvest times decided? Is there testing for root, stem, edible parts uptake of any contaminants?... **…4.5.9.1** Crop Harvest Waiting Periods. Table B3. We have the same questions as posed under 3.8.1.	O-7-35 Restrictions on harvest times for crops grown for human consumption are established in federal rules and based on pathogen reduction. The waiting period is determined by the kind of crop, the type of biosolids, and the method of application. We refer the commenter to EPA's Control of Pathogens and Vector Attraction Reduction[46], wherein the basis for the requirements of the rule are explained and many citations to supporting literature are provided. As regards testing of crops for contaminants, EPA did look at research for the pollutants they

Comment	Response
	ultimately chose to regulate. To the extent they are found in biosolids, the nine currently regulated pollutants are generally not in forms that are mobile or subject to uptake by crops under normal growing conditions. Research is continuing on other contaminants of concern, including PFAS. Please also see the response to comments I-3-2, and I-26-1.

7. Permit Process

Comment	Response
B-1-1 1. Interested Parties List a. Most people on the list are not fans of facility to maintain a degree of improbity DOE should maintain and notify, b. Some Interested Parties may not want to give facility personal information. c. If notice is returned cannot deliver or if sent certified and was not signed for the person should be removed from list 2. Public Notices a. should be standardized within the state and for each type of activity IE (treatment works vs Land application) b. Just because a site doesn't have a following when someone starts to raise Issue, they will always go to I wasn't notified, a standard procedure will reduce this. We say we do X and does X. 3. Public Hearings a. DOE should develop Criteria for when a hearing will be held i. Do they have an Issue or unaddressed issue? ii. Is there a misunderstanding of project and scope? 1. Meeting Or Hearing needed iii. If they Just don't like a project there is not a need 4. Comments Periods a. Should be limited to 45 Days, DOE can still receive and review but they do not need to be considered in response, even after Permit is issued DOE can and has added Conditions i. Even as I submit these late, it is used to stall	B-1-1 1. Ecology concurs and revised permit language in sections 3.2.3 and 4.2.3. 2. The public notice process is probably as standardized within the rules and permit as can be accomplished. The balance we are trying to achieve is what falls between a diligent effort to inform potentially interested parties, and an overly burdensome process. Ecology has implemented a new online service that will allow interested parties to Register for Updates[25] so that they can be notified of permit-related activities. We believe that will help to address the concerns of citizens who feel the agency does not ensure adequate notice. 3. We can appreciate the commenter's desire to avoid elements of public process that might appear to have no benefit, but the agency disagrees with this recommendation. We maintain determining whether or not to hold a public hearing is most equitable when conducted in keeping with WAC 173-308-310 (14) - Public hearings and meetings[62]. The commenter notes in particular that someone simply not liking a project should not be cause for a public hearing. We understand that persons opposed to any project may not be swayed by a hearing, and may not bring technical issues to the table. But not liking something is in fact justification for holding a hearing, and provides citizens with a necessary opportunity to voice their concerns. It is unlikely that Ecology would convene a hearing over a single concerned person, instead our approach would be to work with that person to understand their concerns In this process of soliciting comments on the draft general permit, Ecology has made changes and

Comment	Response
a project without any gain b. Response to comments Needs to be Prompt DO NOT wait tell the end of the comment period to start working on response the delay in response leads people to believe that you were not listening i. 30-day ideal ii. 60 days ok iii. Over 90 days Not ok… …7. Maps a. The size requirement to 8.5*11 I believe that 11*17 or A4 should be allowed as it is fairly standard paper size and it keeps more area on one page for a better view of the site without having a lot of pages trying look and find a certain feature and understanding where thing lay in relation to an application Zone… …9. Seasonal timing a. Should be condition based without abstract dates, As the weather In Washington can be moody from wet springs and dry falls to dry springs and wet falls… …11.We appreciate the that DOE is trying to stream line the process so that they can focus more attention to Facility's that are producing & land applying.	commitments that will improve the program, based on comments from stakeholders. A public hearing may uncover important information that would lead either to better permit conditions or to improving the understanding of interested parties. 4. Ecology agrees that in many cases it takes too long to move a proposal through public process and reach a final determination. Changes in the permit process proposed with this general permit are intended to improve agency response time overall. Notice periods are generally required by rule to be thirty days, and Ecology must allow time following a public hearing for interested parties to submit comments. If a hearing is not requested and Ecology determines after initial public notices that a hearing is appropriate, a second notice is required. In that case, it will likely require a minimum of 90 days to close the comment period. The commenter argues that late comments should not be considered in a response to comments. The agency is not prevented from considering late comments, but we are not obligated to include the comments or our answer in our official response. Ecology would not expect to honor late comments that simply object to a proposal, or only iterate information already submitted by others. If late comments identify an important issue not previously brought to the agency's attention, that issue would need to be resolved before approving a site. The commenter recommends that Ecology not wait until the end of a comment period to begin working on comments. We agree, but this is not always possible depending on the amount and content of comments received. Ecology believes the overall timeframe for making determinations on permit applications and site

Comment	Response
	proposals is too slow. That is why we created an approach with the proposed general permit that will expedite permit approvals for facilities without active beneficial use programs. The quality of applications is a significant problem for Ecology staff. With this permit cycle, Ecology is moving toward expectations for permit applications and site proposals that are much more structured and consistent. Applicants will see more templates and less flexibility on the form of application throughout the permit cycle. Ecology believes moving in the direction of consistency and expectations for better quality submittals is necessary for the long-term health of the program. 7. Ecology has observed that maps can be poorly prepared and that different scales only exacerbate difficulties with preparation and interpretation. Ecology has revised the permit to allow for a different size sheet if approved by Ecology. Note that scales specified are minimums. Applicants should bear in mind that quality maps are critical for the purpose of supporting proposals. 9. Land applying outside of approved land application dates is a site-specific question, and is not within the scope of this response to comments. Facilities can discuss this with the appropriate biosolids coordinator. 11. Ecology notes the commenter's support.

Comment	Response
B-3-2 1.1.3. - Page 2 Persons Required to Apply for Coverage under this Permit Unless you are obtaining an individual permit in accordance with WAC 173-308-3107, you must apply for coverage under this permit if you own or operate a treatment works treating domestic sewage, including but not limited to: Publicly owned treatment works Privately owned treatment works that treat only domestic sewage, or treat domestic sewage separately from industrial wastewater Comment 2 Highlighted text should be replaced with "Publicly or privately owned treatment works" Type of ownership should not make a difference. See definition of Treatment works in 173-308-080… …SECTION 3.23 Identification and Notice to Interested Parties - Page 25 COMMENT 7 Given that most interested parties are often irritated parties it would make more sense for Ecology to maintain the IPL for each facility rather than the facility itself. Interested parties typically do not trust the facility they are inquiring about, at least that has been our experience.¬ They want to talk to the agency governing the facility and be assured their voice is heard. In our experience "Interested Parties" do not want our facility to have their private email address, phone number or mailing address. We suggest that information be treated to the same protection as a whistleblower. Ideally, Ecology would maintain those lists	B-3-2 The commenter recommends a change in 1.1.3 of the permit to say that public and privately owned treatment works are required to obtain permits, based on the idea that ownership should not matter. In fact, ownership does matter. Under federal rules, all publicly owned treatment works treating domestic sewage are required to obtain coverage. That requirement extends to the state program as well. Also under both sets of rules, privately owned treatment works that treat domestic sewage separately from industrial wastewater are required to be covered. Privately owned treatment works that treat only industrial wastewater or industrial wastewater combined with domestic sewage, are not covered under the program. EPA felt there were too many possible variables to capture those facilities under the national umbrella. In reference to comment 7, the commenter recommends that Ecology be the agency to maintain an interested party list for purposes of notification on permit activities. This recommendation is based on the commenter's experience that interested parties may not trust the permit applicant/holder, and may not want to share their personal contact information. The commenter recommends that contact information should be confidential. Ecology agrees with the commenter as regards maintaining a list of interested parties and carrying out notification. Unfortunately, state rules place the burden for maintaining the interested party list on the permit holder, and we cannot entirely relieve the permit applicant/holder of this burden. That does not mean, however, that Ecology cannot coordinate on maintaining a list of interested parties. Ecology has created a new online service that will allow

Comment	Response
confidentially, and each facility would be responsible for submitting requests they receive to Ecology. COMMENT 8 "If an interested party provides both an email and physical mailing address, the facility must notify using both addresses, or confirm receipt of notification by one." We suggest that facilities be able to choose which method of communication to use. Or the IP can specify which method they prefer. Either or, not both.	interested persons to register directly with Ecology, and to be notified of activities in specific counties or even statewide. That may reduce the burden for the permittee and provide more assurance to the interested party. There is no way to maintain confidentiality for the list of interested parties. If they wish to be recognized, their contact information and any associated communications become public records and subject to disclosure. That being said, interested parties can submit comments without providing contact information (but they have to provide contact information if they want to be notified). In reference to comment 8, the commenter recommends if an interested party provides both an email and physical mailing address, that facilities be able to choose which method of communication to use. Alternatively that the interested party can specify which method they prefer. The choice should be either-or, but not both. Ecology disagrees. We recognize this creates an additional burden, but we also know emails and physical addresses change, where such changes may not render a person disinterested. Interested parties may in fact be so concerned that they deliberately provide a second means of notification. Ecology wants to note that the new system for interested parties to Register for Updates[25] with Ecology will make email notification easy, and something Ecology can support. Ecology generally also handles the physical mailings. It is essential for the permit holder, however, to collect information on interested parties when presented.

Comment	Response
I-7-5 Ecology says "the draft permit streamlines some requirements, reducing the regulatory burden for the [biosolids industry] in the state." This matches the complaint expressed (at a public meeting) by one of the officers of FMF that "there is too much paper work" while submitting blatantly inadequate and incorrect boiler plate for the required environmental analysis of the proposed Lincoln County site that was to be sludged.	I-7-5 The commenter argues against streamlining the permit process, implying Ecology's efforts to lessen the regulatory burden were in response to the complaint of a specific regulated entity, or is intended to specifically benefit that entity. That is not correct. The streamlining effort will not reduce the burden for facilities that have active biosolids management programs (like FMF). But it will allow Ecology to focus more time and attention on facilities with active programs. Please see our separate discussion titled: “General vs individual permits and expediting coverage” in the key topics section at the front of this response to comments for more information about the streamlining effort.
I-46-1 Please reconsider the way you are managing biosolids, and deny automatic permits. We need to consider long term safety and pollution of farmland, neighborhoods and watersheds.	I-46-1 The streamlining effort will not reduce the burden for facilities that have active biosolids management programs. It will allow Ecology to focus more time and attention on facilities with active programs. For more information, please see our separate discussion titled: “General vs individual permits and expediting coverage” in the key topics section at the front of this response. Biosolids land application has been regulated in Washington for decades. Experience supports that biosolids are safe when applicable rules and permit requirements are followed.

Comment	Response
I-47-4 It is time for the Washington State Biosolids Permit Program to address per-and poly-fluoroalkyl substances (PFAS) contamination with Site-Specific Permits that protect the state's lands, waters and its impacted communities from these "forever chemicals" that are now found everywhere - including inside people. General permits cover a "designated geographical area" and are too "general" in scope to provide enough protections.	I-47-4 Ecology believes the general permit program is the optimum approach for managing biosolids in Washington state. In our view, the implementation of individual permits would be a major step backward. For more information, please also see our separate discussion titled: "General vs individual permits and expediting coverage" in the key topics section at the front of this response. Our current permit structure establishes overarching requirements for about 380 facilities, augmented by both individual facility-specific and site-specific criteria as needed. Individual permits would not support agency staff to accomplish better oversight or take quicker action. They would increase the administrative burden on permittees without benefit, and it would distract from the agency's overall efforts to deliver an effective statewide program. If Ecology wishes to establish limits for PFAS in biosolids or to require soil sampling for PFAS at all land application sites, our first choice of mechanisms would be our rules in WAC 173-308[24]. However, we could establish a separate pollutant standard for PFAS in our general permit. We have not proposed to do so in this draft general permit, but we could modify the permit at a future date - even just for that specific purpose alone - before it is formally due to be reissued. Please also see the response to comments O-8-9 and O-9-1 for more information about PFAS.

Comment	Response
I-48-5 The state's rules for permitting the use of sewage sludge as fertilizer expired in September of 2020 so now the government must go through a public rule-making process to re-authorize the so-called "statewide general permit for biosolids management" for the next five years. They have released a draft for public comment. Ecology sees it as seeking minor adjustments to the existing regulatory framework for disposing of sewage sludge on farm and forest land and expect to rubber stamp it and go on with business as usual. I see it, and many other concerned citizens see this comment period as an opportunity to fundamentally question the wisdom, the morality and the science around whether we should be permitting this activity in the State of Washington at all. Ecology will state again and again, defending the sludge permitting program, that the draft permit language conforms to state and federal regulations (like if a batch of sludge passes tests for the nine contaminants and comes out okay, then it's alright to simply ignore the hundreds of other chemicals the regulations don't bother to mention). But the real question is, does the draft conform to whether or not Washingtonians will tolerate the continued pollution of our lands, waterways and food supply? The answer must be "No!"… ... Ecology says it will "consider all feedback before a final decision is made. So far the at the time of this writing the written comments submitted so far overwhelmingly favor the cancellation of the statewide general permit for biosolids management. Ecology must do as	I-48-5 The state rules concerning biosolids are found in Chapter 173-308 WAC[24] and remain in effect with no expiration date. Ecology is in the process of reissuing the statewide general permit in accordance with those expired rules. Ecology received other comments showing support for and opposition against the general permit and is considering all of them. This includes evaluating the merit of all comments and the overall implications for public policy. In addition to considering public comments received, Ecology must base regulatory decisions on peer-reviewed research and practical experience. Since its inception, the Washington State biosolids program has been the subject of ongoing research in a variety of topic areas focused on the safety and efficacy of the beneficial use of biosolids. The science-based review of the biosolids program continues to demonstrate safety with regard to human health and the environment. We understand the commenter wishes for land application of biosolids to end in the state of Washington. To address this, we refer the commenter to the key discussion titled "Consequences of ceasing all biosolids land application" that readers can find in the key topics section at the front of this response to comments. Please also see the response to comments I-3-2, I-26-1, and the key topic discussion titled: "Food chain crops and biosolids" for additional information about the safety and extent of beneficial use of food crops. In reference to streamlining some requirements, the streamlining effort will not reduce the burden for facilities that have active biosolids management programs. It will allow Ecology to focus more time and attention on facilities with

Comment	Response
they say. Consider that overwhelming message from commenters and act on it. Cancel the statewide permit!... …Ecology says "the draft permit streamlines some requirements, reducing the regulatory burden for about half of the 375 or so [biosolids] facilities in the state" as if that's a good thing? Less regulation: Just what we need when we are faced with hundreds of known contaminants and emerging contaminants of concern. I oppose any "streamlining" of biosolids regulations in WA. If you really want to streamline the process, end it. Do not re-issue the statewide biosolids permit.	active programs. Please also see the response to comment I-7-5. The commenter may wish to read our separate discussion titled: “General vs individual permits and expediting coverage”, that readers can find in the key topics section at the front of this response to comments.
I-49-7 Ecology says "the draft permit streamlines some requirements, reducing the regulatory burden for the [biosolids industry] in the state." This mirrors a complaint expressed (at a public meeting) by one of the officers of FMF that "there is too much paperwork." FMF had submitted blatantly inadequate and incorrect boiler plate language in the required environmental analyses (SEPA checklists and SSLAP's)... ...The tendency of your department is toward diminished scrutiny and public oversight. Last year, you eliminated comment on specific local permit applications in favor of the one general permit process we now deal with. Of course, it seems futile to generate comments to the Department itself, rather than to a higher independent regulatory authority. Unfortunately, this is the unaccountable system we are stuck with. As a now retired 20 year state employee, I know how insular and corrupt some departments can be in their dedication to an almost sacred model of	I-49-7 We see that the commenter makes a connection between the complaint of a regulated entity about the burden of the permit process, and changes Ecology made in this permit cycle to relieve some of the administrative burden for permit applicants. The expedited permit system will benefit those facilities that do not have active management programs. For more information, please also see the response to comment I-7-5, and our separate discussion titled: “General vs individual permits and expediting coverage” in the key topics section at the front of this response to comments. The commenter remarked, "Last year, you [Ecology] eliminated comment on specific local permit applications in favor of the one general permit process we now deal with." The agency did not eliminate any part of the process last year, or in any preceding year. The biosolids permit process in Washington has been the same for nearly twenty-five years. It provides for comments on the statewide general permit, comments on applications for coverage under the general

Comment	Response
practice. Often these models last way beyond their deserved time because the careers of so many staff become too vested in them. State agencies are vulnerable prey to the private contractors they deal with. There is also the revolving door between state employees and private consultants. This is how the public interest and even public safety gets forgotten. I have a friend who retired from Ecology who said, "We don't tell people not to pollute. We just let them know the limits." Another Ecology staffer confided that he consistently refused to work in the Waste 2 Resources Program because of its unprincipled practice.	permit, and comments on approvals of specific sites.
I-53-3 1. The use of the General Permit format on the whole and for biosolids specifically, is not conducive for use by the people having to implement two separate permits for the same discharge. My industrial experience/perspective on the need for WWTPs to meet conditions from two permits vs just one individual NPDES permit is that it is cumbersome, overly burdensome, and consequently, more difficult to maintain compliance to all provisions from both permits. The use of general permits like this is not common practice across the US for a reason, they are not as effective as integrating all applicable requirements into one individual NPDES permit. I strongly suggest that Ecology consider rescinding the use of general permitting for WWTP biosolids and integrate applicable provision into individual NPDES permits.	I-53-3 We gave a great deal of consideration to individual permits at the outset of permitting in the late 1990s. We concluded that separate permits (NPDES and biosolids) was the best approach. If anything it has presented less of a burden overall than would have incorporating requirements in individual NPDES permits. Although the EPA and some other states have used different permit approaches, the system currently in place is one that works in Washington. Please see comment I-105-3. The commenter may wish to read our separate discussion titled: “General vs individual permits and expediting coverage” that readers can find in the key topics section at the front of this response to comments.

Comment	Response
I-55-7, I-56-6, I-57-5, I-58-5, I-59-5, I-64-5 Please disallow the waste to be spread on ski slopes.	I-55-7 The program does not explicitly allow or prevent biosolids from being land applied on ski slopes, but we cannot identify a circumstance where it has been done - or even proposed. Biosolids site-specific land application plans require information on slope and current and adjacent land uses among other things. It is likely that slope and possibly land use would prevent approval for any non-exceptional quality biosolids. It is possible that exceptional quality biosolids could be applied on a ski slope, but it seems highly unlikely since products are generally designed for other uses and intended for other customers. If the commenter is aware of a ski slope where biosolids have been used, please contact staff in our regional office with that information. Thank you.
I-105-3 Just by nature, having general permits for some portion of the regulated community, NPDES for others and both an NPDES and general permit for yet another segment, complicates and confuses those who must comply. In review of the 2007, 2015 and draft General Biosolids Permit, there is no clear reference or definition in any version that describes the difference between the regulated segment(s) and how applicable discharge permits must be managed. The above example regarding Emerald Kalama and Fire Mountain Farms is also a good example of this problem. FMF is now covered by the General Biosolids Permit. Emerald is covered by NPDES Permit WA0000281. It is unclear whether FMF was covered by any type of permit when they entered the agreement back in 1996. The question that we ask is, "were there missing elements of the General	I-105-3 Ecology agrees that some means of creating a better connection between permitting programs would benefit biosolids management. We have not prohibited the acceptance or land application of other types of sludges (or fertilizers or manures) at biosolids land application sites. Our permit process does require that all other nutrient inputs be identified and considered when determining agronomic rates. Ecology will need to do more investigation to determine the best approach. Concerning the commenter's remarks about Fire Mountain Farms' permit coverage over the years, the first general permit for biosolids management was not issued until 1998. Ecology did not have the lead for permitting biosolids land application in 1996 or before. At that time, the responsibility rested with the local jurisdictional health authority.

Comment	Response
Biosolids Permit that would have made a difference or that would have prohibited Emerald or FMF from making and implementing their arrangement?" The answer that we came to is that "it is not clear" from reading both permits or by review of related Agreed Orders and/or Federal Registers and delisting documents. Recommendation: We suggest that clarifying language and/or a flow chart should be added to the General Biosolids Permit that will clearly show what each regulated segment must do and not do in order to meet all conditions of the applicable permits to which they must comply. Better yet would be to combine the General Biosolids Permit requirements into the NPDES program so that a subject facility has regulatory conditions outlined in one permit document. An improved permitting framework would greatly benefit and assist the regulated community in meeting State biosolids management program requirements.	Finally, the commenter suggests combining biosolids requirements in facility NPDES permits. That is in fact an allowable approach under federal rules. Ecology gave that approach serious attention in the 1990s as it developed the biosolids program. At the time, local jurisdictional health departments still had an overall significant interest in being involved in biosolids management under the new state program. That was possible due to the close working relationship between Ecology and those agencies in the implementation of permitting under previously applicable solid waste rules. It would not have been possible to maintain that relationship had we moved the permitting elements into the NPDES system. Our WQ staff were not at the time, nor are they now, adequately prepared to implement biosolids permit requirements under their NPDES permits. Lastly, while the idea of a consolidated permit does have its appeal, we are not convinced it would improve permittee comprehension or implementation of biosolids program rules. The treatment processes for biosolids are very well integrated in basic operations. The knowledge required and operational issues for biosolids management at land application sites really emerge as a separate skill set.
I-105-4 The Permit references a "biosolids management program" in numerous locations in the document but does not define what a biosolids management program is or what the specific requirements of the program are. In the Ecology document, Biosolids Management Guidelines for Washington State, it explains that the permit application "is a comprehensive description of the applicant's biosolids management program [Program],	I-105-4 We would like to clarify some terminology that will help to address the commenter's concerns. The word "program" is used in the context of biosolids management in a relatively generic form. Ecology's biosolids program refers overall to the management of biosolids across Washington state, including administrative processes, technical attributes, and activities carried out by Ecology staff and permitees as well as their facilities. We implement state rules with a general

Comment	Response
and includes biosolids production and quality data, site monitoring data, maps, a listing of other environmental permits, names of contractors applying biosolids, and detailed land application plans." The guidance document is 235 pages long and not well publicized, leading me to believe that it is not likely that many sites that are subject to the Permit have reviewed it and thoroughly understand what they must do in order to comply with all aspects of the Program. There is no provision in the Permit for sites to have a Biosolids Management Plan [Plan] to meet the Ecology's Program. And the permit application format is not conducive to laying out the site's Plan or for tracking compliance. Without a Plan to work from, it is more likely for sites, once their permit application is approved, to not consider the Program until it was time to submit their next annual report. Without a Plan, many sites might miss related notifications that must be made when biosolids management practices change or new dischargers are added. Recommendation: The Permit should include a requirement for subject facilities to have an approved Biosolids Management Plan to meet the requirements of the Ecology biosolid management program. It is another added provision that would help with the issue of facilities that are subject to the Permit from accepting prohibited discharges or from using prohibited biosolids.	permit that is designed to meet, and often times exceeds federal requirements. The commenter remarks about Ecology's Biosolids Management Guidelines[60] saying that they are not well-publicized, and at 235 pages unlikely to be understood by users. These guidelines were first published in 1993, and then later updated. They were widely circulated in Washington and even nationally. Ecology has always referenced them in our general permits (this being the fifth), and they are posted on our website. Our Biosolids Management Guidelines[60] are as much for staff as they are for the regulated community or public. The guidance document is broad in its potential applicability, and there is no expectation that treatment plant staff would need to have complete knowledge. Staff are informed by the guidelines, as well as other sources, and use that knowledge to review, revise, and approve applicant proposals. Ecology's permit process generally steers applicants along the correct pathways so that regulated parties are not required to have an in-depth knowledge of our guidance. Once an application for coverage is approved, there is a reasonable expectation that facility operators understand and will be able to comply with applicable requirements. Individual sites, where non-Exceptional Quality biosolids are applied to the land, are required to have Ecology approved land application plans. Ecology biosolids staff considered separate biosolids management plans for generating facilities. Staff did not support that change because all of the applicable information is already being supplied in a permit application. Permit applications are prepared in a manner that is helpful for staff review. Components include a boilerplate application form, a basic schematic for the facility, a general land application plan if

Comment	Response
	required, a site-specific land application plan if applicable, a transportation plan, a sampling and analysis plan and various other documents. Each of the plan elements contains supplements depending on the nature of a facility's operations. From these documents, Ecology staff can determine how biosolids are produced, used, and treated. Ultimately, staff did not see value in having a plan that would essentially identify permit and operational elements that are already required to be assembled as part of the permit process.
I-118-4 I attended the June 4, 2021, ZOOM Public Hearing for the General Permit which started off detailing how this new General Permit would improve communications between Ecology and the permittees. In reviewing this timeline concerning possible impacts of biosolids, I would ask that Ecology look to improve communications with citizens. The ongoing obfuscation and dismissive tone that Ecology staff uses is very effective in discouraging concerned citizens from participating, making others angry and yielding distrust on everything that Ecology says on this issue. Ecology staff has stated that if Biorecycling was not in business in Mason County there would be more groundwater pollution as septic pumpers would off load septage in the woods and septic pumping costs would increase and households would not pump their septic systems when appropriate regardless of the fact that septage from septic tanks is under the jurisdiction of local health jurisdictions. Ecology needs to be more transparent in its communications on risk assessment, scientific uncertainty, emerging new science, and possible technical	I-118-4 Ecology does not intend to obfuscate or be dismissive. We value an open and transparent process, and would welcome improvements to communications. We hope the commenter will agree that good communication between Ecology and regulated facilities improves prospects for compliance. We have developed a new tool for interested parties, to Register for Updates[25] to be notified of permit events. Registrants can choose to be notified of statewide activities, or just for specific counties. For example, an interested party in Mason County could register to be informed about events happening in both Mason County and Thurston County, or they can choose the entire state. We chose the approach by county over registering by facility because it will not always be clear to residents whether facilities land apply materials in the same county they reside, or send them elsewhere for land application, which is typically the primary concern. We created this new system in the hopes it would provide a user friendly, accessible way to improve communications between Ecology and the public. We have advertised this new tool via emails, at our public meetings, and on our website.

Comment	Response
solutions. Ecology needs to be more forward and holistic and look at the human waste stream and its impacts on all species, orcas, humans, birds, the food chain.... (When Mason County submitted its most recent solid waste plan update adding a section for Human Waste, Ecology responded that it was not necessary.) A working advisory committee including scientists, tribes, federal, state and local agencies and elected officials, septic system providers and pumpers, operators of wastewater treatment plants and sewage/septage land application and biosolids, agriculture and aquaculture growers, legislators, Washington attorneys general, citizens in the watershed and look at the whole of the human waste stream. A review of the existing knowledge is essential to understand the impacts of biosolids on communities and the environment. A full EIS for the general permit would inform the statewide the human waste committee planning.	The commenter notes that a section on human waste was not required in the county's most recent update of its solid waste management plan. Biosolids are by law not a solid waste, so they were removed from consideration under state and local solid waste planning efforts. The commenter says that a review of the existing knowledge is essential to understand the impacts of biosolids on communities and the environment. The commenter wishes for Ecology to take a more holistic approach and assemble a working advisory committee. The federal government, states, regulated entities, universities - worldwide, in fact, have been convening and discussing biosolids management for decades, and likely will continue for many years into the future.
I-122-1 I am concerned about Dept. of Ecol. stand on sewage sludge, and the use of sludge. The topic of sewage sludge needs a realistic and honest and open debate of how to really clean it up. I hope this can be done, so that sludge can be utilized in a way that is healthy for everyone and every place. There are people studying and having good outcomes cleaning sludge up, with algae and maybe even fungi, or maybe even for methane use, but in a way that's health for all. I realize these methods may seem more costly, but what about the cost of all our health from careless use of sludge.	I-122-1 Ecology supports removing contaminants from the environment, and that includes working to make biosolids an even better resource. While it may be possible to do this by updating wastewater treatment technologies for particular contaminants, it is not possible for all. The costs of updating treatment technologies becomes expensive and are eventually passed on to customers through their sewer and water bills. So Ecology biosolids staff often advocate for eliminating contaminants at the source, to keep them from entering the waste stream in the first place. One way to do that is to stop using things that harm the environment. If there are other ways, they should be considered and

Comment	Response
We need an honest and open approach to deal with sludge, please.	implemented if feasible. Ecology believes it has engaged in an open process with this draft general permit. We have done so in the past and we expect to do so in the future. Please see our response to comment I-118-4 for one possible approach.
I-124-2 This comment was submitted verbally during the June 24th Public Hearing. And I also say that as a statewide permit here, we need to be looking at this across the state. We need to be applying, land applying biosolids, in my opinion, in areas that have less rainfall than 42 inches of rain a year. So therefore I'd say we should not be putting biosolids on that Newaukum prairie site at least, until, we shouldn't be putting it on after September 1 of each year, because the growing season's over with.	I-124-2 Please see the response to comment B-1-1, where we address number 9. For more information about land application timeframe allowances.
LG-1-4 4) Section 1.2 Structure of this General Permit There are several areas within the permit that describe which sections (Baseline, Active Septage, and/or Active Biosolids) apply to a facility. It may be helpful to have a flowchart similar to the one provided in Section 2.1 to simplify how a facility can determine which sections are applicable… …9) 2.3. Maintaining Contact Information "All facilities must provide and update as necessary the name, title, physical address, mailing address, and a valid, actively monitored email address for the following contacts." Clarify who updated contact information should be sent to. Assuming the Biosolids Coordinator.	LG-1-4 Ecology added a flow chart to 1.2 of the permit to help facilities determine which sections of the permit are applicable. Ecology added language in 2.3 of the permit directing readers to the regional biosolids coordinator.

Comment	Response
LG-2-1 LOTT Clean Water Alliance is a wastewater utility located in Olympia, Washington, with an active biosolids management program. LOTT finds that the draft biosolids permit is fair and reasonable. We appreciate the re-organization of the permit, as it makes the guidelines and regulations more clear	LG-2-1 Ecology believes the new approach will both create a cleaner distinction between biosolids and septage respective regulatory obligations, and reduce the burden on baseline only facilities. In turn, this will allow Ecology to focus on facilities that are most in need of agency oversight and resources. We hope it will also improve public confidence in the program overall.
LG-3-1 Thank you for the opportunity to comment on the Washington State Department of Ecology's (Ecology) draft General Permit for Biosolids Management (general permit). We appreciate your work to streamline requirements and reduce regulatory burden for some facilities in our state. King County's Wastewater Treatment Division (WTD) serves about 1.8 million people within a 424 square mile service area. In 2020, our three regional treatment plants and two smaller treatment plants together produced 117,092 wet tons of biosolids that were land applied to forests and farms in Washington as a beneficial soil amendment. As one of the largest wastewater treatment utilities in the state, changes to the general permit have potential to significantly impact our 1.8 million wastewater ratepayers and the agriculture and forestry customers that beneficially use 100 percent of WTD's biosolids. We offer comments on four areas: 1) changes to permit structure; 2) requirements for sampling, analysis, and process monitoring; 3) second-generation biosolids products definition; and 4) biosolids and environmental justice.	LG-3-1 Ecology believes the new approach will both create a cleaner distinction between biosolids and septage respective regulatory obligations, and reduce the burden on baseline only facilities. In turn, this will allow Ecology to focus on facilities that are most in need of agency oversight and resources. We hope it will also improve public confidence in the program overall. We point out that beyond the two smaller communities identified by the commenter, the new approach will similarly benefit about half the facilities in the state.

Comment	Response
Changes to Permit Structure [King County] WTD supports Ecology's changes to the structure of this general permit, and specifically separating out "Baseline" category facilities to streamline and reduce the reporting requirements for these facilities. WTD agrees with Ecology that this will reduce the administrative burden for some facilities to apply for coverage under the general permit without compromising any environmental protection. WTD also appreciates the benefit of the resulting reduced administrative burden to Ecology, which should speed the process of granting approval and allow ECY to focus on the permit reviews that need the most attention. Under this proposal, WTD's Carnation and Vashon are now recategorized as "Baseline" facilities. WTD supports this changed designation. Both facilities send their biosolids to WTD's South Treatment Plant for further treatment, meeting the requirement for Baseline classification. Clearly, South Treatment Plant's categorization as an "Active Management Facility" allows for ample regulation and reporting of those biosolids under the general permit. This change is practical without compromising any of the rigor of the permit process.	

Comment	Response
LG-4-2 We appreciate Ecology's reorganization of the permit. Creating a baseline section that applies to all permittees and a specialized section that apply to active septage management and to active biosolids management makes the permit easier to follow. This approach more accurately conveys the difference between septage management and biosolids management to permittees and to the public. We also commend Ecology on the "Automatic Coverage for Some Facilities" provision in Section 2.1.2. This will reduce the burden on small facilities (including or North End Treatment Plant #3) that are not actively managing biosolids without compromising the environmental and health protection this permit provides.	LG-4-2 Ecology believes the new approach will both create a cleaner distinction between biosolids and septage respective regulatory obligations, and reduce the burden on baseline only facilities. In turn, this will allow Ecology to focus on facilities that are most in need of agency oversight and resources. We hope it will also improve public confidence in the program overall.
LG-5-1 The Discovery Clean Water Alliance (Alliance) is providing written comment for the Statewide General Permit for Biosolids Management published by the Washington State Department of Ecology (Ecology) on May 5, 2021. The Alliance is a regional wastewater transmission and treatment utility serving the central portions of Clark County, WA. The Alliance partner agencies collectively represent approximately 123,000 residents, and the Alliance owns and operates the largest wastewater treatment facility in Southwest Washington with a biosolids land application program, the Salmon Creek Wastewater Treatment Plant (NPDES Permit No. WA0023639). The Alliance strives to safeguard the health of both the community and the natural environment, while at the same time fostering a prosperous economy.	LG-5-1 Ecology recognizes the Discovery Clean Water Alliance's contributions to wastewater treatment. Ecology believes the new approach will both create a cleaner distinction between biosolids and septage respective regulatory obligations, and reduce the burden on baseline only facilities. In turn, this will allow Ecology to focus on facilities that are most in need of agency oversight and resources.

Comment	Response
The Statewide General Permit for Biosolids Management is an important Ecology responsibility, and we thank Ecology for its efforts for your continual improvement of these regulations. After review of the recently published permit and coordination with the Northwest Biosolids group, the Alliance is providing the following comments for consideration. The Alliance strongly supports continual improvement of regulations such as these. It is critical that regulations keep pace with technology and science-based research to ensure that agencies can continue to implement their biosolids programs in a responsible and efficient manner. Ecology's development of the permit appears to be well-organized and straightforward for staff to navigate. The separation of sections that apply to all permittees (a baseline section) and then a specialized section for active septage management and for active biosolids management is helpful. This new approach provides clear direction to staff managing these programs how to meet the requirements and compliance standards. Alliance strongly supports the "Automatic Coverage for Some Facilities" provision (Section 2.1_2). Ecology's approach here addresses the potential compliance burden(s) on many small facilities while also retaining a high degree of public health and environmental protection requirements that should be expected from the applicable permittees. … We appreciate the opportunity to comment on the recently published permit. We further acknowledge the work of Ecology staff in updating this important permit which allows	

Comment	Response
the Alliance to continue its biosolids program in an environmentally responsible and cost-effective manner.	
LG-6-1 The City of Vancouver appreciates the opportunity to provide comments regarding the draft Statewide General Permit for Biosolids Management. Furthermore, the City commends Ecology's Biosolids Management staff for incorporating updates and changes to the previous permit into this draft permit, which result in pragmatic and workable program elements for facilities and entities who manage sewage sludge and biosolids. The City of Vancouver operates a sewage sludge incinerator and the Vancouver Westside WWTF is named in Section 2.6.1 Incineration and thereby authorized to continue incinerating biosolids generated at the facility, and to accept biosolids for incineration from other facilities who meet certain requirements in Section 2.6.3 of the permit… …During the past 5 years the City of Vancouver has received sewage sludge or biosolids from other wastewater treatment facilities on a temporary basis, with review and written authorization from Ecology's regional biosolids coordinator. This activity reflected the requirements in Section 2.6.3 of the permit and appears to work well for the involved parties. These procedures were delineated in a Notice of Final Coverage Under the General Permit for Permit No. BA0024350, issued by Ecology in a letter to the City dated July 17, 2018. The City also recognizes and appreciates the requirements listed in Section 2.4.2 Accepting Biosolids from Federal, Tribal, or Out of State	LG-6-1 Ecology believes the new approach will both create a cleaner distinction between biosolids and septage respective regulatory obligations, and reduce the burden on baseline only facilities. In turn, this will allow Ecology to focus on facilities that are most in need of agency oversight and resources. We hope it will also improve public confidence in the program overall. We also recognize the importance of enabling facilities to support the needs of other communities from time-to-time. Ecology addressed out of jurisdiction facilities to ensure equal treatment of all facilities that are subject to the state program. Biosolids - or sewage sludge - does enter Washington from areas outside our jurisdiction. We expect generators to conform to state program requirements. Our intent is to ensure agency notification so that we can assess the situation consistent with state program expectations for compliance with rules, permit requirements, and fees consistent with other facilities that operate within our jurisdiction.

Comment	Response
Facilities. While the City doesn't seek or particularly prefer to receive sewage sludge or biosolids from other treatment works, we recognize emergency or temporary needs to receive authorization for disposal at Vancouver's incineration system if such materials are compatible. Again, we appreciate the diligent and pragmatic effort to help make treatment works' biosolids programs successful across the state of Washington.	
LG-7-1 The Three Rivers Regional Wastewater Authority appreciates the opportunity to comment on the Department of Ecology's (Ecology) Statewide General Permit For Biosolids Management. The 'Three Rivers Regional Wastewater Authority is a municipal corporation, which operates a wastewater treatment plant and processes septage and biosolids from other facilities in our region. We are also a member of Northwest Biosolids, which is a regional non-profit organization representing close to 140 members, including public wastewater utilities and private companies across British Columbia, Alberta, Alaska, Idaho, Oregon, and Washington. The Three Rivers Regional Wastewater Authority appreciates Ecology’s reorganization of the permit. Creating a baseline section that applies to all permittees and specialized sections that apply to active septage management and to active biosolids management makes the permit easier to follow. The approach more accurately conveys the difference between septage management and biosolids management to permittees and to the public. The Three Rivers Regional Wastewater	LG-7-1 Ecology believes the new approach will both create a cleaner distinction between biosolids and septage respective regulatory obligations, and reduce the burden on baseline only facilities. In turn, this will allow Ecology to focus on facilities that are most in need of agency oversight and resources. We hope it will also improve public confidence in the program overall.

Comment	Response
Authority also commends Ecology on the "Automatic Coverage for Some Facilities" provision in 2.12. This will reduce the burden on small facilities that are not actively managing biosolids without compromising the environmental and health protection this permit provides. We strongly support and advocate for continual improvement of regulations such as the General Permit. As time passes, it is critical that regulations keep pace with technology and science-backed research. The Three Rivers Regional Wastewater Authority finds Ecology's development of the permit to be very organized and user-friendly. The separation of sections that apply to all permittees (a baseline section) and then a section for active septage management and for active biosolids management allows users an easy format to follow, understand, and comply with. Ecology's new approach conveys to both the public and permittees the clear difference between septage and biosolids management requirements and compliance standards. The Three Rivers Regional Wastewater Authority commends Ecology's for the "Automatic Coverage for Some Facilities" provision (section 2.1.2). Ecology has taken a very prudent approach in understanding the potential compliance burden(s) on many small facilities. This provision also maintains a high degree of public health and environmental protection requirements that should be expected from the applicable permittees. …The Three Rivers Regional Wastewater Authority believes that by providing clarity and focus in this permit, th wastewater and private sectors will be able to more readily	

Comment	Response
implement the necessary compliance programs to ensure a healthy and strong environment for our state citizens. Your willingness to take on this effort is commendable and very much appreciated.	
LG-7-4 The following are specific comments on Sections of the permit, and questions and suggestions are red. 1.2.3. Active Biosolids Management Section Section (4) of this permit applies to facilities with active biosolids management programs, but not those than that manage only septage (1.2.2 above). 2.1. Understanding and Complying with the Permit System Figure 1 – This flow chart outlines the application process. Existing Baseline facilities without active programs are automatically covered on the effective date of the general permit. To confirm your coverage, consult the Facility List provided by Ecology 4.4.4. Frequency of Biosolids Analysis The dry weight tonnage of biosolids applied to the land or prepared for sale/give away per	LG-7-4 We appreciate several editorial corrections offered by Three Rivers Regional Wastewater Authority and made revisions as appropriate.

Comment	Response
365-day period determines the minimum frequency of biosolids analysis (Table B1 below). Table B1 should explicitly say in the table that the tonnage units are dry tons.	
O-2-7 Section 3.8.3 allows Ecology to create exceptions to the rule. This gives Ecology the power to make special deals with no citizen oversight. Strongly suggest removing this exception.	O-2-7 Please see the response to comment O-2-10.
O-2-10, O-7-57 Ecology Discretions There are sections in the permit that give Ecology the discretion to rewrite and go against the permit, apparently whenever the agency wishes. Page 1, Line 17: *Unless modified by this permit or an approval of coverage under this permit, the rules in Chapter 173-308 WAC are applicable.* Page 22, Line 20: *On a case-by-case basis, Ecology may impose requirements that are in addition to or more stringent than the requirements in this permit.* Page 31, Sections 3.8.3 and 4.5.9.3 qualify the requirements in the tables * *Unless a different buffer is approved or required by Ecology* ** Unless approved by Ecology. This gives Ecology permission to approve unusual buffers, to approve application of septage on wetlands, public contact sites or frozen or snow covered ground. Page 35 Line 22: *For facilities with surface impoundments characterizing biosolids under section 2.5.1, the number of samples is determined based on the estimated quantity*	O-2-10 Certain provisions of the permit allow for agency discretion, but this does not happen without opportunity for citizen input. Aside from the general permit process involving stakeholder and public input, an opportunity for public comment is required for permit applications and new land application plans or when proposing to modify an existing plan. The agency cannot decide to make changes to a facility's permit requirements whenever we want. Changes require a defensible rationale and an appropriate notification with opportunity for public involvement. Furthermore, a permit requirement cannot reduce obligations established by program rules. An example would be the requirement for a site-specific land application plan. Ecology could not approve land application without a site-specific land application plan where the rule requires it. An example of a requirement with flexibility built into the rule would be the frequency of pollutant analysis for metals, which can be reduced after two years of monitoring (but to not less than annually). In the case of buffers to surface water - a subject of concern to the commenter, the rule establishes a minimum buffer of ten meters. Guidelines,

Comment	Response
of solids in the impoundment at the time of sampling, or as otherwise approved by Ecology. Page 39, Table B3: Ecology can approve a modified waiting period. Page 39, Section 4.5.9.2: *Public access must be restricted following the application of Class B biosolids. Minimally, you must maintain posted informational signs during the time site access is restricted, in accordance with the requirements in Table B4. Exceptions to these requirements must be approved in writing by Ecology*.	however, contemplate that ten meters may not be adequately protective, so the permit gives fair warning that the requirement in the rule may be modified. At the same time, federal biosolids rules are authorized by the Clean Water Act, a law that literally authorizes the discharge of pollutants to surface water. That is why the rules are written as they are. With respect to the commenter's reference to septage site restrictions in section 3.8.3, we received other similar comments. After reviewing applicable rules, we agree with the commenter's argument here. We adjusted the permit language by removing the asterisks that denoted Ecology's ability to make changes, after "public contact sites, lawns, or gardens", and "flooded, frozen, or snow-covered sites". We agree that land application of septage is not allowed in those situations - nor has it ever been authorized. In response to the commenter's remarks on section 2.5.2, Ecology can specify a number of samples in a lagoon that is not directly related to the quantity of biosolids to be removed. This stipulation is included so that we have leverage to require additional sampling than the minimum required by rule. This would commonly be done in a preliminary sampling event. Ecology continues to permit biosolids using a general permit because of the flexibility it allows for considering characteristics specific to each facility and land application site, in addition to establishing rules applicable to all facilities. The provision on page 22, line 20, which the commenter references, allows Ecology the latitude to impose additional or more stringent requirements through the permit. If we conceded that point, then there would be no site-specific criteria for any site. In conclusion, staff make decisions based on a

Comment	Response
	range of technical considerations, all of which are subject to public review.

Comment	Response
O-2-19, O-7-60 Page 6, Figure 1, Fifth Step says: *Existing facilities with active programs must submit a complete permit application within 90 days of permit issuance* This cannot be correct. Ecology should not issue a permit before the permit application is submitted.	O-2-19 The commenter expressed concern that a permit could be issued before a facility applies for coverage. While it is counterintuitive, it is correct that applications are taken after the issuance of the permit. We included Figure 2 in section 2.1 of the permit to illustrate the cyclical nature of the permitting process. We explain the permitting process in more detail below. The process of being covered under the general permit for biosolids management is a loop that begins with a Notice of Intent (NOI). The NOI is filed with Ecology by existing facilities before the permit is reissued, and is a declaration to come under and comply with the terms and conditions of the general permit. Ecology collected NOIs from all existing facilities prior to drafting the general permit as explained in the Fact Sheet provided for the draft permit. For baseline facilities without an active biosolids management program, the NOI is all that is required unless they want to develop an active program. If they want to modify their coverage to include an active biosolids management program at a future time, a permit application is required. Facilities with active programs are required to comply with state rules and overarching conditions of the permit, regardless of the status of their application or review process. Proposals for new land application sites cannot move forward without notice and a compliance review. New facilities must submit an application for coverage 180 days in advance of operating.

Comment	Response
O-3-2 Northwest Biosolids appreciates Ecology's reorganization of the permit. Creating a baseline section that applies to all permittees and specialized sections that apply to active septage management and to active biosolids management makes the permit easier to follow. This approach more accurately conveys the difference between septage management and biosolids management to permittees and to the public Northwest Biosolids also commends Ecology on the "Automatic Coverage for Some Facilities" provision in section 2.1.2. This will reduce the burden on small facilities that are not actively managing biosolids without compromising the environmental and health protection this permit provides. Northwest Biosolids finds Ecology's development of the permit to be very organized and user-friendly. The separation of sections that apply to all permittees (a baseline section) and then a specialized section for active septage management and for active biosolids management allows users an easy format to follow, understand, and comply with. Ecology's new approach conveys to both the public and permittees the clear difference between septage and biosolids management requirements and compliance standards. Ecology has taken a very prudent approach in understanding the potential compliance burden(s) on many small facilities. This provision also maintains a high degree of public health and environmental protection requirements that should be expected from the applicable permittees.	O-3-2 Ecology believes the new approach will both create a cleaner distinction between biosolids and septage respective regulatory obligations, and reduce the burden on baseline only facilities. In turn, this will allow Ecology to focus on facilities that are most in need of agency oversight and resources. We hope it will also improve public confidence in the program overall.

Comment	Response
O-6-1 Page 33, Section 4.2.3 Identification and Notice to Interested Parties, Second Bullet: This portion of the definition of an interested party is very vague for local governments who have weekly or bimonthly public meetings on a wide range of topics. To avoid having to add every person who attends a City Council meeting and/or makes a public comment to the biosolids interested parties list, the following revision is recommended for the second bullet. They attend a public meeting or hearing, and indicate either verbally on the record or in writing that they would like to be added to the interested parties list for biosolids. Thank you for consideration of this comment.	O-6-1 After consultation with legal counsel, Ecology determined that an interested person should be identified as such if they attend a public meeting or hearing offered by the state biosolids program, so long as they provide a mailing or email address. It is not necessary for a person to explicitly state their interest since they have demonstrated their interest by their attendance. However, persons who attend meetings hosted or held by an authority other than Ecology are not considered interested parties for the purposes of the state biosolids program. That being noted, any person can Register for Updates[25] as an interested party using Ecology's new online service.
O-7-2 Ecology must write permits which protect the natural environment and human health. The Washington State Chapter of the Sierra Club strongly suggests that the Department of Ecology (Ecology) prepare a Draft Biosolids Permit Plan which consolidates the work of staff working on the various elements relevant to the permit. This would include staff working independently on sewage, nutrients, PFAS, CAFOs, and CECs. Whether all these parts currently have guidance or regulations should not hinder this collaboration since these are all being reviewed by the agency and will eventually have Ecology positions. It is important to set recipients of permits on the right path now. We see many parallels between the Draft Statewide General Permit on Biosolids with that of the June 29, 2021 Washington State Appellate Court CAFO decision. To wit, this	O-7-2 Ecology notes this recommendation of collaborative work. The commenter is correct, that issues of concern to biosolids do cut across agency programs and authorities. Staff communicate across programs on a regular basis. That is evidenced in part by their participation in the development of Chemical Action Plans that address the responsibilities of each program/authority. We will try to do a better job of showing cross-program collaboration

Comment	Response
decision makes clear the need for site specific nitrate plans; for permit conditions pertaining to existing manure lagoons, compost areas, and high-risk fields; for stronger groundwater monitoring; for a requirement that farmers monitor water quality; an acknowledgement of climate change impacts; and for individual site pollution-prevention plans. The Appellate Court judges opined that current (CAFO) permits violated state and federal laws by failing to control the discharge of excess nutrients, bacteria and other pollutants, and that permits should include enforceable limits set at levels appropriate to protect public health.	
O-7-7 As well, the Washington State Department of Health (DOH) should be, by regulation, more engaged in this permitting process that affects our water and our health. Regarding the current Draft Biosolids General Permit, we find many areas insufficient. As well, regulations on the reuse of sewage solids as a "*beneficial use*" are old, and the referenced Best Management Practices do not equate to science-based data on which practices should be grounded.	O-7-7 Ecology is the lead agency for regulating and permitting biosolids management facilities, per state statute. We work cooperatively with the State Department of Health (as evidenced by the PFAS Chemical Action Plan[35]) on a range of topics when appropriate. Ecology will consider DOH's request to participate more closely in the next permit cycle. We will also consider working with them on a reassessment of buffers under the state biosolids program. The rules in Chapter 173-308 WAC[24] that support the state biosolids program were last updated in 2007. The age of a regulation is irrelevant if it serves its purpose. It would certainly be appropriate to update state rules if EPA establishes a standard for PFAS or another contaminant in biosolids. Please see the response to comment I-55-8 for additional information. The commenter did not identify any particular aspect of Ecology's biosolids management guidelines[60] that could be improved. The content of the guidelines is largely based on science. Be that as it may, they are still guidelines, not

Comment	Response
	regulations. Ecology uses the guidelines as a tool to help develop permit conditions. Please see the response to comment I-9-4 for additional information.
O-7-11 We strongly recommend the following regarding the Draft General Statewide Permit: Individual permits should be required, rather than general permits… …Another method to ensure oversight is to require individual permits, rather than general permits……It is Sierra Club's position that individual, not general, permits should be developed. The Revised Code of Washington (RCW) 70A.226.005* establishing municipal sewage sludge as a beneficial commodity was written in 1992. *1992 c 174¬ß1. Formerly RCW 70.95J.005 *(1)(e) of the RCW states: Municipal sewage sludge can contain metals and microorganisms that, under certain circumstances, may pose a risk to public health.* University and government studies over the following 30 years establishes that it does pose a risk to public health. "Beneficial Use" ignores the thousands of toxins, hazardous wastes, and dormant pathogens able to reestablish. What is Ecology's justification for not requiring individual permits? Individual permits would result in more oversight by both Ecology and the public… …Current oversight and enforcement is lax. We continue to urge Ecology to permit each site individually. This will require better oversight and enforcement. It will allow public access to site specific documents and allow for informed public comments. It will inform	O-7-11 The commenter argues that individual permits should be developed because they would provide more oversight and public involvement. The commenter ties the argument for individual permits to the age of the enabling statute, apparently arguing that the preference for beneficial use has been eclipsed by newer government and university studies showing that biosolids pose a risk to public health due to the presence of thousands of unregulated hazardous wastes and pathogens that can reestablish themselves. Ecology does not believe individual permits are necessary to implement a biosolids management program that emphasizes beneficial use and remains protective of public health and the environment. The general permit process we use allows for the addition of more stringent requirements that can address individual site conditions, and offers a robust opportunity for public involvement. Further, the general permit itself can be modified to add overarching criteria for all facilities. If we do need to develop overarching criteria based on new information, that revision of the rules in Chapter 173-308[24] would likely be the best approach. Issuing individual permits would primarily add an administrative burden to the process, and would not alter what can otherwise be accomplished under the general permit system. In other words, it would make things slower and more costly, but not better. Neither Ecology nor the general permit process ignores any pollutant. We would not, for example, have a standard for PFAS now if we

Comment	Response
communities when and where sewage wastes are entering their communities.	were issuing individual permits. The mere presence of a substance does not define the risk or need for regulation. The question is whether there is evidence that a substance rises to a level of concern that warrants further investigation, and beyond that, whether a regulatory limit of some kind is necessary to mitigate an unacceptable level of risk. Ecology also prepared a separate discussion titled: "General vs individual permits and expediting coverage" that readers can find in the key topics section at the front of this response to comments. Ecology is aware of studies that raise questions or reach different conclusions about the merits of biosolids beneficial use. However, we are also aware of the many, many studies by universities and government agencies that continue to support the use of biosolids for its benefits to soils, crops, wildlife, and climate change. In our experience, the bulk of research and practical experience continue to support that the beneficial use of biosolids is the best approach.
O-7-15 1.1.5 Local Health Jurisdiction Involvement. How often do you authorize a local jurisdictional health authority to assist in implementation and administration of permits?	O-7-15 Presently there are two agreements in place with local health jurisdictions, statewide. Biosolids were previously identified as a solid waste under federal and state laws. Local health jurisdictions had the lead for permitting, and Ecology provided only technical support at that time. The State Legislature removed biosolids from the definition of solid waste in 1992 and the federal government followed suit in 1993. It took until 1998 for Ecology to fully implement a program under state rules. In the meantime, many local health departments remained interested in partnering with Ecology under delegation agreements. Over time, local health jurisdictions recognized that funding from the state was minimal for biosolids permitting. The subject matter itself is complex

Comment	Response
	and requires more effort than is practical for local staff to remain informed. Over time, other local obligations gradually replaced biosolids. Regardless of delegation agreements, Ecology accepts comments and inquiries from local health jurisdictions at any time. We also reach out on occasion to ask for assistance in evaluating a complaint.
O-7-17 1.2.3 Active Biosolids Management Section: *You are subject to the Active Biosolids Management Section (4) of this permit if: Bullet 5: You treat a mixture of biosolids and septage to meet Class A or B pathogen reduction.* Please verify that the listed facilities are correctly listed as Active or as Baseline.	O-7-17 Ecology put significant effort into a review of facilities for this purpose prior to issuing the draft permit. Following the release of the draft permit, Ecology made multiple revisions based on input from a facility. If a facility is improperly characterized it will not relieve them of any particular responsibility under state rules or the permit. It may obligate them to more public processes than they might otherwise have been obligated to, and may delay related projects and approvals.
O-7-18 Bullet7: WAC 173-308-310(1)(a) exempts active biosolids management facilities from permitting non-exceptional quality biosolids, for further treatment. Is this correct? Rationale? The language is confusing.	O-7-18 WAC 173-308-310(1)(a)[62] provides an exemption to permitting under the state biosolids program for composting facilities that use biosolids as a feedstock if certain conditions are met. The exemption is in place because compost facilities using biosolids as a feedstock may also be accepting certain solid wastes as a feedstock. When that is the case, a local solid waste permit is required. The point of the exemption is simply to avoid a redundant permit process that might result in conflicting requirements. The exemption can be allowed if the local permit addresses all the requirements that would otherwise be in place for the facility under the biosolids rules. If that were not the case, Ecology staff would still require permitting under the biosolids program. Ecology staff review solid waste permits issued by

Comment	Response
	local health jurisdictions, which provides assurance that state biosolids program requirements are met before an exception is allowed.
O-7-20 2.12. Duty to Mitigate: This short section is good, but rarely followed. How will this change?	O-7-20 This particular element is not new and is a boilerplate for NPDES permits in general. It was incorporated into the state biosolids permit program, which is designed to reflect typical requirements from the federal NPDES program. This requirement pertains to established requirements under the permit or state rules and is not speculative in nature. It is a sort of general handle for enforcement purposes, say for example where an operator knows something is malfunctioning, or about to malfunction, or that a process is being circumvented, but it is ignored and then an instance of non-compliance occurs. The operator's efforts or lack of efforts to avoid noncompliance will factor into enforcement decisions.

Comment	Response
O-7-21 2.1.8.1 [Notifying] Interested Parties. How will Ecology ensure this? In the past, interested parties were not notified. We want to see an expansion of the notification process so that the signage is readable from a distance, is placed in several public access points, including for walkers, and is more broadly advertised beyond posting signs. Notification should include newspaper legals and advertisements. For facilities located near rivers and streams that support anadromous fisheries, the permits should be published in tribal newspapers. For facilities located in ethnic communities, public hearings should be advertised in languages used by significant population subgroups. Consider radio and television advertising in lieu of print media. Explain what is in biosolids.	O-7-21 Ecology is not aware of interested parties not being notified. While there is always a possibility for notice to be diverted to a spam folder or lost in the mail, both Ecology and the facilities maintain interested parties lists for the program overall and individual sites respectively. To make becoming an interested party easier, Ecology created an online service where anyone can Register for Updates[25] to be notified of biosolids activities in any county, or even statewide. Please see also our response to comment O-2-11.
O-7-22 2.1.9 Public Hearings. Public hearings should be required. Otherwise, Ecology will not be able to gauge the level of public interest, especially in communities new to land spreading.	O-7-22 Notice of a permit is the same as required for notice of a public hearing. The commenter argues that without hearings, Ecology cannot judge the interest of individuals. If potentially interested parties either do not note or do not respond to an invitation to request a hearing, Ecology cannot expect that they would be any more attentive to a similarly placed notice announcing a hearing. There is a point at which individuals must step forward and make their interests known. Ecology believes the public notice process is appropriate, and has implemented a new registration system to make becoming an interested party easier. Ecology has created an online service where anyone can Register for Updates[25] to be notified of biosolids activities in any county, or even statewide. Ecology can anticipate the likelihood of significant

Comment	Response
	interest and require a hearing ahead of time. Not all permit actions involve land application, not all land application activities are new, and not all beneficial use programs have any registered interested parties. Consequently, this remains a matter of Ecology discretion.
O-7-23 2.1.10 Final Approval of Coverage. Response to comments should be required. If staff does not understand a question or comment, the commenter should be contacted for clarification.	O-7-23 A response is required following any public hearing. Staff also respond to comments or inquiries outside of public processes. We hold meetings just ahead of public hearings to give interested persons an opportunity to ask questions so that they can form good comments, and staff are available during comment periods (in fact, year around) to answer questions. Ecology will follow up on a question or comment if necessary.

Comment	Response
O-7-25 2.17.1 Annual Reports, Are Class A facilities reporting annually, or is this a new requirement? What is the difference between the reports of Class A and Class B facilities?	O-7-25 All permitted facilities must submit an annual report. Reports include the means of achieving pathogen reduction, i.e. Class A or Class B. The commenter probably means to ask the difference in reporting requirements between EQ and non-EQ biosolids. The annual report process is designed to learn how much biosolids were produced, how they were treated, how quality was ensured, and how they were used or distributed. For non-EQ products, which include all Class B products, that report will include information on storage and if any were land-applied, the location and other relevant information. For EQ products, information collected regards how the product was treated and tested to show that it meets EQ standards, and then how much was produced and how much was sold or given away. Ecology does not collect information on the location where EQ products are used.
O-7-30 3.6.1. Site Specific Land Application Plans and 4.5.1. Site Specific Land Application Plans These septage and biosolids land-spreading applications sections lead to Appendix B, *Minimum Content for a Site-Specific Land Application Plan*. The sludge applicators have either not provided this critical information to Ecology (or neighbors) or Ecology has not checked on the completeness or accuracy of the information provided. (j) *The location of any wells located on or within one-quarter mile (402 meters) of the site that are listed in public records or otherwise known to the applicant, whether for*	O-7-30 These requirements are included in WAC 173-308-90003[64], minimum content for a site-specific land application plan. The general permit requires these things from the applicants in the permit application process, and Ecology staff confirm the accuracy during their review of permit applications. All new and active management facilities are required to complete and submit a SEPA checklist in their initial application, which includes searching for threatened and endangered species using the tool available from the Department of Fish and Wildlife, and consulting the maps of critical areas maintained by the respective county

[64] https://app.leg.wa.gov/WAC/default.aspx?cite=173-308-90003

Comment	Response
domestic, irrigation, or other purposes. This information was not provided, but it was easily accessible through Thurston County records. (l) *The presence and extent of any threatened or endangered species or related critical habitat*. Once again, this section of the permit provided to us was blank, but a search through Thurston County records revealed at least two species. (m) *The location of any critical areas on site, as required to be identified under chapter 36.70A RCW in the county's growth management plan*. This section is critically important. As an example, the site-specific permit should have revealed that part of the site proposed in Thurston County was over a Critical Aquifer Recharge Area, but it did not. Given that every septage or biosolidsspreading site in Lewis and Mason counties has contaminated the groundwater below, further landspreading of either of these substances should not be allowed over a Critical Aquifer Recharge area. The new five year general permit should address this deficiency.	to identify any critical areas. Applicants must also review the well log database that Ecology maintains to identify wells near land application sites, and include appropriate precautions in their land application plans when they are found. Ecology staff review each permit application in entirety, both for exisiting active management facilities and all new facilities. Furthermore, the restructuring of the general permit and addition of automatic approval for baseline only facilities will allow Ecology staff to devote more resources to reviewing active management permit applications.

Comment	Response
O-7-37 3.8.3 Buffers. This allows Ecology to create exceptions to the rule, and gives Ecology the power to make special deals with no citizen oversight. We strongly suggest removing this exception.	O-7-37 With respect to the commenter's reference to septage site restrictions in section 3.8.3, we received other similar comments. After reviewing applicable rules, we agree with the commenter's argument here. We adjusted the permit language by removing the asterisks that denoted Ecology's ability to make changes, after "public contact sites, lawns, or gardens", and "flooded, frozen, or snow-covered sites". We agree that land application of septage is not allowed on in those situations - nor has it ever been authorized. We appreciate the commenter bringing this to our attention.
O-7-38 4.2.1 Who Must Provide Public Notice. An Active Biosolids Management Plan exempts providing public notice if: exceptional quality (EQ) or if relying on EQ from beneficial use (BUF). Why not? This is still hazardous material and has the same impacts as land spreading Class B solids. We strongly suggest removing these exceptions.	O-7-38 The commenter may think that biosolids is a hazardous material, but the premise is incorrect under any applicable law or rule. Biosolids are not a solid waste, are not listed as hazardous waste, do not designate as hazardous waste, and the presence of some amount of any substance in biosolids does not mean biosolids are hazardous. A critical outcome of producing exceptional quality biosolids is that they have met all criteria for use without further regulation - under both federal and state laws and rules. Facilities producing exceptional quality biosolids must provide information on their processes, quality, and overall management program as part of their application for coverage under the general permit. Ecology will provide a list of facilities that produce EQ biosolids within 6 months of issuance of the final general permit.

Comment	Response
O-7-49 We strongly recommend the following regarding the Draft General Statewide Permit: ... ...Applicants' adherence should be science-based rather than Best Available Management	O-7-49 Please see the response to comment I-9-4.
O-7-54 When an activity potentially threatens human health or the environment, the proponent of the activity, rather than the public, should bear the burden of proof as to the harmlessness of the activity. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing measures to prevent environmental degradation.	O-7-54 Ecology does not agree that the land application of biosolids poses a threat of serious or irreversible environmental damage to the environment. Biosolids have been beneficially used in Washington for several decades and in the United States for a hundred years, with scarce evidence of adverse consequences. Ecology continues to evaluate new research on the use of biosolids, particularly that focused on emerging contaminants of concern. As regards the proponet bearing the burden of proof, nearly all the biosolids produced in Washington are produced by *publicly owned* treatment works.
O-7-66 There should be an on-line import-export site for the public to track which states and companies are sending waste to Washington State and which states and companies are receiving Washington's sewage wastes.	O-7-66 The amount of biosolids imported or exported to or from Washington is small and generally insignificant in the context of the program. Exports generally involve transfer to facilities with better treatment capability, or in some cases to landfills for disposal when biosolids do not meet criteria for beneficial use. Imports generally involve transfer to facilities within Washington that have better treatment capability. Annual reports submitted by facilities provide this information. Ecology needs to invest time in other areas of the biosolids management program that can have meaningful results.
O-8-10 Washington should modify its General Biosolids Permit to assure that individual permits will allow the state to more actively	O-8-10 The commenter suggests modifying the general permit to assure that individual permits allow the management of site-specific contaminant issues.

Comment	Response
manage sites to address location-specific contaminant issues. Given both the evidence of widespread PFAS contamination of wastewater systems and variability from system to system, we believe that Washington should address chemical contaminant monitoring directly in its General Permit. Every biosolids production site should be required to test at least once for PFAS. While Washington touts the benefits of its "hybrid" system that allows more stringent measures to be added to individual permits, PFAS problems appear to be universal and should be dealt with broadly. Site specific permits grant the state the latitude it needs to mandate more routine monitoring, or source investigation for WWTPs. The state should require special disposal practices or treatment for WWTP effluent to prevent contamination of agricultural lands and receiving waters.	However, a general permit and individual permit are seperate concepts. The approach taken by EPA to date has been to set standards that do not require site-specific limits - that is to say - the standards take into consideration a range of circumstances and risk factors and the applicable limit is set so that it is safe across the board for all situations. EPA established two pollutant threshholds in its rules, that are reflected in state rules. The lower (cleaner) threshold is often referred to as Table 3 or Pollutant Concentration Limits. Biosolids with pollutant values below Table 3 values can be applied to the land without the need to track cumulative pollutant loading. The Table 1 values are Ceiling Concentration Limits. Biosolids exceeding those limits cannot be land applied at all. If biosolids fall between Table 3 and Table 1, cumulative pollutant loading must be tracked on a site. This is a concept from the original federal rules. In practice, land owners are not much interested in biosolids that require tracking of cumulative pollutant loading. Generally if that occurs there are corrections that can be made within a system, and any biosolids above Table 3 are most likely to be landfilled. Regarding PFAS, if review ultimately concludes, for example, that a limit on PFAS is appropriate, state rules can be revised to include the appropriate standard, or more expeditiously, the general permit could be amended. In either case, the requirement would extend through to an individual site. The commenter advises that every site that produces biosolids should test at least once for PFAS. We don't necessarily disagree with the fundamental idea. As we have remarked elsewhere, sampling for PFAS, at this point, requires a higher degree of skill than will be

Comment	Response
	available to most treatment works. Statewide sampling - even one time - would be extremely costly. Cost is not strictly a reason not to follow through, but it does argue for consideration as to the wisest use of our resources. The PFAS Chemical Action Plan[35] lays out the agency strategy for addressing PFAS, including at wastewater treatment plants, and for biosolids specifically. We are working on tasks as resources allow, and trying to identify ways to tackle more tasks. The commenter remarks that we require special disposal practices or treatment for WWTP effluent to prevent contamination of agricultural lands and receiving waters. The biosolids permit and program do not address the quality of effluent at all. Effluent quality is managed by Ecology's Water Quality program. We are not disregarding the commenter's concern here, but it just does not fall within the scope the biosolids general permit to address. Please see also the response to comment I 47-2.
O-8-13 6. Washington Ecology needs to clarify the interaction between the various permits that regulate the receipt, storage, treatment and land application of biosolids Just by nature, having general permits for some portion of the regulated community, NPDES for others and both an NPDES and general permit for yet another segment, complicates and confuses those who must comply. In review of the 2007, 2015 and draft General Biosolids Permit, there is no clear reference or definition in any version that describes the difference between the regulated segment(s) and how applicable discharge permits must be managed. We suggest that clarifying language and/or a flow	O-8-13 See the response to comment I-105-3.

Comment	Response
7 chart should be added to the General Biosolids Permit that will clearly show what each regulated segment must do and not do in order to meet all conditions of the applicable permits to which they must comply. An improved permitting framework would greatly benefit and assist the regulated community and improve compliance to applicable requirements.	
T-1-1 The Nisqually Indian Tribe provides the following comments to the Department of Ecology's request for comments on the New Draft Statewide General Permit for Biosolids Management and Associated SEPA Checklist. We understand that Ecology intends to issue a statewide general permit for the management of biosolids, although it recognizes individual permits could better protect public health and the environment and could be more efficient, less burdensome, and less costly. The Nisqually Indian Tribe also supports the comment letter submitted by Mr. Ed Kenney and the issues that he has raised. Nisqually has seen historic, ongoing, and proposed future applications of biosolids in the Nisqually watershed. Our experience informs us that individual, site-specific permits written to the unique physical and biological conditions of a proposed site best protect the resources needing our common stewardship. Nisqually has significant concerns about the adverse impact the inadequate management of biosolids in the Nisqually Watershed will have on our treaty rights and trust resources through the sole use of a general permit. Each watershed in the State is unique in multiple ways, and capturing that in a general permit, even with the ability to condition, is	T-1-1 Ecology does not believe individual permits for biosolids would be more efficient, less burdensome, or less costly. Nor does the agency believe they are necessary for the biosolids program in order to protect public health and the environment. The general permit is developed out of a common set of best management practices, and does exactly as the commenter suggests. Staff takes into consideration local conditions as they set permit requirements so that management practices are appropriate to the individual circumstance. Regardless of whether a permit is individual or general, permits respond to risk in one way or another. Standards for pollutants currently regulated under state and federal rules were derived from risk-based conservative scenarios designed to be protective for a wide range of beneficial use activities. State requirements are equal to or more conservative than federal rules in terms of surface and groundwater resources. Ecology recognizes that steelhead - anadromous (sea-going) rainbow trout – require a healthy environment to recover and remain healthy into the future. Biosolids are applied to a very small amount of land in Washington, and although PBDEs can be

Comment	Response
challenging at best and inadequate far too often. We have observed through the use of the previous general permit did not adequately protect our trust resources. We have invested a tremendous amount of tribal, State, and Federal resources into protecting and restoring habitat in the Nisqually to benefit the ecosystem and to support multiple listed species' recovery. In many cases, these protected and restored lands and waters represent the last best hope for critical species to survive the rapidly changing climate and, in the case of Nisqually steelhead, from going extinct. The location and connection of these lands and waters, and the future work to improve baseline conditions in the Watershed, is unique to the Nisqually, and simply cannot be addressed in this general permit that applies statewide. We have observed through the use of the previous general permit did not adequately protect our trust resources. A general permit allows a certain level of risk to be applied to the surrounding environment; it is only after the impacts have been discovered that remediation and risk reduction occur. On the other hand, an individual permit written to address local conditions and needs greatly reduces the risk to the environment from unintended consequences before those unintended consequences occur. This precautionary approach is most protective of the environment and of the Tribe's treaty rights. As one particular example, only individual permits can presently require that the risk factors associated with the source and content of bio-solids be clearly identified and monitored on site. If a general permit does not require certain actions, such as source	found in biosolids, biosolids are not a major source of PBDEs released to the environment. PBDEs are not water-soluble and tend to cling to particulates in the wastewater treatment process. Therefore, they are more likely to be found in the biosolids than in the effluent. The commenter, however, is supposing a direct connection between the land application of biosolids in the Nisqually River Basin and impacts on steelhead in the Nisqually River system. Since land application sites are specifically designed to protect surface water with buffers, impacts to surface water are unlikely. It is of course possible that some other source of PBDEs in the basin is contributing to the burden in steelhead, or they may be exposed during the part of their life cycle that is spent in saltwater. We note that another commenter remarked on a news story in the Seattle Times, reporting on an EPA study of the Nisqually, "The Nisqually estuary was more contaminated than expected with drugs, including cocaine, Cipro and Zantac. The source of the drugs there was unknown, the researchers reported. However, the Nisqually River, Nisqually Reach and McAllister Creek do not meet water-quality standards for fecal coliform. That makes leaking septic systems a possible source of the drugs." Ecology previously prepared a chemical action plan for PBDEs. While we do not believe PBDEs in biosolids are a significant environmental concern, we do concur with the commenter that they are a concern in general. For more information about general vs individual permit requirements, please see our separate discussion titled: “General vs individual permits and expediting coverage” in the key topics section at the front of this response.

Comment	Response
identification and complete toxic screening, conditions on an application to the general permit cannot require them. This is a critical issue for the Tribe, particularly because our ESA-listed steelhead suffer from the highest observed levels of toxic loading of polybrominated diphenyl ethers (PBDEs) in the Puget Sound region. Adding biosolids from unknown sources likely containing elevated levels of PBDEs to the Watershed would increase the risk of extinction to this incredible biological and treaty-protected resource. The Nisqually Watershed cannot withstand this risk, even though other watersheds in the State with much lower loading might be able to. Individual permits tailored to a site's unique physical and biological conditions offer the only solution for ensuring the areas of our State requiring our protection the most, such as the Nisqually Watershed, receive it. We have observed that individual permits can offer the same ease in management as general permits if individual permits begin from a common set of best management practices (BMPs). There are likely some common application standards based on Ecology's many years of experience in this issue that can be captured in BMPs. If these BMPs serve as the basis for each individual permit, Ecology could have some uniformity in management while having the opportunity to consider each particular biosolid source in the context of the surrounding ecosystem and to protect each unique aspect of each site. We highly encourage Ecology to develop and implement mechanisms within this new general permit the ability to require individual permits for any facilities in the Nisqually Watershed. Under WAC 173-308-90005(1)(b),	

Comment	Response
the Director has the authority to issue a site specific individual permit for facilities within appropriate geographic areas. The Nisqually Watershed is an "appropriate geographic area" given its high loading of PBDEs and the risk the inadequate management of biosolids poses to the Watershed's ESA-listed steelhead. The Nisqually Watershed requires the protection only an individual permit can offer. If Ecology utilizes a general permit for the management of biosolids throughout most of the State, it should exempt facilities in the Nisqually Watershed from that coverage and should require those facilities to apply for individual, site-specific permits.	
T-1-2 We also request that Ecology provide additional protections to water quality and environmental health and equity in the general permit by requiring: 1.Source identification of all biosolid materials.	T-1-2 Providing protections to water quality and human health and the environment is an integral part of the program. Whenever biosolids are received by a treatment works or by a land application facility, their source is known. The generator is required to provide the person who prepares or applies the biosolids with information needed to ensure that applicable regulations are complied with. We do not require facilities to make this information publicly available. However we do receive the necessary info from facilities to track the movement of materials across the state. If interested parties want access to this data, they may make a public disclosure request[65] for biosolids annual reports.

[65] https://ecology.wa.gov/Footer/Public-records-requests

Comment	Response
T-1-6 We also request that Ecology provide additional protections to water quality and environmental health and equity in the general permit by requiring: 4. A system to evaluate and determine eligibility of proposed permit holders including past performance with regards to compliance and reporting.	T-1-6 Ecology notes the commenter's request. However, there is no provision in our rules or statute that would allow us to deny coverage to an applicant that is in compliance with program requirements.

8. Sampling

Comment	Response
I-47-2 Like the state of Maine, Washington's Site Specific Biosolids permits should at the very least require testing of soils for PFAS before biosolids are applied. If PFAS contamination is found, biosolids should not be applied	I-47-2 Ecology tries to remain informed of activities in other states. At this time most states have not established limits for PFAS in biosolids. We will continue to evaluate the risk and alternatives. Please see the response to comment I-7-3 and O-8-11.
I-108-2 Who and how often are the biosolids checked for fecal coliform requirements?	I-108-2 The frequency of sampling depends on the amount of biosolids that are applied to the land or sold or given away per year. More biosolids means more sampling. The frequency ranges from once per month to once per year. In most cases, the more important aspect is process monitoring – maintain temperature in a specific range and meeting other treatment criteria. The sampling only validates a continuing process. When a specific process is not documented, more samples and additional limitations on land application are required.
LG-3-2 Requirements for Sampling, Analysis, and Process Monitoring More specifics are needed in two permit sections related to sampling, analysis, and process monitoring (Sections 3.4.6 and 4.4.6). Section 3.4.6 states that 40 CFR 136 methods are approved for use. However, 40 CFR 136 primarily lists methods for effluent testing, not biosolids. Having a specific list of methods included in this permit will avoid confusion about which methods are allowed for biosolids testing. The 2015 permit included a table of "Analysis Methods, Preservation and Holding Times." It would be helpful to add a similar, updated table to this permit, as well.	LG-3-2 The commenter asks for more detail in 3.4.2 and 4.4.2 around the lab accreditation requirement. Ecology added some additional language to clarify that the lab method must be accredited by Ecology (if accreditation is available), and that accreditation must be for a specific matrix appropriate to the sample (in most cases this will be the solid and chemical materials matrix for biosolids). The commenter asked for an updated table of approved analytical methods and accreditation requirements. We are aware that the table associated with the past permit was useful to permittees. Since methods change, Ecology prefers to provide the requested table outside of

Comment	Response
The updated table should note the changes to approved methods listed for Total Phosphorus since 2015. Please see enclosure for a proposed table to add. Sections 3.4.2 and 4.4.2 regarding lab accreditation requirements should also be more specific. The permit includes general language noting the requirement to be analyzed by a lab properly accredited in the appropriate matrix. It would be more effective and helpful if this were more specific as follows: Labs must be accredited by the Ecology Lab Accreditation program; and , Permit should list type of accreditation required for each matrix being tested (Biosolids/Soil = Solids and Chemical Materials Accreditation; Surface/Groundwater = Non-Potable Water Accreditation).	the permit. That will allow us to update the table from time to time, and make it easier to include additional information or guidance. The commenter asked for more clarity on the point of compliance for second-generation products. Ecology revised permit language regarding second-generation products.
O-2-4, O-7-28 Sections 3.4.2 and 4.4.2 say: *Soil sampling and analysis plans must conform to cooperative extension guidelines or generally accepted guidance or be prepared by a soil scientist, agronomist, crop adviser, or other certified or licensed professional.* This requirement is so general that it is not enforceable. There should be a listing of accepted guidelines.	O-2-4 All sampling and analysis plans are reviewed and approved by Ecology. The requirement to have an approved sampling and analysis plan is a fully enforceable requirement of the program, as is the requirement to follow the approved plan. The language also gives fair notice to applicants, and allows Ecology to reject poorly prepared plans and those developed by unqualified individuals.

Comment	Response
O-2-6 Section 3.6.3 Soil Testing Required, does not specify testing for phosphorous. It should. When biosolids are applied next to rivers, as they are in Yakima County, there is a risk of phosphorous runoff into a body of water with consequent eutrophication. Section 3.6.4 Application Rates should address phosphorous needs of the crop as well as nitrogen.	O-2-6 Ecology notes the recommendation to include phosphorous in analysis. Generally, nitrogen is the limiting element, and buffers are protective of other resources. In some cases staff already request (or permit holders simply provide) phosphorous and other macronutrients including sulfur, potassium, and total Kjeldahl nitrogen (in soils as well as biosolids). However, this is a site specific determination, and therefore is not within the scope of this response to comments.
O-2-8 Section 4.5.3: There is no protocol for soil sampling. Many fields are non-homogeneous with high and low areas and different soil types in the same field. In order to obtain useful soil samples, there must be guidelines for where to sample, how deep to sample, and how many samples to take. There should testing for phosphorous as well as nitrogen. Testing for nitrogen should be for nitrate, ammonia, and total Kjeldahl nitrogen (TKN).	O-2-8 We recognize that soils can vary across sites. Soil types are just one factor considered in evaluating sites, which is why sampling plans must be prepared by a knowledgeable individual or based on accepted guidance. All plans are subject to review and approval . Ecology follows soil sampling guidance like the one produced by the University of Idaho Cooperative Extension[66] to evaluate the appropriateness of a soil-sampling plan.

[66] https://idahopar.org/PAR/resources/SoilSampling.pdf

Comment	Response
O-7-27 3.4.1 Representative Sampling [Septage]: What is a sufficient number of samples? Are the samples analyzed separately, or combined before analyzing?	O-7-27 There are multiple management scenarios that drive determinations about the type, number, and timing of samples for both biosolids and septage. Some samples are discrete "grab" samples, and others are composites (multiple grab samples combined). In some cases, subsamples (sampling of samples) is needed, and in other cases samples may be split. This is the reason a sampling and analysis plan is required. When pH adjustment is required for septage (the most common driver for septage sampling), sampling must occur at the time of land application. Before and after samples must be taken to show that the pH adjustment is maintained for the required amount of time.
O-7-33 Section 3.6.3 Soil Testing Required: This does not specify testing for phosphorous. It should. When biosolids are applied next to rivers, as they are in Yakima County, there is a risk of phosphorous runoff into a body of water with consequent eutrophication.This was addressed in the recent CAFO decision: *Excess phosphorous in soil is problematic due to the potential detrimental impact to surface water. Like nitrate, an overabundance of phosphorous in a waterbody also contributes to eutrophication. In addition, when enough phosphorous is present, cyanobacteria, a type of algae, can out-compete other algae and cause blooms that produce liver, nerve, or skin toxins. These toxins are a significant public health threat that can cause sickness in both humans and animals.* https://www.courts.wa.gov/opinions/pdf/D252952-1-II Published Opinion.pdf. Section3.6.4 Application Rates should address	O-7-33 Please see the response to comment O-2-6.

Comment	Response
phosphorous needs of the crop as well as nitrogen.	
O-7-39 4.4.1 Representative Sampling of biosolids or soil. What is a sufficient number of solids and soil samples? Are the samples analyzed separately, or are the samples mixed before analyzing so that they are "averaged"?	O-7-39 Please see the response to comments O-2-4, and O-2-8.
O-7-40 4.4.3. Frequency of Process Monitoring. Monitoring should include the crop's roots, stems, leaves, edible parts of the crops, as well as once applied to grazing areas - plants and soil.	O-7-40 The risk assessment performed by U.S. EPA in support of the original federal program rules considered the potential for plant uptake of regulated pollutants and developed limits in biosolids accordingly. Ecology disagrees that plant tissue analysis is an appropriate regulatory requirement for biosolids beneficial use. Rather, standards for pollutants in biosolids need to be established so that they are acceptably protective of target individuals in each pathway of exposure. By establishing standards for biosolids' quality, environmental and human health endpoints are protected. In addition to the response above, please see the response to comment I-3-2 for additional

Comment	Response
	information.
O-7-41 4.5.3 Soil Testing Required. There is no protocol for soil sampling. Many fields are nonhomogeneous with high and low areas and different soil types in the same field. In order to obtain useful soil samples, there must be guidelines for where to sample, how deep to sample, and how many samples to take. There should be testing for phosphorous as well as nitrogen. Testing for nitrogen should be for nitrate, ammonia and total kjeldahl nitrogen (TKN).	O-7-41 Please see the response to comment O-2-8.

9. Environmental Justice

Comment	Response
I-55-3, I-56-7, I-57-6, I-58-6, I-59-6, I-64-6 I work actively on food safety, sovereignty and justice issues… …~Permits should reflect the 2021 HEAL ACT. I-61-4 And, lastly, permits should reflect the 2021 HEAL ACT as well. O-7-53 We strongly recommend the following regarding the Draft General Statewide Permit:... The permit should incorporate the HEAL Act	I-55-3 Several commenters made similar remarks about environmental justice. Please see the response to comment I-113-3, and comments LG-3-4, and LG-4-5.
I-98-2 As a local farmer and avid outdoorsman in the Inland Northwest, we should not have to bear the cost burden of waste disposal. Find a better and more sustainable way other than emptying peoples medicines and wastes cheaply to attract unsustainable growth	I-98-2 We are not sure that the commenter's focus is actually environmental justice, but the concern seems to be the idea that something produced in one location creates an unreasonable burden for the commenter in another location, which is one element of consideration for environmental inequities. The commenter did not explain and it is not clear to Ecology how the beneficial use of biosolids attracts unsustainable growth. Treatment plants around the state - including every treatment plant in the inland northwest region of the state, generate biosolids. In terms of cost, biosolids are an alternative to commercial fertilizer and growers benefit economically from land application of biosolids. Customers of publicly owned wastewater treatment systems and owners of onsite wastewater treatment systems also benefit from the reduced cost of beneficial use. If the commenter is arguing that biosolids produced on the western side of the state applied

Comment	Response
	to a location on the eastern side enables the western producer to grow unsustainably, we can understand that reasoning, though we do not agree. There are examples of programs on both sides of the state where biosolids are managed close to the point of generation, as well as examples of where they are exported to be managed in other counties. That choice is one to be made by the generator. The fact is that there is far more demand for biosolids on the east side of the state than there are biosolids. Biosolids are not pushed to locations for beneficial use, they are pulled by demand. Please the see response to comments I-1-1, I-4-1, and I-7-3.
I-113-3 I believe it is environmentally unjust to continue to allow King County and other municipalities to use Central and Eastern WA as a dumping ground of sewage sludge. This is environmentally and socially unfair to economically disadvantaged areas. Clearly, King County being a much wealthier county compared to Yakima for example, can afford alternative methods of disposal. However, until they are regulated and required to do so, the eastern part of our state will continue to be their inexpensive method of disposal. This is not a equitable solution we should permit. This is environmentally unjust in my view. Counties should find alternative methods to treating their own sewage sludge opposed to dumping it on baron land as if they are doing eastern counties a service. They are actually contaminating land and water sources with this disposal method. Please stop allowing this practice immediately.	I-113-3 The commenter argues that it is unfair to export biosolids from wealthier areas like King County to economically disadvantaged areas in central and eastern Washington. This ignores the fact that receiving farms and landowners actually seek out biosolids for their proven benefits to crops and soils. There is value in returning nutrients in biosolids to soils that were depleted of nutrients by agricultural practices. Biosolids are delivered and applied in accordance with agronomic rates to sites where they are requested, and only after a review of a complete land application plan. The demand for biosolids in eastern Washington far exceeds the supply. That being noted, as the commenter suggests, there is also merit in looking for solutions closer to home. Some communities have chosen to do that. Ecology is committed to further examining environmental justice related to biosolids beneficial use during the five-year life span of the permit. We believe that is the appropriate next step to take.

Comment	Response
LG-3-4 Biosolids and positive outcomes on environmental justice King County shares Ecology's commitment to environmental justice. King County also agrees that there are many positive outcomes from beneficial use of biosolids, including building organic matter in soils and providing a comprehensive suite of micro- and macro-nutrients that crops need at a relatively low cost. For this reason, at the request of priority communities in underserved areas of King County, WTD has partnered with community gardens to provide donations of biosolids compost. We wish to underscore Ecology's commitment, as stated in the Fact Sheet on the general permit, to examining biosolids and environmental justice comprehensively, including opportunities for positive outcomes	LG-3-4 We appreciate the commenter's commitment to Environmental Justice, and note their support for Ecology's continued efforts and commitment. Please see also the response to comment I-113-3.
LG-4-5 Fact Sheet Commitment to Environmental Justice. Tacoma has recently been investigating biosolids from an equity standpoint. Our view is biosolids are a valuable resource that benefits the user (customer). Our focus has been on how to make sure that all people have access to the benefits of our products. We would suggest that Environmental Justice must look at equitably distributing the value of biosolids and the biosolids manufacturing process as well as making sure no group of people bears a disproportionate burden of harms or risks.	LG-4-5 Ecology is committed to further examining environmental justice related to biosolids beneficial use during the five-year life span of the permit. We believe that is the appropriate next step to take. Please see also comment I-113-3.

Comment	Response
O-2-18 In light of the HEAL Act is it acceptable for people in populous areas to export their sewage sludge to rural communities where people are poorly equipped to question the impact on public health and the environment?	O-2-18 Ecology's biosolids program requires public notice in several ways to inform the surrounding public of the land application of biosolids at all sites, rural and urban alike. In the absence of biosolids land application, other fertilizers and soil amendments would be utilized which each have their own impacts. Animal manures and commercial fertilizer for example are more widely used on crops with fewer regulatory requirements. Although manure on rare occasions has been positively linked with outbreaks of illnesses, it is commonly understood that the benefits on crop growth and soil maintenance it has outweighs this drawback. Therefore, Ecology applies the same logic in supporting their use to that of biosolids, because the bulk of research and practical experience show when used in accordance with state and federal rules and permit requirements biosolids are a safe and effective soil amendment. Ecology agrees that environmental justice is important work that can only improve our program. We have committed to further examining environmental justice related to biosolids beneficial use during the five-year life span of the permit. We believe that is the appropriate next step to take.

Comment	Response
O-5-5 Biosolids Permit violates definition of environmental justice: The production and use of biosolids will disproportionately affect people who work in wastewater treatment plants, biosolids processing facilities, and farm workers. This demographic generally has less education and access to healthcare and in the case of farmworkers are often immigrants. The Permit will also disproportionately affect people who can not afford to eat certified organic produce - the only food guaranteed to be grown without biosolids.	O-5-5 Ecology notes the commenter's concern surrounding environmental justice but so far has not reached the same conclusion. Ecology is committed to further examining environmental justice related to biosolids beneficial use during the five-year life span of the permit. We believe that is the appropriate next step to take. Please see response to comments I-113-3, and comments LG-3-4 and LG-4-5.
O-7-9 Ecology must do better at informing the neighbors of land spreading events, as they have nothing to gain and much to lose. This is in line with the 2021 HEAL ACT.	O-7-9 All permitted biosolids facilities in Washington state must notify the public of their operations prior to receiving final coverage and land applying biosolids. Permitted facilities that land apply non-exceptional quality biosolids must also notify the public if/when they add new land application sites to their operations. Notification includes legal notice in a newspaper of general circulation, and posting signs at the site to notify those nearby of the application and any site restrictions thereafter. If there is an interest, a 30-day comment period is also held to allow the public to give input on the project. Finally, all interested parties identified by the facility will be notified via mail or email of the pending land application operations. To make becoming an interested party easier, Ecology has created an online service where anyone can Register for Updates[25] to be notified of biosolids activities in any county, or even statewide. Ecology is committed to further examining environmental justice related to biosolids

Comment	Response
	beneficial use during the five-year life span of the permit. We believe that is the appropriate next step to take.
O-7-59 ESHB 5141 - The Healthy Environment for All Act (HEAL) (5) (c) relies on "evidence Based" ‚Äì systematic review of available data...; loss or impairment to ecosystem. The Act and Ecology's plans must be activated in 2023. How will the sewage waste regulations, that permit the spreading of pollutants that impair the ecosystem and public health, be folded in to the agency's implementation plan? Is it acceptable for people in populous areas to export their sewage sludge to rural communities where people are poorly equipped to question the impact on public health and the environment? These issues must be addressed.	O-7-59 Ecology is committed to further examining environmental justice related to biosolids beneficial use during the five-year life span of the permit. We believe that is the appropriate next step to take. Please also see the response to comments I-113-3 and LG-3-4.

Comment	Response
O-7-70 Ecology should adopt the 2021 HEAL ACT in this permit. In doing so, it should consider the well being of drivers hired to haul the waste. They should be made fully aware of their hazardous loads, and they should be provided protective gear.	O-7-70 Ecology will evaluate environmental justice concerns related to biosolids management, per our commitment in the Fact Sheet for the permit. The commenter identifies truck drivers as members of a group disproportionately impacted by biosolids. We have not seen this to be the case. We invite the commenter to bring that concern forward during our environmental justice evaluation. Please see response to comment I-113-3, and comments LG-3-4 and LG-4-5.
O-2-11 For facilities located near rivers and streams that support anadromous fisheries the permits should be published in tribal newspapers. For facilities located in ethnic communities, public hearings should be advertised in languages used by significant population subgroups. Consider radio and television advertising in lieu of print media. Explain what is in biosolids.	O-2-11 Ecology published notices of the draft general permit in English, Korean, Vietnamese, Chinese and Spanish in more than two dozen papers of general circulation across the state. We did not receive a single response from an individual depending on a language other than English (although we note that persons may have read the notices in a language other than English). Radio and television advertising is prohibitively expensive and not justifiable. We have made a commitment (see the Fact Sheet for the permit) to examine biosolids permitting in the context of environmental justice during the next permit cycle. Everyone can Register for Updates[25] for future notifications, which makes becoming an interested party more accessible than previously, however we have always maintained interested parties lists as have our permitted facilities.

10. Buffers

Comment	Response
B-1-4 8. Buffers a. Buffers should be based on science not fear mongering. b. Property Boundary Buffers Should be no more that surface water.	B-1-4 Ecology's Biosolids Management Guidelines[60] layout the appropriate buffers for surface waters and property boundary and are rooted in science. As discussed in the guidelines, surface water buffers range from 33 to 200 feet depending on many factors. Climate, soil, slope, site vegetation, and farming and application methods to name a few must be considered. Whereas property boundary buffers range from 5 to 200 feet depending on property type, desires of neighboring property owners, application process, public access restrictions, odor control, etc. The factors used to establish buffers for surface waters and property boundaries are different. Adjusting property boundary buffers based on surface water buffers would not be appropriate.
LG-7-3 Table B5: Additional Site Management Restrictions for Class B Biosolids Table BS lists buffer distances for adjacent properties "as defined by Ecology." Does Ecology have guidelines for how property buffers are to be determined? If this is so, guidance should be cited here.	LG-7-3 Please see the response to comment O-3-4.

Comment	Response
O-3-4, LG-4-4 Table B5: Additional Site Management Restrictions for Class B Biosolids Table B5 lists buffer distances for adjacent properties "as defined by Ecology" Does Ecology have guidelines for how property buffers are to be determined? If this is so, guidance should be cited here.	O-3-4 Buffers to adjacent properties will vary depending on a variety of things including (but not limited to) the use of the adjacent property, and method of application. Our state Biosolids Management Guidelines (WDOE 93-80)[60] are an important resource in evaluating and establishing site-specific conditions. Refer to page 4-21 of the aforementioned guidelines for more information on property boundary buffers We reference these guidelines in 1.1 of the General Permit. Based on other comments received, Ecology will reevaluate guidelines for buffers during the upcoming permit cycle if resources allow. See also the response to comment O-7-8.
O-7-72 The sewage wastes must not be applied or allowed to run or blow onto non-permitted areas.	O-7-72 Application of non-exceptional quality biosolids to unpermitted areas is not allowed. Sites are designed with buffers to surface waters and adjacent properties that are intended to prevent offsite impacts.

11. EQ Products

Comment	Response
I-63-1 I appreciate the opportunity to comment on the Department Of Ecology's (Ecology) Statewide General Permit For Biosolids Management. I have been using the biosolids from the Three Rivers Regional Wastewater plant in Longview, Washington for my garden for about 10 years. I have numerous friends and family that use this product. For the landscaping areas, I have had to make my own blend of the product to be more appealing. It has been very cumbersome, but the end result has been great on my plants. I was so glad to hear that this permit would allow the Three Rivers Regional Wastewater Plant to be able to blend their biosolids with other products to have an end product that I can use on my landscaping. As a taxpayer, I feel any savings for the treatment plant's biosolids disposal and additional testing regimen costs helps our community. By being able to give away a more appealing blended product to taxpayers, the better it is for everyone. It is a shame to miss out on such a great commodity as biosolids is to our gardens/landscaping; it should be recycled back into our ground. I strongly support the approach Ecology is making on second-generation product derived from Class A EQ biosolids. And, that products made from Class A EQ biosolids do not need to be further regulated. This is nothing more than what I am doing as a resident and mixing it myself. Facilities should not have more stringent rules than the taxpayers. Not to mention, it is safer than unregulated fertilizers that people put in their gardens every year. I feel that Ecology should keep pace with technology and	I-63-1 Ecology notes the commenter's support of the biosolids program and change in regulation for second-generation EQ products. We made this decision consistent with the most recent interpretation of federal rules by U.S. EPA. We agree that biosolids are a valuable resource that return organic matter and nutrients to soils.

Comment	Response
science-backed research, which has proven that it is safe to use and more beneficial than other alternatives.	
I-105-5 The Permit requires that a General Land Application Plan (GLAP) and/or a Site-Specific Land Application Plan (SSLAP) for non-exceptional quality biosolids or septage that is applied to the land but are not required for Exceptional Quality (EQ) biosolids. The exceptions listed in WAC 173-308-310(8)(a)(ii) or (iii), are quite subjective and include statements like "may be required" or "if the department finds there would be a strong benefit to the public". It would seem that "the department" would not know if land application from a particular facility is or is not beneficial to the public if there is no plan for them to review. The lack of a requirement for facilities that land apply EQ biosolids to have a land application plan, risks the application of biosolids to land that might contain hazardous contaminates, both currently regulated and emerging (e.g., PFAS, pharmaceuticals and personal care products (PPCP)). EQ biosolids are most common to larger wastewater treatment plants and thereby are most likely to contain discharges from industry, commercial laundries, airports, military bases, and landfill leachate. Recommendation: Add a requirement to the Permit that General and Site-Specific Land Application Plans must be prepared for all Exceptional Quality biosolids, without exception.	I-105-5 The commenter is remarking here about state program rules, which are not open for revision at this time. We note the commenter's concern about the language being written loosely. Under federal rules, no plan is required for land application of exceptional quality (EQ) biosolids. The intent of the federal program was for EQ material to be managed as a commodity and not as a waste. EPA recently reinforced this with an updated interpretation of their regulations[4]. Ecology supports the approach under federal and state rules that treats exceptional quality biosolids as a commodity. Although there is no further regulation as biosolids, other regulations may apply, such as registration as a commercial fertilizer if appropriate. Also, requiring a land application plan for EQ biosolids will not address the commenter's concerns regarding the presence of contaminants in biosolids. Standards for biosolids quality are established separately from land application plans and must be met prior to using the biosolids as intended. Using PFAS as an example, if a standard is set for PFAS in biosolids, Ecology would ultimately amend the regulations in Chapter 173-308[24] to include a new pollutant limit. In the interim, we could modify the general permit to impose the requirement, or we could add it for individual facilities as a condition of approving their coverage under the general permit. None of those solutions, however, would involve any

Comment	Response
	modification of a land application plan. Rather, they would require sampling and confirmation of biosolids quality before the biosolids were applied in accordance with an approved land application plan.
LG-1-3 3) Section 1.1.4. Activities Regulated Under this Permit Fifth Bullet -- "Selling or giving away biosolids in bags or other containers with a capacity of one metric ton (1.1 U.S. tons), or less." Assuming this means wet tons since it references a container.	LG-1-3 The commenter remarks about the concept of bags or other containers with a capacity of one metric ton or less. The requirement only addresses the "capacity" of the “bag”, or "other" container (generally referring to pickup trucks and trailers). Since it is the capacity of the object in which biosolids are deposited, the form of biosolids - wet or dry - is irrelevant. The phrase, "bag or other container with a capacity of one metric ton or less" derives from federal rules and refers specifically to EQ products. Ecology has used this threshold as the basis for labeling requirements for EQ products distributed in small quantities. We will consider expanding the label or information sheet requirement to include bulk EQ biosolids as a consequence of comments received during this comment process. See comment SG-3-1.
LG-1-11 We found the new permit straightforward and generally only had minor comments. The main comment is that we would appreciate clarification on the definition of second-generation exceptional quality biosolids… 14) Section 4.6. Exceptional Quality Biosolids Define exceptional quality, first generation and second generation biosolids for clarity.	LG-1-11 Other commenters expressed a similar concern. We revised the language in the permit’s Glossary of Terms, Appendix D.

Comment	Response
LG-3-3 Second-generation biosolids products definition The permit is clear that second-generation exceptional quality biosolids products are not regulated under the general permit. However, a more thorough and careful definition of "second generation exceptional quality biosolids products" would be helpful, particularly clarifying where the point of compliance occurs for these products.	LG-3-3 Please see the responses to comments O-3-3 and LG-1-11.
LG-4-3 The concept of second-generation Biosolids products is new and needs to be more carefully defined. We agree with the concept that products made from Class A-EQ (Exceptional Quality) biosolids do not need to be further regulated, but suggest that the point of compliance be specifically defined. 4.6. Exceptional Quality Biosolids This permit does not regulate second-generation EQ biosolids products. Once the biosolids component of the second-generation product meets the Exceptional Quality Class A requirements of the Rule the second Generation products manufactured from the biosolids component are no longer regulated under this Permit. The Facilities that manufacture second-generation exceptional quality biosolids products must ensure physical separation of those products from first-generation exceptional quality biosolids. Appendix D - Glossary of Terms Second-generation exceptional quality biosolids products: Products made from biosolids that have met the requirements for Class A exceptional Quality Biosolids. These	LG-4-3 Please see the responses to comments O-3-3 and LG-1-11.

Comment	Response
products include blended soils composts and potting soils.	
LG-5-2 The concept of second generation Biosolids products is new and needs to be more carefully defined. We agree with the concept that products made from Class A-EQ (Exceptional Quality) biosolids do not need to be further regulated but suggest that the point of compliance be specifically defined. In addition to the above comments, the Alliance has reviewed and agrees with the comments submitted by NW Biosolids, particularly those related to Section 4.6 ... and Appendix D which may have a direct impact to the SCTP biosolids program now and with planned program advances in the future.	LG-5-2 Please see the responses to comments O-3-3 and LG-1-11.

Comment	Response
LG-7-2 The Three Rivers Wastewater Authority greatly appreciates the Ecology's approach to second generation products derived from Class A-EQ (Exceptional Quality) biosolids. We believe that the concept of second generation biosolids products needs to be more carefully defined. We strongly agree that products made from Class A-EQ biosolids do not need to be further regulated, but suggest that the point of compliance be specifically defined… …4.6 Exceptional Quality Biosolids Exceptional quality (EQ) biosolids have been to the highest regulatory standard and are not subject to further regulation once the standard has been met. Examples of EQ biosolids include thermal drying, lime pasteurization, temperature-phased (including thermophilic) anaerobic digestion, and auto-thermal aerobic digestion. Process controls and biosolids quality must be stringently documented. Biosolids generated from these treatment processes may in some cases be made into second-generation products such as manufactured soil and compost. This permit does not regulate second-generation EO biosolids products. Publicly-owned or private facilities that manufacture second-generation exceptional quality biosolids products must ensure separation of those products from first-generation exceptional quality biosolids. The separation between first and second-generation EQ biosolids products must be physically distinct, and ensure no possibility of mingling. Operators must able to identify each product at all times. All first-generation exceptional quality biosolids products must comply with the	LG-7-2 See the response to comment O-3-3 and LG-1-11.

Comment	Response
labelling and information sheet requirements of 4.6.I. If you guarantee a nutrient content, or represent your as a commercial fertilizer, in addition to the requirements of this permit you may be subject to regulations implemented by (etc, etc)... ... **Appendix D - Glossy of Terms** **First-generation exceptional quality (EQ) biosolids**: Exceptional quality biosolids produced from the treatment of non-exceptional quality biosolids, and meeting all standards for Class A pathogen reduction, vector attraction reduction, and pollutant concentration. Standards must be met at the time EQ biosolids are distributed or made into a second-generation product. **Second-generation exceptional quality (EQ) biosolids products**: Products that blend first-generation EQ biosolids with other materials to make products like manufactured soil or compost. Further monitoring and testing of second-generation products is not required.	
O-3-3 The concept of second generation Biosolids products is new and needs to be more carefully defined. We agree with the concept that products made from Class A-EQ (Exceptional Quality) biosolids do not need to be further regulated but suggest that the point of compliance be specifically defined... …The following are specific comments on sections of the permit:… *[Commenter provided their recommended revision of 4.6 Exceptional Quality Biosolids]* 4.6 Exceptional Quality Biosolids Exceptional quality (EQ) biosolids have been treated to the highest regulatory standard and are not subject to further regulation once the	O-3-3 The commenter asked Ecology to do a better job defining the point of compliance for second-generation products. We have revised the language in the permit to address this. Under federal rules, no plan is required for land application of exceptional quality (EQ) biosolids. The intent of the federal program was for EQ material to be managed as a commodity and not as a waste. EPA recently reinforced this with an updated interpretation of their regulations[4]. Regarding the point of compliance, we will clarify here. Ecology will not accept at face value arguments that material remaining in control of a generator is no longer subject to program rules because it is a second-generation product. The

Comment	Response
standard has been met. Examples of EQ biosolids processes include thermal drying, lime pasteurization, temperature-phased (including thermophilic) anaerobic digestion, and auto-thermal aerobic digestion. Process controls and biosolids quality must be stringently documented. Biosolids generated from these treatment processes may in some cases be made into second-generation products such as manufactured soil and compost. This permit does not regulate second-generation EQ biosolids products. Publicly-owned or private facilities that manufacture second-generation exceptional quality biosolids products must ensure separation of those products from first-generation exceptional quality biosolids. The separation between first and second-generation EQ biosolids products must be physically distinct, and ensure no possibility of mingling. Operators must be able to identify each product at all times. All first-generation exceptional quality biosolids products must comply with the labelling and information sheet requirements of 4.6.1. If you guarantee a nutrient content, or represent your product as a commercial fertilizer, in addition to the requirements of this permit you may be subject to regulations implemented by (etc,etc) Appendix D First-generation exceptional quality (EQ) biosolids: Exceptional quality biosolids produced from the treatment of non-exceptional quality biosolids, and meeting all standards for Class A pathogen reduction, vector attraction reduction, and pollutant concentration. Standards must be met at the time EQ biosolids are distributed or made into	manufacture of second-generation products needs to be thoughtful and deliberate. To avoid confusion, and apply EPA's interpretation noted above, Ecology is adding two requirements to the final general permit: First, in addition to being physically and distinctly separate from other biosolids products, all second-generation products must be conspicuously labeled or identified as such. This can be accomplished by labeling on bags or containers, by posting a sign in the middle of a product stockpile, locating a sandwich board in front of a product stockpile, or some similar means of identifying the product. Secondly, all facilities manufacturing second-generation products must declare that activity in the permit application. Facilities must describe in general terms how and where the product is manufactured, its intended use, and where manufacturing and stockpiling will occur. Please also see the response to comment LG-1-11.

Comment	Response
a secondgeneration product. Second-generation exceptional quality (EQ) biosolids products: Products that blend first-generation EQ biosolids with other materials to make products like manufactured soil or compost. Further monitoring and testing of second-generation products is not required.	

12. Alternative Management Methods

Comment	Response
I-9-2 WA state needs to seriously research alternative methods of disposal such as pyrolysis, gasification or extraction of useful materials. I-49-10, I-71-2 We call on the state to seriously research alternative methods of disposal such as pyrolysis, gasification or extraction of useful materials.	I-9-2 Please see the response to comments I-47-3, I-117-3, and O-8-11.
I-31-3 Please protect our water and food instead of contaminating it. There are other ways to safely dispose of this sludge.	I-31-3 Please see the response to comments I-3-2, I-26-1, I-47-3, I-117-3, and O-8-11.
I-35-2 The Centralia coal plant is scheduled to close down in a few years. The state could possibly procure this facility to burn bio solids and sell the ash that is produced.	I-35-2 Thank you for your comment. Incineration does not constitute beneficial use - it is disposal, and so Ecology would not support that approach. The idea of using the ash from incineration seems appealing, but all five biosolids incinerators operating in Washington have investigated the possibility at one time or another and it has never developed as a viable tool.

Comment	Response
I-47-3 Ecology should assist producers in finding safer alternative ways to dispose of them	I-47-3 Ecology notes this recommendation. Others have also said that Ecology should research emerging technologies. Ecology is open to alternatives that do not constitute disposal (as incineration and landfilling do), but we aren't charged or funded for researching new ways of handling biosolids, or with assisting generators in identifying alternative methods. We certainly value research, but considering limits to Ecology resources, it makes better sense to take advantage of research activities funded at higher levels of government or academia. Organizations like NW Biosolids, Water Environment Federation, and the Water Research Foundation invest significant efforts in identifying and communicating information on new technologies and many other issues related to biosolids management. At this time, we have not identified any better options than land application. Please also see the response to comments I-117-3, and O-8-11.
I-67-3 Other countries, particularly The Netherlands, have tried different approaches that would be more responsible for public health. I refer you to a recently published book Pipe Dreams by Chelsea Wald for some of these ideas. Other methods of disposal, not mentioned in her book, include pyrolysis and gasification	I-67-3 We appreciate the referral. Staff are aware of various approaches to wastewater management. All methods produce a solids product that must be managed. We note in particular the commenter's desire to find alternative methods of management. Ecology does not have the resources nor the assignment of researching alternative treatment systems. That work falls to academic institutions, service providers, and entrepreneurs. If there is a lower-cost or better approach to beneficial use, Ecology is interested. Please also see the response to comment I-47-3.

Comment	Response
I-75-2 Please find a better way to dispose of human waste.	I-75-2 Please see the response to comments I-47-3, I-117-3, and O-8-11.
I-113-2 ...We need to work together as a state to find alternatives to treating this sludge with modern technologies to reduce contamination. These newer methods will be costly, yet the health of humans, our environment, aqua life and wildlife are worth protecting. In essence I believe current methods resort to our literally poisoning ourselves and these current methods must be altered. Instead of pointing out all of the obvious chemicals contained in sewage sludge, I prefer to present alternative solutions in a proactive manner. This is what I believe needs to be enforced by your agency. I understand the legislature will need to agree and state funding will need to be provided to make this possible, yet let's not give up there. First, the legislature needs to set aside monies for a through investigation on cumulative health impacts related to the spread of sewage sludge.We need to protect our ground water in addition to our waterways as explained in the Sierra Club letters. I would like to see DOE and DHS work together to determine the impacts and chemicals contained in this waste from a toxicology standpoint. Secondly, I would like DOE to change the classification from bio solids to a hazardous waste. If sewage sludge contains chemicals and RCRA wastes, why would it not be classified as hazardous waste? I believe the state should fund construction of modern regional treatment and disposal facilities that can properly dispose of the	I-113-2 Ecology notes the commenter's effort to identify an alternative approach. The scope of Ecology's obligations is very broad. The agency sees biosolids as an important issue, but it is not likely to rise to the level of importance where Ecology would specifically request additional funds from the Legislature for research. Particularly in light of the large amount of research already complete that shows beneficial use of biosolids is safe and an effective soil amendment. EPA also recently was awarded nearly six million dollars in grant funds for biosolids reasearch[49]. The commenter's idea of directing biosolids to a singular location for eventual treatment would require impractical transportation logistics for this proposal to succeed. We want to point out that the specialized treatment facilities the commenter advocates, already exist in the form of modern wastewater treatment facilities. Although the commenter is seeking a level of treatment beyond what is presently provided. We think if there is a need for additional treatment, it might be better considered in the context of upgrading existing treatment works that are already in place for the purpose. Going one step further, we want to point out that treatment may not be the solution; rather, reducing the use of substances of concern in manufacturing products commonly used in everyday life may be more effective. This has been the case with phasing out the use of PFOS and PFOA in manufacturing. Research has documented the decline of these two forms of PFAS in various sampling events since their use was phased out over the last ten to twenty

Comment	Response
sewage sludge, funded and monitored by the state. Municipalities should have to pay fees to their regional facility to dispose of their sewage sludge waste. This would assist in the operation and maintenance costs of operating such facilities for the long term. It would be equitable and fair for communities to pay by the load based on their jurisdiction and population. This would allow smaller municipalities to participate in equal methods of disposal. It is unrealistic to expect small communities to construct their own modern treatment facilities, this would be too costly. Railroads should be utilized opposed to trucks whenever possible to reduce carbon emissions and preservation of our highways and roads. If sewage sludge was temporarily contained in landfills (Hanford) until these modern facilities are built, it could be later extracted from the contained landfill and trucked to the facilities, later being processed in an environmental manner. Certainly not to be left in the landfill for the long term of course. This is far better than spreading it on land. Once a farmer tills his soil with sewage sludge it is near impossible to mitigate it. In addition to spreading in in forests and sloped areas which can travel to other water sources both above and below ground. temporarily containing the sewage sludge is key to saving our environment. We cannot afford to risk the environment with our current practice for five more years. Municipalities should be paying for temporarily landfilling their sewage sludge until it can be extracted and processed properly. ...I hope this makes sense and I understand that what I am explaining is a long and costly process. However, once land and water is contaminated it is very difficult and costly to	years[30]. Please also see the response to comments I-47-3, I-117-3, and O-8-11.

Comment	Response
restoring those natural resources back to their original condition. We live in a beautiful state and need to protect our natural resources. As climate change continues to heat up our state and less water becomes available, this will become even more important. Let's work together on proactive solutions before it is too late. The online meeting I attended with Director Laura Watson today was a step in the right direction. Please realize their are many volunteers like myself who would like to assist you agency in these efforts. Please let us know how we can be of assistance. Our passion for the environment and love of our state is proof of that. We are a wealth of knowledge and experience, therefore I hope you will tap into these resources to help solve a very big problem in our state. It truly does take a village, thank you for your time in reviewing my ideas and concerns. Please contact me if I can be of assistance and confirm via email that you have received this letter prior to the deadline tonight for submission.	
I-114-3 It is time to look into a thermo incinerator like Switzerland has which eliminates all toxins.	I-114-3 Incinerators do not eliminate all toxic substances. Even though they are required to incorporate best available technology, they still emit contaminants to the environment and contribute to climate change. Additionally, they produce ash that generally must be disposed of in a landfill. Setting aside the merit of Swiss approaches to biosolids management, land application is not uncommon across Europe.

Comment	Response
I-117-3 Please task your agency to look into newer technologies available to treat this unhealthy material through perhaps thermal decomposition, or hopefully advancing technologies that are being explored in Europe and developed by individuals and in some local areas in the US today... Please request funding from the Federal Government to create a safer alternative if the cost in R&D just seems too high, as was inferred in a DOE meeting with Preserve the Commons members several years ago.	I-117-3 While Ecology sees biosolids as an important issue, biosolids staff do not have the ability to assign tasks to the agency overall, and Ecology is not tasked with nor funded to research new or alternative methods of biosolids management. Research and development activities are mostly undertaken by universities, businesses and entrepreneurs, and stakeholder organizations. Communities that manage wastewater treatment systems must periodically upgrade those systems. They often investigate alternative technologies while deciding on the best upgrade. Additionally, every year there are conference events where vendors show off the latest technologies. One thing interested parties can do is participate in local processes that develop the strategies for things like wastewater treatment. The commenter asks Ecology to request funding from the federal government to cover the high costs of research and development to create a safer alternative to land application of biosolids. We support additional research into issues of concern for biosolids management, as well as new and improved technologies and methods of management. However, there is a whole body of risk assessment work conducted on biosolids that provides substantive evidence of efficacy and safety when used in accordance with our state and federal regulations, and permit requirements. Ecology feels the current land application practices are safe. We ask the commenter to consider that Washington is one state among fifty. Improved practices, whatever they may be, will not be unique to Washington. Ecology was critical of U.S. EPA for many years as they disinvested from the national biosolids program. They have now "reinvested" with new staff, starting about four

Comment	Response
	years ago, and recently awarded nearly six million dollars in grants to conduct further research[49]. Organizations like NW Biosolids and the Water Research Foundation also support research into issues like contaminants of concern and emerging technologies. Please also see the response to comments I-47-3, and O-8-11.
O-5-8 Because it is impossible to test for all contaminants and the likelihood of removing these contaminants in the near future is slim, Ecology needs to explore alternative disposal methods for sewage sludge that will be protective of human health and the environment. Funding sources need to be acquired for research and development and to assist wastewater treatment plants to transition to a more sustainable approach to solids management. Furthermore, Ecology should be hesitant to permit new biosolids facilities.	O-5-8 Please see the response to comments I-47-3, I-117-3, and O-8-11.
O-8-11 Washington state's Biosolids Program should consider the ecological and health impacts of all disposal methods for contaminated biosolids. Measures to prevent PFAS from entering the wastewater system are essential because neither land application, landfilling nor incineration will fully destroy or contain the chemical wastes. Incineration is energy-intensive and will destroy PFAS, which are	O-8-11 Ecology agrees that health and ecological impacts should be considered in the management of biosolids. Stopping PFAS from entering the wastewater system would help keep them from ending up in our water, air, and soil. Biosolids are a product of the wastewater treatment system, so developing new disposal techniques for them would not eliminate PFAS and other contaminants from our environment. It may be better to focus on reducing or eliminating

Comment	Response
highly heat-resistant. Instead, incineration can spew a range of harmful breakdown products into the air, ultimately contaminating land and water far from the incineration site (Stoiber 2020). Waste ash from incinerators still needs to be disposed of in landfills and managed in perpetuity. Sending biosolids to a landfill is space-intensive and expensive. Even lined landfills will eventually leak, and PFAS and other persistent pollutants are commonly measured in the groundwater near landfills. Most landfills contain the liquid wastes or "leachate" but do not have sophisticated systems to remove PFAS and other contaminants. Some landfills send leachate to a WWTP for disposal, which ultimately circulates waste back into the environment. Some landfills have chosen to contain leachate by reinjecting it back into the landfill or by filtering the liquids to concentrate the chemicals onto a polymer or carbon filter material, which itself must be contained for centuries	altogether the manufacturing of products containing PFAS. Research has documented the decline of two forms of PFAS - PFOA and PFOS - in various sampling events since their use was phased out over the last ten to twenty years[58]. We expect levels of those two PFAS forms to continue declining, and others would follow suit if they were no longer used in the manufacturing process. EPA is also currently developing a new risk-screening tool, which it will formally submit to the Science Advisory Board early in 2022. Once the tool has been vetted and approved, EPA will be able to better assess pollutants in biosolids under various management scenarios. Ecology is striving to collect accurate concentration data and use that information to assess risk to human health and the environment from PFAS in biosolids, while we look for a safer alternative to use in manufacturing processes. Please also see the response to comments I-47-3, and I-117-3.

13. Transportation

Comment	Response
B-3-3 2.4. - Page 14 Requirements for Transporting Sewage Sludge or Biosolids Transportation of biosolids must be consistent with an Ecology-approved spill response plan. All generators are responsible for ensuring the safe and properly documented transportation of biosolids they generate, from the time of generation through the time of final use or disposal. Any facility subject to this permit is responsible for the performance of any contractor or subcontractor they retain for the transportation of biosolids. Transporters must comply with Title 81 RCW and rules adopted thereunder, as applicable. You may only transport non-exceptional quality biosolids to another facility for further treatment, an approved land application site, an approved storage site, or an approved disposal facility. [Highlight by commenter]. Comment 4 Highlighted language could be interpreted to preclude hauling EQ biosolids to a permitted site.	B-3-3 The commenter recommends a change in 2.4 of the draft permit to make clear that exceptional quality biosolids can be transported - not just non-exceptional quality biosolids. Exceptional quality biosolids are not regulated (under the biosolids program) beyond the point of production. We revised language in the draft permit for clarification to read, "Non-exceptional quality biosolids may be transported only to another facility for further treatment, an approved land application site, an approved storage site, or an approved disposal facility."

14. Jurisdiction

Comment	Response
B-3-4 2.4.2. -- Page 15 Accepting Biosolids from Federal, Tribal, or Out of State Facilities Treatment works must have written approval from Ecology before accepting biosolids from a federal, tribal, or out of state facility. Treatment works subject to this permit, may not accept biosolids for further treatment or disposal unless the generating treatment works complies with the following requirements. Generating facilities must: Comment 5 Pumpers pump tanks and grease traps on tribal and federal land. How does this section affect them? Requiring treatment works treating domestic sewage to ensure compliance with this section is overly burdensome. The agency issuing the NPDES permit should ensure the facilities produce suitable sewage sludge or biosolids for further treatment or land application or prohibit the facility from using any treatment facility in the state until they have Ecology approval. The facility can then use the approval document to assure any facility receiving the material for further treatment or use that compliance has been met.	B-3-4 This provision is not meant to impact pumpers servicing onsite wastewater systems, regardless of location. Onsite wastewater treatment systems and similar devices are not TWTDS and therefore are not subject to permit coverage. Pumpers servicing these systems do not require advance approval from Ecology. We revised permit language to clarify this permit requirement. Septage pumpers generally do not service treatment works treating domestic sewage. However, on occasion, pumpers do provide service to an actual TWTDS. Usually, it is a small system that needs to remove solids and has no other practical management option. In those cases, the pumper must ensure that the material is handled as biosolids and not as septage because the standards for treatment are different. Ensuring permission for materials from out of jurisdiction TWTDS is still required. This provision is meant to identify out of jurisdiction wastewater treatment facilities that participate in the state program. Ecology established long ago that treatment works participating in the state program should be treated equally. Facilities exporting to Washington should pay a fee equal to a similar facility residing within the State's jurisdiction. We do not believe it is an unreasonable burden to ask that Ecology be notified or to require approval. That gives the agency an opportunity to contact the generating facility and advise them of any consequences for participating in the state program (including but not limited to fees). Washington also has an agreement with Oregon. They expect advance notification and cooperation is critical to staying on good terms with our neighbors. The information required should be readily

Comment	Response
	available, and it is a necessary step for the receiving treatment works to ensure compliance. Ecology does not believe this requirement places any significant burden on the receiving treatment works. Instead, the generator is tasked with ensuring their own compliance. Please see also the response to comment LG-6-1.
I-113-7 In addition I believe WA should not accept any sewage sludge from other states or Canada until we have a handle on this problem.	I-113-7 Banning import/export could amount to an unlawful constraint on interstate transportation. Ecology requires any biosolids exported to Washington to meet the standards applicable for a similar facility with the same management approach. We don't believe there is justification for simply prohibiting importation, and especially when some of our facilities export to Oregon. Please also see the response to comment O-7-24 for more information.
O-7-24 2.4.1 What facilities are transporting non-EQ sewage wastes out-of-state? For transparency, this information should be listed. 2.4.2 Which facilities accept "biosolids" from federal governments, tribes, or from out-of-state? For transparency, this information should be listed.	O-7-24 In the context of the state program, amounts imported or exported are not significant. It is also not possible to know this information with confidence at any specific time since we cannot predict the occurrence of circumstances that might drive the need. All facilities exporting biosolids from or to Washington, must meet applicable requirements of both jurisdictions. Part 2.4.2. Accepting Biosolids from Federal, Tribal, or Out of State Facilities is included in the permit to ensure all biosolids originating from outside state jurisdiction, comply with state regulations and permit requirements. Import/export of biosolids is not very significant for the overall state program. It is usually related to the generating treatment plant not having the

Comment	Response
	ability to meet treatment standards, or it not being practical to pursue beneficial use on their own, and so they seek out a facility to meet those needs. Ecology's focus is to ensure that importers/exporters are not sidestepping regulatory obligations, including applicable fees and standards. The permit requires that treatment works must notify Ecology before accepting biosolids for the *first* time from an out-of-state jurisdiction. This will help Ecology ensure that facilities exporting biosolids to Washington meet the same standards as those produced in Washington, and pay fees if appropriate. If biosolids are being sent to a Washington facility for further treatment then they must provide notice to Ecology and information to the receiving facility, so that they can ensure the imported biosolids will not adversely impact their operations. If biosolids are imported for beneficial use, a permit or permit review is required to ensure compliance with Washington requirements. With these requirements implemented, Ecology feels maintaining a list of facilities that import/export materials to/from Washington state jurisdiction is unnecessary.

15. Labeling

Comment	Response
I-7-2 Seriously? The public has to fight the WA State DOEcology to implement public health and related science? Again? WTF is wrong with you scientists at DOE?: In many other such battles around Washington, "Biosolids" (the marketing name for the sewage sludge) is heavily pushed by Ecology as free fertilizer for farmers, and compost for gardeners. Read the labels of what you buy in the gardening stores.	I-7-2 The name "biosolids" was chosen, and codified in state law (RCW 70A.226[23]), to indicate sewage sludge that has been treated to meet standards for beneficial use. It also differentiates them from other sludges, as there are many. Please see also the response to I-55-4.
I-55-4, I-56-8, I-57-7, I-58-7, I-59-7, I-64-7 Please require that crops grown in this sewage waste and commercial composts be labeled as such I-61-3 Crops grown in the biosolids should be labeled as grown in that manner. We deserve to know what may be in the food that we eat. I-113-6 I also believe food grown and sold in stores should be labeled as being exposed to sewage sludge if that indeed occurred. How else will the public know what they are consuming if labeling is not required by law?	I-55-4 Biosolids are a treated residual that results from the treatment of wastewater. A good portion of biosolids are actually the beneficial microorganisms grown in a wastewater treatment plant to treat the wastewater. Ecology does not require labeling for crops grown on soils amended with non-exceptional quality biosolids, which is consistent with federal program rules. We are not aware of any other states that have such a requirement. Labeling would be unnecessarily prejudicial considering crops grown using manure, commercial fertilizer, and pesticides, do not require labeling. Several commenters shared their concerns about the possibility of contaminants in biosolids, such as PFAS, requesting more stringent sampling to ensure safety. Meanwhile, it is common for foods, produce included, to be packaged in materials that may contain PFAS, or other contaminants. The bulk of research and practical experience support that beneficial use is safe for human health and the environment when done so in accordance with state and federal regulations, and permit requirements. Ecology applies the same logic in supporting the use of other soil amendments, which also carry some risk. Animal

	manures and commercial fertilizer for example are more widely used on crops with fewer regulatory requirements. Although manure on rare occasions has been positively linked with outbreaks of illnesses, it is commonly understood that the benefits on crop growth and soil maintenance it has outweighs this drawback. Many fertilizer products are produced from fossil fuels and contribute to global warming. And so it is reasonable that the use of biosolids is not singled out with labeling. The amount of agricultural land to which biosolids are applied is very small (less than 0.2 percent statewide), and the amount of crops grown on biosolids is even smaller compared to the overall food supply. Ecology requires labels or an information sheet for exceptional quality biosolids *products*, which are those sold or given away to the public for use without further regulation. Generally, those are small quantities - bags, pickup truck, or trailer loads - although larger (bulk) quantities can be distributed. Note that the label or information sheet requirement is for the biosolids product, not for produce grown with the product. It is unnecessary to label non-exceptional quality biosolids products. They cannot be distributed to individuals for further use without additional site management and access restrictions implemented under the state permit program. Compost is generally regulated under solid waste rules, and labeling of crops grown with compost is not required. Ecology estimates about 739,000 tons of compost were produced in Washington in 2020, and about 46,000 tons (about 6 percent) were made in part with biosolids. Any compost produced using biosolids must meet standards for an exceptional quality biosolids product, plus any additional requirements for compost under state solid waste rules. Rules for compost facilities are found in Chapter 173-350 WAC - Solid Waste Handling Standards, and specifically WAC 173-

	350-220[67] for composting facilities. For more information on composting in general, please visit Ecology's composting guide[68].
O-5-7 We also respectfully request that all products made from biosolids be properly labeled. The term biosolids was coined years ago to mask the origins of this product to make it more marketable but this term is deceiving. Potential language could include "biosolids derived from sewage sludge" and be put on all biosolids products including: class A and class B, first and second generation, exceptional and non-exceptional. In addition, the results of the above testing should be included on the label.	O-5-7 Please see the response to comments I-7-2 and I-55-4.
O-7-6 We strongly recommend the following regarding the Draft General Statewide Permit:... ...The permit should require truth in packaging labels for compost and fertilizer Ecology must ensure more oversight and require more enforcement to protect the soils, waters and public health. One way to ensure public protection is through truth in labeling. This sewage-solid-laden compost and fertilizer, sold to the public loose as tonnage or packaged, whether pure or mixed with other wastes, should inform the public the	O-7-6 Please see the response to comment I-55-4.

[67] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-220
[68] https://ecology.wa.gov/Waste-Toxics/Reducing-recycling-waste/Waste-reduction-programs/Organic-materials/Managing-organics-compost

product contains municipal and/or industrial toxic wastes. A brief list of these contaminants and pathogens should be noted, with information about who to contact for more details.	
O-7-44 4.6.1 Labeling Requirements for Exceptional Quality Biosolids Bullet 3: "encourages proper use." There should be a stronger word than "encourages." Bullet 5: In addition to the requirement of adding to the label that the product contains or is derived from biosolids, which is a good rule, "biosolids" should be defined along with a warning of other contaminants and pathogens that could be in the product.	O-7-44 Regarding requirements for labeling, please see the response to comment I-55-4. Regarding the requirement to encourage proper use, Ecology believes that is the best approach. It matches the language in state rules. Neither we nor producers can control what homeowners do once they purchase a fertilizer or similar product. We think the best approach is to help people understand that there is a correct amount of (any) fertilizer or soil amendment, and more is not better.
O-7-45 Appendix B - Minimum Content for a Site-Specific Land Application Plan [SSLAP] (1)(c) concentrations of pollutants in the biosolids (if known) Is this referring to only the eight or nine heavy metals believed as "beneficial use"? The receiver should be made aware of the long list of pollutants, including PFAS.	O-7-45 The requirement identified by the commenter falls under section (1) of the plan requirements, which are consistent with federal requirements, and reads as follows: " Whether or not it is known or can be determined that biosolids containing pollutants in excess of the values WAC 173-308-160[69] Table 3 have ever been applied to the site, and if so: This requirement applies to past practices (not the quality of biosolids that might be applied), and the information must be provided to Ecology by the proponent in order to determine whether cumulative pollutant loading rates might apply to the site. If pollutants in excess of the values in Table 3 have not been applied, then the cumulative loading rate restriction is not triggered. Biosolids in Washington generally fall far below federal limits. It is unlikely that a landowner would accept biosolids with levels of any pollutant that would require cumulative tracking, and we are not aware

[69] https://app.leg.wa.gov/WAC/default.aspx?cite=173-308-160

	of it happening under the current program. For more information on the cumulative loading of regulated pollutants, please refer to a separate discussion titled “Heavy metals and biosolids” that readers can find in the key topics section at the front of this response to comments. There is currently no requirement to speculate in a label about pollutants that might be present on a site where EQ biosolids might be used, nor would such a requirement be reasonable. Recipients of EQ biosolids are informed of the source by the label or information sheet, and recipients of non-EQ biosolids are part of a permit process where information on compliance changes hands.

16. Liability

Comment	Response
O-7-47 **IV. Neighboring Lands Concerns**. *The legislature declares that a program shall be established to . . . ensure that municipal sewage sludge . . . is managed in a manner that minimizes risk to public health and the environment.* RCW 70.95J.005(2). *Biosolids must not be applied or allowed to run onto non-permitted areas. . . Properly designed surface and groundwater buffers protect water quality off-site. . . When designing property buffers, your objective will be to reduce any nuisance to neighbors and the public.* Ecology Biosolids Management Guidelines, Publ. No. 93-80, p. 4-21, -22. *Facilities and sites where biosolids are applied to the land must comply with other applicable federal, state and local laws, regulations, and ordinances* . . . WAC 173-308-030(6). *The intentional deposit of microscopic particles could give rise to action for trespass as well of claim of nuisance.* Bradley v. American Smelting, 104 Wash.2d 677 (1985) Alexander-Barrett-Comments-on-FMF-Rosman-SSLAP-10-31-16-FINAL.pdf http://protectmillcanyon.org O-2-12, O-7-48 The permit does not address insurance, bonding, liability, and compensation when a spill occurs. In 2015 a LOOP truck spilled 30,000 pounds of biosolids into Swauk Creek near Blewitt Pass. These things happen. There should be provisions to ensure that the responsible party and not the taxpayers, returns the natural environment to as normal as possible, and that there is adequate supervision of the restoration.	O-7-47 The commenter here calls on language from statute, rule, guidelines, and legal precedent. Use in agriculture is a common practice in Washington and throughout the United States. All sites are permitted with respect to activities on adjacent property. O-2-12, O-7-48 Ecology does not agree that additional financial measures would insulate taxpayers from the consequences of accidents. All costs are eventually passed back to ratepayers, including those for servicing onsite wastewater treatment systems. In the case mentioned by the commenter, the truck was operated by a local government. Generators and trucking companies carry liability insurance. Violations of permit requirements are subject to enforcement that can include civil and criminal penalties.

O-7-46 Appendix C -- Delegation of Signature Authority. This may be the appropriate section, or there could be a separate section, about who holds liability for ruined land where sewage wastes are spread.	O-7-46 Chapter 70A.226 RCW[23] grants Ecology the authority to pursue both civil and criminal penalties under the enabling statute for the state biosolids program. In addition, Ecology has enforcement authority under Water Quality laws. The size of any monetary penalty will vary with the nature of the offense, whether it was knowing and willful, and the history of the regulated party. Ecology could assess a higher penalty and negotiate to reduce the penalty based on the offending party's willingness to correct actual damages resulting from non-compliance. Any liabilities beyond that are the province of the courts.

17. Acknowledgement

Comment	Response
I-29-1 I think this is acceptable.	I-29-1 Ecology notes your comment.
I-49-1 I endorse the very expert critique that the Washington State Chapter of the Sierra Club is sending you on your program's proposed renewal. I have participated in some in its construction.	I-49-1 Please see our response to comments O-7 and O-8, submitted by the Washington State Chapter of the Sierra Club.
I-53-1, I-105-1 I am a retired career EHS professional that is extremely concerned about the historic, current, and future impact of the Washington State General Permit for Biosolids and its impact on people, ecosystems, and the environment. I retired in January 2019 after 42 years with DuPont and a spin-off company, Axalta Coating Systems, as their Global Environmental Competency Leader. I am a Chemical Engineer with a BS and MS in Hazardous Materials Management by education and a health and environmental manager by career. Since May 2019, I have been the Sierra Club -- Michigan Chapter, Toxics & Remediation Specialist. I have reviewed the Draft Statewide General Permit for Biosolids Management and the Ecology "Per- and Polyfluoroalkyl Substances [PFAS] Draft Chemical Action Plan" and have the following additional comments.	I-53-1 As regards the PFAS Chemical Action Plan[35], the CAP was developed in a separate process. Ecology accepted comments on the CAP from October 7, 2020 to January 22, 2021. Our response here regards the draft general permit and we will not address comments specific to the CAP. Ecology has made commitments in the plan to address the question of PFAS in biosolids.
I-56-1 Washingtonians care deeply about the environment, sustainability, public health, and related priorities. I support the Sierra Club's science and the recommendations.	I-56-1 Ecology notes your comment Please see our response to the entirety of comments O-7 and O-8, submitted by the Washington State Chapter of the Sierra Club.

Comment	Response
I-68-1 It should be ok to place this waste on farmlands or forest land. It will help grow plants. I think it is a good use of sewage and helps grow plants. The toxins in this is probably quite minimal.	I-68-1 Ecology notes the commenter's support for beneficial use on farm and forestlands.
I-86-1 I support the application of biosolids to agricultural land for soil enhancement, provided that the biosolids do not contain toxic levels of metals or carcinogens. I support an integrive approach to biosolids, so that after pathogens have been killed, its nutrients can replenish the soils from which they came.	I-86-1 Ecology notes the commenter's support of beneficial use when pollutant limits are not exceeded and pathogen reduction has been met.
I-123-1 *This comment was submitted verbally during the June 22nd Public Hearing.* Okay, great. Hey, good morning everyone, this is Heather trim. I'm executive director of Zero Waste Washington and, 2 comments, 1 is about this actual public hearing. I'm really grateful that you're doing it via an online method, but I do think that it is not okay not to be showing who all the attendees are. If we were coming in person to a hearing, you would be able to see all the attendees, including the guests like me and then also the people who are presenting, and I think that that, I think legally, it just seems, very strange that you're not able to, show everyone. And I do feel that you should for future hearings. And right now, if you could just show everyone on the share screen, that would be ideal to show who all is here.	I-123-1 We appreciate the commenter attending our virtual June 24, 2021 public hearing on the draft general permit for biosolids land application and appreciate their feedback on the meeting itself. Unfortunately the Cisco's Webex software we used to host this virtual public hearing does not allow attendees to see other attendee's names in an event. If you would like to get a list of those who attended, you can make a public records request[65].

Comment	Response
O-5-1 Thank you for taking the time to consider our comments on the draft General Permit for Biosolids Management… …RE Sources is a non-profit organization located in northwest Washington and founded in 1982. We work to protect the health of northwest Washington's people and ecosystems through the application of science, education, advocacy, and action. Our priority programs include Protecting the Salish Sea, Freshwater Restoration, Climate Action, and Fighting Pollution- all critical issues affecting our region. Our North Sound Baykeeper is also a member of the Waterkeeper Alliance, with over 300 organizations in 34 countries around the world that promote fishable, swimmable, drinkable water. RE Sources has thousands of supporters in Whatcom, Skagit, and San Juan counties, and we submit these comments on their behalf.	O-5-1 We appreciate the efforts of RE Sources in trying to ensure a healthy future for citizens in northwest Washington as well we expect the rest of the state.
O-7-1 Thank you for the opportunity to comment on the Washington State Department of Ecology's Statewide General Permit on Biosolids Management. These comments are being submitted by the Washington State Chapter of Sierra Club. The Washington State Chapter of the Sierra Club is a 501(c)(4) non-profit organization with over 100,000 members and supporters in Washington State and over 3.8 million nationally. Headquartered in Seattle, the Washington State Chapter members and supporters live throughout the state of Washington. Many Sierra Club members and supporters are directly affected by the land spreading of sewage solids/biosolids whether delivered by truckloads to neighboring farms, forests and recreational sites, or purchased	O-7-1 We recognize the efforts and dedication of the Sierra Club to environmental issues. We agree that a detail of the acronyms could be helpful to identify facility operations based on their names. For example, some facilities identify as Sewage Treatment Plants (STP), some as Wastewater Treatment Plants (WWTP), and some as Water Reclamation Facilities or Plants (WRF/WRP). We will not update the Fact Sheet since its role of providing background and supporting information for the process is fulfilled, but will keep this in mind for future renditions of the list. Ecology is the lead agency for regulating and permitting biosolids management facilities, per state statute. Ecology recognizes the interests of

Comment	Response
from commercial vendors for gardens… …A list of Acronyms should precede the Facility List on Page 11 of the FACT SHEET… …The Washington Department of Health should be more engaged in the permitting process… …Last, the act of our commenting on the Draft Biosolids General Permit Plan does not imply that we agree with land spreading this waste, for we do not.	the State Department of Health in certain specific contaminants as well as in protecting drinking water resources. Ecology will consider DOH's request to participate more closely in the next permit cycle. We are also considering working with them to reassess buffers under the state biosolids program.
O-8-1 Thank you for the opportunity to comment on the state biosolids permit. We, the undersigned advocacy organizations, would like to comment on issues related to the presence and management of toxic chemicals including per- and poly-fluoroalkyl substances (PFAS) in wastewater and biosolids in the state's draft general biosolids permit. Blaine AC, et al. 2013. "Uptake of Perfluoroalkyl Acids into Edible Crops via Land Applied Biosolids: Field and Greenhouse Studies." Environmental Science &Technology 47(24): 14062-14069. https://doi.org/10.1021/es403094q Colorado. 2020. PFAS Narrative Policy Work Group. Colorado Department of Public Health and Environment. https://cdphe.colorado.gov/pfcs/narrative-policy-work-group Li Y. 2021. "Assessing Potential Exposure to Per- and Polyfluoroalkyl Substances (PFAS) in Produce and Drinking Water in Chatham County, NC." Master's Thesis, Duke University.	O-8-1 Ecology sees that the Sierra Club joined Toxics Free Future in submitting comments, in addition to comments submitted separately by Sierra Club.

Comment	Response
https://dukespace.lib.duke.edu/dspace/handle/10161/22618 Maine. 2021. Per- and Polyfluoroalkyl Substances (PFAS). Maine Department of Environmental Protection. https://www1.maine.gov/dep/spills/topics/pfas/ index.html Massachusetts. 2021. PFAS in Residuals. Massachusetts Department of Environmental Protection. https://www.mass.gov/info-details/pfas-in-residuals Michigan. 2021. Michigan Biosolids PFAS-related information and links. Michigan Department of Environment, Great Lakes and Energy. https://www.michigan.gov/egle/0,9429,7-135-3313_71618_3682_3683_3720- 534046--,00.html Naidenko O, Evans S. "2020 PFAS in Wastewater: Disposal Challenges." 2020. Water Solutions. 57-61. New Hampshire. 2021. Biosolids. New Hampshire Department of Environmental Services. https://www.des.nh.gov/land/biosolids Stoiber T, Evans S, Naidenko OV. 2020. "Disposal of products and materials containing per-and polyfluoroalkyl substances (PFAS): A cyclical problem." Chemosphere, 260:127659. https://www.sciencedirect.com/science/article/ pii/S0045653520318543	

Comment	Response
United States Environmental Protection Agency. 2018. Office of the Inspector General. EPA Unable to Assess the Impact of Hundreds of Unregulated Pollutants in Land-Applied Biosolids on Human Health and the Environment. Report No. 19-P-0002. United States Environmental Protection Agency. 2020. Session 6: PFAS Treatment in Biosolids—State of the Science. Mark Mills, EPA Office of Research and Development. September 23, 2020. PFAS Science Webinars for EPA Region 1 and State & Tribal Partners. https://www.epa.gov/sites/production/files/2020-10/documents/r1-pfas_webinar_day_2_session_6_mills_final.pdf United States Food and Drug Administration. Undated. Analytical Results of Testing Food for PFAS from Environmental Contamination. https://www.fda.gov/food/chemicals/analytical-results-testing-food-pfas-environmental-contamination Vermont. 2020. Solid Waste Management Rules. State of Vermont. Agency of Natural Resources, Department of Environmental Conservation. Rule number 20P-005. https://dec.vermont.gov/sites/dec/files/wmp/SolidWaste/ Documents/SWRule.final_.pdf Washington Ecology. 2021. Per- and Polyfluoroalkyl Substances Draft Chemical Action Plan. https://apps.ecology.wa.gov/publications/summarypages/2004035.html	

Comment	Response
T-1-3 We do not see these issues clearly identified in the proposed general permit and are willing to work with staff to incorporate these critical elements into the general permit. The Nisqually Indian tribe is interested in the further development of this program and reserves the right to seek a government to government meeting to resolve any remaining areas of disagreement.	T-1-3 We appreciate the interest of the Nisqually Indian tribe. Ecology needs to consider the program on a statewide basis - while not overlooking individual site or watershed issues. Please see also our response to comment I-118-4.

18. Posting of Sites

Comment	Response
O-7-32 (11) *A description of how access to the site will be restricted (e.g. signs posted around the site or other approved method of access restriction.* Only a handful of such signs around large acreages of septage and biosolids spreading sites is typical. There should be more! (See comment under 2.1.8.1) In addition, at one site in Mason County, septage haulers were allowed to deposit their loads with no paperwork required and no advance notification. A local urban sewage treatment plant had this policy for a short time, as well. Nighttime recreational dumpers brought in loads of septage so toxic and corrosive that the plant needed to be shut down to allow the bacteria to regrow.	O-7-32 The minimum requirement is to post signs at all significant points of access and at a minimum every 1/2 mile around the perimeter. Ecology can require additional signs if circumstances warrant. Persons concerned about inappropriate access to a proposed or existing site should contact staff in our regional office. Ecology is unaware of a circumstance where septage haulers were allowed to deposit loads with no paperwork or notification. Nor are we aware of a circumstance where a sewage treatment plant allowed nighttime offloading from recreational vehicles. The commenter did not provide any substantiation for these claims. Biosolids management requires record keeping, and sewage treatment plants generally charge for their services.
O-7-36 We strongly recommend the following regarding the Draft General Statewide Permit:... ... The permit should strengthen signage regulations… …**3.8.2** Public Access Restriction. A font size should be specified. The size for easy observance can vary depending on distance. Signage should be easily visible to public passers-by whether on foot or by vehicle. Same for Section 4.2 Notification.	O-7-36 There are two circumstances when posting notice is required: 1. Sites where septage or Class B biosolids are applied require advisory posting of site access restrictions. 2. When there is an opportunity for public comment. The contents for each type of notice are described both in the rules and within the permit. The content for notices restricting access is found in WAC 173-308-275[70] and sections 3.8.2 (septage) and 4.5.9.2 (biosolids) of the general permit. The content for notices advertising public events is found in WAC 173-308-310(13)[62] and (14), and sections 3.8.2 (septage) and 4.5.2 (biosolids) of

[70] https://app.leg.wa.gov/WAC/default.aspx?cite=173-308-275

Comment	Response
	the general permit. Font sizes are not specified because as the commenter pointed out, observance varies depending on site characteristics, and it would be impossible to specify a font size that would suit all sites. Ecology will consider developing a clearer policy to establish a minimum size for signs and lettering. If someone is concerned about a specific site's signage we recommend contacting the regional biosolids coordinator[63].
B-1-2 5. Tables S2& B4 Site restriction signs a. If the generator is not doing the land application under their permit should not be listed on the sign b. It could create confusion as the generator may not be familiar with application area or Operation that is going on c. It could also lead to Generator being harassed because someone doesn't like Biosolids application. d. I could also lead to Questions, Comments, Complaints going to someone at a city and never making it back to the permitted beneficial use facility (BUF) e. Sign should have i. Site restriction ii. Permitted BUF & contact information iii. Responsible DOE region office	B-1-2 The content of signs restricting access and including the name of the generator is actually specified in rule under WAC 173-308-210[71], along with other information. Ecology cannot revise this requirement under the general permit.

[71] https://app.leg.wa.gov/WAC/default.aspx?cite=173-308-210

19. Enforcement

Comment	Response
O-7-51 We strongly recommend the following regarding the Draft General Statewide Permit: ... The permit should strengthen oversight and enforcement I-55-2, I-56-3, I-57-2, I-58-2, I-59-2, I-64-2 Please increase oversight and enforcement for when and where the sludge is spread.	O-7-51 At Ecology, our goal is to always strengthen oversight and enforcement. Successful implementation requires time for both staff review of proposals and data, and time in the field inspecting outcomes. We have made changes to this permit so that staff spend less time on administrative or bureaucratic tasks and more time on critical reviews and in the field. To achieve this increased efficiency, we streamlined the permitting process for facilities that do not have an active biosolids management program. This means facilities that do not land apply and do not sell or give away biosolids, all of their materials are sent either for disposal or for further treatment at another facility. This will reduce the time spent on administrative tasks for WWTPs as well as Regional Coordinators. Regional Coordinators can spend this time focusing on the technical assistance and oversight portions of their work. We will stay on this course and hope to show improvement in permit processing and oversight. Ecology will continue to look for other efficiencies in program implementation.

20. Climate Change

Comment	Response
O-7-52 We strongly recommend the following regarding the Draft General Statewide Permit:... ... The permit should address climate change in relation to changing soil qualities	O-7-52 Existing research has shown that the beneficial use of biosolids results in carbon being sequestered in the soil. This reduces the release of carbon dioxide to the atmosphere, and works towards the goal of reducing global climate change. Another climate change benefit from the land application of biosolids is that it also avoids the greenhouse gas impacts of incineration and landfilling. The use of biosolids also avoids the use of commercial fertilizers that consume large amounts of fossil fuels in their manufacture.[72][73] We have not yet seen any research that demonstrates any impact to soils from beneficial use of biosolids that would result in an adverse impact to climate.

[72] https://pubmed.ncbi.nlm.nih.gov/34167053/
[73] https://pubs.acs.org/doi/10.1021/es2010418

21. Site Specific Comment

Some commenters remarked about circumstances at individual sites with which they are familiar. The purpose of this comment process was to address the terms and conditions of the general permit. Circumstances specific to individual sites or facilities must be addressed during their respective review process.

Comment	Response
B-2-1 This is disgusting. How can you possible accept this as a best managment practice. There is a guy that dumps this shit on his fields above Rock Lake. That drains straight into the lake! Probably going to be on the rock lake conservation district about that.	B-2-1 We acknowledge and understand the commenter's concerns. The general public has the opportunity to comment on individual sites during a specific comment period for their permit application/approval process. Commenters can also contact staff in the appropriate regional office[63] with concerns about a specific site related to permitting status, operations, or compliance. Any person interested in permit activities can Register for Updates[25] to become an interested party and be notified of biosolids activities. Be sure to select the county or counties where you are concerned about land application. You may also select the county where biosolids are treated prior to land application, but that will not necessarily inform a subscriber about land application in a separate county.

I-5-1 My family used to live in Mill Canyon and I still visit and have friends who live there and rely on the water there. Please don't allow the use of sewage sludge to empact the water in this and other rural areas. People leave cities in search of a more pollution free environment and then unthinking pollution comes looking for them. The idea of sewage sludge sounds like good reuse of waste products, but we all know a lot more goes down drains than water and natural waste. Chemicals of all kinds,many known to be hazardous to humans and animals. There are gardens, some the source not only of food for local families but also sold to markets in nearby cities and are the only source of income to some people. Please protect the safety of water that touches so many lives.	I-5-1 Please see response to comment B-2-1.
I-6-1 I vote NO! Protect Mill Canyon Watershed. Sewage Sludge has too many contaminants that can be passed to other areas in dust and into other owners' water supplies. Some things are tested for, but too many chemicals, micro-plastics, pharmaceuticals, other harmful substances and unknown contaminants are not tested for. Our land and our water sustain us; keep them safe.	I-6-1 Please see the response to comment B-2-1.
I-7-4 Of course none of this matters to the Department of Ecology, which is in the grip of the waste and other polluting industries. Ecology staff is very aggressive in pursuit of their "partnership" (Ecology caseworker's term) with one of the state's main wholesalers of sludge, Fire Mountain Farms. FMF has been repeatedly slapped on the wrist by its partner,	I-7-4 Please see the response to comment B-2-1 to obtain information or inquire about a specific site. More information can be found on the cleanup site[74] concerning the cleanup activities of Fire Mountain Farms and Emerald Kalama Chemical that you have referenced. While state and federal law currently consider the waste to be “listed” as hazardous waste, the companies collected data

[74] https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Industrial-facilities-permits/Emerald-Kalama-Chemical

Ecology, for code violations like storing chemical wastes in the same piles of "biosolids" that it land spreads around the state. FMF intentionally created a "mixed" product to spread on agricultural fields that sometimes was comprised of as much as 15% of listed hazardous waste. A search of Ecology documents by Yelm-based Preserve the Commons found that much of it was flammable with large quantities of paint thinner.	that showed that this waste does not contain enough harmful chemicals to be considered dangerous. As a result, Ecology and the EPA approved a petition from both companies in spring of 2020 to manage this waste as solid waste instead of a dangerous waste."
I-20-1 The smell when they spread the bio solids on hayfield is sickening. Plus traffic from trucks dumping sewage uphill from me is terrible. The biofield is on Web Hill Road, Shelton. I drink water from down hill well. I now have cancer. I can't prove corilation between it but I can blame them.	I-20-1 Please see the response to comment B-2-1 to obtain information or inquire about a specific site. Ecology has been watching the site near the commenter's home closely for more than ten years. The North Ranch site operated by BioRecycling is the only one in the state with offsite resource protection wells placed at the cost of the operator to monitor for potential contamination downgradient of the application site. No off-site contamination has been detected, and data show an overall improvement in response to significant shifts in management practices at the site.
I-48-7 The Department of Ecology has had a checkered history managing its biosolids program and enforcing its own regulations. The Agency knew for 20 years that one company it permits to spread biosolids intentionally created a "mixed" product to spread on agricultural fields that sometimes was comprised of as much as 15% of listed hazardous waste. A search of Ecology documents by Yelm-based Preserve the Commons found that much of it was flammable with large quantities of paint thinner. The company has violated regulations on several occasions and been slapped on the wrist repeatedly by Ecology, but Ecology	I-48-7 Please see the response to comment B-2-1.

allows the outfit to continue operations at full bore. Other applicants have submitted erroneous and incomplete environmental impact assessments required under the State Environmental Protection Act (SEPA). Ecology has accepted flawed "SEPA checklists" and went ahead and approved those biosolids applications. Only concerted public outcry has ever caused Ecology to reject an errant SEPA checklist. Apparently, it's too much trouble for the agency to check the accuracy on its own. Environmental assessments of potential biosolids-receiving farms, primarily left up to the applicant but really the responsibility of the agency, have routinely been cursory, bordering on negligent. In some cases, assessments failed to identify existing wells and drinking water springs in the affected area or failed to make note of critical aquifer recharge area designations of potential sites. Post-application monitoring of biosolids disposal sites (farms, etc.) is non-existent-- No mandated groundwater testing-- No mandated soil testing-- No mandated crop tissue analysis.	
I-49-2 I'm going to focus here on my experience and that of others with your program's very sloppy practice. I did this once before, and am used to the lack of response any more detailed than to simply cite the parts of the code under which your actions are based. So, that might be my first suggestion: That you give real and attentive replies to criticisms of your practice. As some of your staff may recall, my contact with your department has to do with the process which resulted in the 2017 permit you issued for land application of sludge on Rosman Farms in Lincoln County. In that case the farmland borders Mill Canyon, home to commercial organic food producers and a	I-49-2 Please see the response to comment B-2-1 to obtain information or inquire about a specific site. We cannot speak to the commenter's apparent dissatisfaction with a previous site-specific process, although we regret the commenter did not feel heard. Generally, our goal for any public process is to provide clear evidence that we have heard a comment. That does not necessarily mean that we will have agreed with it. If we have not agreed, then we try to provide some explanation as to why.

natural spring supplying many neighbors drinking water (directly downhill from one of the targeted wheat fields). The concern was about migration of toxins through flooding, wind storms and the fact (established by USDA soil maps) that most of the farmer's land is classified as HEL, Highly Erodible Land. (In fact it straddles 2 canyons.) At that time a federal soil scientist called it the most inappropriate location for such an application of potentially toxic material, and said that his agency would never approve such a venture. The farmer's fields had also been (and probably continues to be) the recipient of dumping by a local septage company. Fortunately, local citizens organized through Protect Mill Canyon Watershed to block that land application of "biosolids". ... ...Of course none of this matters to the Department of Ecology, which is in the grip of the waste and other polluting industries. Ecology staff is very aggressive in pursuit of their "partnership" (Ecology caseworker's term in the Rosman Farms case) with one of the state's main wholesalers of sludge, Fire Mountain Farms. FMF has been repeatedly slapped on the wrist by its partner, Ecology, for code violations like storing chemical wastes in the same piles of "biosolids" that it land spreads around the state. FMF intentionally created a "mixed" product to spread on agricultural fields that sometimes was comprised of as much as 15% of listed hazardous waste. A search of Ecology documents by Yelm-based Preserve the Commons found that much of it was flammable with large quantities of paint thinner… ...In our case, there were 3 separate Site Specific Land Application Plans, all contradictory, in effect at the same time. They listed only wells in our canyon, including one	

on the opposite wall of the canyon from the one that could be affected by the land application. They didn't even appear to be aware of the springs that support animal (including human) and plant life, probably because it would have required more research than simply looking up records of registered wells. The caseworker was overheard to say in frustration, "Why are these people drinking from springs?" Among the listed wildlife, coyotes were absent. They obviously never set foot in our canyon. They even got the land descriptions wrong.	
I-65-1 What are the permitted hours of operation I have tanker trucks passing my house at 5;30 in the morning going up to the lagoon	I-65-1 Please see the response to comment B-2-1.
I-90-1 Please do not reauthorize the spreading of biosolids on farm and forest land in Mills Canyon.	I-90-1 Please see the response to comment B-2-1.
I-105-6 In the April 2021 Response to Public Comments: Fire Mountain Farms Biosolids Permitting Agreed Order, Ecology repeatedly quotes Prosser RS and PK Sibley. 2015. Human health risk assessment of pharmaceuticals and personal care products [PPCPs] in plant tissue due to biosolids and manure amendments, and wastewater irrigation, in their responses and excuses for not considering public concerns about potential contaminates in land applied biosolids. This study and article contains conflicting data and erroneous conclusions and should not be used as a supporting reference for continued land application of biosolids. Examples of misleading data and erroneous conclusions	I-105-6 Please see the response to comment B-2-1 to obtain information or inquire about a specific site. We are continuing to work on various substances of concern, and are staying in touch with U.S. EPA as they develop a new risk screening tool.

includes: "While the values for a number of the hazard quotients reported in the original paper have changed, the conclusion from the paper has not: the majority of hazard quotients for individual chemistry were < 0.1 and indicate de minimis hazard to human health. However, when additivity is assumed, a number of the hazard quotients exceeded 0.1 indicating the potential of the mixture to pose a risk to human health and the need for further assessment." And "Assuming additivity, the mixture of PPCPs could potentially present a hazard. Further work needs to be done to assess the risk of the mixture of PPCPs that may be present in edible tissue of plants grown under these three amendment practices." Health risk studies should not simply look at single contaminate hazard indices when it is known that there are numerous contaminates (in this case, PPCP) with similar, cumulative effects present in biosolids and where additive impacts must be considered. Recommendation: Ecology should gain a better understanding of the articles and topics that they quote in response to valid public concerns about their health and should definitely stop quoting this particular study. Perhaps it would be wise to consult the Washington Health Department when using such articles as supporting evidence of continued land application of biosolids. Protection of public health and the environment is Ecology's responsibility.	

I-118-1 Although I am a member of Hood Canal Improvement Club, the Lower Hood Canal Watershed Coalition and the Mason County Onsite Septic Advisory Committee my comments below are solely my own. I have been involved in the biosolids issue and its possible contributions to surface, ground and marine waters since 1999. I present a timeline with actions and inactions on sewage sludge, septage, biosolids that stand out for me. In 2003, a watershed-coalition sponsored a discussion that included the biorecycling operator, septic pumpers, Mason County and Ecology staff. Ecology staff stated that the operator was a "model" for the state and meeting all permit requirements. In 2004-2005, fish kills occurred in Lower Hood Canal and drove the establishment of the Low Dissolved Oxygen Program for Hood Canal which triggered an investigation on whether this biorecycling facility was a possible contributor to excess nitrogen to Hood Canal. Former Congressman Norm Dicks requested the EPA to look at possible water quality impacts from the septage/sludge land application site Biorecycling at Webb Hill in Mason County. In 2006 Curt Black, EPA Region 10, Office of Environmental Assessment submitted Issues Identified for the Biorecycling Site (Webb Hill Road) in Mason County for the Potential Loading of Nitrates and Other Contaminants to Hood Canal, March 30, 2006. Ecology staff requested edits to this document to minimize the probable water quality impacts from this site. In an April 2007 cover letter accompanying the final report, Tom Eaton, Director of ;'Washington Operations, EPA Region 10, makes recommendations for further monitoring to determine contaminants in neighboring drinking water wells and an "assessment of	I-118-1 Please see the response to comment B-2-1 to obtain information or inquire about a specific site. Multiple Ecology staff thoroughly reviewed all of the reports and documents related to arguments that the BioRecycling operation was impacting Hood Canal. Ecology did not find any connection between BioRecycling's operation and the decline of water quality in Hood Canal, which is well documented as being attributable to other sources.

underlying soil how it relates to groundwater flow." In 2007, WRIA 16-14b planning group took up the possible contamination from this site. With funding from Ecology, Aspect Consulting prepared its September 6, 2007, Phase I report for the WRIA 16-14b group This report found nitrogen levels above federal and state drinking water standards in the first aquifer below the surface of the biosolids application site. Ecology staff ordered Biorecycling at Webb Hill to immediately cut its land application in half. In 2009, Agreed Order Nbr. 6348 between Ecology SW and Biorecycling operator was signed. This legal document had no timetable, no benchmarks, no penalties. Through 2017, this operation has yet to achieve the appropriate agronomic rate as required in its permit. It is essential that an Agreed Order have some teeth to be enforceable. May 17, 2012, Ecology staff gave a presentation to WRIA 16/14b watershed planning group and confirmed Curt Black's , EPA, 2006 analysis that Biorecycling at Webb Hill Road drains to the Skokomish River, Hood Canal, and possibly Oakland Bay. and that 20% of the groundwater from this site drains to Hood Canal.	

I-124-1 *This comment was submitted verbally during the June 24th Public Hearing.* Hello, I'm Allen R. Guenther, Bob Guenther and I live at 376 State Route. 508 in Chehalis. Can you hear me okay? Okay, so I've lived here for well over 40 years across the road from the Newaukum Prairie site. And we have endured just a lot of problems, especially with odors in the biosolids applications on that site. We've experienced everything from debris on the highway going a half a mile either way on the highways. We've experienced extreme odors. I've had Laurie Davies - Kyle's been down here several others and unfortunately, by the time folks get here, as Kyle said, some of the odors have diminished. But what I want to say is The Department of Ecology has come a long ways in the last few years on making the applications more stringent and controlling it better than they have. But in the case of this lagoon that we have here on the Newaukum Prairie site, in the case of that lagoon what has happened over the years is as that lagoon is being filled, then it goes anaerobic and then when they go ahead and pump it out to put it on the ground, it stinks to high heaven. So, I just wanted to say is that since the Kalama chemical incident where that lagoon was had Kalama chemical stuff put in it, material, they haven't pumped anything out of that lagoon for a long time and are ordered to remove the Kalama chemical liquid out of that lagoon. I want to say there's been no or odor since they have started pumping that. So I want to make sure that we give credit where credit's due. But the thing I want to say that if we're going to land apply biosolids, that we should have a predict amount that is going to	I-124-1 We appreciate the commenter attending our virtual June 24, 2021 public hearing on the draft general permit for biosolids land application. We acknowledge and understand the commenter's concerns, and noted the commenter's support for an improved biosolids program. Ecology agrees, with this sentiment and is always working to improve upon our biosolids program. We believe the changes made to this iteration of the general permit for biosolids management are proof of our efforts. Ecology requested comments on the whole of the draft general permit for biosolids management. This comment seems to pertain to a particular site and therefore is beyond the scope of this comment period and response. Please see the response to comment B-2-1 for more information about how to inquire about specific land application sites and becoming an interested party.

be put on the land, especially just such as the Newaukum site. And we should tell that in within 24 hours, or within 6 to 10 hours after the material is applied on the land. What's happening to us, what has happened, and I've got lots of pictures and and incidents to show, is that when it's applied after September 30th, then the growing season's over and that material does not have a chance to uptake in the, with the grass and actually I believe sincerely that a good share of that liquid flows down to the Newaukum River, which is about 2 miles away. So I'm not, I'm not against applying biosolids in a proper manner, but I don't believe in the past we've been doing it in a proper manner. Kyle Dorsey talks about injecting. I've watched injecting going on down here where the injection unit would go along and the clay soil would close right up behind the injector and put the material right back out on top of the ground. So, in the clay soil at least in this area, it doesn't work because of the of the moisture content that's in the soil. So, I'm just saying, I think there's a better way of doing business and I think Mr. Thode can work on that. And I realize it costs quite a bit more money to till in as you receive it, but there's no reason that you can't set aside land that's going to receive biosolids at an agronomic rate that is acceptable, and till it in when it's when it's put on the ground…. …If there's any questions I'd be happy to answer. And I hope I didn't rattle on here too long. But I think statewide permit, I think we do have to dispose of biosolids. I have no problem with that. I'm heartened to hear that we can go to class A biosolids eventually down the road, and we fought this biosolids issue in Lewis county for a long time. I was on a	

biosolids committee before they built the new sewage treatment plants in Centralia and Chehalis, and today if I'm not mistaken, the class A biosolids is being applied on fields, and I've seen it applied, there is absolutely hardly any odor and the crops grow like heck. So, I think there's a, a better methodology of doing it than what we've been doing in the past, and I think Ecology is on the right track. I hope to heck that we do not permit that lagoon at Newaukum prairie to be used again. Because Kyle Dorsey and Laurie Davies and myself, and Bob Thode stood on that, stood on that dike a number of years ago, when that lagoon was built. And I said to all of them, that lagoon will leak and, it did leak. And then Ecology made the Thode's put a rubber liner in there because it was leaking. And I was told, I told folks that day that will leak and I was told, oh, you don't have to worry about that because it's an impervious clay liner on the bottom of this lagoon and it won't leak. That very day Kyle Dorsey was walking around at the bottom of that lagoon in buck brush. Buck brush is what grows in wetlands and that's where that sets; right in the middle of a wetland. So anyway, that's my two bits worth at this point in time. Statewide I know we have to do away with, do land applications of biosolids. I'm not out to break anybody. I'm out to make sure that we do it a little bit better and a little different than we have been. The odors have been horrific at this house at times. You can't, sometimes, there were times that we couldn't even set in the living room without the odor of biosolids. And it was hard to get Wyn down here, Wyn Hoffman down here to actually witness it. But a case in point is Denny Hadler, Lewis County commissioner. I called him one day,	

and I said Denny get out here and smell this. And Denny puked in the ditch when he stopped by the, by the biosolids application site. He threw up! And I also had a friend that was an entodontist. And the entodontist said to me, Bob, that is the worst smell I've ever experienced. And if you've done, ever been around a root canal, you know what that smells like. So, I guess I'm at fault for not getting attention of the Department of Ecology to come down when it was the worst. But you can talk to my neighbors. You can talk to a lot of folks. And it, it was pretty bad, but I think it's, I think it's going to get better. I think there's an opportunity to work with the Fire Mountain Farms, and get this done, right. It's all a matter of money. It's going to cost more money to till it in as the material comes. But I think that we can do that in a predictive manner. And we can do that without the water table being three feet from the top of the ground. Right now they're bailing hay down there on that on that site. The southwest extreme corner of that site that was receiving biosolids over the years, you probably get stuck in there with a tractor today. So I'd say, you outa, you outa check the water levels, because I think in that that particular area, it's within 3 feet of the surface. So, any other questions or anything I won't rattle on any longer. Thank you.	

O-7-26 3.4 and 4.4. Requirements for Sampling, Analysis, and Process Monitoring: These sections for septage and biosolids are good. Yet with the current state of Ecology's oversight, a land-spreading corporation can pollute a site with nitrates for over 20 years and regulators seem to look the other way. For example, this occurred when the reputable firm, Aspect Consulting, found nitrate concentrations in groundwater over 100 feet below the surface above statewide drinking standards. The testing requirements and the oversight was extremely lax before and after application. This is true, too, when material listed as hazardous or dangerous waste can be mixed with biosolids and pollute the air, soil and groundwater for decades.	O-7-26 In 2008 Ecology performed a thorough assessment of the circumstances at this site. Ecology concluded that the likely source of the problem was the mineralization of accumulated organic nitrogen to nitrate. Mineralization is the conversion of organic, or slow-release nitrogen, to the nitrate form that plants can readily use. Excess nitrate in the soil is easily leached by winter rainfall, and can thus impact groundwater. Ecology agrees the agency should have observed this happening sooner. Once Ecology identified the issue, we took very significant actions to correct the problem. No offsite contamination has been observed, and groundwater quality beneath the site has improved significantly.

22. Beneficial Use

Comment	Response
I-2-2 ...Also, if biosolids are so safe, why aren't they used in cities on public parks and vegetation around the state capital and other government buildings as proof that they are safe and don't cause odors in the neighborhood??? Doing this would convince me that biosolids are safe and inoffensive.	I-2-2 Biosolids that meet certain standards have been used as a soil amendment in public parks and on the ground of government buildings. Biosolids that meet Class B pathogen reduction standards - which are most common in Washington and the U.S. - are not allowed for use in public contact areas. They require additional site management and access restrictions that make them impractical for use in publicly accessible areas like parks. Biosolids that meet Class A pathogen reduction (below detectable limits) and other qualitative criteria have been used in parks and around public buildings. Perhaps the most well-known example is the Whitehouse. Biosolids or biosolids compost may be used in the preparation of topsoil and landscape mixes and can be a component of some commercial fertilizer products. Biosolids were a component in the manufacture of a product used for landscaping at the Department of Ecology offices in Lacey. Many local treatment works have successful programs where the public picks up biosolids for use in homes and gardens. About twenty percent of the biosolids produced in Washington meets the higher quality standards for use in public contact areas.

Comment	Response
I-9-3 The idea of putting this sewage sludge on our farms, vegetable gardens and lawns scares me, because I know what could be in it. The thought of children playing and rolling around on grass fertilized with sewage sludge is abhorrent. How is it possible that the Department of Ecology, of all organizations, promotes this?	I-9-3 The bulk of research over several decades supports that the beneficial use of biosolids is a safe practice, when biosolids are land applied in accordance with our state and federal regulations, and permit requirements. We (including children) are exposed to many of the things the commenter is likely concerned about in biosolids, during the course of our average daily activities. We don't think that's okay, we just want to point out that if the commenter wants to reduce those exposures, biosolids represent a very, very small potential for exposure from the end of the chain. We need to look at manufacturing and purchasing. The concern for children having contact with grass is a valid one when viewed from the perspective of risk. In its original assessment, EPA considered the potential transfer of pollutants from hands to mouth. Biosolids applied to areas with a high potential for public contact (lawns, parks, et cetera) must also meet standards for Class A pathogen reduction, which means they have been treated - and sampled - to support that pathogens are reduced to below detectable limits.
I-35-1 As more bio solids are becoming available it would be beneficial to reuse the solids in other applications in addition to farming. Other beneficial uses such as the state could use the class A bio solids to make earthen medians on the interstates highways and off ramps. The material could be used to fill in and level new building sites. There is growing interest in the ability to make clay bricks out of the bio solids which likely would reduce building costs.	I-35-1 We appreciate the commenter's recognition of alternative beneficial uses. Ecology can support any practices that are safe for human health and the environment, and that do not constitute disposal. Ecology's focus is on beneficial use, but we do not mandate the form of that beneficial use. Biosolids have been used in at least one highway project here in Washington that we know of. The needs of the site and quality of the biosolids would need to match, but beneficial use in highway construction, maintenance, or landscaping is certainly something Ecology could

Comment	Response
	support. Biosolids are not suitable for fill. Biosolids must be applied at agronomic rates to remain beneficial as a soil amendment and protective of state waters. If applied as fill, the depth of application would far exceed any agronomic rate, presenting a hazard to groundwater. Most importantly, biosolids are not structurally suitable as fill. The idea of using biosolids in the manufacture of bricks seems to come and go. Ecology is not aware that it has every achieved a significant foothold as a management practice. Please also see the response to comments I-35-2 and I-47-3.
I-60-2 I am not against the reuse of human waste. I in fact completely advocate for it in all levels of society. It needs to be done much differently than the current system though. Human feces and urine can be made into excellent fertilizer that our depleted soils desperately need. The lack of human waste compost is the missing link in our food chain. But we need to stop mixing our waste with our water and with other waste. Our waste needs to be isolated and mixed with carbon (like chipped wood and biochar) then composted onsite using aerobic composting or captured in movable containers and taken to neighborhood composting sites. These sites would process the waste into compost that could go back to farms, provide jobs, and sequester carbon helping to combat climate change. The existing infrastructure for moving the waste could still be used, but the product would be clean and be a healthy part of the soil it goes into, instead of a toxic byproduct that needs to be gotten rid of somehow. This will sound like a radical restructuring of	I-60-2 Ecology notes the commenter's alternative approach. We appreciate the idea of returning organic matter and nutrients to soils where they can do real good. That is actually a primary goal of biosolids beneficial use (though we acknowledge the commenter's lack of support for the current system). Perhaps localized small-scale composting projects can work on the community level. We recommend the commenter reach out to their solid waste management advisory committee to discuss the idea. We do want to advise the commenter that composting to meet regulatory standards is more complex than most people appreciate.

Comment	Response
our lives, but we have gone through radical changes in order to get through the Covid pandemic, so proving that we are able to adapt. We need to be able to adapt. We need to take radical action to reverse climate change. We need to stop shitting in our water, and rebuild our towns and cities with localized composting facilities. The availability of large amounts of good compost would promote local farming and local food systems, reducing the need for excessive transportation and refrigeration... ...I doubt that my ideas will be taken seriously. But I am serious, and having practiced human waste composting for the last 25 years, I am living proof that it can be done.	
I-116-3 Here is an alternative. Use the material to fertilize non-food timber crops. If you want advice on how to do this please contact me.	I-116-3 Biosolids are used to fertilize timber in Washington. They are also used as a component of compost, and some products may be used in the manufacture of topsoils and other products that are not used (typically) for growing food crops. Biosolids could be used exclusively on non-food crops, like timber, but generators are generally driven by logistics of opportunities, and there is also a demand for use in agriculture that is far in excess of the supply. Ecology notes the commenter's offer of assistance. The University of Washington did groundbreaking research on forest application many years ago. Several communities in Washington have significant expertise and longstanding programs of forest application. The commenter may want to reach out to treatment works in his area if he has ideas to support forestland application.

Comment	Response
O-7-68 The Draft Biosolids General Permit Application language continues to shield Department of Ecology permitters, as well as sludge processing and hauling corporations, rather than protecting the health and welfare of Washington State residents, guest farm workers, wildlife, and our natural resources. Not only should this practice stop, but Ecology should urge those in this business to adopt safer methods. Seemingly, Ecology is not proactively working towards soil health. Some states are.	O-7-68 The state biosolids program is somewhat more restrictive than the federal program and allows facilities to operate within established rules and permit requirements. As stated elsewhere in this response, Ecology fully supports reducing contaminants in biosolids, the place to do that is at the point of manufacturing or perhaps use. Please see the response to comment I-7-3 for additional information. Large amounts of research have been done on biosolids over several decades. The overarching conclusion of the bulk of reliable research is that the beneficial use of biosolids is safe when regulations and good management practices are followed. However, there is a need for further study of certain contaminants that may be found in biosolids. Those efforts are ongoing at multiple levels across the country. In the meantime, if additional regulations are necessary to protect human health or the environment, Ecology will certainly address that need.
O-7-69 Taking effect July 1, 2021, the State of New York passed NY State Senate Bill S-4722A that will reflect the latest scientific soil health and resiliency advancements. An act to amend the agriculture and markets law, the state finance law and the soil and water conservation districts law, in relation to establishing the soil health and climate resiliency act This includes, but is not limited to, no-till, cover cropping, managed grazing, perennial pasture, and precise application of added nutrients to achieve nitrous-oxide emission reductions. www.nysenate.gov/legislation/bills/2021/s4722	O-7-69 We commend the state of New York for taking steps to ensure healthy soils. We reviewed the bill in question and found that it contained no reference to sewage sludge or biosolids, and the only reference to pollutants regarded preventing them from leaving a site. The bill supports a broad range of practices intended to protect soils, and in that regard is not inconsistent with principles of biosolids management.

23. Protecting Water Resources

Comment	Response
B-1-5 Issue with Post harvest nitrate fall Sampling a. If you apply x and get less than 15ppm N post-harvest then you can apply 60# more N Why can't we do a single application of X+60 and not do a fall 60# application	B-1-5 Post-harvest soil testing is used to evaluate soil nutrient status after harvest. For a variety reasons unrelated to biosolids application, crops uptake nutrients throughout the growing season at different rates. Excess heat, late or early frosts, limited or excess water, crop pests, and disease directly affect crop productivity. Reduced productivity generally relates to decreased nutrient uptake. The reverse is also true. Excellent growing conditions and sufficient (but not excessive) soil water increase productivity and generally increases nutrient uptake. A single spring application at a rate intended to supply nutrients for an entire year would provide an excessive amount of nutrients during the primary growing season, thereby increasing the possibility of leaching below the root zone where it would not be taken up by plants and could then impact groundwater.
I-2-1 I am opposed to spreading biosolids only a few miles from my house since I rely on my well for drinking water. No government agency has tested my well or anyone elses in my neighborhood in Onalaska to check for contamination. If this dumping is to continue this testing should be done.	I-2-1 We understand the commenter's concern about their drinking water supply. Everyone should take interest in potential impacts to their source of drinking water. A great deal of testing is done on biosolids and for the operations of wastewater treatment plants - in general to ensure safety. The responsibility for testing individual water supplies typically falls to the homeowner. There are many possible sources of contamination for wells (one of the reasons we implement rules to protect our groundwater quality in general). The most common contaminants in individual supply wells are nitrate and coliform bacteria. Fecal coliform bacteria indicate the presence of contamination from sewage or animal waste that

Comment	Response
	may contain pathogens of concern. Common sources of nitrogen and fecal coliform contamination are excess fertilization, livestock, and failing septic systems. Shallow wells and those not properly sealed and maintained are most vulnerable. Land application of biosolids several miles distant is an unlikely source of contamination. For more information on how to get your water tested, please see a separate discussion we prepared on "Getting well water tested."
I-3-1, I-21-5 Biosolids should not be permitted to be applied to land unless they have been tested and found to successfully meet standards established for contaminants regulated in drinking water. I-39-2 Until biosolids are required to be tested for all regulated contaminants that get tested for in public drinking water, they should not be put on land.	I-3-1 The goal of good biosolids management is to protect surface and groundwater resources. Both state rules and the general permit incorporate provisions for buffers to surface water, and in the case of seasonally high groundwater, the requirement for a groundwater protection plan. Ecology prepared separate discussions addressing common questions that readers can find in the key topics section at the front of this response to comments. Please refer to these for more information, in particular the following discussions touch on the commenter's inquiry: "Drinking water standards inappropriate for biosolids."

Comment	Response
I-3-3, I-21-4, I-31-1 ...AND contaminants in biosolids can find their way into surface waters and drinking water.	I-3-3 The biosolids program is implemented with the protection of water resources in mind. As part of the permit process, applicants must identify surface waters within one-quarter mile of a proposed land application site. Establishing buffers to nearby surface waters is part of the permit process. The width of a buffer depends on the method of application and intrinsic site features like slope, soil type, and vegetative cover. Buffers were developed with the help of area universities and are described in our Biosolids Management Guidelines[75]. There may be seasonal application restrictions as well.
I-12-1 Please, no sludge in our waterways. We like to swim and fish in the rivers. Water is precious to our community.	I-12-1 Ecology concurs with the commenter, that water is a precious resource. The permit program is designed to protect surface waters adjacent to land application sites. Applicants are required to submit a topographic map of the proposed site and surroundings. They must identify any surface water bodies within 1/4 mile of the site. Ecology's Biosolids Management Guidelines[60] provide criteria for evaluating site suitability. Those include, for example, slope, soil type, vegetative cover, and site productivity. The guidelines also establish recommended buffers to specific features, including surface water bodies. Ecology can require a larger buffer than recommended by guidance if warranted. There is some public notice and opportunity for comment on all permit applications and proposed sites - beyond what is happening here with the draft general permit. Particulars depend on specific permit history and the amount of public

[75] https://apps.ecology.wa.gov/publications/SummaryPages/9380.html

Comment	Response
	interest. You can Register for Update[25] on Ecology's web to be informed of permit actions in any county of interest. You can then decide if you want to participate in the process.
I-37-1 Sewage Sludge should not be stored on any part of the Olympic Peninsula. We are endangering a prime water source. In the age of climate change fresh water is one of our most valuable resources.	I-37-1 Ecology absolutely agrees that water is a critical resource. We are at a loss, however, to identify an alternative to storing them for some period of time. Biosolids are an unavoidable result of wastewater treatment. Wastewater treatment is a necessity for the more than 7.7 million people living in Washington. Therefore, we need a way to make use of biosolids, as we all contribute to their production. As explored in our discussions, disposing of all biosolids via landfilling or incineration is not feasible or desirable for many reasons. Refer to the key topic discussion titled "Consequences of ceasing all biosolids land application" for additional information. In Washington, Ecology is mandated to maximize the beneficial use of biosolids over disposal. Biosolids must be stored onsite at the treatment works where they are generated until they can be transported for final use or disposal. At the treatment works, biosolids are often treated in large, above-ground tanks called digesters. From there, biosolids may be pumped to an onsite holding system. In some cases, they are held in drying beds where the water is allowed to evaporate or drain back to the treatment plant over time. In other cases, they are stored in lined lagoons where they may be held for many years before removal. When biosolids are applied to the land they are often stored temporarily at the land application site. Dewatered biosolids typically have the consistency of moist soil, but some treatment processes result in biosolids that are very dry - nearly devoid of moisture. Temporary

Comment	Response
	storage at a land application site is referred to as "staging." It is short-term in nature - a few days to a few weeks. In rainy areas, storage during the winter months requires some kind of cover or containment. All storage or staging of biosolids is designed to protect surface and groundwater resources.
I-39-3 Contamination in biosolids will make their way to source water and most public drinking water supplies because conventional public water treatment facilities do not effectively treat for soluble contaminants.	I-39-3 We agree that protecting drinking water (in fact, all water) is important. Ecology believes land application of biosolids when applied at agronomic rates following regulatory requirements and good management practices is safe. Biosolids have been applied to the land in Washington for at least forty to fifty years, and nationwide for a hundred years. There are a few isolated incidents of impacts to water resources. We would expect such impacts to be much more widely spread and frequent in occurrence if the commenter's concern is largely valid. The commenter remarks about the ineffective treatment of soluble contaminants. The fate and transport of contaminants in wastewater and biosolids is a complex subject. Contaminants partition to the effluent, solids, and even the air. Some contaminants are degraded in the treatment process or degrade in the environment after treatment. Others are more persistent. Those that are persistent, bioaccumulate, or are toxic are of continued interest to Ecology and others. There is a lot of interest in per and polyfluorinated alkyl substances at the moment. PFAS are substances that help things not stick to other things. They are found in a wide variety of common consumer products including cookware, recreational equipment, carpets, and clothing, and consequently, they are also found in wastewater and biosolids. Some PFAS are more water-soluble than others. Ecology has recently

Comment	Response
	done some limited analysis of PFAS in wastewater influent and biosolids, and awaiting results. In the meantime, EPA is preparing a new risk-screening tool that will help them further evaluate contaminants in biosolids and better determine if further study or regulation is needed.
I-41-3 ...runoff affects non-target land and bodies of water.	I-41-3 Land application sites are approved with both buffers to water resources and adjacent properties in mind. Buffers take into consideration adjacent land uses, the method of application, weather, and intrinsic features including slope, soil type, and vegetative cover in buffer areas. See also the response to comment I-3-3.
I-51-2 Applying septage to the ground ... should not be allowed where water table is high.	I-51-2 Ecology requires a groundwater protection plan for land application sites where the seasonal water table is nearer than three feet to the surface. A common outcome is to restrict application until confirming that the water table is receding past three feet. That can be accomplished by inspecting postholes dug at the time for the purpose, or by installing short monitoring tubes.
I-55-5, I-56-4, I-57-3, I-58-3, I-59-3, I-64-3 Please disallow the land spreading of septic waste and sludge within 200 feet of public and private wells, surface water bodies, and above critical aquifer recharge areas.	I-55-5 The State Department of Health submitted comments about buffers to drinking water sources and offered to work with Ecology on the next permit process. Our current buffers were developed with the assistance of area universities and in consultation with local jurisdictional health authorities. Buffers as currently established have generally been effective. We did not entirely agree with comments from the Department of Health, but we also have no objection to taking a closer look at the buffers we

Comment	Response
	currently use. We think, however, that we should look at buffers of all types, not limited to drinking water sources. This is a task then that Ecology will put on the list of things to do during the next permit cycle if resources allow. Should a future research show the need for significantly different buffers, the agency could modify the current general permit or permit conditions to reflect this.
I-55-6, I-56-5, I-57-4, I-58-4, I-59-4, I-64-4 Please, to avoid runoff, disallow spreading sludge during wet seasons of rain and snow.	I-55-6 Regulations prohibit application to flooded, frozen, and snow-covered ground. Regulations also require a groundwater protection plan if seasonally shallow groundwater is present on a site. The program does allow some flexibility to land apply during wetter times of the year, but prior approval from Ecology is required. Most permits are approved with start and end dates established for land application, and approval for application outside those dates requires justification.
I-61-2 Adequate oversight is also necessary for when and where the sludge is spread to protect water sources.	I-61-2 Site inspections are an integral part of the permit approval process. They give Ecology staff insight into site characteristics such as slope, surrounding property, weather, and distance to surface and groundwater. The new approach we designed for approving facilities under this permit is intended to reduce staff obligations for facilities that require only perfunctory attention (those that do not have active management programs), and thereby increase staff availability for work on facilities with active management programs, including inspections.

Comment	Response
I-84-2 Please review the science. There are unhealthy contaminants that will be consumed by children, adults and animals. I sell water filters. The chemicals from biosolids from sewage get into our drinking water and can cause serious harm to people who unknowingly drink contaminated water. This is a threat to health and life.	I-84-2 Ecology has invested and will continue to invest significant time and effort reviewing the science of contaminants in wastewater and biosolids. Generally, regulated contaminants are not in a form that is water-soluble or available for plant uptake under normal growing conditions. A great deal of attention is being invested in the study of PFAS in wastewater and biosolids. Some forms of PFAS are more water-soluble than others and may present a concern. We do not think overall that the concentrations of contaminants in biosolids pose a threat to water quality or the food chain. We are continuing to look and evaluate, and have regular contact with other programs within Ecology that are doing this same as well as other agencies including U.S. EPA. Please also see the response to comments I-3-2 and I-26-1, as well as the separate discussions at the start of this response to comments titled “Ground water protection and biosolids”, “Understanding regulated pollutants in biosolids”, and “Food chain crops and biosolids”.

Comment	Response
I-108-3 Is it wise to apply biosolids in areas with rising nitrates in well drinking water? Well water contamination is obvious evidence that is contrary to the "determination of non-significance." I guess it depends WHO finds it significant or not, but for my family, we like to drink clean water, eat wholesome grains, and breathe clean air that doesn't have a fecal smell for a year. Asking as a concerned citizen.	I-108-3 The commenter asks about applications of biosolids in areas with rising nitrate levels in groundwater, and whether that is a good practice. That is an excellent question. Another way to ask the question: if a crop is being grown, is fertilizer needed? Biosolids land appliers gather information on crop nitrogen demands-how much nitrogen does the crop need, and residual soil nitrate-how much nitrate is already in the soil. This information is then used to determine appropriate application rates, or agronomic rates. Ecology staff review agronomic rates as well as residual soil nitrate, and may require adjustments year to year. Excess soil nitrate in a single year should not pose a threat to groundwater; however, years of excess nitrate accumulation must be avoided. This permit program provides feedback from annual soil samples on success at matching agronomic rates. Rates can always be adjusted to protect groundwater from excess nitrate. Crops need nitrogen to produce good yields, and farmers need good yields to stay in business. Depending on the crop, climate, and local soils, plants may use nitrate as deep as five feet in the soil profile. On biosolids land applications sites, we require soil tests to evaluate the amount of residual nitrogen, typically in the first two feet, although it can be the first three feet or even the top foot. We look for a limited amount of residual nitrogen as an indication of proper agronomic rates, and generally for declining concentrations in deeper samples. We would also like to point out that, The use of commercial fertilizer products is not subject to a permit or the same kind of scrutiny as are biosolids.

Comment	Response
I-109-4 1. Public health and environmental risk The proposed general permit poses grave risk of contaminating both surface and groundwaters. Because biosolids derive from our collective waste stream, they contain concentrations of untreated chemicals from household and business use-everything we eat, drink, use for cleaning, and launder. This means that biosolids inherently contains myriad harmful substances, including: dozens of different chemicals derived from detergents, fragrances, and pharmaceuticals, that are collectively referred to as "contaminants of emerging concern," including PFAS;2 polybrominated diphenyl ethers (PBDEs) and other dioxins;3 phthalates; and biological contaminants such as norovirus and the novel coronavirus.4 Many of these substances can cause significant short and long-term ecological and human health impacts at relatively low concentrations, raising significant public health and environmental risks. Contaminants of emerging concern and dioxins found in biosolids evade treatment in municipal wastewater treatment plants. As such, they tend not to break down in soil, and can be transported by and to water. According to at least one peer-reviewed study of runoff following biosolids application, contaminants in biosolids are transported by runoff and can enter surface waters in dangerous concentrations.[5]Another peer-reviewed study states that "[r]ecent studies have demonstrated that the application of PFC contaminated biosolids can have important effects on local environments, ultimately leading to demonstrable human exposures,"	I-109-4 The commenter says that the general permit poses a "grave risk of contaminating both surface and groundwater." That is conjecture not supported by the commenter, and not observed by Ecology or supported by nationwide experience. The commenter says that biosolids contain concentrations of untreated chemicals from everything we do - a myriad of harmful substances. The commenter goes on to list examples. As Ecology has noted previously and elsewhere in this response to comments, we do not argue that biosolids contain some amount of substances that have properties of concern. The agency takes issue however with the commenter's broad-brush approach. First, it is incorrect to imply that all of these things are untreated. All of these things in fact do undergo treatment. Treatment is less effective for some contaminants. It would be fair to say that some contaminants pass through the treatment process with properties of concern still intact. The commenter also disregards pretreatment standards imposed on certain significant industrial users and implies that businesses simply discharge at will to the sewer system, which is not correct. The commenter says there are dozens of different chemicals in biosolids, derived from detergents, fragrances, and pharmaceuticals. So the commenter is clearly acknowledging that many substances over which they question agency efforts regarding biosolids management are in fact present in substances that we use every day, including some we put on our bodies. The commenter gives some specific examples of "contaminants of emerging concern:" • PFAS

Comment	Response
notes that " relatively high transport from soils to surface and well water is possible," and describes a case study in Alabama.[6]	• polybrominated diphenyl ethers (PBDEs) • other dioxins • phthalates • biological contaminants such as norovirus and the novel coronavirus. The term, "contaminant of emerging concern," is problematic because it is not specifically defined and is to an extent subjective, depending on the perspective of an individual making such observations. We dislike the term (although we admit to using it) because it can be taken to mean that we have just now noticed something and that no work or corrective steps have been taken. Manufacturers in the U.S. voluntarily phased out the use of two forms of PFAS (PFOA and PFOS) of greatest concern between ten and twenty years ago. The phase-out had demonstrable benefits in reducing the amount of those substances in the environment[58]. The commenter goes on to cite a study on perfluorinated compounds in Decatur, Alabama which is on the end of worst-case scenarios and has no analogous counterpart in Washington of which we are aware. Because the substances in question are persistent and bioaccumulative, we expect unfortunately to find them in the environment from multiple sources, but also expect that the contribution from biosolids is likely very small. Ecology has committed, nevertheless, to evaluating PFAS in biosolids in the Chemical Action Plan[35], recently released in coordination with the State Department of Health. Ecology developed a CAP for PBDE's, a group of flame retardants. The CAP acknowledges the presence of PBDEs in biosolids but did not classify biosolids as a significant source of release of PBDEs to the environment. In addition, like PFAS, the use of certain forms of PBDEs that were of

Comment	Response
	greatest concern has been phased out. In 2001 EPA concluded that a regulatory standard for dioxins in biosolids was not warranted[76]. The commenter did not acknowledge that work or decision by EPA. We want to observe that EPA may reevaluate that determination when their new risk-screening tool is ready for use. Lastly, the commenter lumps norovirus and coronavirus in with contaminants of emerging concern. While norovirus is not new, coronavirus certainly is. Research on the coronavirus found it is among the easiest of viruses to deactivate, and that it does not endure wastewater treatment[53]. Biosolids must meet pollutant limits, achieve a 99% reduction in pathogens (at a minimum) during the treatment process, and comply with restrictions on application and crop harvest timing. These application and harvest restrictions are designed to allow for the remainder of pathogens to be destroyed before the crop is harvested. Other common soil amendments also carry some risk. Animal manures and commercial fertilizer for example are more widely used on crops with fewer regulatory requirements. Although manure on rare occasions has been positively linked with outbreaks of illnesses, it is commonly understood that the benefits on crop growth and soil maintenance it has outweighs this drawback. Therefore, Ecology applies the same logic in supporting their use to that of biosolids, because the bulk of research and practical experience show when used in accordance with state and federal rules and permit requirements biosolids are a safe and effective soil amendment.

[76] https://www.epa.gov/biosolids/final-decision-not-regulate-dioxins-sewage-sludge

Comment	Response
I-109-5 Contamination would contribute to an already dangerous level of pollution in many areas. For example, the Nisqually River, Nisqually Reach, and McCallister Creek exceed water quality standards for fecal coliform, and water and sediments contain contaminants of emerging concern. According to a recent Seattle Times article summarizing an EPA study, The Nisqually estuary was more contaminated than expected with drugs, including cocaine, Cipro and Zantac. The source of the drugs there was unknown, the researchers reported. However, the Nisqually River, Nisqually Reach and McAllister Creek do not meet water-quality standards for fecal coliform. That makes leaking septic systems a possible source of the drugs.[7] Footnotes [2] These chemicals include perfluorinated chemicals (PFOS, PFOA); polychlorinated alkanes (PCAs), polychlorinated naphthalenes (PCNs); organotins (OTs), polybrominated diphenyl ethers (PBDEs), triclosan (TCS), triclocarban (TCC); benzothiazoles; antibiotics and pharmaceuticals; synthetic musks; bisphenol A, quaternary ammonium compounds (QACs), steroids; phthalate acid esters (PAEs) and polydimethylsiloxanes (PDMSs). See Bradley O. Clarke, Stephen R. Smith, Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids, Environment International, Volume 37, Issue 1, 2011, Pages 226-247, ISSN 0160-4120, https://doi.org/10.1016/j.envint.2010.06.004 ; see also Kinney et al., 2006, Survey of organic	I-109-5 Ecology agrees that if you find a persistent contaminant in septage, sewage, effluent, or biosolids, you can probably find it in all of them to some extent. But we would not necessarily expect to find any particular substance at the same concentrations in each media. Further, the implication for the presence of substances in those media differs. The commenter implies that the presence of a substance in biosolids automatically means that the substance will be transferred to a sensitive environmental endpoint in amounts that will create a significant risk to human health or the environment. The commenter states that there are unexplained levels of certain substances in Nisqually River, Nisqually Reach, and McAllister Creek, but does not connect them in any way with any particular use of biosolids. Given the very limited use of biosolids in the Nisqually watershed, it is likely the source of those contaminants is something other than biosolids. An article cited by the commenter from the Seattle Times suggests that the source may be on site wastewater treatment systems. Ironically, this supports rather than refutes the agency's position that more stringent regulation of biosolids land application, or elimination altogether, would not achieve a positive impact on the endpoints of concern.

Comment	Response
wastewater contaminants in biosolids destined for land application. Environmental Science and Technology, Vol. 40, No. 23, pp. 7207-7215. [3] Kim et al., 2017, Review of contamination of sewage sludge and amended soils by polybrominated diphenyl ethers based on meta-analysis. Environmental Pollution, Vol. 220 Part B, pp. 763-765 (finding consistent presence of PBDEs in biosolids in varying concentrations across 288 samples). [4] Viau et al., 2011, Toward a Consensus View on the Infectious Risks Associated with Land Application of Sewage Sludge. Environmental Science and Technology, Vol. 45, Issue 13, pp. 5459-5469. [5] Yang et al., 2012, Steroid hormone runoff from agricultural test plots applied with municipal biosolids. Environmental Science and Technology, Vol. 46, No. 5, pp. 2746-2754, doi:10.1021/es203896t. [6] Lindstrom AB, Strynar MJ, Delinsky AD, Nakayama SF, McMillan L, Libelo EL, Neill M, Thomas L. Application of WWTP biosolids and resulting perfluorinated compound contamination of surface and well water in Decatur, Alabama, USA. Environ Sci Technol. 2011 Oct 1;45(19):8015-21. doi: 10.1021/es1039425. Epub 2011 Apr 22. PMID: 21513287. [7] Seattle Times, Drugs found in Puget Sound salmon from tainted wastewater (Feb. 23, 2016). Available at: https ://www. sea ttletimes.com/seattle-news/environment/drugs-flooding-into-puget-sound-and-its-salmon/ If these chemicals are present in leaking septic effluent they are certainly also present in septage and biosolids. When present in water	

Comment	Response
and sediments, the chemicals make their way into salmon and cause adverse health effects and death.[8] Similarly, testing of sediment in outfall areas near the King County Elliott West CSO treatment plant has exceeded screening levels, including total PCBs, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, benzyl butyl phthalate, bis(2-ethylhexyl) phthalate, chrysene, dibenzo(a,h)anthracene, fluroanthene, indeno(1,2,3-c,d)pyrene, and mercury.[9] Like leaking septic, overflow sewage likely presents many of the same threats as biosolids.	
O-2-9, O-7-43 Section 4.5.9.3. Buffers: The distance from surface waters is defined as 33 feet. The permit does not state where the measurements will be taken. The edges of rivers and streams fluctuate throughout the year. Is the point of measurement the high water mark? Biosolids are applied near surface waters that flood every year. The permit not address differences in soil porosity and varying distances for mixing zones in which ground and surface waters interact. It is likely that many mixing zones (hyporheic zones) extend beyond 33 feet from the edges of large rivers. Thirty three (33) feet is inadequate to prevent leaching of heavy metals, nutrients and toxic chemicals into rivers that support fisheries.	O-2-9 The baseline minimum buffer to surface waters in federal rules for land application of biosolids is 10 meters (hence, 33 feet in state rules). Ecology staff interpret the setback to be from *ordinary high water*. The fact that it is a minimum does not mean it is a standard. Buffers are typically more conservative, and take other site factors into consideration. Ecology also considers soil types, site topography, method of application, cropping practices, and weather in setting buffers and limiting wet season applications. The technical support documents for the original federal rule for an evaluation explain the rationale behind the ten-meter setback. We also want to point out that EPA has revised its model for pathways of exposure and expects to release a risk-screening tool for biosolids next year. The screening tool may lead to reconsideration of the federal minimum buffer. That work is appropriate for EPA to do, as opposed to Ecology. In the meantime, staff will continue to consider necessary factors when setting site buffers to

Comment	Response
	sensitive features.
O-2-16 FOTC performed a study in 2018 that found dioxins and furans in domestic well water in the Lower Yakima Valley where sewage sludge/biosolids are applied to farmland. Ecology is performing follow-up testing. The EPA acknowledges that dioxins and related chemicals remain in the sewage sludge from wastewater treatment plants. How can Ecology protect people with domestic wells from this contamination?	O-2-16 Biosolids are applied in the Yakima Valley, as are a wide range of fertilizers, pesticides, and other agricultural products. In addition, there are many other sources of pollutants (including and not limited to dioxins and furans) aside from those originating from the land application of biosolids. Ecology reviewed the results of work by Friends of Toppenish Creek. Results for dioxins were mostly at or below background levels, with the exception of one well. In that case, the well was not near any known land application site, was poorly constructed, and immediately adjacent to a burn pit (presumed to be the likely source of contamination). The FOTC study did not connect biosolids to any observed groundwater contamination. EPA evaluated the presence of dioxins and furans in biosolids and concluded that additional regulation was not necessary to protect human health and the environment[76]. Ecology has occasionally seen or required analysis for dioxins and furans in biosolids and has not found levels outside the expectations on which EPA based its decision. That being noted, the best protection people have is to be vigilant and monitor individual wells as recommended elsewhere in this document. EPA will release a draft risk-screening tool next year. When complete, it is possible they will give additional attention to dioxins and furans. That will come down to prioritizing the substances of most concern.

Comment	Response
O-7-8 The Draft Permit must strengthen language to better protect the surface and subsurface water bodies. There should be longer and deeper distances to buffer the waters from receiving biosolids, whether from runoff, wind, rain, ice and snow or injection into the soils. We strongly recommend the following regarding the Draft General Statewide Permit:... ... The permit should include expanded buffers for surface and subsurface water bodies	O-7-8 Ecology will reevaluate buffers during the lifecycle of the new permit if resources allow. We will evaluate the literature, standards of other states, and consult with other agencies as appropriate. If we determine that changes in buffers are necessary prior to the expiration of the permit, we can either modify the permit to reflect those changes or incorporate those changes on a case-by-case basis with the approval of individual facilities or land application sites.
O-7-31 (10) If the seasonal groundwater is three feet (0.91 meters) or less below the surface, a management plan should be included that describes how the groundwater will be protected. For example, limiting applications to the time of year when groundwater has receded to more than three feet (.91meters) below the surface. Employees who spread the septage on winter days should know where those areas are located. Ecology officials have allowed an employee to spread septage across the site in the middle of winter for another year before being required to build a lagoon for winter septage deliveries. These types of decisions betray the public's trust, considering that portions of the site's groundwater had already been found to be contaminated for decades. Instead, perhaps a five-year moratorium on the land spreading of septage would have been a better choice.	O-7-31 This comment remarks about circumstances specific to an individual site, which is outside the scope of this response to comments. The general public has the opportunity to comment on individual sites during a specific comment period for their permit application/approval process. Interested persons can also contact staff in the appropriate regional office[63] with concerns about a specific site related to permitting status, operations, or compliance. Please also refer to the key topic discussion Ecology has provided regarding “Ceasing Land Application” at the start of this response to comments.

Comment	Response
O-7-61 Pages 44-45, Site Specific Land Application Maps must contain: Item (10) should be rewritten to say, If the seasonal groundwater is three feet (0.91 meters) or less below the surface, a management plan is needed describing how you will protect groundwater. For example, you may propose General Permit for Biosolids Management Publication 21-07-006 45 May 2021 to limit applications to the time of year when groundwater has receded to more than three feet (0.91 meters) below the surface. No land spreading until March 21 and no land spreading if snow remains on the ground, or if there is a forecast for snow or over one-half inch of rain, or if the soils are saturated. Groundwater wells, recharge areas, watersheds should be mapped. This waste, including if the contents contain PFAS, should not be allowed anywhere near these water areas.	O-7-61 Different considerations affect the proper start and end dates for biosolids land application. Most typically, Ecology staff establish dates that are somewhat conservative based on site assessment, and require the proponent to obtain permission to apply outside those dates. Staff consider a variety of factors when reviewing and approving requests. Ecology will consider developing a standardized approach for staff to assess these requests. Please also see the response to comment O-2-2.
O-7-71 Ecology should disallow the land spreading of septage, sludge and effluent within 200 feet of public and private wells and above critical aquifer recharge areas, oppose the spreading of this waste in forested areas, near wetland and where there are slopes and where forest surface water flows to larger surface-water bodies.	O-7-71 Application in recharge areas is not directly prohibited although such areas can be identified during site analysis. Buffers are required for wetlands and surface water. Prohibiting applications in forest areas is not consistent with program rules, and is not warranted based on longstanding experience. Lastly, almost any site will reveal some degree of slope. Prohibiting application on sloped areas is not practical. Ecology guidelines make recommendations for assessing slopes and limits of application. Site-specific conditions depend on factors including the degree of slope, surrounding land and water features, nature and extent of buffer areas, soil types, method and season of application.

Comment	Response
	Ecology will examine setbacks to wells and other features over the course of the five-year permit cycle if resources allow. The State Department of Health has expressed an interest in evaluating setbacks to drinking water sources. Please also see the response to comment I-55-5.
SG-2-1 We have the following comments: We are concerned the biosolids general permit isn't consistent with state and federal requirements for source water protection of drinking water supplies. The biosolids general permit is tied to the federal Clean Water Act "as it existed on February 4, 1987," in keeping with RCW 70A.226.CK)7 & WAC 173-308- 010. Meanwhile, source water protection requirements for public drinking water systems stem from 1985 & 1996 amendments to the federal Safe Drinking Water Act. The 1986 amendments enabled states to establish wellhead protection programs for public drinking water wells. In 1995, this was expanded to incorporate source water assessment programs for surface as well as ground water supplies. (See Safe Drinking Water Act (SDWA): A Summary of the Act & Its Maior Requirements, p. 21) As enacted in Washington (WAC_240z29Qz135) this requires: 1. For Group A well & spring sources: a. Establishment of sanitary control areas (SCAs) with a radius of 100' (wells) & 200' (springs); and b. Establishment of wellhead protection areas (WHPAs) that reflect times of travel (TOT) to the water source, should contamination occur in that area (5-month & 1-, 5- &10-year TOTS). 2. For Group A surface water sources,	SG-2-1 The commenter is concerned that setbacks to various drinking water sources may not be consistent with other laws and regulations, or not protective even if they are. In the latter case, the commenter provided example setbacks from several other states. The commenter is additionally concerned that federal allegations were developed at a time when there was less attention to potential contaminants like PFAS. Ecology will consider including DOH staff in a review of buffers under the state biosolids program. We do want to be consistent with other regulations and programs. Ecology believes the buffers currently required under the state biosolids program are protective, but it is a theme that recurs throughout comments. We think a reassessment of the basis for buffers to various features has merit. Rather, it is something we should undertake earlier in the permit cycle. Depending on the outcome, we can modify our general permit requirements, or at a minimum be prepared to implement changes in the next permit cycle. The basis for current federal regulations evolved significantly in the late 80s and early 90s as EPA adopted rules under 40 CFR Part 503[13]. EPA has done numerous biennial reviews and additional surveys of biosolids quality in the meantime. EPA is presently working on a new risk screening tool, which they plan to refer to their Science Advisory Board in 2022. The tool will allow EPA to focus on contaminants with more potential for impacts.

Comment	Response
establishment of individualized watershed control programs. 3. For Group 8 systems (any source), establishment of a IT SCA; plus our WHPA mapping reflects a standard 600' "preliminary short-term groundwater contribution area" (WAC 246-291-125). Federal standards for biosolids application appear to be rooted in science that was developed in the 1970s, when the potential of using biosolids as soil amendments was initially being studied. The IT buffer for septage & Class B biosolids (General Permit tables 3.8.3 & 4.5.9.3) coincides with the SCA associated with a Group A or B public drinking water wells but overlooks the 200' SCA for Group A spring sources & any tailored protections associated with watershed control programs for surface systems. Nitrates remain a basic concern in relation to drinking water. Plus, at now approaching 50 years old, the foundational science does not take into account contemporary unregulated contaminants in waste water such as pass-through pharmaceuticals, personal care products, or newer-generation "forever chemicals" like PFAS. It is unknown to what extent such materials are retained in biosolids, even if treated or amended. We have concerns about the lack of updated scientific information & would welcome the opportunity to engage with Ecology in taking a deeper look at this when this general permit is next up for review. In the meantime, a precautionary approach is advisable to offer a greater degree of protection to public water consumers statewide. While maintaining the current 100' buffer reflective of the SCA for Group A & B public	EPA's pathways analysis includes drinking water. We agree with the commenter that nitrates remain an issue of concern. The state biosolids program requires analysis of biosolids for nitrogen content, calculates application rates based on technical guidance developed by Washington State University and Oregon State University, and requires pre- or post-application soils analysis for residual nitrate. To the best of our knowledge, the approach taken to manage nitrogen from biosolids is equal to or superior to that employed for any other program adding nutrients to soils, such as commercial fertilizer or manure.

Comment	Response
water systems using well sources & for private wells, we encourage Ecology to consider these increased distances for the listed features: For Group A public water systems using spring sources, a 200' buffer reflecting the SCA. For Group A public water systems using surface sources, a buffer of at least 200' away from the surface water intake, & as consistent & coordinated with the individual public water system's watershed control area. There is precedent for this in some other states. A comparison with several others' buffering requirements for biosolids shows a range of up to 2,500', depending on the feature, method of application, & class of biosolid material. We have attempted to generalize them in this table, but they're somewhat "apples & oranges" so state-by-state information is also included below. The commenter submitted a summary of buffers from some other states in the form of a table, included below. The commenter also included supplemental language related to interpretation of the values for each state in the table. That additional information can be found in with their original comment.[77]	
T-1-5 We also request that Ecology provide additional protections to water quality and environmental health and equity in the general permit by requiring: ...3. Require enhanced water quality monitoring of surface and ground water in and around the application site, including	T-1-5 The biosolids program is implemented in a way that Ecology believes is protective of surface and ground water resources. Effective monitoring must occur at regular intervals and take into consideration numerous variables and conflicting sources. Groundwater monitoring requires at least one up and three downgradient wells around any site of interest,

[77] https://swm.ecology.commentinput.com/?id=SpmPs

Comment	Response
establishing a baseline prior to application.	and needs to occur over time to provide representative data. Ecology believes the best approach is to establish protective buffers and limit contaminants in biosolids in a way that protects surface water and other resources, without the need for monitoring. Ecology is committing to reevaluate buffers for all purposes during the life of the general permit if resources allow. If results argue for immediate changes, the general permit can be modified or individual approvals can be properly conditioned. Otherwise, any changes can be reflected in the next draft permit.
I-17-2 Our species is struggling with contaminqtes. Without our permission. it all ends up in the rivers. Detroit poisoned a whole generation of children with lead.	I-17-2 Ecology disagrees with the lament that, "...Without our permission,' It all ends up in the rivers." Not all wastewater treatment plants discharge effluent to surface water. Some discharge to land application sites. For those that discharge to surface water, not all discharge to rivers. Some discharge to saltwater bodies. We realize this does not address the commenter's overall concern. We point this out because it is important to think broadly here. The goal of good biosolids management is to protect our water resources. Specifically, we expect no impact on water quality from biosolids. When pollutants enter the sewage system, they must be dealt with at a sewage treatment plant. There are regulatory limits on all of the discharges from a wastewater treatment plant. Those limits are established in permits that incorporate a public comment process (as does this one). In Washington we give permission, and issue permits in a publicly visible process. The quality of solids from an onsite septic system is very similar to the quality of solids generated from a more

Comment	Response
	sophisticated wastewater treatment plant. Even if an individual adheres to a very "green" lifestyle, each of us contributes to the problem by the purchases we make and the services we use.

24. Terms/Definitions

Comment	Response
B-3-1 1.1.1. - Page 2 Explanation of the Terms "Sewage Sludge", "Biosolids", and "Septage" Sewage sludge is the solid, semisolid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Biosolids are produced by treating sewage sludge to meet standards that allow them to be beneficially used for their nutrient and soil conditioning value. Septage is a type of biosolids that comes from septic tanks and similar systems. In this permit, when we use the term septage, we mean only septage. When a facility mixes septage and biosolids together, the mixture must be treated to the same standards for biosolids produced from the treatment of sewage in a wastewater treatment plant. [yellow highlight from commenter]. Comment 1 Highlighted language should read "When a facility mixes septage, sewage, sewage sludge and/or biosolids together."… …1.2.3. -- Page 5 Active Biosolids Management Section (4) of this permit applies to facilities with active biosolids management programs, but not those than manage only septage (1.2.2 above). You are subject to the active biosolids management section (4) of this permit if: You apply biosolids (or septage treated to standards for biosolids generated at a wastewater treatment plant) to sites approved specifically for you. You sell or give away biosolids you treat to exceptional quality standards.	B-3-1 The commenter remarks several times about clarifications around the use of the terms biosolids and septage. In particular, the commenter recommends adding the words sewage sludge and sewage in several locations, and specifying domestic sewage or municipal sewage. Ecology reviewed the language in the draft permit the commenter referenced and determined making these adjustments would actually make the permit language less clear, rather than clarify it as the commenter intends. In 1.1.1 the point we want to make is that the requirements for treating and managing biosolids derived from the treatment of domestic sewage in a wastewater treatment plant are different than those for septage. Biosolids is a finished product suitable for beneficial use. Septage is a form of biosolids and can also be used beneficially as long as treatment and/or site management criteria are met. However when a permittee mixes biosolids and septage, the resulting material must be treated to biosolids standards. The purpose of the explanatory language the commenter recommends altering is to highlight that the requirements for treating and managing biosolids derived from the treatment of domestic sewage in a wastewater treatment plant are different than those for septage. Since the requirements differ, mixing them together necessitates establishing which criteria apply. The nuances of the language surrounding biosolids and septage are tricky and derive from different terminology in federal rules, state rules, and state laws. We have inserted the term sewage sludge, in some fashion, where we think it can

Comment	Response
You treat and send biosolids to another facility for land application. You treat septage to meet Class A or B pathogen reduction. You treat a mixture of septage and biosolids to meet Class A or B pathogen reduction. You are a beneficial use facility (BUF) as defined in WAC 173-308-0808. You receive non-exceptional quality biosolids for further treatment, except for compost facilities operating only under a local solid waste permit in accordance with WAC 173-308-310(1)(a)7 You operate a surface impoundment and expect to remove solids during the five-year term of the permit. Consult your regional biosolids coordinator for guidance. Comment 3 Highlighted text should read "produce" Highlighted text should be read "mixture of septage, sewage, sewage sludge and/or biosolids"… …4. Permit Section: Active Biosolids Management -- Page 32 Active Biosolids Management Facilities covered in this section have active biosolids management programs. If you have an active biosolids management program, you are: •Producing exceptional quality biosolids to sell or give away. This includes wastewater treatment plants, composters, and other treatment facilities. Treating biosolids and directly applying biosolids to the land or have a legal arrangement to have your biosolids applied to the land where you remain directly responsible for all compliance aspects.	help to clarify. In 1.2.3. of the permit, the commenter recommends replacing the word “treat” with the word “produce”. Ecology did not make this change because the original language (using the word “treat”) was chosen to further differentiate between baseline program operations and active biosolids program operations. Baseline facilities do not treat biosolids for land application. We understand that biosolids is something that has already been treated, but it is most appropriate to remain focused on "treatment" here. In section 4, the commenter recommended a change to say treating sewage sludge to produce biosolids, instead of just referring to treating biosolids. Ecology made the change, but we want to emphasize that persons subject to the permit have a base level obligation to understand the concepts behind definitions and terms. The agency will not contemplate arguments along the lines that someone thought it was okay to manage septage mixed with *sewage sludge* as septage because the permit language only remarked about *biosolids* mixed with septage.

Comment	Response
Comment 6 Highlighted text should read "Treating sewage and/or sewage sludge to produce biosolids"… …Statewide General Permit for Biosolids Management-Draft" Appendix D Glossary of terms, page 48- "Treatment Works Treating Domestic Sewage: A publicly owned treatment works or any other sewage sludge or wastewater treatment devices or systems, regardless of ownership, used in the storage, treatment, recycling, and reclamation of municipal or domestic sewage or sewage sludge , including land dedicated for the disposal of sewage sludge. Treatment works treating domestic sewage also includes beneficial use facilities and septage management facilities as defined in this section, and a person, site, or facility designated as a treatment works treating domestic sewage in accordance with WAC 173-308-310(1)(b)7. This definition does not include septic tanks or similar devices or temporary, small-scale storage as defined in this section. Comment 9 Based on this definition we would contend that municipal sewage should be included in the following: Page 2 1.1.1."Explanation of the Terms "Sewage Sludge", "Biosolids", and "Septage" Sewage sludge is the solid, semisolid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Biosolids are produced by treating sewage sludge to meet standards that allow them to be beneficially used for their nutrient and soil conditioning value."	

Comment	Response
Specifically changed to- "generated during the treatment of domestic sewage and/or municipal sewage"	
I-9-4, I-49-9 Recommendations: I would like to see Ecology replace "best management practice" with "independent current science" as a guideline.	I-9-4 Best Management Practices (BMPs) distill complex science into actual practices users can implement to protect human health and the environment. Generally, the guidelines that we rely upon are the product of university research. Our state guidelines were developed with the assistance of local universities. Thus the beneficial use of biosolids and the adequateness of regulatory standards are well supported by peer-reviewed research, and the guidelines and BMP's we use are based on independent science.
I-22-2 Bio-sludge is not the same as carefully selected waste that is made into compost.	I-22-2 "Bio-sludge" is not a recognized term. Biosolids are a treated residual that results from the treatment of wastewater. The term biosolids was selected to differentiate because there are many kinds of sludges from different processes. When used properly, the word biosolids tells you the origin of the material and confirms that it has met standards that make it safe for beneficial use. Compost is a soil amendment product that can include biosolids as a feedstock. That is to say, compost does not exclude biosolids as an ingredient or even as a primary component. Composting is a process that involves time at elevated temperatures, conditions similar to those for biosolids treated in digesters at wastewater treatment plants.

Comment	Response
I-50-1 I support the Sierra Clubs position on the matter of the application of biosolids. Hard to believe the use of sewage is even being considered.	I-50-1 To be clear, this proposal is not suggesting beneficial use of sewage. Biosolids are a treated residual that results from the treatment of wastewater. The term biosolids was selected to differentiate because there are many kinds of sludges from different processes. When used properly, the word biosolids tells you the origin of the material and confirms that it has met standards that make it safe for beneficial use. Beneficial use of biosolids has occurred in Washington since the 1970s, and for a hundred years in the United States. Please see our responses to the O-7 comment series from the Sierra Club for more information.
I-108-4 For years I have observed the application of biosolids from Spokane County and noticed a large difference in compost quality. In some cases, the fecal odor is present for over 12 months. It smells like raw sewage. In other applications, the only odor is that of earth compost. It is apparent that some of these application are not really field ready but are being applied anyway.	I-108-4 Ecology notes the commenter's concerns. However, Ecology requested comments on the whole of the draft general permit for biosolids management. This comment seems to pertain to a particular site and therefore is beyond the scope of this comment period and response. Please see the response to comment B-2-1 for more information about how to inquire about specific land application sites and becoming an interested party. We want to address the commenter's remarks about compost. Compost is a soil amendment product that can include biosolids as a feedstock. That is to say, compost does not exclude biosolids as an ingredient or even as a primary component. Composting is a process that involves time at elevated temperatures, conditions similar to those for biosolids treated in digesters at wastewater treatment plants. While there can be biosolids compost, most biosolids produced in Washington are not composted. Some biosolids produced in Spokane

Comment	Response
	County are composted, and some are applied directly to the land. The land application of biosolids is a common agricultural practice. We recognize that it can create odors that are bothersome to some people - whether passers-by or neighbors. Generally, odors from land application activities fall in the same category as those from the land application of animal manures (or commercial fertilizers or pesticides). They are expected in rural, agricultural areas and residents must have a greater degree of tolerance.
LG-1-10 12) Section 4. Permit Section: Active Biosolids Management Facilities covered in this section have active biosolids management programs. If you have an active biosolids management program, you are: • Producing exceptional quality biosolids to sell or give away. This includes wastewater treatment plants, composters, and other treatment facilities. • Treating biosolids and directly applying biosolids to the land, or have a legal arrangement to have your biosolids applied to the land where you remain directly responsible for all compliance aspects. • Sending your biosolids to a BUF that applies them to the land under a separate permit (this does not relieve you of responsibility for proper management of your biosolids). • Applying biosolids to the land as a permitted BUF Assuming Section 4 also applies to facilities	LG-1-10 We rearranged the bullets the commenter is referencing to eliminate any confusion. We listed the exceptional quality biosolids bullet last to distinguish from non-exceptional quality biosolids.

Comment	Response
that produce non-EQ biosolids. I guess this is inferred by the second bullet point but not stated directly.	
LG-6-2 Comment: Vancouver's incinerator as well as other sewage sludge incinerators in Washington incinerate sewage sludge generated from their facilities. The term "sewage sludge" (as opposed to "biosolids") is consistent with the definitions in Chapter 173-308, descriptions in 40 CFR Part 503, and in 40 CFR Part 62, Subpart LLL. The City recommends making the reference to "sewage sludge or biosolids" in Section 2.6.1.	LG-6-2 Ecology concurs and has made the recommended change.
O-2-3, O-7-62 Page 47 Glossary of Terms defines: Septage or domestic septage: Liquid or solid material removed from septic tanks, cess pools, portable toilets, type III marine sanitation devices, vault toilets, pit toilets, RV holding tanks, or similar systems that receive only domestic sewage. Septage may also include commercial or industrial septage mixed with domestic septage if approved in accordance with the provisions in WAC WAC 173-308-020(3)(g). This is the definition of septage from WAC 173-350-100 and from WAC 173-308-080. WAC 173-308-005 states: (c) Septage. Unless the context requires otherwise, "septage" is the term used in this chapter to refer to septage that is or will be managed as septage. This last definition is circular, confusing and provides an unclear exception for "context".	O-2-3 Ecology is not able to revise any part of the rules in Chapter 173-308 WAC with this general permit process. We understand the commenter's confusion, and this is actually something we have taken a step toward clarifying with the new permit structure. EPA and state law classify septage as a form of biosolids. Different regulatory requirements apply (same rule, different standards and practices), and the permit holders are a different group - generally small business versus local government. When we talk about biosolids in general, the discussion often includes septage, but it is necessary to keep the context in mind. In the draft permit, we pulled the elements applicable for managing only septage, into a section apart from what is applicable for managing biosolids. We wanted to make this differentiation clear for our own purposes, as well as for our permittees. In some cases, facilities that receive septage for treatment also receive biosolids generated by wastewater treatment plants. If they receive both, the operator must adhere to more stringent

Comment	Response
	standards of treatment that are not commonly used in most scenarios where septage is managed by itself. When septage only is applied to the land, the qualitative standards are somewhat less, but the management restrictions are greater. The point then of the apparent circular reference is to establish that when we discuss program requirements in the context of septage management, we really specifically mean only the material that qualifies as septage.
O-7-64 The Draft Permit designates processed sewage sludge as “biosolids.” In other words, “biosolids” is given its own classification. In fact, the two terms are interchangeable. Designations and treatment methods aside, the resulting product is highly toxic and should not be land applied or promoted and sold as compost or fertilizer.	O-7-64 While the two words are used interchangeably by some, this isn’t accurate in the context of Washington's program. The term biosolids was selected as a better descriptor for treated sewage sludge because there are many different kinds of sludges. Biosolids are established by law as sewage sludge that meets standards for beneficial use. Not all sewage sludge meets those standards. The commenter states that biosolids are highly toxic. Ecology disagrees. Wildlife and vegetation respond positively in areas where biosolids are applied to the land. Please see response to comment I-7-3 for more information.

25. Program Authority

Comment	Response
I-48-2 Most people don't know that a lot of the food we eat is grown on fields where municipal sewage is used for fertilizer. When they do find out about this, most people ask, is it legal? Unfortunately, the Dept. of Ecology interprets existing regulations in such a manner that it is considered legal, but there are compelling reasons why Ecology should not consider the land application of sewage sludge to be legal. How many reasons? Let's start with 352 Since 1992, the Department of Ecology has regrettably been directed by the state legislature to maximize the "beneficial use" of biosolids ("biosolids" is what defenders of the practice of land application euphemistically call sewage sludge). It's a legislative mandate that runs counter to Ecology's mission. The agency claims it "is committed to considering how agency activities, including permitting, may adversely affect the environment, and health of people, and communities of our state." It's a mission that the agency has been all too eager to ignore as it instead embraced its new biosolids role with aplomb, capitalizing on it and promoting it. This has resulted in decades of state-generated propaganda trumpeting the "benefits" of land application of sewage sludge accompanied by vigorous organized efforts to de-legitimize scientific data that points out the inherent hazards of the practice. The quasi-public "Northwest Biosolids" organization is an example of this powerful propaganda machine. The Board of Directors is made up of an incestuous amalgam of private waste treatment industry representatives and governmental municipal	I-48-2 Based on annual report data from 2020, Ecology estimates that biosolids are applied to about 30,000 acres of land in Washington each year, a state with more than 15,000,000 acres of farmland and more than 43,000,000 acres overall. That means biosolids are applied to less than 0.2 percent of agricultural land and well less than 0.2 percent of all land in Washington, annually. For details on how we arrived at those figures, please see the separate discussion at the start of this response to comments titled “Food chain crops and biosolids”. Ecology is carrying out a responsibility we were charged with by the Washington State Legislature to establish a biosolids program that, to the maximum extent possible, ensures municipal sewage sludge is reused as a beneficial commodity and is managed in a manner that minimizes risk to public health and the environment. Ecology staff and its partners work hard to implement a responsible, beneficial program, and to address problems and concerns as they arise. NW Biosolids has supported education and research related to biosolids for many years, generally outside the political arena. The Board of Directors is elected by their membership. NW Biosolids is managed by a contractor that provides support for stakeholder groups, and is located in Gig Harbor. Ecology does not believe the beneficial use of biosolids poses a significant threat to human health or the environment, but does believe we can improve program implementation. That includes revising rules or permit conditions as needed, based on a reasoned analysis of available information. That extends, for example, to include

Comment	Response
waste management officials all of whom share a financial interest in the continuation of the industry that has grown up around the land application of sewage sludge (in fact, they share a building on Jackson St. in Seattle with the King County Solid Waste Division). It has an enormous budget to keep pumping out lies about the "safety" of biosolids. It adopts policy positions, lobbys for them and authorizes participation in litigation to defend the industry. You know it's gotta be bad when they have to set up a massive disinformation campaign and hit squad to maintain their ill-gotten privilege. Northwest Biosolids is like the Koch brothers of sludge... ...Science backs up banning the land application of sewage sludge even if the regulations don't. It's a new era. Trump is no longer president. Let's go with science. Which brings me to my final points: In fact, if interpreted appropriately, CURRENT LAW DOES PROHIBIT THE LAND APPLICATION OF SEWAGE SLUDGE. Consider the following: RCW 69.04.020 - Food, Drugs, Cosmetics, And Poisons "Contaminated with filth." The term "contaminated with filth" applies to any food, drug, device, or cosmetic not securely protected from dust, dirt, and as far as may be necessary by all reasonable means, from all foreign or injurious contaminations. Surely this is being violated every single time sewage sludge is applied to agricultural soils. Why is this law not being enforced? RCW 7.48.140 - Actionable nuisances Public nuisances enumerated. It is a public nuisance: (1) To cause or suffer the carcass of any animal or any offal, filth, or noisome	additional regulation of PFAS in biosolids as appropriate. The current permit restructuring is an example of our commitment to bettering the implementation of the biosolids program. Ecology believes we are implementing the state biosolids program consistent with its authorizing statute. We are always willing to examine obligations under other laws and rules, but are not inclined to interpret them in a way that runs contrary to our view of the best application of science and public policy. Please also see the key topic discussion at the start of this response to comments titled “Understanding the 2018 Office of the Inspector General (OIG) report” for more information about the number 352 the commenter referred to.

Comment	Response
substance to be collected, deposited, or to remain in any place to the prejudice of others; The above pretty much is the definition of the land application of sewage sludge. Why is this law not being enforced? 21 U.S. Code ¬ß 342 - Adulterated food A food shall be deemed to be adulterated- (a)Poisonous, insanitary, etc., ingredients (1)If it bears or contains any poisonous or deleterious substance which may render it injurious to health; but in case the substance is not an added substance such food shall not be considered adulterated under this clause if the quantity of such substance in such food does not ordinarily render it injurious to health. (2)(A) if it bears or contains any added poisonous or added deleterious substance ... that is unsafe within the meaning of section 346 of this title; or ... (3) if it consists in whole or in part of any filthy, putrid, or decomposed substance, or if it is otherwise unfit for food; or (4) if it has been prepared, packed, or held under insanitary conditions whereby it may have become contaminated with filth, or whereby it may have been rendered injurious to health; ... Sewage sludge is known to potentially contain hundreds of toxic pollutant contaminants, e.g. "poisonous or deleterious" substances, but because no regulations exist requiring every batch of sludge to be tested for their presence (in contravention of the intent set forth in this law), it's highly likely that food grown on sewage sludge-treated fields including meat and dairy products are adulterated, as defined by this statute, but regulators are apparently	

Comment	Response
allowed to look the other way. This law, is still being violated because of the absence of data quantifying the "poisonous or deleterious" substances known to potentially be present. 21 U.S. Code ¬ß 346 - Tolerances for poisonous or deleterious substances in food; regulations Any poisonous or deleterious substance added to any food, except where such substance is required in the production thereof [Ed. Note: Which is questionalable in the case of sewage sludge used as fertilizer since many other non-toxic fertilizer products are readily available to growers] or cannot be avoided by good manufacturing practice shall be deemed to be unsafe for purposes of the application of clause (2)(A) of section 342(a) of this title; but when such substance is so required or cannot be so avoided, the Secretary shall promulgate regulations limiting the quantity therein or thereon to such extent as he finds necessary for the protection of public health, and any quantity exceeding the limits so fixed shall also be deemed to be unsafe for purposes of the application of clause (2)(A) of section 342(a) of this title. Again, the EPA itself has identified at least 352 pollutant contaminants in sewage sludge but regulations only exist for nine of them in direct contravention of this statute. 21 U.S. Code ¬ß 346 continued: While such a regulation is in effect limiting the quantity of any such substance in the case of any food, such food shall not, by reason of bearing or containing any added amount of such substance, be considered to be adulterated within the meaning of clause (1) of section 342(a) of this title. In determining the quantity of such added substance to be	

Comment	Response
tolerated in or on different articles of food the Secretary shall take into account the extent to which the use of such substance is required or cannot be avoided in the production of each such article, and the other ways in which the consumer may be affected by the same or other poisonous or deleterious substances. The "Secretary," as well as the Dept. of Ecology, should consider the fact that the use of sewage sludge is NOT required and CAN BE AVOIDED in the production of food. Furthermore, the "Secretary," as well as the Dept. of Ecology, are FAILING, in the case of the land application of sewage sludge, to take into account "other ways in which the consumer may be affected by the same or other poisonous or deleterious substances."	
I-49-6 As shocked as I was to observe the caseworker playing the role of cheerleader instead of regulator, I now realize that she was "just following orders". In 1992, the Washington State legislature deemed "biosolids" to be a beneficial resource and mandated that the Department of Ecology promote its use on soil. (Garbage out of the effluent, and garbage back in to our crops). This foolish mandate from the state, based on very outmoded science, if any at all, has made Ecology into an active promoter of pollution, rather than a judicious guardian of the public interest. Other states, like Wisconsin, Michigan and Maine have started to rein in the sludge industry, but not Washington.	I-49-6 Ecology believes we are implementing the state biosolids program consistent with its authorizing statute. We are always willing to examine obligations under other laws and rules, but are not inclined to interpret them in a way that runs contrary to our view of the best application of science and public policy. Ecology does not believe the beneficial use of biosolids poses a significant threat to human health or the environment, but does believe we can improve program implementation. That includes revising rules or permit conditions as needed, based on a reasoned analysis of available information. The current permit restructuring is an example of our commitment to bettering the implementation of the biosolids program. In addition to the response above, see the response to comment I-23-1. Ecology also prepared standard responses to common questions received. Please refer to these for additional information. In particular the following

Comment	Response
	standard responses touch on the commenter's inquiry: "The wastewater treatment process and biosolids", "Understanding regulated pollutants in biosolids", and "Food chain crops and biosolids".
I-88-2 Ecology could certainly exert its authority on its own and still be in compliance with the legislature's intent that the agency "beneficially reuse" sewage sludge "in a manner that minimizes the risk to public health and the environment," by telling the legislature that its own concern about sewage sludge safety when applied to ag lands is great enough to compel it to recommend the phasing out of land-application in favor of other ways to "reuse" sludge (all it would take is for Ecology to complete an honest review of existing literature on the subject).	I-88-2 If Ecology believed that biosolids posed a significant risk to human health or the environment, we could focus on approaches that would curtail beneficial use. Ecology does not agree, however, that land application should be phased out. We believe the current program does minimize risks to public health and the environment and is adaptable to continue managing risks as necessary. A better solution, we think, is to look back up the pipe to the source of any contaminant of concern, and work to reduce its use or to require approaches that limit its discharge to public sewer systems. In fact, we are working with that approach in mind right now for PFAS compounds. We do believe that we should continue to evaluate and revise practices whenever and however necessary to ensure the continued protection of public health and the environment.

Comment	Response
I-109-2 A. Biosolids Statutory and Regulatory Criteria The Department of Ecology is affirmatively responsible for ensuring that permitted activities, including land application of biosolids, protects waters of the State. RCW 90.48.010 states in part that: It is declared to be the public policy of the state of Washington to maintain the highest possible standards to insure the purity of all waters of the state consistent with public health and public enjoyment thereof, the propagation and protection of wild life, birds, game, fish and other aquatic life, and the industrial development of the state, and to that end require the use of all known available and reasonable methods by industries and others to prevent and control the pollution of the waters of the state of Washington. Consistent with this policy, the state of Washington will exercise its powers, as fully and as effectively as possible, to retain and secure high quality for all waters of the state. As part of effectuating that policy, RCW 90.48.080 mandates that: It shall be unlawful for any person to throw, drain, run, or otherwise discharge into any of the waters of this state, or to cause, permit or suffer to be thrown, run, drained, allowed to seep or otherwise discharged into such waters any organic or inorganic matter that shall cause or tend to cause pollution of such waters according to the determination of the department, as provided for in this chapter. This provision is broad in scope, covering any mechanism by which "any organic or inorganic matter" pollutes groundwater or surface waters. These broad provisions are reinforced by the State Environmental Policy Act, RCW	I-109-2 The commenter cites various state and federal laws and rules, and draws on their interpretation of agency responsibilities. The implication of the commenter's remarks is that the agency is not meeting its obligations. Ecology implements permit requirements that meet or exceed federal requirements that EPA would apply if it were implementing the program, and which to the best of Ecology's knowledge are generally consistent with approaches used by most other states in implementing biosolids beneficial use. Ecology believes we are implementing the state biosolids program consistent with its authorizing statute, and in compliance with other applicable rules. We are always willing to examine obligations under other laws and rules, but are not inclined to interpret them in a way that runs contrary to our view of the best application of science and public policy. Ecology does not believe the beneficial use of biosolids poses a significant threat to human health or the environment, but does believe we can improve program implementation. That includes revising rules or permit conditions as needed, based on a reasoned analysis of available information. The current permit restructuring is an example of our commitment to bettering the implementation of the biosolids program.

Comment	Response
43.21C.020, which recognizes that "each person has a fundamental and inalienable right to a healthful environment," and commands that it is the "continuing responsibility of the state of Washington and all agencies of the state to use all practicable means" to protect a safe, healthful, and productive environment. SEPA further requires that "[t]he policies, regulations, and laws of the state of Washington shall be interpreted and administered in accordance with the policies set forth" in SEPA. RCW 43.21C.030. With respect to biosolids specifically, RCW 70A.226.005(2) states: The legislature declares that a program shall be established to manage municipal sewage sludge and that the program shall, to the maximum extent possible, ensure that municipal sewage sludge is reused as a beneficial commodity and is managed in a manner that minimizes risk to public health and the environment. This provision presents dual mandates that apply "to the maximum extent possible." While biosolids must be reused, Ecology may only authorize such reuse in a manner that minimizes environmental and health risk. If Ecology cannot ensure that environmental and health risks are minimized, the agency may not permit biosolids application. Ecology implements RCW Chapter 70A.226 through the rules promulgated at WAC Chapter 173-308. The regulations detail testing requirements and concentration thresholds for certain pollutants, WAC 173-308-160, require pathogen and vector reduction, WAC 173-308-170 to - 180, require screening of manufactured inerts, WAC 173-	

Comment	Response
308-205, and set agronomic rate of application, WAC 173-308-190, among other requirements. Notably, WAC 173-308-190(6) provides that "[w]hen the potential for groundwater contamination due to biosolids application exists, the department may require groundwater monitoring or other conditions in accordance with the provisions of chapter 173-200 WAC. If it is determined that an enforcement criterion may be violated, an evaluation must be conducted to demonstrate compliance with the provisions of chapter 173-200 WAC." Finally, WAC 173-308-191 mandates that "[b]iosolids may not be applied to the land if they are likely to adversely affect a threatened or endangered species or its critical habitat." While the biosolids regulations focus on specific pollutants, this does not mean that those are the only pollutants that are subject to regulation or that may cause contamination. WAC 173-380-030 confirms that "[b]iosolids facilities and sites where biosolids are applied to the land must comply with the requirements of chapter 90.48 RCW and chapters 173-200 and 173-201A WAC," which are the Water Pollution Control statute and regulations protecting groundwater and surface water. The regulations contain anti-degradation provisions which prohibiting contamination of waters of the State. WAC 173-200-030; WAC 173-201A-300. WAC 173-201A-240 prohibits introduction of toxic substances to surface waters beyond background levels. The State law requirements are in addition to those imposed by the Federal Clean Water Act and implementing regulations. 40 CFR ¬ß 503.5 ("[n]othing in this part precludes a State or political subdivision thereof or interstate	

Comment	Response
agency from imposing requirements for the use or disposal of sewage sludge more stringent than the requirements in this part or from imposing additional requirements for the use or disposal of sewage sludge."). Where there is land application within the confines of a wastewater treatment facility, a NPDES permit is required. 40 CFR ¬ß 122.26(b)(14)(ix).	
O-7-12 What is Ecology's justification for not including language on effluent as land-based fertilizer and aquifer enhancement? The use of fertilizer for these purposes will be looked to as supplemental to land-based sewage solids as drought increases, and to minimize the amount released into openwater bodies.	O-7-12 This permit process concerns biosolids only. The commenter is referring to discharge from wastewater treatment plants (effluent). The underlying authority in RCW 70A.226[23] does not address the quality or uses of wastewater effluent. That work is the responsibility of our Water Quality Program and is administered under other laws, rules, and permits

26. SEPA

Comment	Response
I-109-1 Thank you for accepting and reviewing comments on the draft general permit for biosolids and septage application. These comments and materials are submitted on behalf of Ed Kenney, a Washington resident with deep concern for water quality, human health, and fisheries in the State. Please consider these comments to apply both to the draft permit and the associated State Environmental Policy Act (SEPA) checklist and proposed determination of non-significance (DNS). In general, the proposed permit and DNS are inadequate in that they focus solely on regulated metals, nitrogen, and bacteria, without accounting for modern pollutants with significant human health risks: microplastics, PBDEs, PFAS, pharmaceuticals, and other contaminants of emerging concern. This deficiency means that Ecology cannot meaningfully assess environmental impacts of issuance of the general permit for application of biosolids, and that the protections for surface waters and groundwater are insufficiently protective In a June 24, 2021 public meeting, Ecology stated that 86,000 tons of biosolids were land applied in Washington in 2019. Even under a conservative and unrealistic assumption that the use of biosolids will remain unchanged, that amounts to a total of 430,000 tons (860 million pounds over the five-year life of the general permit. This staggering quantity mandates caution in regulating biosolids. At the same meeting, Ecology asserted that it	I-109-1 Ecology's issuance of a new general permit is not a decision about whether land application of biosolids should continue as a lawful activity in Washington. That decision was made by enactment of RCW 70A.226[23], in which the legislature directed Ecology "to meet federal regulatory requirements" for biosolids and "specifically directed Ecology to adopt rules to implement a biosolids management program that 'to the maximum extent possible' ensures that biosolids are 'reused as a beneficial commodity'"[78]. The issuance of a new general permit also is not a decision about what sampling, pollutant limits, setbacks from surface water and other such requirements and restrictions should be imposed for the safe management of biosolids. Those regulatory requirements were decided by Ecology's promulgation of the regulations in WAC 173-308[24]. The biosolids general permit does not and cannot adopt or repeal regulations. Rather, it communicates how facilities are to comply with WAC 173-308[24] and provides a permit template under which individual facility coverage may be granted and to which site specific land application plans, facility spill plans, and site specific requirements can be appended as necessary. A new general permit isn't even a requisite for authorizing facilities to manage biosolids—by rule, facilities maintain continuing coverage granted under the prior general permit and Ecology is currently authorizing new or amended coverage by agreed orders. The commenter's substantive argument (as opposed to their SEPA procedural argument) is

[78] *Dept. of Ecology v. Wahkiakum County,* 184 Wash.App. 372, 380-81 (2014)

Comment	Response
lacks means to regulate pollutants other than the nine metals identified by the United States Environmental Protection Agency (EPA) in 40 CFR 503.13, and nitrogen. As explained herein, this position is both inaccurate and fails to meet Ecology's statutory duties to protect waters of the State. Given inadequate information and reasonable risk of harm to the environment and human health, Ecology must take a precautionary approach, make a determination of significance, and prepare an environmental significance. While Mr. Kenney acknowledges that Ecology faces legislative direction to make beneficial use of biosolids in a manner that minimizes risk to public health and the environment, preparation of an environmental impact statement will allow the agency the time and information needed to balance these dual mandates. Careful consideration of alternatives is essential before approving such an extensive, impactful, and risky program… …B. SEPA Procedural Requirements SEPA requires that Ecology prepare an environmental impact statement (EIS) for major actions having a probable significant, adverse environmental impact. RCW 43.21C.031. In order to determine whether an EIS is required, Ecology must prepare a threshold determination based on a rigorous review of direct, indirect, and cumulative effects of the proposal. WAC 197-11-330. Impacts likely to be significant include impacts	that the protections for groundwater and surface water under Ecology's biosolids regulations are insufficiently protective and that Ecology should either halt the beneficial use of biosolids or adopt new requirements as a precaution against possible risks from certain contaminants in biosolids (e.g., "ban biosolids application on hydric soils and periodically inundated areas, impose greater buffers from surface waters, and require more distance to groundwater for all biosolids application"). The flaw with this argument is that a halt on biosolids use would be inconsistent with Ecology's statutory directive, and the commenters' proposed additional protections would be "rules" as defined in RCW 34.05.010(16)[79] that could only be adopted or amended as part of a notice and comment rulemaking process. RCW 34.05.310-395[80]. However, if resources allow, Ecology will reevalutate buffers for all purposes during the lifecycle of this general permit. Please see the response to comment O-7-8 for more details. In deciding whether a decision may have adverse effects requiring the preparation of an environmental impact statement, an agency is not required to factor in effects that it lacks statutory authority to prevent as part of the decision being evaluated[8182]. Even if the purpose of the present SEPA threshold determination was to consider whether the biosolids rules in WAC 173-308[24] have a probable significant adverse environmental impact, it is clear that they do not for the simple reason that

[79] https://app.leg.wa.gov/rcw/default.aspx?cite=34.05.010
[80] https://apps.leg.wa.gov/rcw/default.aspx?cite=34.05.310
[81] *Dep't of Transp. v. Public Citizen*, 541 U.S. 752, 765-770, 124 S.Ct. 2204, 159 L.Ed.2d 60 (2004)
[82] *Chuckanut Conservancy v. Washington State Dept. of Natural Resources*, 156 Wash.App. 289-90 (2010)

Comment	Response
"to environmentally sensitive or special areas, such as loss or destruction of historic, scientific, and cultural resources, parks, prime farmlands, wetlands, wild and scenic rivers, or wilderness," impacts that "[a]dversely affect endangered or threatened species or their habitat actions that "[c]onflict with local, state, or federal laws or requirements for the protection of the environment" and those impacts that "involve unique and unknown risks to the environment, or may affect public health or safety." WAC 197-11- 330(3)(e). Ecology must make the threshold determination "based upon information reasonably sufficient to evaluate the environmental impact of a proposal," and may require the applicant to submit more information or conduct independent further analysis if such reasonably sufficient information is not provided by the project proponent. WAC 197-11-335. The reasonably sufficient information requirement is ongoing. The lead agency "shall withdraw" the determination of nonsignificance if "[t]here is significant new information indicating, or on, a proposal's probable significant adverse environmental impacts" or [t]he DNS was procured by misrepresentation or lack of material disclosure." WAC 197-11-340(3). While SEPA review may reference thresholds and requirements set forth in other statutes and regulations, SEPA compliance is an independent legal duty, and SEPA supplements existing authority. Polygon Corp. v. Seattle , 90 Wash. 2d 59, 65, 578 P.2d 1309, 1313 (1978); Columbia Riverkeeper v. Port of Vancouver USA , 188 Wash. 2d 80, 95, 392	the rules' effects are beneficial, not adverse[83].)Ecology's biosolids rules ensure that application of biosolids on the land will meet federal rules, and that unlike under federal rules, biosolids preparation and land application will be subject to the additional oversight of a permitting program with site-specific requirements to protect human health and the environment. The fact that those rules could perhaps be even more restrictive under a more conservative application of the precautionary principle does not make them a major action with significant adverse effects on the quality of the environment[82]. In the absence of a state permitting program, treatment works could land apply under federal rules and without specific permit coverage. When the legislature enacted the state biosolids law, it stated that the "purpose of this chapter is to provide the department of ecology and local governments with the authority and direction to meet federal regulatory requirements for municipal sewage sludge," citing "the federal clean water act as it existed February 4, 1987." RCW 70A.226.007[23]. Section 405(d) of the Clean Water Act, 33 U.S.C. Sec. 1345(d)[84] requires EPA to establish numeric limits and management practices that protect public health and the environment from the reasonably anticipated adverse effects of chemical and microbial pollutants during the use or disposal of sewage sludge. It also requires EPA to review sewage sludge (biosolids) regulations every two years to identify any additional pollutants that may occur in biosolids, and then set regulations for those pollutants if sufficient scientific evidence shows they may harm human health or the environment. EPA considers the federal program to be self-

[83] *Leavitt v. Jefferson County,* 74 Wash. App. 668 (1994). As required by RCW 70A.226.020(1),

[84] https://www.govinfo.gov/app/details/USCODE-2011-title33/USCODE-2011-title33-chap26-subchapIV-sec1345

Comment	Response
P.3d 1025, 1032 (2017)… …2. Proposed changes to the general permit and SEPA review Mr. Kenney acknowledges that Ecology has incomplete information and cannot fully know the contents of all biosolids. However, these challenges are not a valid reason to ignore the presence of harmful contaminants. Ecology has a duty to the public to protect waters of the State, and a duty under SEPA to obtain and consider all reasonable available information: "If information on significant adverse impacts essential to a reasoned choice among alternatives is not known, and the costs of obtaining it are not exorbitant, agencies shall obtain and include the information in their environmental documents."WAC 197-11-080(1). Ecology's SEPA obligation requires the agency to consider environmental impacts of all contaminants likely present in biosolids, even if they are not specified under biosolids regulations. Columbia Riverkeeper , 188 Wash. 2d at 95. Accordingly, Mr. Kenney requests that Ecology make the following changes to the general permit documentation and SEPA review to better protect the environment and public health: • Coordinate internally with Ecology staff working on the PFAS CAP, and coordinate and consult with the Washington Department of Health, the Washington Department of Fish and Wildlife, and Washington tribal governments. • Given the risk to groundwater and surface waters and limited testing conducted of biosolids available for a variety of contaminants, ban biosolids application on	implementing, meaning facilities can engage in beneficial use practices without a permit as long as they comply with federal rules. 40 C.F.R. Part 503[13]. The state program, on the other hand, requires more from generators and users of biosolids, and provides closer oversight. The state program protects surface and groundwater by requiring permittees to identify those resources on and near the site on site specific land application plans, to comply with setbacks from those resources, to limit the seasons of application to minimize risk of runoff, to follow a groundwater protection plan on sites where groundwater is seasonally shallow, and adhere to agronomic usage rates determined by post-harvest or pre-application soil nitrate and phosphorous analysis. The commenter attempts to frame the action under SEPA review as a decision to release harmful materials to the environment, by way of permitted biosolids land application, at concentrations that are likely to be harmful to human health and the environment. But that characterization of the action under review is not accurate. It may be that SEPA would require a determination of significance for the issuance of new biosolids general permit if scientific research had demonstrated that microplastics or chemical or microbial contaminants present at concentrations in municipal biosolids were causing significant adverse environmental impacts when applied in compliance with in Washington's biosolids permitting program. But that circumstance does not exist. Neither the studies cited by the commenter nor any of the other scientific research collected by Ecology in its chemical action plans or by EPA in its biennial reviews supports the conclusion that municipal biosolids as generated in Washington contain levels of microplastics, PFAS or any other

Comment	Response
hydric soils and periodically inundated areas, impose greater buffers from surface waters, and require more distance to groundwater for all biosolids application. • In the SEPA analysis, identify information gaps and obtain information to fill those gaps to the maximum extent feasible. To the extent information truly cannot be obtained, "indicate in the appropriate environmental documents its worst case analysis and the likelihood of occurrence." WAC 197-11-080(3)(b). • Disclose and discuss the progress on the WWTP sampling study referenced in the draft PFAS CAP, including the methodology and any initial results. Biosolids Management Comment Letter. • Identify and discuss all other States (such as Maine) that monitor, test, and/or regulate PBDEs or PFAS and other chemicals in biosolids. Explain the implications for this information on the Washington regulatory program. • Prior to making a threshold determination, specifically identify a list of contaminants of priority concern (including PBDEs and PFAS) and: 1) assess their likely prevalence in biosolids, 2) assess their probable human health and environmental impacts given the scale of application in Washington, 3) test biosolids from various WWTPs, 3) test groundwater and runoff at application sites. • Require as a condition of the general permit that WWTP operators test biosolids for PFAS and other contaminants of emerging concern and report to Ecology. Ecology	chemicals or microbial contaminant that are likely to cause substantial adverse environmental impacts. Other than a study of soils in fields in Alabama that had received biosolids generated from a facility that treated wastewater from fluorochemical manufacturing facilities, the studies simply point to a need for prioritization of certain biosolids contaminants for further scientific research. That includes the substances the commenter refers to as “modern contaminants.” We want to point out that the contaminants the commenter identifies as modern, are not recent in origin, although our understanding of their impact on human health and the environment has greatly evolved in recent years. The key question for review under SEPA is whether the proposal creates a probable, or reasonable likelihood of a more than moderate adverse environmental impact[858687]. (Probable is used to distinguish likely impacts from those that are merely speculative. Although scientific study and understanding is growing and evolving with respect to contaminants known to occur in biosolids, neither EPA nor Ecology have yet concluded that there is sufficient scientific evidence of human health or environmental risk from the contaminants mentioned by the commenter to require the adoption of regulatory amendments for the protection of human health and the environment. Ecology acknowledges that the potential for risks from certain contaminants, including microplastics, PFAS and other contaminants identified by the commenter, merit further study.

[85] https://apps.leg.wa.gov/wac/default.aspx?cite=197-11-060
[86] https://app.leg.wa.gov/WAC/default.aspx?cite=197-11-782
[87] https://app.leg.wa.gov/wac/default.aspx?cite=197-11-794

Comment	Response
indicates that these tests are available for $1,000-$1,500, which is a reasonable cost to impose on the regulated entity given the risk to public health. If entities profit from land application of biosolids, it is entirely appropriate and reasonable to pass through costs of testing to those companies to gather data. Requiring testing would provide Ecology with a broad data set to effectively regulate PFAS and other chemicals. Evaluate and disclose the extent to which biosolids application sites risk becoming contaminated over time in a manner that requires cleanup under State or Federal law (including the Model Toxics Cleanup Act, RCW 70A.305.010, et. seq. , and the Resource Conservation and Recovery Act, 42 U.S.C. 6901 et. seq.)... …F. SEPA Checklist Specific Comments The SEPA Checklist and associated threshold determination must fully disclose sufficient information to determine whether a proposal has probable significant adverse environmental impacts. WAC 197-11-335. The determination includes consideration of cumulative effects, WAC 197-11-330(3)(c), and may not weigh purported benefits of the proposal against the adverse impacts, WAC 197-11-330(5). "Significant" means "a reasonable likelihood of more than a moderate adverse impact on environmental quality." The general permit authorizes millions of pounds of land application of biosolids over a period of five years, which, as documented above, contain unknown amounts of dangerous chemicals and microplastics. While Mr. Kenney recognizes that there would be	At present, however, the conclusion that continued application of biosolids in Washington consistent with WAC 173-308[24] will cause substantial adverse environmental impacts attributable to microplastics, PFAS or other chemical contaminants is speculative and cannot be said to be likely. During the public hearing the commenter references (which occurred in June 2021), Ecology noted that there was no EPA validated method to sample for PFAS in biosolids. And until one could be established, sampling for PFAS in biosolids would not accurately inform us about its presence (without proven sampling protocols) or of the risks it presents, if any, at different concentrations in biosolids (without detailed understanding of its fate and transport in biosolids, soils, plant-uptake and routes of exposure, etc.). At the time of the public hearing, Ecology's position was that waiting for an EPA approved and validated method prior to sampling for these chemicals in biosolids was the best practice. However, after a time it became clear that EPA was stalled on identifying a method they could formally approve. EPA eventually encouraged states to work directly with experienced labs and to move ahead with analysis as needed. To date EPA have only a single-lab validated method (the standard is multi-lab validated)[45]. Since then, Ecology has been discussing a possible research effort with U.S. EPA. Ecology is actively studying PFAS and other contaminants of concern and is working diligently to make science-based decisions with respect to the need for any additional regulatory requirements. The commenter made reference to Ecology's PFAS Chemical Action Plan[35] published in 2021 by Ecology in cooperation with the State Department of Health. Ecology has published

Comment	Response
phased SEPA review for individual projects, in order to be meaningful SEPA review must be carried out "at the earliest possible time to ensure that planning and decisions reflect environmental values, to avoid delays later in the process, and to seek to resolve potential problems." WAC 197-11-055(1). Early review is particularly necessary here, where there are significant cumulative effects of biosolids application across the State, and the identified issues are common to all biosolids. PFAS, contaminants of emerging concern, and microplastics exist in all biosolids, and are not site- specific issues well suited for later phased review. The programmatic phase is also the only meaningful opportunity to conduct environmental review of Class A "exceptional quality" biosolids, application of which is not subject to later SEPA review. The general permit clearly creates "a reasonable likelihood of more than a moderate adverse impact on environmental quality," and thus is significant and requires preparation of an environmental impact statement. Because application of biosolids can reasonably be anticipated to contaminate both groundwater and surface waters across the State with chemicals already recognized by Ecology to pose a serious threat to human health, the proposal presents cumulative effects to wildlife, "unique and unknown risks to the environment," and "may affect public health or safety. WAC 197-11-330(3). Ecology mainly points to data gaps as the explanation for why it cannot regulate acknowledged risks. Under SEPA regulations, significance depends on context and intensity. "The context may vary with the physical setting. Intensity depends on the magnitude and duration of an impact." WAC 197-11-794.	other Chemical Action Plans in the past for lead, mercury, polybrominated diphenyl ethers, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls. Biosolids were considered during the development of each Chemical Action Plan. Lead and mercury are already regulated in biosolids, but the mercury CAP did lead to reductions of mercury in biosolids. For the CAPs pertaining to organic pollutants, Ecology did not determine that additional regulation was necessary for biosolids. Of course, that could change based on new information at any point in the future, but to date, neither Ecology nor EPA has identified additional regulatory requirements in regard to biosolids preparation or use as an appropriate action for controlling the release of those substances to the environment. U.S. EPA is also preparing a new risk-screening tool to assist with prioritizing pollutants (including PFAS) for further analysis or development of regulatory standards. Given the current state of scientific research, an environmental impact statement would not produce any more information than Ecology and EPA have already gathered.

Comment	Response
Here, PFAS are "forever chemicals," so the duration of the impact is perpetuity. Furthermore, "[t]he severity of an impact should be weighed along with the likelihood of its occurrence. An impact may be significant if its chance of occurrence is not great, but the resulting environmental impact would be severe if it occurred." The impacts of widespread biosolids application are undoubtedly severe, given the reasonable threat of harm to human health of PFAS, including, according to Ecology, "probable links to immune system toxicity, high cholesterol, reproductive and developmental issues, endocrine system disruption, ulcerative colitis, thyroid issues, certain cancers, and pregnancy-induced hypertension " Preparation of a programmatic EIS is the statutorily mandated mechanism by which to address these data gaps and assess associated risks and impacts. Rather than forge ahead in the face of admitted incomplete information, Ecology must carefully assess the likelihood and severity of impacts, reasonable alternatives, and the mechanism to mitigate them. In addition to the general request for a determination of significance and preparation of an EIS, Mr. Kenney raises the following specific concerns with the SEPA checklist: • ¶ 1. The checklist improperly excludes consideration of population growth, when Washington is a quickly growing State. The checklist should consider more recent population trends, including during the COVID pandemic. • ¶ 1. The description of pollutants should distinguish between pollutants that are regulated, and pollutants more broadly, as	

Comment	Response
this section appears to use the terms interchangeably. The SEPA analysis must consider impacts of all pollutants reasonably likely to be contained in biosolids irrespective of their regulation. The general statement that "Generally, pollutants in biosolids occur in very low concentrations, below the level where an adverse effect is expected" is inadequate. This cursory analysis lumps all pollutants together and contains no useful information. • As detailed above, high priority pollutants (including PBDEs and PFAS) should be identified, along with a discussion of their likely presence of the pollutants and risks to the environment and human health. The one summary sentence dedicated to a serious and complex systemic issue is clearly inadequate. • ¶1. The citation to WAC 173-308-90003 should acknowledge that this is the minimum content of a land application plan, but not necessarily sufficient to protect groundwater or adequate to fulfill Ecology's duties to protect groundwater. • ¶1. The checklist states that "If the regulation of other pollutants becomes necessary during the course of the permit cycle, that is sufficient cause for Ecology to open the permit for modification." This statement lacks basis or thresholds, and is circular in that it states that if regulation is necessary then it is necessary. In order to be meaningful, mitigation must include specific triggers, criteria, and regulatory responses as part of a robust adaptive management system with public involvement. • ¶2. The general statements regarding	

Comment	Response
"decades of science" are inadequate.¬†Citation must be provided. Emphasis should be placed on recent science, rather than decades-old science, given the concerns regarding PFAS, microplastics and other more recently understood issues. • ¶2. The purported benefits of biosolids are immaterial to the threshold determination. • ¶4. The statement that "Parks, wilderness areas, and wild and scenic rivers are likely too remote to be desirable for the land application of non-EQ biosolids" is inaccurate. • ¶4. Application of biosolids to hydric soils raises high probability of groundwater contamination, which must be analyzed. As a mitigation measure, Mr. Kenney recommends barring biosolids applications from hydric soils and areas that are periodically inundated. • ¶6. The analysis states that "[t]he permit itself will not increase demands on transportation or public services and utilities." This is the incorrect legal standard for SEPA review, which requires consideration of both direct and indirect effects. Ecology must consider the full impacts of biosolids application over time, including emissions and traffic associated with application.	
I-118-5 On January 9, 2019, I submitted comments that the Statewide Biosolids General Permit could work. Now, my position that a full EIS is needed for these sewage/sludge/septage biosolids operations. If not now, when?	I-118-5 Ecology does not agree that an EIS is required. An EIS is required when a proposal creates a likelihood of a more than moderate adverse environmental impact. Ecology does not believe the general permit creates such a likelihood. Please see the response to comment I-109-1.

Comment	Response
I-113-4 Regarding the permit, I would urge you to not consider issuing a DNR (Determination of Non Significance) regarding environmental impacts. Instead I would like to see a full Environmental Impact Study be performed.	I-113-4 The threshold for a determination of significance is the "reasonable likelihood" (not some distant possibility or anomalous circumstance) of a "more than moderately adverse" impact on environmental quality. Ecology does not believe biosolids management reaches that threshold, and accordingly has not required an Environmental Impact Statement. We also note that individual facilities are subject to environmental review, as well as specific land application sites. Please see the response to comment I-109-1.

27. T and E Species

Comment	Response
I-109-9 E. The General Permit Fails to Protect Threatened and Endangered Species Biosolids application is not allowed where the application is likely to adversely affect a threatened or endangered species or its critical habitat as listed under Title 232 WAC or section 4 of the Endangered Species Act. WAC 173-308-191. Notably, the regulation prohibits any likely harm to threatened or endangered species or their critical habitat and does not allow for de minimus exceptions or mitigation measures. This is a particularly significant issue for southern resident killer whales, which are top tier predators of salmon and marine life and thus bioaccumulate toxins. Issuance of the general permit without protections for protected species would not only potentially violate State law, it would also likely violate the Federal Endangered Species Act (ESA). The ESA prohibits the "take" of species listed as threatened or endangered on the federal endangered species list. 16 U.S.C. 1538(a)(1)(B). The ESA defines "take" as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." Id. 1532(19). By regulation, the National Marine Fisheries Service has defined "harm" to include "significant habitat modification or degradation which actually kills or injures fish or wildlife by significantly impairing essential behavioral patterns, including, breeding, spawning, rearing, migrating, feeding or sheltering." 50 C.F.R. 222.102; Babbitt v. Sweet Home Chapter, Communities for Great Ore., 515 U.S. 687 (1995). Under what is known as the " Strahan theory,"	I-109-9 Ecology does not believe the general permit will result in an adverse effect to threatened or endangered species and no consultation with NMFS is required. When an environmental checklist is required under the State Environmental Policy Act for a facility or land application site, potential impacts to threatened and endangered species are considered. All facilities subject to the permit must conduct a SEPA review. We have developed simple guidance that we will make available for applicants to use to ensure that this important requirement is not overlooked. Please also see comment O-7-30 for additional information.

Comment	Response
a governmental entity may be liable under the ESA for authorizing harm carried out by private third parties. See Strahan v. Coxe , 127 F.3d 155, 158, 163 (1st Cir. 1997) (state agency caused takings of the endangered right whale because it "licensed commercial fishing operations to use gillnets and lobster pots in specifically the manner that is likely to result in violation of [the ESA]"), cert. denied, 1998 U.S. LEXIS 7103 (Nov. 2, 1998) (No. 97-1485); Defenders of Wildlife v. Administrator, Envtl. Protection Agency, 882 F.2d 1294, 1300-01 (8th Cir. 1989) (federal agency caused takes of the endangered black- footed ferret through its "decision to register pesticides" even though other persons actually distributed or used the pesticides); Loggerhead Turtle v. Cty. Council of Volusia Cty. , 148 F.3d 1231, 1251 (11th Cir. 1998) (finding plaintiffs had standing where they alleged harm from county's failure to regulate artificial beach lighting, which harmed turtles). An agency may receive authorization from the U.S. Fish and Wildlife Service and/or National Marine Fisheries Service to issue permits that cause harm to listed species, under ESA Section 10. See 16 U.S.C. 1539(a)(2)(B). For example, Washington State Department of Natural Resources has an incidental take permit for authorization of forest practices that cause likely harm to listed species. Ecology lacks such authorization for the biosolids program. The ESA authorizes citizen suits "to enjoin any person, including the United States and any other governmental instrumentality or agency (to the extent permitted by the eleventh amendment to the Constitution), who is alleged to be in violation of any provision" of the Act. 16 U.S.C. 1540(g)(1)(A). Agency	

Comment	Response
officials acting in their official capacity are not protected by the eleventh amendment, and so state agencies are functionally subject to suit. Such suits may result in injunctive relief, civil penalties, and an award of costs and attorneys' fees. In order to fully protect listed species and protect the State from liability, Mr. Kenney suggests that Ecology consult with the National Marine Fisheries Service and U.S. Fish and Wildlife Service to determine whether an incidental take permit and associated habitat conservation plan is required.	

28. Manures

Comment	Response
O-2-13 **Biosolids as Fertilizer:** If biosolids are marketed as soil amendments and fertilizer, then biosolid application should meet the standards that are in place for manure management. See Ecology's National Pollutant Discharge Elimination System (NPDES) permit for Concentrated Animal Feeding Operations (CAFOs). Permitting for biosolids should: • Address stormwater runoff and emergency plans for once in 25 year storm events. • Prohibit application of biosolids to the land when there is no crop growing. • Require spring soil sampling to a depth of three feet prior to biosolid application. • Require soil testing to a depth of 3 feet each fall at the end of harvest on land that received biosolid applications. Develop a protocol to reduce future biosolid and fertilizer application if nitrate levels in the fall sampling exceed 15 parts per million (ppm). • Require composting and other treatment of sewage sludge and septage to take place on a hardened surface with > 95% compaction. • Require groundwater monitoring when beneficial use facilities are located on land with well drained soils. • There should be no land application of biosolids to fields with saturated soil. Applicators should estimate the amount of nitrogen lost to volatilization.	O-2-13 The commenter links the marketing of biosolids to soil amendments and fertilizers, and then argues if that is the case that biosolids should be subject to rules for manure management. Biosolids and manure have many similarities, but they are subject to different regulatory requirements administered by different programs and different agencies. Rules governing manure (in the context of dairy manure and concentrated animal feeding operations - CAFOs) are fairly complex. Responsibilities are divided between Ecology and the State Department of Agriculture. Ecology has responsibility for regulating practices at concentrated animal feeding operations (CAFOs, which include stockyards, many dairies, etc). Agriculture has responsibility for activities related to manure management at sites that do not fall under CAFO rules, and operates in a sort of middle ground cooperating with Ecology on certain operational aspects at CAFOs. The commenter provided a list which we understand to represent her recommendations for biosolids based on requirements for manure management. The commenter recommends an emergency plan for the event of a 25-year storm. That is not a specific requirement from the Department of Agriculture. Ecology's storm-related CAFO requirement pertains only to the capacity of facilities where manure is stored. The storm requirement does not apply to sites where manures (or biosolids) are land applied. Ecology standards for biosolids surface impoundments come from solid waste rules in chapter 173-350 WAC, which in turn are based on water quality program standards. Biosolids surface

	impoundments require 18" of freeboard - well in excess of any storm event. Solid waste rules have a 25-year storm event provision for tanks, but it is not in place for tanks storing biosolids. The commenter recommended prohibiting biosolids application when there is no crop growing. Neither Ecology nor Agriculture imposes this requirement for manure. Ecology's CAFO program requires that a crop must be planted within 30 days. The requirement is in place to protect groundwater by ensuring uptake of nutrients - especially nitrate. This will work in many farming systems, but it does not work in dryland situations where there is a fallow year between harvests. In dryland systems, rainfall is scarce so the potential for leaching of nitrate to groundwater is minimal if agronomic rates are adhered to. Biosolids are often applied prior to planting, but in some cases, like pasture, biosolids are applied when the grass has been mowed or grazed. Most of the nitrogen in biosolids is in an organic form and must be mineralized (converted to available forms) before plants can use it. All land application sites have a goal, whether it is to produce hay, or to reclaim a site where nothing is growing and restore it for wildlife habitat. Applying biosolids to a site where no crop would be grown is not allowable under the state program. The commenter recommends requiring soil sampling to three feet before biosolids are applied, and each fall. The commenter also recommends a reduction in future applications if soil nitrates exceed 15 parts per million. Neither Ecology nor Agriculture impose these requirements for manure management. Ecology requires sampling to one foot in western Washington and two feet in eastern Washington for manure sites, which is similar to biosolids sites. For manure management, there is a requirement to adjust application manure rates if

	residual nitrate exceeds 30 ppm. Biosolids guidelines are similar. A single approach is not optimum and would actually provide information that is not helpful. There is some available nitrate in soils regardless of additions from biosolids or fertilizers. That happens as part of the nitrogen cycle. Most of the nitrogen in biosolids is in the organic form (commonly called slow-release nitrogen) and is not immediately available after application. On the wetter west side of the state, fall rains can leach excess nitrate from the rooting zone. So post-harvest or "report card" sampling is done in the fall after harvest, and before the onset of significant rainfall. At that point, most of the excess nitrate (if any) will be in the first one to two feet. The time and expense of looking in the third foot is generally not justified, although it could be required if appropriate. Looking at soil nitrate in the spring in higher rainfall areas is not helpful because during the winter months, excess nitrate will be leached from the soil profile, and in the following spring only small amounts of nitrate become available at any time. Sampling on say April 1 would not suddenly find all the nitrate that would be available in the soil profile during the course of the growing season. And sampling on April 15 would yield a different result as plants grow and more organic nitrogen is mineralized, but again, would not tell the whole story. The expectation of nitrogen dynamics is built into agronomic rate determinations and the fall report card analysis is instructive to make adjustments in the following year if necessary. In drier areas of the state on the east side, sampling to three feet is not required, but can be informative because nitrate moves slowly through the soil profile. Third foot analysis is generally a consideration when a site has a history of moderate or higher levels of nitrate in the first two feet. On drier sites, post-harvest sampling can

	be used, but pre-plant analysis can also be used because unlike higher rainfall areas typical of the west side, nitrate is not so readily leached from the soil profile. Agronomic rate determinations along with timely soil nitrate analysis provide information to allow adjustment to rates in the following year if necessary. A residual of 15 parts per million of nitrate in a three-foot sample would be quite low and would not be cause for modifying future application rates. In a one-foot sample it would be at the higher end of acceptable levels and would bear watching. The commenter recommends that composting and other treatment processes take place on hardened services with compaction greater than 95%. Biosolids composting and other forms of treatment occur at facilities that have been permitted and approved, including engineering review. Biosolids compost facilities must meet standards for design and operation in WAC 173-350-220[67]. The commenter recommends groundwater monitoring at land application sites with well-drained soils. Ecology's CAFO program is evaluating groundwater monitoring for manure management. Ecology biosolids staff do not support groundwater monitoring as a general requirement for biosolids land application. Ecology believes the science behind agronomic rate determination is protective of groundwater when coupled with soil sampling. We want to point out that groundwater monitoring is also not required where commercial fertilizers are used. The commenter recommends prohibiting application to saturated soils. Site-specific plans are approved with seasonal limitations in mind. That includes not applying to

	soils that are flooded, frozen, or snow-covered. Buffers protect surface water resources The commenter recommends that applicators should estimate nitrogen lost to volatilization. Losses to volatilization are considered in agronomic rate calculations for both biosolids and manure.
O-7-56 Biosolids as Fertilizer If biosolids are marketed as soil amendments and fertilizer, then the application of biosolids should meet the standards that are in place for manure management. (See Ecology's National Pollutant Discharge Elimination System (NPDES) permit for Concentrated Animal Feeding Operations (CAFOs).) Permitting for biosolids should: • Address stormwater runoff and emergency plans for once in 25-year-storm events. • Prohibit application of biosolids to the land when there is no crop growing. • Require spring soil sampling to a depth of at least three feet prior to biosolids application, depending on the soil porosity. • Require soil testing to a depth of at least 3 feet each fall at the end of harvest on land that received biosolids applications. Develop a protocol to reduce future biosolids and fertilizer application if nitrate levels in the fall sampling exceed 15 parts per million (ppm). • Require composting and other treatment of sewage sludge and septage to take place on a hardened surface with > 95% compaction. • Require groundwater monitoring when beneficial use facilities are located on land with well-drained soils. • There should be no land application of biosolids to fields with saturated soil.	O-7-56 Please see the response to comment O-2-13.

• Applicators should estimate the amount of nitrogen lost to volatilization.	

29. Rules

Comment	Response
LG-1-1 1) General Comments Several items included in this permit are covered under regulations in the Washington Administrative Code. For example, minimum sampling frequency, allowable pollutant limits, and labeling requirements all have requirements under their respective sections in the WAC. We assume this general permit prevails in case there are any differences between the general permit and the WAC.	LG-1-1 The commenter notes that several items in the permit are also covered under regulations in the Washington Administrative Code (WAC 173-308), with an expectation that the general permit prevails in the case of any inconsistency. This comment actually goes to the heart of a dilemma in drafting the general permit. Ecology could perhaps write the general permit to say, "Follow the rules in Chapter 173-308 WAC[24], except for the following modifications..." The rules, however, are not written in the fashion of a permit and would be difficult for most treatment works to directly implement as permit requirements, and not all rules apply in all situations. Some items are carried over directly from the rules because the agency believes it improves the prospects for user comprehension and compliance. That being said, the general permit cannot reduce or alleviate a requirement of the rule if that flexibility is not allowed in the rule. Ecology is not aware of any inconsistency where the general permit would be less stringent. If there is any inconsistency between the rule and the permit where no flexibility is provided, we expect that the rule would prevail.

30. Right to Farm

Comment	Response
B-1-3 6. DOE should recognize that biosolids is a standard Ag Practice and is covered under State and Local Right to Farm ordinances. a. https://www.nebiosolids.org/pa-supreme-court-finds-biosolids-recycling-normalagricultural-operation/	B-1-3 The article provided by the commenter is about the PA supreme court ruling in favor of a biosolids management company, citing that biosolids recycling on farms is a "normal agricultural practice". Their state's Right to Farm Act protects agricultural operations that have been operating for at least a year before a nuisance suit or ordinance is brought. There are additional stipulations included in the act about practices needing to remain largely the same. Ecology has consistently supported that the land application of biosolids to agricultural lands is a common means of management.

31. Clarifications

Comment	Response
LG-1-2 2) Biosolids Facility List Column 4 of Table The Biosolids Facility List has N/A listed under the column "Counties Where Land Applying" for Pierce County's Chambers Creek WWTP. Change N/A to Douglas County. Pierce County has a contract with the Boulder Park BUF to land apply biosolids in Douglas County.	LG-1-2 The commenter requested a change in their status on the list of biosolids facilities published with the general permit. Ecology has made the correction as noted.
LG-1-6 6) Section 2.1 Understanding and Complying with the Permit System-Second box under Existing Facilities "Existing Baseline facilities without active programs are automatically covered on the effective date of the general permit. To confirm your, consult the Facility List provided by Ecology." Change last sentence to: To confirm which sections of this permit apply to your facility, consult the Facility List provided by Ecology. (Or something similar) …11) Section 2.21 Compliance Schedules Error! Bookmark not defined	LG-1-6 Ecology revised the language in question.

LG-1-7 7) Section 2.1 Understanding and Complying with the Permit System Second box under New Facilities "New facilities are not subject to automatic coverage." Add that new facilities must apply for coverage. …13) Section 4.5 Requirements for Non-Exceptional Quality Biosolids Applied the Land – change “Applied TO the Land.”	LG-1-7 Ecology made the suggested clarifications.
LG-1-8 8) Section 2.1 Understanding and Complying with the Permit System Fifth box under Existing Facilities "Existing facilities without active programs that submitted an NOI in a timely manner do not need to submit a permit application." Define "in a timely manner."	LG-1-8 Ecology revised the language in the fifth box of 2.1 to specify a specific timeframe.
LG-4-1 The City of Tacoma Environmental Services Department appreciates the opportunity to comment on the Department of Ecology's (Ecology) Statewide General Permit For Biosolids Management. The City of Tacoma operates two wastewater treatment facilities. The North End Treatment Plant #3 is a 7.2 MGD plant that sends all of its sludge to another facility (Tacoma Central Treatment Plant #1) for further processing. Our Central Treatment Plant produces approximately 7,000 dry tons of biosolids every year. Over 85% of our biosolids are sold as second-generation biosolids products… …The following are specific comments on sections of the permit and Fact Sheet: 1.2.3. Active Biosolids Management Section	LG-4-1 We appreciate several editorial corrections offered by City of Tacoma Environmental Services Department and made revisions as appropriate.

Section (4) of this permit applies to facilities with active biosolids management programs, but not those than that manage only septage (1.2.2 above). 2.1. Understanding and Complying with the Permit System Figure 1 – This flow chart outlines the application process. Existing Baseline facilities without active programs are automatically covered on the effective date of the general permit. To confirm your coverage, consult the Facility List provided by Ecology 4.4.4. Frequency of Biosolids Analysis The dry weight tonnage of biosolids applied to the land or prepared for sale/give away per 365-day period determines the minimum frequency of biosolids analysis (Table B1 below). Table B1 should explicitly say in the table that the tonnage units are dry tons… …Thank you for this opportunity to comment on the Statewide General Permit For Biosolids Management. We trust our comments are useful.	

O-2-1 Please consider these comments regarding Ecology's proposed General Permit for Biosolids from the Friends of Toppenish Creek (FOTC), a 501 C (3) non-profit in Yakima County. Friends of Toppenish Creek is dedicated to protecting the rights of rural communities and improving oversight of industrial agriculture. FOTC operates under the simple principle that all people deserve clean air, clean water and protection from abuse that results when profit is favored over people. FOTC works through public education, citizen investigations, research, legislation, special events, and direct action. **Grammatical, clerical, miscellaneous problems:** Page 1, First Sentence: There is no Chapter 70A.225 RCW. The statute is Chapter 70A.226 RCW. Page 5, Fourth line correction: Section (4) of this permit applies to facilities with active biosolids management programs, but not those than that manage only septage (1.2.2 above). Page 6, Figure 1, Second Step correction: Existing Baseline facilities without active programs are automatically covered on the effective date of the general permit. To confirm your permit, consult the Facility List provided by Ecology. Page 6, Figure 1, Fifth Step says: Existing facilities with active programs must submit a complete permit application within 90 days of permit issuance. This cannot be correct. Ecology should not issue a permit before the permit application is submitted.	O-2-1 We agree that all of Washington's citizens are entitled to a healthy environment. Ecology has committed to examining biosolids in the context of environmental justice in the coming permit cycle We appreciate several editorial corrections offered by Friends of Toppenish Creek and made revisions as appropriate.

O-2-2 Pages 44-45, Site Specific Land Application Maps must contain: Item (10) should rewritten to say, *If the seasonal groundwater is three feet (O. 91 meters) or less below the surface, a management plan describing how you will protect groundwater. For example, you may propose General Permit for Biosolids Management Publication 21-07-006 45 May 2021 to limit applications to the time of year when groundwater has receded to ~~less than~~ more than three feet (0.91 meters) below the surface.*	O-2-2 We revised the requirement to clarify that one approach would be to restrict application to times when groundwater is more (not less as originally stated by mistake in the general permit) than three feet below the ground surface.
O-3-1 Northwest Biosolids appreciates the opportunity to comment on the Department of Ecology's (Ecology) Statewide General Permit For Biosolids Management. Northwest Biosolids is a regional non-profit organization representing close to 140 members, including public wastewater utilities (75%) and private companies (25%) across British Columbia, Alberta, Alaska, Idaho, Oregon, and Washington. Our organization has worked to advance environmental stewardship through extensive research and the beneficial use of biosolids in the Pacific Northwest for almost 30 years. Of the approximately 226,000 dry tons of biosolids generated in our region, nearly 90 percent of the biosolids are used in agriculture, forestry, land reclamation, and landscaping. Since our incorporation in 1993, Northwest Biosolids has provided comments and inputs on regulations and guidelines, emphasizing the importance of setting standards that are based on science and research. Close to half of our annual budget is directed towards local universities to conduct technical studies to	O-3-1 Thank you for your comments. Ecology acknowledges the longstanding commitment of NW Biosolids to improving and working toward sustainable biosolids management practices that keep pace with technology and science-based research. We appreciate several editorial corrections offered by NW Biosolids and made revisions as appropriate.

evaluate practical and sustainable options for biosolids management. We strongly support and advocate for continual improvement of regulations such as this General Permit. As time passes, it is critical that regulations keep pace with technology and science-backed research… The following are specific comments on sections of the permit: 1.2.3. Active Biosolids Management Section Section (4) of this permit applies to facilities with active biosolids management programs, but not those than that manage only septage (1.2.2 above). 2.1. Understanding and Complying with the Permit System Figure 1 – This flow chart outlines the application process. Existing Baseline facilities without active programs are automatically covered on the effective date of the general permit. To confirm your coverage, consult the Facility List provided by Ecology. 4.4.4. Frequency of Biosolids Analysis The dry weight tonnage of biosolids applied to the land or prepared for sale/give away per 365-day period determines the minimum frequency of biosolids analysis (Table B1 below). Table B1 should explicitly say in the table that the tonnage units are dry tons… Northwest Biosolids believes that by providing clarity and focus in this permit, the wastewater and private sectors will be able to more readily implement the necessary compliance programs to ensure a healthy and strong environment for our state citizens. Your willingness to take on this effort is very much appreciated. Thank you for this opportunity to comment on the Statewide General Permit For Biosolids	

Management. We trust our comments are useful.	
O-7-73 Page 1, First Sentence: There is no Chapter 70A.225 RCW. The statute is Chapter 70A.226 RCW. Page 5, Fourth line correction: Section (4) of this permit applies to facilities with active biosolids management programs, but not those than that manage only septage (1.2.2 above). Page 6, Figure 1, Second Step correction: Existing Baseline facilities without active programs are automatically covered on the effective date of the general permit. To confirm your permit, consult the Facility List provided by Ecology.	O-7-73 We appreciate several editorial corrections offered by Friends of Toppenish Creek and made revisions as appropriate.

32. EPA Federal Program

Comment	Response
I-118-2 In 2000, General Audit Report: Water Biosolids Management and Biosolids 2000-P-10, March 20, 2000 explained there is virtually no federal oversight of state biosolids programs in non-delegated states. Washington and many other states fall into this category.	I-118-2 Per the commenter, the observation is based on a report from more than twenty years ago. Ecology has remarked over the years about EPA's unfortunate choice to disinvest from the national biosolids program - a decision that dates to around the time of the report mentioned by the commenter. In the last five years, EPA has committed new resources to biosolids in the headquarters office, and has implemented the Enforcement and Compliance History Online (ECHO) system, which includes biosolids reporting obligations for major treatment works.
LG-1-5 5) Section 1.1.6 Role of EPA "The United States Environmental Protection Agency (EPA) has a responsibility for implementing a national biosolids management program. EPA and Ecology work cooperatively on program implementation. EPA provides periodic technical assistance to the state. In return, the state provides information on request to EPA regarding biosolids management in Washington." Include reference to EPA Part 503 Rule since it is a critical piece of biosolids management.	LG-1-5 The commenter recommended adding a reference to 40 CFR Part 503[13] in 1.1.6 of the permit. Ecology concurs and did so.

Comment	Response
LG-1-9 10) Section 2.17. Reporting and Notification "Some facilities have a separate obligation to report to U.S. EPA. This permit does not address federal reporting requirements." Add reference to EPA Part 503 rule on federal reporting requirements.	LG-1-9 Ecology has received requests for assistance from facilities obligated to report under the federal program. As much as we would like to help, staff are not familiar with the federal (ECHO) system, and we really cannot represent EPA's position because we are not delegated to do so. Ecology would have no objection to using its communication resources to remind facilities of federal reporting deadlines, and including links and contacts where facilities can obtain assistance. We have added a reference to the federal reporting requirement in section 2.17. of the general permit.

33. Chemical Action Plan (CAP)

Comment	Response
I-53-1, I-105-1 I am a retired career EHS professional that is extremely concerned about the historic, current, and future impact of the Washington State General Permit for Biosolids and its impact on people, ecosystems, and the environment. I retired in January 2019 after 42 years with DuPont and a spin-off company, Axalta Coating Systems, as their Global Environmental Competency Leader. I am a Chemical Engineer with a BS and MS in Hazardous Materials Management by education and a health and environmental manager by career. Since May 2019, I have been the Sierra Club -- Michigan Chapter, Toxics & Remediation Specialist. I have reviewed the Draft Statewide General Permit for Biosolids Management and the Ecology "Per- and Polyfluoroalkyl Substances [PFAS] Draft Chemical Action Plan" and have the following additional comments.	I-53-1 As regards the PFAS Chemical Action Plan[35], the CAP was developed in a separate process. Ecology accepted comments on the CAP from October 7, 2020 to January 22, 2021. Our response here regards the draft general permit and we will not address comments specific to the CAP. Ecology has made commitments in the plan to address the question of PFAS in biosolids.
I-53-4 3. There are numerous and baseless assumptions in the Biosolids Section of the Action Plan. For example: "Since there is no known industrial production of PFAS in Washington, biosolids exposure pathways in Washington are primarily from homes and consumer products. Secondary manufacturers may be a source of some contamination in municipal waste streams, but primary exposure is largely from consumer products ." And conditions in other scientific studies that have evaluated PFAS from land-applied biosolids, "are not reflective of the rates, likely concentration, or availability of PFAS in Washington biosolids under current rules."	I-53-4 This comment regards Ecology's Chemical Action Plan for PFAS[35]. The chemical action plan was available for public review from October 7, 2020 to January 22, 2021. We do not agree with the commenter's assessment, but it is not appropriate to further respond to comments on the Chemical Action Plan in this document. As Ecology works through the CAP and performs other work related to the evaluation of PFAS in biosolids, it may become appropriate to address the commenter's concerns.

Comment	Response
• How can Ecology know if they have yet to sample and analyze Washington State biosolids? These statements are simply subterfuge and speculative assumptions and clearly an attempt to fool people that do not know any better. The facts are that all industrial activities that include PFAS-containing products, even secondary manufacturers, have been found to significantly contribute to PFAS in WWTP influent. PFAS-contaminated effluent from industry, airports, and military bases from historic and current use of fluorinated AFFF and landfill leachate are also significant sources of PFAS to WWTPs. • Results from a recent Sierra Club and Ecology Center study that sampled and analyzed commercial biosolids-derived fertilizers and soil amendments, found that the Tacoma Central Wastewater Treatment Plant soil conditioner TAGRO Mix, contains significant levels of total inorganic fluorine and Levels of PFAS, including PFOA and PFOS. Actual TAGRO results: Total Inorganic Fluorine (13,000 ppt), Pre- and Post-TOP: Total PFAS 87 ppt and 457 ppt respectively. For reference, this is similar to concentrations found in fish collected in highly polluted areas and thousands of times higher than the amounts that are regulated in drinking water. PFAS from highly contaminated sludges from industrial sites have been determined to contaminate local water supplies and agricultural products. We are concerned that the concentrations of PFAS in fertilizers and compost made from sludge-biosolids could lead to accumulation in food plants grown in fertilized beds in home gardens or agricultural fields. Ecology should consider	

Comment	Response
the numerous composting facilities in the State where private citizens are unknowingly purchasing and using potentially PFAS-contaminated compost for home and garden use. 4. Another ludicrous statement in the Action Plan, Section 8.5 is that "In general, the chemistry of biosolids is reflective of the chemistry of people's daily lives, as is the dust in homes (Haug et al., 2011; Hundal, Lakhwinder, Kumar, & Basta, 2011). Washington residents are exposed to PFAS from carpets, food packaging, personal care products and cosmetics, surface coatings on textiles, paints, lubricants, waterproof fabric, ski wax, and a wide variety of other sources." It is irresponsible to make such an assumption without data. The impact of PFAS in biosolids is much more significant than what people typically are exposed to in their daily lives. The levels of PFAS in biosolids are much higher that "dust in homes". There is significant impact to people from drinking water contaminated with PFAS or, more likely, from eating vegetables, dairy, seafood, and fish. Land application of PFAS-contaminated biosolids contributes to all of these routes of exposure. If Ecology does not require testing for PFAS in WWTP effluent and biosolids, there is no way of knowing if PFAS is present and no way to control land application of highly impacted biosolids or use of these biosolids in commercially available compost and fertilizer. • Levels of PFAS exposure to people that work with biosolids (e.g., WWTP operators, compost facility employees, sludge haulers/appliers) are extremely high and must be taken into consideration when states look at levels of PFAS in biosolids.	

Comment	Response
Exposure to farmers and their neighbors during land application needs to also be factored in. • After discovering high levels of PFAS in milk produced from dairy cattle feeding on contaminated fields, Maine is measuring the amount of PFAS in biosolids and ensuring that the materials do not contaminate agricultural lands (Maine 2021). When biosolids exceed screening levels, the state requires modeling or testing to ensure the repeat application has not pushed agricultural fields over the screening level of 2.5 ppb for PFOA and 5.2 ppb for PFOS. Maine's testing of one contaminated dairy found that the PFOS and PFOA levels in milk exceeded the concentrations it measured in the soils themselves. Unfortunately, Maine still allows contaminated biosolids to be spread on other agricultural lands. 5. The Ecology Action Plan alleges that "there may be some industrial discharge, but the vast majority of perfluorinated compounds in Washington municipal wastewater would originate from domestic sources - our homes and consumer products. The Plan uses contamination such as that identified in Decatur, Alabama biosolids and infers that it is highly unlikely to occur in Washington. The data for PFOA concentrations from Decatur sewage sludge are fragmentary but show high levels in 2005 and 2006: 528 ng/g and 683 ng/g in 2005, and 1,875 ng/g in 2006. The facts are that even in a State like Michigan, where there also is no commercial production of PFAS compounds, levels of PFOS were found in one WWTP's biosolids in 2018 at 3,100 ug/g. Filter cake from the same Treatment Plant contained 8,600 ¬µg/Kg	

Comment	Response
PFOS. The primary industrial PFAS discharger to the WWTP is an electroplating facility. To be clear, there is only one industrial discharger to this WWTP, and they had 3,100 ppb PFOS in their land applied biosolids. Control of this one source greatly reduced the levels of PFOS in receiving surface water and in the fish. Ecology should, at a minimum, survey all WWTPs that receive industrial effluent and/or landfill leachate and require them to sample their effluent for PFAS. Those that indicate levels of PFAS that will adversely impact surface waters, should also test their biosolids for PFAS and consider prohibiting land application if PFAS is above risk-based levels and until sources are controlled and PFAS is reduced to acceptable levels. • How or why would Washington State be any different? If you do not test, you will not know what sources to control, and the State will never get to levels of PFAS in biosolids that will allow continued land application without harm to the environment and to people. • EGLE has conducted several rounds of sampling to evaluate the presence of PFAS in surface waters (streams and drains) in one Michigan area.¬†Since 2018, a total of 209 surface water samples have been collected. The PFOS concentrations in these samples ranged from non-detect ((<0.2 parts per trillion) to 11,000 parts per trillion (ppt). Overall, results suggest that some surface waters in the area have elevated levels of PFAS, specifically PFOS. In December 2019, EGLE confirmed one source of PFAS to surface waters in this area. The source was an agricultural field that received biosolids from a local municipal Wastewater Treatment Plant	

Comment	Response
(WWTP) in the 1980s. Testing confirmed elevated PFAS levels, specifically PFOS, in soils and surface water where the biosolids were applied. The levels of PFOS in surface water correspond to levels seen in prior surface water sampling events. 6. Ecology makes the following statement in the Action Plan: "While resistant to degradation, short-chain PFAS appear to be less bioaccumulative and to have fewer significant toxicological effects." In general, newer generation-or "shorter-chain"-PFAS are more mobile in water, less removed by water filtration systems, and more readily taken up by plants than longer-chain compounds. One study of vegetables that included celery, peas, radishes, and tomatoes grown in PFAS-tainted water found that different PFAS chemicals accumulated in different parts of the plant (Blaine 2014). The FDA measured PFAS levels in the 20 to 200 ppt range for leafy greens grown near The Chemours Company's Fayetteville site in North Carolina. PFAS may have come from contaminated soils, water, or air deposition. A follow-up study in the area measured high levels of one chemical, PFDA, in tomatoes and potatoes (Li 2021). Ecology must include consideration of the potential hazards of short-chain PFAS in WWTP effluent and biosolids. • In respect to toxicological effects of short-chain PFAS, much more is becoming known every day. For example: o What health effects are associated with PFBS? Animal studies have shown health effects on the thyroid, reproductive organs and tissues, developing fetus, and kidney following oral exposure. Based on information across different sexes, lifestages, and	

Comment	Response
durations of exposure, the thyroid appears to be particularly sensitive to oral PFBS exposure. The data are inadequate to evaluate cancer effects associated with PFBS exposure. ASTDR Measures of individual exposures to immunotoxic PFASs included PFBA that accumulates in the lungs. Elevated plasma-PFBA concentrations were associated with an increased risk of more severe course of COVID-19. Given the low background exposure levels in this study, the role of PFAS exposure in COVID-19 needs to be ascertained in populations with elevated exposures. * *Severity of COVID-19 at elevated exposure to perfluorinated alkylates P Grandjean,1,2 C.A.G. Timmermann,2 M. Kruse,3 F. Nielsen,2 P. Just Vinholt,4 L. Boding,5 C. Heilmann,6 and K. Mølbak5,7	

34. Fertilizer Registration

Comment	Response
I-40-1 It meets the definition of a Fertilizer as defined by RCW 15.54.270 http://app.leg.wa.gov/RCW/default.aspx?cite=15.54.270 Fertilizer tonnage tax and fees should be assessed by Washington State Department of Ag Fertilizer as well as product registration. This is being applied as a fertilizer, why is it not being treated as such.	I-40-1 Please see the response to comment O-4-1.
O-4-1 On Behalf of Far West Agribusiness Association and the Washington State Fertilizer Advisory Committee, we would like to address the issue of Biosolids and their application to farm ground. The question that arose is why are Biosolids not considered commercial fertilizer and regulated in the same manner as commercial fertilizers? In your draft statement, you clearly state: "Biosolids are the organic matter left over after domestic or municipal sewage is treated at a wastewater treatment plant or septage management facility. Once processed, they are land applied and used to grow crops like wheat, corn, grass, hay, and hops." And in another document you state: "Biosolids are an important source of soil nutrients for farmers and land managers. Farming and other activities remove nutrients from the soil. Biosolids provide nutrients when used on farms and forestlands, in manufactured compost, and topsoil and fertilizer products." In the RCW 15.54.270, the definition of fertilizer is stated: "(4) "Commercial fertilizer"	O-4-1 Under WAC 16-200-701[88] and WAC 16-200-703, biosolids are not regulated as commercial fertilizers if producers meet certain administrative requirements and do not represent them as commercial fertilizers. Ecology and the State Department of Agriculture discussed and resolved this many years ago. The keys are that unpackaged biosolids (most biosolids) cannot claim to be commercial fertilizers. Packaged products must actually include a statement on the label that they are not commercial fertilizers. That being said, some biosolids generators actually want to be seen and used as commercial fertilizers. In those cases, they are subject to state biosolids program rules, and then are also subject to registration and paying inspection fees, AKA tonnage tax like other commercial fertilizers. Please see also the response to SG-3-1.

[88] https://apps.leg.wa.gov/wac/default.aspx?cite=16-200-701

Comment	Response
means a substance containing one or more recognized plant nutrients and that is used for its plant nutrient content or that is designated for use or claimed to have value in promoting plant growth, and shall include limes, gypsum, and manipulated animal and vegetable manures..." We would like to have you address including Biosolids into the category of fertilizers and be regulated by way of applicable fees, registrations, tonnage taxes, etc. as fertilizers.	
SG-3-1 The Washington State Department of Agriculture (WSDA) has delegated authority from Chapter 15.54 RCW to regulate the distribution and storage of Fertilizers, Minerals and Limes in Washington State. As the state lead agency (SLA) in Washington State, WSDA maintains a broad range of fertilizer specific programs including product registration, compliance, enforcement, bulk distributor licensing, sampling, and inspections. The following summarizes WSDA's comments in response to the Department of Ecology's Statewide General Permit for Biosolids Management. The disclaimer requirement in section 4.6.1 should not be limited to exceptional quality biosolids and should apply to all biosolids applied to the land. According to WAC 173-308-260, "Unless registered as a fertilizer by the Washington state department of agriculture," any person who prepares biosolids that are sold or given away in a bag or other container must affix a label or information sheet that includes "a	SG-3-1 Ecology appreciates and respects the line between biosolids and commercial fertilizer products. The commenter asks Ecology to require a label or information sheet with all biosolids that are distributed, regardless of quality or quantity. Please keep in mind that our response here concerns biosolids that are not registered as commercial fertilizers. The commenter interprets the biosolids program rules in WAC 173-308-260[89] to mean that there is no distinction as to labeling requirements between exceptional and non-exceptional quality biosolids. The rules provide that "Unless registered as a fertilizer by the Washington state department of agriculture, any person who prepares biosolids that are sold or given away in a bag or other container must affix a label or information sheet that includes a disclaimer stating that the product is not a commercial fertilizer and that all nutrient claims are estimates or averages and not guaranteed." WAC 173-308-260[89] addresses exceptional quality (EQ) biosolids products only, and specifically pertains to biosolids sold or given away in a bag or

[89] https://app.leg.wa.gov/WAC/default.aspx?cite=173-308-260

Comment	Response
disclaimer stating that the product is not a commercial fertilizer and that all nutrient claims are estimates or averages and not guaranteed." Also, WAC 16-200-703 states "Unpackaged biosolids and packaged biosolids that do not meet the definition for commercial fertilizer must include a legible and conspicuous disclaimer on their labeling. The disclaimer must specifically state that the product is not a commercial fertilizer, and that any nutrient claims are estimates or averages and are not guaranteed." Neither WAC differentiates between exceptional quality biosolids or non-exceptional biosolids. Section 4.6 makes a reference to section 4.7. However, there is no section 4.7 in the draft document. WSDA would like to thank the Department of Ecology for the opportunity to read and comment on the draft permit. We hope that the information we have provided is useful. In addition, many years ago, the Departments of Ecology and Agriculture worked together to address the issues of co-authorities of biosolids being applied to the lands of Washington State. Many things have changed in the biosolids industry over the years and the rules of 1998 may not properly address the current issues. We see this as an opportunity for our two agencies to once again work together to keep regulation of these materials safe, effective, and fair for all parties involved. Once this Statewide General Permit for Biosolids Management is finalized we would like to meet to discuss collaboration between our two agencies and to discuss modernization of both of our rules.	other container. This rule states “Biosolids sold or given away in a bag or other container must meet the exceptional quality standards.” EQ biosolids are those products that meet standards making them suitable for distribution without further regulation by Ecology. Requiring an accompanying label ensures customers are aware they are not a fertilizer. While at the same time informing the producers that making a commercial fertilizer requires a significant escalation in process and obligations. The commenter also cites WAC 16-200-703, and notes no distinction as to the quality or quantity of biosolids: "Unpackaged biosolids and packaged biosolids that do not meet the definition for commercial fertilizer must include a legible and conspicuous disclaimer on their labeling. The disclaimer must specifically state that the product is not a commercial fertilizer, and that any nutrient claims are estimates or averages and are not guaranteed." The author of this response was the Ecology representative who participated in the development of the Agriculture rules that address biosolids. Ecology agrees that the rule is at best not clear, but recalls the intent regarding unpackaged biosolids was to address EQ products. This stemmed from the concern that consumers could obtain pickup or trailer loads of material directly from a treatment plant. That discussion extended even to the notion that a treatment plant might provide a bag for convenience only. Agriculture saw that as "bagged," material nevertheless, hence the requirement for a label or information sheet (in the case where materials are picked up via trailer or truck). EQ products sold at retail in bags are expected to meet all labeling requirements. Non-EQ products cannot be distributed to

Comment	Response
	consumers in the fashion of commercial fertilizer, and cannot be applied to lawns or gardens. They are delivered and applied to sites specifically permitted to receive biosolids, at approved agronomic rates and where additional constraints are in place regarding site management and access., In some cases, biosolids are applied to a site directly under the control of the generator, but a large amount of biosolids are delivered to sites managed by a separately permitted entity (a Beneficial Use Facility).The content of a label or information sheet in this instance would add no value. Ecology can best address the commenter's concern by revising the general permit to specifically state that non-EQ biosolids are not commercial fertilizers unless properly registered, and that generators cannot make, nor can users rely on any guarantee of nutrient value. With clear and consistent rules between our agencies being the goal, and if resources allow, Ecology would be willing to work with WSDA to modernize both our rules where biosolids and fertilizer rules are unclear.

35. Forestland Application

Comment	Response
O-7-55 • The permit should address forest dumping… …Application of sewage sludge/biosolids to forestland are inadequately addressed in this permit. By failing to list restrictions on application to forest land, the permit gives implicit permission to apply biosolids to frequently fragile ecosystems in dangerous ways. Deficiencies in the permit include, but are not limited to: , • The only suggested guidelines that address application to forests are over 20 years old. • It does not require the forest ranking system described in Biosolids Management Guidelines for Washington State by Cogger, Sullivan, Henry & Dorsey. • It does not state whether septage can be applied to forestland. • It does not recognize that plants in higher elevations frequently prefer low nitrogen soils; are harmed by reactive nitrogen in the ambient air. • It does not address the application of high pH sewage sludge/biosolids to soils with a naturally low pH. • It fails to recognize the fact that sewage sludge/biosolids may irreversibly change the composition of forest soils. • It does not recognize the wide range of agronomic rates for trees. • It does not address mixed stands that contain red alder. • It provides no guidelines for identifying and protecting endangered species during spray application of sewage	O-7-65 The commenter submitted comments specific to the use of biosolids on forestlands. Some of these comments are similar to others we received. Since this group of comments regards the use of biosolids in forest settings, we are addressing them as a group here. The commenter argues that the lack of restrictions on application to forest land is implicit permission to apply biosolids to frequently fragile ecosystems in dangerous ways. Ecology disagrees. Permission is not implicit under the state program; it is explicit. Any land application of biosolids site must ultimately be approved by Ecology. The commenter argued numerous deficiencies in the permit as follows: • The only suggested guidelines that address application to forests are over 20 years old. Age does not negate the value of guidance. That being noted, they are only guidelines and are not directly enforceable. A proponent may use any defensible source to propose an application site. Proposals and practices that adhere to established guidelines are more likely to be approved. Each proposal is evaluated on its own merit. • It does not require the forest ranking system described in Biosolids Management Guidelines for Washington State by Cogger, Sullivan, Henry & Dorsey. The ranking systems outlined in our guidelines are there to assist proponents in developing a proposal, and to assist staff in evaluating a proposal. They are not a required element of a proposal. The ranking system for forested sites is intended to help proponents and staff compare

Comment	Response
sludge/biosolids. • It does not specify how soil testing will be performed in forests. • It does not address forested areas where the soil depth is one foot or less. • It fails to account for the nature of snow melt and runoff. • It fails to limit application in areas with slopes greater than 10%. All permits for application of sewage sludge/biosolids to forested areas should be individual permits with clear restrictions that prioritize preservation of this public resource…. …We appreciate several editorial corrections offered by Friends of Toppenish Creek and made revisions as appropriate	sites. The ranking system for forested sites remarked upon by the commenter is immediately preceded by this explanation: "There are no absolute total values that specify whether a site is acceptable; that is, if you add up all the values, they will not fall within good or poor ranges. This system is best used when comparing two sites." • It does not state whether septage can be applied to forestland. Septage can be applied to forest land. Logistics and management requirements likely make it impractical for septage land appliers. • It does not recognize that plants in higher elevations frequently prefer low nitrogen soils; are harmed by reactive nitrogen in the ambient air. Most nitrogen in the environment occurs as N2 gas and is not reactive. Reactive nitrogen consists of the forms that can fertilize plants, or perhaps be returned to the earth as an element of acidic rainfall. We briefly reviewed several articles on this problem. As far as we can ascertain, this concern regards the overall sharp increase in reactive atmospheric nitrogen attributable to many sources from industry, agriculture, and transportation. The contribution from biosolids is exceedingly small in this context. • It does not address the application of high pH sewage sludge/biosolids to soils with a naturally low pH. The pH of biosolids is only significantly elevated when lime or another alkaline material is used for pathogen or vector attraction reduction. Most lime-stabilized biosolids are used in agricultural settings which tend to acidify over time. Application of lime stabilized biosolids in a forest environment is possible, but the amount of lime applied is unlikely to have a significant impact on

Comment	Response
	the naturally acidic soils. This is both because of the small percentage of biosolids compared to the volume of soil and because of native soils natural buffering capacity. • It fails to recognize the fact that sewage sludge/biosolids may irreversibly change the composition of forest soils. Anything we add to the soil has some impact. The benefit of biosolids with respect to soils and crops is well established by peer reviewed university studies. • It does not recognize the wide range of agronomic rates for trees. The permit also does not address the range of agronomic rates for crops such as hay, wheat, and corn. The agronomic rate is determined for each site and crop, and based on authoritative resources. Describing actual rates for every crop or type of tree within the permit would be impractical. • It does not address mixed stands that contain red alder. Alder are nitrogen fixers. They are capable of converting nonreactive nitrogen to a plant-available form. Alder also prefer wetter areas and are more likely to be found in buffers or on the margins of approved sites. Again, agronomic rates are determined when the nature of the crop is known and stand composition is considered when approving agronomic rates. • It provides no guidelines for identifying and protecting endangered species during spray application of sewage sludge/biosolids. An environmental checklist is required for site approval. If threatened or endangered species or their critical habitat is identified, appropriate permit conditions can be established to protect

Comment	Response
	those resources. If it is not possible to protect those resources, the site may not be viable for biosolids land application. • It does not specify how soil testing will be performed in forests. All site sampling and analysis are performed in accordance with a sampling and analysis plan that must be approved by Ecology. Forest application sites typically have a several-year rotation. It is important to understand that forested sites often have an understory that will compete for nutrients and abundant organic matter in the forest floor that will tie up available mineral nitrogen. These factors are taken into account when designing and approving soil testing plans. • It does not address forested areas where the soil depth is one foot or less. We are not aware of any such sites at present. A site where soils overall are less than 12 inches is an unlikely candidate for biosolids application because the focus is on growing trees as a crop. Sites with shallow soils are less likely to support stands intended for commercial harvest. • It fails to account for the nature of snow melt and runoff. The potential for runoff (whether from rainfall or snowmelt) is evaluated with a site proposal and is a significant consideration in establishing buffers and seasons of application. • It fails to limit application in areas with slopes greater than 10%. Our biosolids management guidelines were developed with assistance from the University of Washington College of Forest Resources. The commenter wants to see those guidelines more strongly reflected in the general permit. We have addressed that question above here. The commenter may wish to consult table 7-5 which

Comment	Response
	addresses slopes in forested areas. All permits for the application of sewage sludge/biosolids to forested areas should be individual permits with clear restrictions that prioritize the preservation of this public resource. We have addressed the question of general versus individual permits elsewhere in our response. Some biosolids are applied on publicly owned lands. Most biosolids are applied on privately owned lands where crops (including trees) are grown for market. The presumption of "public resource" is questionable.

EXHIBIT E

Per- and Polyfluoroalkyl Substances Chemical Action Plan

Hazardous Waste and Toxics Reduction Program
Washington State Department of Ecology
Olympia, Washington

Publication 21-04-048
Revised September 2022

DEPARTMENT OF ECOLOGY
State of Washington

Washington State Department of Health

Publication Information

This document is available on the Department of Ecology's website at:
https://apps.ecology.wa.gov/publications/summarypages/2104048.html

Cover photo credit: Manuel Santiago, September 12, 2019: Pexels

Related Information

- Focus on: PFAS Chemical Action Plan[1]
- Draft Per- and Polyfluoroalkyl Substances Chemical Action Plan[2]

Contact Information

Hazardous Waste and Toxics Reduction Program

Washington Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600
Phone: 360-407-6700
Website: Washington State Department of Ecology[3]

Participating Programs and Offices

Washington Department of Ecology programs: Air Quality, Environmental Assessment, Hazardous Waste and Toxics Reduction, Rules and Accountability, Solid Waste Management, Spills, Toxics Cleanup, Water Quality

Washington Department of Health offices: Drinking Water, Environmental Public Health Sciences

ADA Accessibility

The Department of Ecology is committed to providing people with disabilities access to information and services by meeting or exceeding the requirements of the Americans with Disabilities Act (ADA), Section 504 and 508 of the Rehabilitation Act, and Washington State Policy #188.

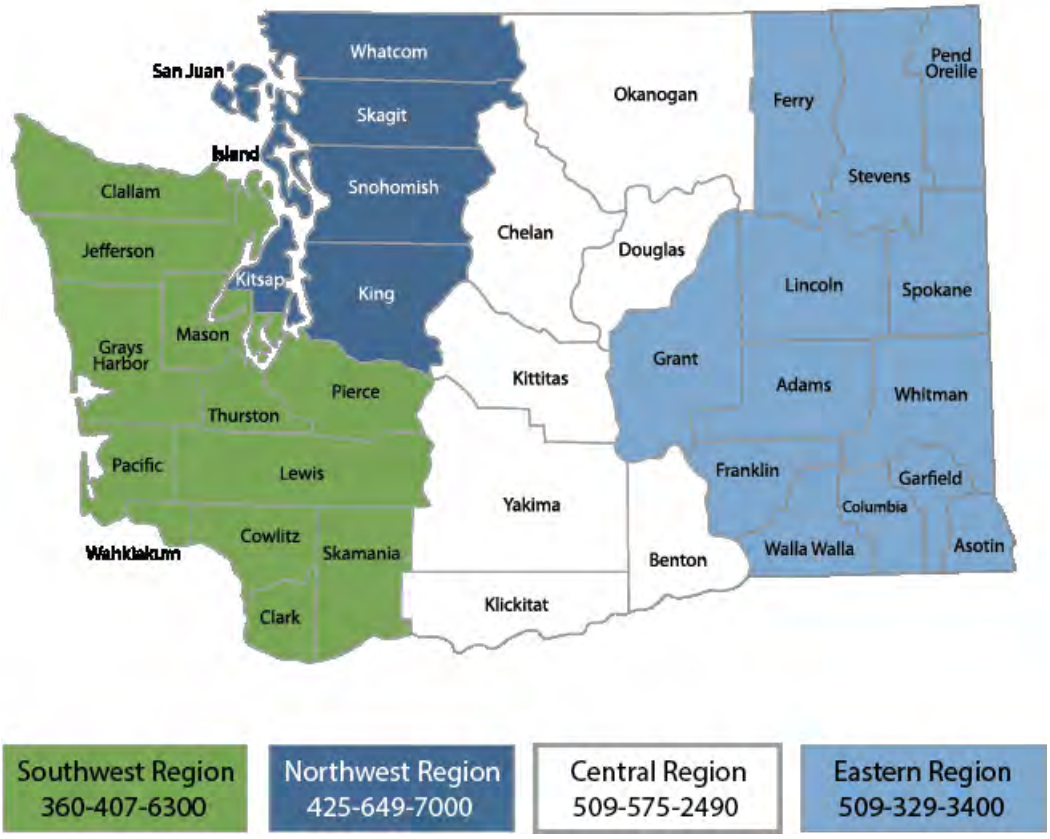
To request an ADA accommodation, contact Ecology by phone at 360-407-6700 or email at hwtrpubs@ecy.wa.gov. For Washington Relay Service or TTY call 711 or 877-833-6341. Visit Ecology's website for more information.

---

[1] https://apps.ecology.wa.gov/publications/summarypages/2004048.html
[2] https://apps.ecology.wa.gov/publications/summarypages/2004035.html
[3] www.ecology.wa.gov/contact

Department of Ecology's Regional Offices

Map of Counties Served



Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	3190 160th Ave SE Bellevue, WA 98008	425-649-7000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

Per- and Polyfluoroalkyl Substances Chemical Action Plan

Hazardous Waste and Toxics Reduction Program
Washington State Department of Ecology
Headquarters Building
Olympia, Washington

Revised September 2022 | Publication 21-04-048

Table of Contents

List of Figures and Tables

Figures

Tables

Executive Summary

Per- and polyfluoroalkyl substances (PFAS) are a family of more than 9,000 synthetic organic chemicals. PFAS can withstand high temperatures and survive highly corrosive environments. They are used in the manufacture of coatings, surface treatments, and specialty chemicals in cookware, carpets, food packaging, clothing, cosmetics, and other common consumer products. PFAS also have many industrial applications and are an active ingredient in certain types of fire-fighting foams (aqueous film-forming foams, or AFFF). PFAS coatings resist oil, grease, and water.

A Chemical Action Plan (CAP) identifies, characterizes, and evaluates uses and releases of a specific Persistent Bioaccumulative Toxin (PBT), a group of PBTs, or metals of concern, and recommends actions to protect human health or the environment.

The Departments of Ecology (Ecology) and Health (Health) (jointly "we") developed this PFAS CAP to recommend actions to address PFAS in the environment and resulting human impacts. This CAP builds on work that started in 2016, when we convened an advisory committee to inform and guide our PFAS CAP development work. In April of 2018, we issued an Interim CAP for PFAS (Interim CAP), recommending actions to address problems with PFAS. The Interim CAP was updated in January 2019.[4] Following additional input by the Advisory Committee, we issued Preliminary CAP Recommendations[5] (Preliminary Recommendations) in May 2019. These recommendations also took into account the Washington State Legislature's 2018 adoption of laws that impact PFAS use in firefighting foam and food packaging in the state.

A Draft CAP,[6] informed by Advisory Committee input received in July 2019 and updated based on new information available about PFAS between May 2019 and early 2020, was issued for public comment in October 2020. Comments were received through January 2021 and were considered to finalize this CAP.

Why are we concerned about PFAS?

PFAS use leads to persistent perfluorinated breakdown products in our environment. PFAS are used in many applications for consumer, commercial, and industrial products. For most products, the supply chain is not transparent and we know little about the specific PFAS and amounts they contain, or the potential to expose humans or the environment during production, use, and disposal. Many PFAS—such as those used for firefighting foam—degrade in the environment to form perfluoroalkyl acids (PFAAs). No known natural mechanisms can break these PFAAs down. Some places PFAS have been detected in Washington include surface waters, groundwater, wastewater treatment plant (WWTP) effluent, freshwater and marine sediments, freshwater and marine fish tissue, and osprey eggs. Any toxic or other hazardous effects of these chemicals will be with us for many decades.

[4] https://apps.ecology.wa.gov/publications/documents/1804005.pdf
[5] https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PrelimRecommendations-2019-PFAS-CAP.pdf
[6] https://apps.ecology.wa.gov/publications/documents/2004035.pdf

Nearly everyone in Washington is likely exposed to PFAS. National surveys show that most people tested have some PFAS in their blood. Many sources lead to exposure. Workers in jobs related to PFAS-containing products have the highest exposures. People consuming PFAS-contaminated drinking water or food can also be highly exposed. For most people, exposure occurs through food, drinking water, and contact with things like disposable packaging or treated textile products, to name a few.

Some PFAS are bioaccumulative. Bioaccumulation of PFAS has been confirmed in marine and terrestrial species, zooplankton and other invertebrates, and fish. Animals living far from sources of PFAS show bioaccumulation. PFAS have also been shown to be taken up by plants, especially short-chain PFAS. Long-chain PFAS tend to be more bioaccumulative in biota. Some PFAS are known to bioaccumulate in people because they are readily absorbed following ingestion, resist metabolic breakdown, and are poorly excreted from the human body.

Some PFAS show harmful effects to wildlife and to people. In animal studies, several PFAAs produce developmental, liver, and immune toxicity. Epidemiological studies suggest links between PFAA exposure and several negative health outcomes in human beings, including increases in cholesterol levels, immune suppression, and lower birthweights. Higher exposures have also shown associations with some cancers, such as testicular and kidney cancers.

Replacement products are still poorly understood. U.S. manufacturers have ceased manufacturing and using long-chain PFAS, such as perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), with the exception of certain specialty uses. Certain short-chain PFAS used as replacements may be lower in toxicity and bioaccumulation, but their exposure and toxicity characteristics are still being studied. Other replacement PFAS appear to have concerning toxicity and biopersistence. Short-chain replacements can be more mobile in the environment and just as persistent long-term, resulting in potentially expensive remediation should they be confirmed harmful to wildlife and humans.

Responding to PFAS contamination is expensive and requires cross-agency coordination. When PFAS concentrations in drinking water supplies exceed health advisory levels, timely mitigation is needed to protect human health. Without identified funding, public water systems and their ratepayers must absorb expensive response costs. Multiple local, state, and federal agencies may be involved in investigating and responding to a drinking water contamination event.

Recommendations for action

We are recommending actions to address PFAS contamination of the environment and the resulting potential impacts to animal and human health. We base these recommendations on our assessment of scientific information available regarding the behavior of PFAS.

1.0 Ensure drinking water is safe

1.1 Identify funding for PFAS drinking water mitigation

Water systems may incur a costly response to PFAS detections, especially when there is no responsible party identified. Without funding, public water systems and their ratepayers must absorb these costs. Lower-income and overburdened communities are less able to absorb unplanned ratepayer cost increases when PFAS contamination of their water supply is identified. Funding would support a more equitable water system response. Potential immediate and long-term costs include:

- Continue providing water or alternate water supplies while incurring costs to implement necessary permanent mitigation actions.
- Investigate contamination sources.
- Find an alternative water source and/or design and install expensive treatment systems on contaminated water sources.
- Maintain and monitor new treatment systems.
- Replace and dispose of used treatment system media.

Recommendation

State agencies, the Washington State Legislature, and water systems should work together to fund PFAS drinking water mitigation. These costs should be reimbursed by responsible parties under applicable laws. Once PFAS water contaminants are classified as hazardous substances by the federal government or meet the definition of hazardous substance under the state of Washington's statutes or rules, they can be addressed under the state Model Toxics Control Act (MTCA) framework.

Drinking Water State Revolving Fund is a U.S. Environmental Protection Agency (EPA)-funded loan program administered by Health. The loans are used to:

- Improve drinking water infrastructure.
- Finance the cost of installing treatment or other infrastructure improvements over a number of years.

Drinking Water State Revolving Fund can provide emergency loans in the event a water system is issued a “Do Not Use” order by the Department of Health as a result of PFAS contamination. The program recently funded a reservoir project for City of Spokane to allow Spokane to provide reliable water service to Airway Heights. Airway Heights has PFAS in their wells and is now relying on City of Spokane for its water.

EPA provides funding to Health’s Office of Drinking Water for set-aside activities and source water protections. Health can use these funds in limited circumstances to defray costs of additional water testing.

Other funding programs in the state could be tapped for loans or grants to help with costs of new infrastructure in response to PFAS contamination:

- Public Works Assistance Account overseen by Public Works Board.
- Community Development Block Grant overseen by Department of Commerce.
- Rural Development loans and grants overseen by U.S. Department of Agriculture.

Public water systems can pursue reimbursement from potentially liable parties under the state MTCA when PFAS are concluded to be hazardous substances under MTCA. Even under MTCA, water systems may have to carry costs long-term or permanently because:

- The process of identifying responsible parties and being reimbursed can take years.
- Responsible parties may be difficult, if not impossible, to determine.
- The potentially liable party could be a local entity under the same public administration as the water utility (for example, a local fire station).
- Legal costs to the affected water system operator to pursue liable parties can also be significant.

Privately owned water systems regulated by the Washington State Utilities and Transportation Commission (defined in Chapter 80.04.010(30) Revised Code of Washington [RCW]),[7] and having 100 or more connections or charging more than $557 per year per customer) may have fewer options to secure funding, being primarily limited to the Drinking Water State Revolving Fund.

In each of these cases, the costs borne by the water system would be long-term or permanent.

Cost

Initial investigation and mitigation costs at PFAS-contaminated sites are reported in the millions of dollars. These costs have been borne by the U.S. Department of Defense (DOD), the water systems or local governments impacted, and the agency programs at Health and Ecology that support water systems and contaminated site cleanup.

For example, the Issaquah PFAS Pilot Project received $400,000 through the State Building Construction Account for groundwater assessment work to be conducted during the 2019 – 2021 biennium. An additional $750,000 was allocated as part of the 2021 – 2023 state Capital Budget[8] for additional groundwater investigation and pilot project design.

Funding of $450,000 was also provided for the West Plains PFAS Groundwater Fate and Transport study. Modeling will assist with geochemical fingerprinting PFAS sources across the West Plains area. The Spokane Regional Health District—in collaboration with Fairchild AFB, Spokane County, and Eastern Washington University—will undertake the study. These allocations were focused on very specific activities, but the 2021 – 2023 Capital Budget included several much larger appropriations to help address PFAS-contaminated drinking water, such as:

- $5,950,000 to the Department of Commerce to provide assistance with PFAS treatment at the City of DuPont water wells.

[7] https://app.leg.wa.gov/rcw/default.aspx?cite=80.04.010
[8] http://lawfilesext.leg.wa.gov/biennium/2021-22/Pdf/Bills/Session%20Laws/House/1080-S.SL.pdf

- $5,569,000 to the Department of Health (as a drinking water construction loan) for treatment of PFAS-contaminated groundwater at the Lakewood Water District.

With mitigation measures identified, implementation funds are sought from granting sources as described above. In addition to costs for investigating the source of the contamination, filter maintenance and monitoring also require ongoing expenditures. Such costs could also be covered under grants, but may require additional resources from water supply systems.

Each contaminated drinking water site has specific needs, which complicates cost estimation. Without knowing the number of impacted systems in the state, we are unable to estimate total costs to implement this recommendation.

1.2 Provide technical support for site characterization, source investigation, and mitigation at contaminated sites

Local water districts and governments often lack the expertise and resources to investigate sources of PFAS contamination. Technical assistance helps them understand the advantages and disadvantages of various options to reduce levels of PFAS in water and soil. Appropriate actions are informed by site-specific conditions and a knowledge of evolving drinking water treatments and cleanup methods. Research into the unusual properties of PFAS will inform mitigation as replacement PFAS products also make their way into the environment. To recover mitigation costs, Ecology must identify the party or parties responsible for the source of contamination.

Recommendation

Ecology and Health will continue to develop expertise and provide technical assistance and guidance to drinking water purveyors, local jurisdictions, and responsible parties in order to address PFAS contamination and conduct cleanup actions.

Those actions include:

- Ecology will continue to collaborate with involved parties at PFAS contamination sites in the state. These efforts will help to better understand the sources, composition, and distribution of PFAS contamination in soil and water. Identification and evaluation of appropriate cleanup actions and their costs will be informed by this work. This work is being done within Ecology's existing resources.
- Health will continue to provide water systems with advice and assistance to understand the mitigation options and guide voluntary action on unregulated PFAS until the rulemaking for PFAS in drinking water is complete. To-date, technical assistance has focused on public water systems near military bases with PFAS detections in groundwater. Department of Health continues to include local health departments in outreach and guidance. This work is being done within Health's existing resources.
- Ecology will look at using Safe Drinking Water Action Grants (a category of Remedial Action Grants for Local Governments) to help address PFAS-contaminated drinking water once Maximum Contaminant Levels (MCLs) have been promulgated for the PFAS compounds of concern or site-specific cleanup levels have been established.

- Ecology plans to investigate PFAS contamination in groundwater and surface water. These efforts would support local health departments, cities, counties, and other public entities in Washington when PFAS contamination is discovered. Initial investigation efforts could identify areas at high risk of contamination. This could include areas where trainings or firefighting activities used large quantities of PFAS-containing AFFF, or where spills released the foam. Ecology could prioritize funding for site-specific assessments and groundwater testing. Funding for this action is estimated below.
- Ecology plans to consider the number of people impacted, the concentration of the PFAAs in the drinking water, and vulnerable populations present when prioritizing mitigation and cleanup activities. Ecology may use mapping tools such as Environmental Justice (EJ) screen and Information by Location (IBL) in the Washington Tracking Network (WTN) portal to characterize the demographics of the population served by impacted drinking water.
- Ecology may seek to obtain chemical identities from products and at contaminated sites to find chemical "fingerprints" useful in identifying source locations. Analytical methods may not yet be developed to obtain all the required data.

Cost

To support PFAS investigations as needed, Ecology requested resources from the Legislature to:

- Provide monitoring assistance to local jurisdictions when PFAS contamination is discovered.
- Assist with investigations, including researching potential sources, collecting samples, conducting laboratory analysis, and installing monitoring wells.

This type of environmental monitoring work was funded in 2020 and 2021 through the approved state 2019 – 2021 supplemental budget.[9]

1.3 Support biomonitoring and other health studies to answer important health questions

Biomonitoring can help us understand the best way to reduce human exposure to PFAS. Biomonitoring helps people compare their PFAS exposure level to national averages, and could connect residents to health information as it becomes available.

Recommendation

Health should continue to find opportunities for Washington residents to participate in exposure and health studies. These studies help answer important community and public health questions about PFAS exposure and health outcomes. For example, Health requested and supports inclusion of Airway Heights as one of eight sites in the Agency for Toxic Substances and Disease Registry's (ATSDR) PFAS Exposure Assessment study. Health also applied for but was not awarded a cooperative agreement to include a Washington site in the ATSDR Multisite PFAS Health Study.

[9] https://ofm.wa.gov/sites/default/files/public/budget/statebudget/20supp/Z-0776.2Operating.pdf

State agencies should also support investigations into pathways of PFAS contamination in food, drinking water, and indoor environments. They should pursue policies to mitigate and reduce these sources of human exposure over time.

Cost

Biomonitoring studies are expensive and the state would need funding to support these types of investigations. Additional funding could be secured through competitive grants for such activities. Benchmark costs have been estimated based on reports from several sites in the U.S. where biomonitoring testing has been conducted for residents near areas of PFAS contamination. Costs averaged up to $1,000 per person tested.

2.0 Manage environmental PFAS contamination

Ecology establishes cleanup levels for hazardous substances in the environment. The cleanup level concentrations, under specific exposure conditions, are considered sufficiently "protective of human health and the environment." Currently, no enforceable federal or Washington state regulatory standards exist to determine whether a site with PFAS contamination requires cleanup or to regulate cleanup of PFAS at contaminated sites. Further, best practices for conducting such a cleanup are not established.

To support PFAS groundwater contamination investigation in the Lower Issaquah Valley Aquifer, Ecology developed investigatory levels for PFOS and PFOA. These were advisory values, not regulatory cleanup levels.

Ecological receptors contribute to Washington state's health and economy overall. Collecting additional data and extending cleanup levels to other environmental media is crucial to protecting them.

2.1 Establish PFAS cleanup levels for soil and groundwater

Recommendation

- Using existing authority under MTCA, Ecology plans to develop cleanup levels for PFOA, PFOS, perfluorononoic acid (PFNA), perfluorohexane sulfonic acid (PFHxS), and perfluorobutane sulfonic acid (PFBS)—the five PFAS for which the State Board of Health (SBOH) is planning to promulgate state action levels in 2021. Ecology will use SBOH drinking water standards or action levels adopted in rule to develop these cleanup levels.
- Ecology will explore methods for investigation and cleanup of PFAS contamination.
- Ecology will conduct monitoring for PFAS compounds in environmental media (soils, surface water, and sediment) and wildlife tissue to identify sources of contamination and assess exposure.
- Once sufficient supporting data are available, Ecology plans to develop cleanup levels for individual or mixtures of PFAS in soil, sediment, freshwater, and saltwater to protect ecological receptors.
- In this context, the following activities will be implemented to support activity under the recommendations above:

- Trophic transfer and bioaccumulation of PFAS compounds should be further evaluated in aquatic and terrestrial food webs to further understand exposure.
- Selected individual PFAS compounds, as well as common PFAS mixtures, should be evaluated for ecotoxicity in aquatic and terrestrial biota, using both laboratory and field methods.
- Ecological risk assessment should be performed for PFAS compounds by detailing exposure and effects in order to estimate risks to non-human biota.
- An uncertainty analysis should accompany PFAS ecorisk assessment to promote transparency in the risk assessment and communication processes and to more clearly identify data gaps.
- Results of these risk assessments should support potential interventions (for example, species protections) and characterization of potential impacts on ecological services.

- Ecology will provide information to interested parties about cleanup efforts.

Cost

The cost to develop cleanup standards is being funded out of Ecology's Toxics Cleanup Program operating budget, and is expected to be approximately $42,000 based on the cost of developing advisory levels. This estimate does not include work to collect additional exposure data, nor to develop cleanup levels for other environmental media (sediment and surface water).

Costs to develop and evaluate methods for addressing PFAS contamination are difficult to estimate due to significant uncertainties around:

- How (and in what concentrations) most PFAS affect people, animals, and plants.
- How best to measure the types and amounts of PFAS in the environment.
- How PFAS move through the environment and change over time.
- How to effectively clean up environmental PFAS contamination—including factors like protectiveness, feasibility, and cost.

Ecology is planning to conduct additional environmental monitoring in 2020 and 2021 funded through the approved state 2020 supplemental budget,[10] however specific projects have not yet been selected.

2.2 Partner with local organizations in communities with contaminated water or contaminated sites

When testing identifies PFAS-contaminated drinking water in a new community, it can be challenging to communicate effectively with area residents.

Communities are unique, and there may be:

- Cultural and language barriers to effective communication.
- Economic, systemic, and social barriers to act on public health advice.

[10] https://ofm.wa.gov/sites/default/files/public/budget/statebudget/20supp/Z-0776.2Operating.pdf

These barriers disproportionately affect low-income and other historically overburdened communities, including communities of color. During PFAS investigation and mitigation, state agencies should collaborate with local leadership and organizations to strengthen community awareness and engagement.

Community-based and community-led organizations (that are rooted in and directly serve these communities) can offer meaningful engagement support. For example:

- A recent $120,000 two-year grant funded a local organization providing educational materials and conducting outreach in a community impacted by industrial activities.
- In one affected community, a local church group volunteered to distribute bottled water to elderly and disabled residents.

Recommendation

Department of Health will identify local health departments or community-based organizations to address health equity related to contaminated sites in public communications. Health will coordinate with Ecology to distribute funding to those organizations selected for assistance. Health's new Community Engagement Guide[11] may support this effort.

Funded organizations would:

- Address potential health equity issues through culturally and linguistically informed engagement.
- Find trusted messengers or platforms to deliver audience-tested risk communication messages to engage historically overburdened and higher risk populations.
- Support impacted populations in finding their own solutions through collective action and decision-making.
- Engage the community throughout the course of the public health response, source investigation, and site cleanup.
- Invite area residents to actively participate on advisory committees, in site information meetings, and in public decision-making about remediation.
- Aim to remove participation barriers by providing child care, reducing transportation costs, and planning for convenient meetings times at familiar locations.
- When possible, appropriately compensate community advisors for participation—particularly in areas with low-income populations.

Cost

If PFAS are classified as hazardous substances under MTCA, community-led public engagement would be eligible for funding through Ecology's Public Participation Grant program (in the Contaminated Site Project category). Designated PFAS funds should be allocated specifically to PFAS-related impacts to communities.

[11] https://www.doh.wa.gov/Portals/1/Documents/1000/CommEngageGuide.pdf

Local outreach efforts depend on the extent and type of community outreach required for a specific contamination concern. As such, at this time, it is not possible to estimate the funding needed for these efforts.

2.3 Work to prevent PFAS releases from firefighting foam use and manufacturing

PFAS-containing Class B firefighting foam has been associated with drinking water contamination in Washington state. In their risk-based efforts to identify and mitigate PFAS in drinking water, both the military and Health focused on firefighting foam release sites. However, firefighting foam is not the only likely source of PFAS in state drinking water. Other states that are expanding testing for PFAS in drinking water have identified manufacturing and commercial sources such as:

- Manufacture of waterproof leather shoes.
- Manufacture of parchment paper.
- Taxidermy.
- Textile coating.
- Metal plating and finishing.
- Car washes.
- Pulp and paper mills.

In addition to the manufacturing processes themselves, wastes generated during some manufacturing processes can result in releases of PFAS to the environment if they are improperly managed. More work is needed to understand PFAS use, sources, pathways of exposure, and effects on human health and the environment resulting from industrial use or manufacturing.

Recommendation

Ecology will continue to work proactively with industry, manufacturers, and businesses to eliminate releases to the environment from the use of PFAS-containing AFFF or other manufacturing processes using PFAS.

To address PFAS in AFFF, Ecology would continue implementing the Firefighting Agents and Equipment Toxic Chemical Use law (Chapter 70A.400 RCW[12]), as follows:

- Collaborate with firefighting foam users to develop and share outreach materials and best management practices that address the proper use, storage, and disposal of PFAS-containing AFFF.
- Ensure that industrial use of PFAS-containing AFFF provides for containment procedures along with collection of this foam and contaminated soil or sediment for proper designation and disposal. Costs to industrial users to collect and dispose of released PFAS-containing AFFF include plan development, employee training, methods for containment, and disposal of waste.

[12] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

- Continue identifying organizations and industries which store and use AFFF in training and emergency firefighting, including the use of AFFF in highway tunnels.
- Assist state and local governments, airports, industry, and fire districts with prioritizing the quantification, disposal, and replacement of PFAS-containing AFFF, especially in communities with cumulative impacts, health disparities, and environmental justice considerations.
- Share information about PFAS-free Class B firefighting foam with firefighting foam users as information or research is available, including GreenScreen® certifications.
- Provide funding to airports to purchase equipment to test their firefighting capabilities without the use of PFAS foam.
- Conduct compliance and enforcement actions to ensure the law is being followed.

Ecology will work proactively with industry, manufacturers, and businesses to eliminate releases to the environment from PFAS use in manufacturing or other processes.

- Ecology will review data from other states and countries to identify industrial or manufacturing uses of PFAS. Ecology will also consider data collected through the implementation of other CAP recommendations to identify potential industrial and manufacturing PFAS discharges. Ecology will use this information to identify industries in Washington that have used or continue to use commercial quantities of PFAS. Ecology will also track future Toxic Release Inventory (TRI) reports (starting 2021) for industries.
- Ecology will evaluate PFAS release potential from those industries which may have used or continue to use PFAS.
- Ecology will reach out to these industries to discuss their use of PFAS, identify opportunities to switch to safer alternatives, implement best practices, and ensure proper waste management.

Cost

Ecology identified additional foam stockpiles managed by commercial airports, manufacturing, and transportation facilities that represent a large pollution source, but do not currently qualify for the disposal program established under Chapter 70A.400[13] RCW. Ecology estimates that it will cost between $500,000 and $1,500,000 to collect, transport, and dispose of such foam, including 0.25 full-time equivalent (FTE) to manage this program. Ecology included this cost in its fiscal year (FY) 2021 – 2023 budget request.

Ecology has requested approximately $36,000 for monitoring and compliance activities to be conducted under Chapter 70A.400 RCW in FY 2021 – 2023.

Ecology estimates that support to industry to investigate and support reduction of non AFFF-related PFAS use would require the resources of 0.25 FTE for one year, at the cost of approximately $50,000. This funding has not yet been budgeted or requested.

[13] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

3.0 Reduce PFAS in products

People are exposed to PFAS in their homes when they use products, and via exposure to house dust that contains PFAS. Ingesting contaminated food and drinking water leads to the greatest portion of chronic exposure to PFAS (specifically to PFOS and PFOA) for the general population.

According to EPA, some of the most significant sources of human exposure to nine PFAS in the U.S. are carpets and commercial carpet-care liquids, which contribute to PFAS in residential and commercial indoor environments. Infants and children have higher exposure due to inhalation and ingestion of house dust. High PFAA levels were also identified in ski waxes, leather samples, outdoor textiles, and some baking papers.

Actions need to be implemented to remove or reduce levels of PFAS from products that contribute to human or environmental exposure. Removing chemicals from consumer products can reduce chemicals in indoor air and dust. These actions directly impact human and environmental exposures. Research is needed to understand how these products contribute to human exposure.

3.1 Reduce PFAS exposure from carpets and rugs, water and stain resistance treatments, and leather and textile furnishings

Recommendation

We recommend that as part of the work conducted under Chapter 70A.350[14] RCW, the following regulatory actions be considered:

- Requesting that manufacturers:
  - Identify products that contain PFAS.
  - Disclose their use of priority chemicals in product ingredients.
  - Release information on exposure and chemical hazard.
  - Describe the amount and function of PFAS in products.

In addition to the work conducted under Chapter 70A.350 RCW above, we recommend the following actions:

- Implement a purchasing preference policy for PFAS-free carpet. Work with vendors on the state flooring contract to offer PFAS-free carpet on all state master contracts and all agency contracts. Purchasing PFAS-free carpet could result in increased costs to the state.
- If safer alternatives are available, include them in Ecology's Product Replacement Program[15] to replace legacy PFAS-containing carpet in community centers, low-income housing, libraries, daycares, and other environments where children may be disproportionately exposed.

[14] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.350
[15] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Product-Replacement-Program

Cost

The Legislature funds these efforts under the Safer Products for Washington program. As a result of appropriations for the 2019 – 2021 biennium, the 2020 supplemental budget, and the 2021 – 2023 biennium, Ecology received approximately $1.5 million to implement the program as a whole through 2026. As described in its July 2020 report to the Legislature,[16] Ecology identified eleven priority products, three of which were PFAS related (carpets, water and stain resistance treatments, and leather and textile furnishings).

Because Ecology conducts program activities as a whole, it is not possible to distinguish program costs attributed to only the PFAS-related priority products. However, one could approximate the PFAS-related costs as a proportion of entire program costs based on the number of priority products identified—three of eleven. Thus, the cost of activities associated with PFAS-related priority products under Chapter 70A.350[17] RCW would be approximately $409,000.

At this time, Ecology has not estimated the cost of additional actions (i.e., implementing a purchasing preference policy and replacing PFAS-containing carpet under the Product Replacement Program). Ecology is already funding a staff position to coordinate the identification of viable purchasing preference policies with the Washington State Department of Enterprise Services for a number of products, including PFAS-containing carpet.

Establishing the cost of replacing carpet in community centers, low-income homes, libraries, daycares, and other environments where children may be disproportionately exposed would require an estimate of the number of facilities targeted, and the square footage of carpet to be replaced. Funding could then be requested by Ecology's Product Replacement Program.

3.2 Identify additional sources and uses of PFAS and consider them in the second Safer Products for Washington cycle

The priority products identified in 2020 under the Safer Products for Washington program do not account for all sources and uses of PFAS. Ecology will continue research to better understand how other products contribute to PFAS concentrations in homes, workplaces, and the environment. These include, but may not be limited to, PFAS in:

- Water-resistant clothing and gear.
- Nonstick cookware and kitchen supplies.
- Personal care products (including cosmetics and dental floss).
- Cleaning agents.
- Automotive products.
- Floor waxes and sealants.
- Ski waxes.
- Car waxes.

[16] https://apps.ecology.wa.gov/publications/summarypages/2004019.html
[17] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.350

Recommendation

Ecology should engage with overburdened communities regarding consumer products that may contain PFAS. Communities use consumer products differently. Ecology should identify consumer products which might be disproportionately exposing overburdened communities.

Ecology should conduct preliminary investigations into the availability and feasibility of safer alternatives, prior to Phase 2 of Cycle 2 of Safer Products for Washington, for the products listed above. If safer alternatives are identified in the preliminary investigations, outreach should be conducted to increase voluntary adoption in the marketplace.

Ecology should determine if the products listed above are significant sources or uses of PFAS. If so, they should be evaluated during Phase 2 of Cycle 2 of Safer Products for Washington to determine if they should be recommended as priority products. If identified as a priority product in the report to the Legislature, the product will be evaluated to determine if safer alternatives are feasible and available. If they are, Ecology may determine that a restriction or ban is appropriate.

Cost

Ecology will make budget requests to fund future cycles of the Safer Products for Washington program, including consideration of the products listed above.

Ecology estimates that the costs of future cycles of product consideration under Safer Products for Washington would be similar to those incurred to-date (see Recommendation 3.1 above), but could vary based on the complexity and the number of additional chemical-product combinations considered.

3.3 Implement other reduction actions for PFAS in products

Ecology should investigate uses and regulatory actions to further reduce exposures and releases to the environment from the priority consumer products containing PFAS.

Recommendation

Actions should include:

- Gather input from low-income and other historically overburdened communities, including communities of color. Develop a list of ways to reduce exposure that include low cost and subsidized approaches. These may be particularly important measures to employ in communities with higher exposure from drinking water. No cost estimate is provided to conduct this evaluation or to develop exposure reduction recommendations.
- Establish a purchasing preference policy for products free of intentionally added PFAS. Work with vendors to offer PFAS-free textiles, furniture, and paints. If possible, select products that do not have stain- or water-resistance or use safer alternatives. Apply this policy to all state master contracts and all agency contracts.

- Consider PFAS as a class when the list of chemicals of high concern to children (CHCC), WAC 173-334-130,[18] is updated.
- Propose a ban on the import or sale of all products in Washington containing phased-out long-chain PFAAs. Long-chain PFAAs include perfluorinated carboxylates (PFCAs) with seven or more fully fluorinated carbons (for example, PFOA) and perfluorinated sulfonates (PFSAs) with six or more fully fluorinated carbons (for example, PFHxS and PFOS), their salts, and precursor compounds capable of forming long-chain PFAAs.

Cost

No cost estimate is provided to conduct the evaluation of low-income or overburdened communities or to develop exposure reduction recommendations. Exposure reduction actions would be specific to the needs expressed by specific communities.

The costs for banning the import and sale of certain PFAS cannot be estimated. This activity would require legislative action—an estimate for implementing such an action can only be completed once the specifics of any enacted legislation are known.

The costs for considering PFAS as a class when the CHCC is next updated would be included in the staff and agency resources allocated to such an update. Such funding requests have not yet been made.

4.0 Understand and manage PFAS in waste

Products people use in their homes and businesses can release PFAS. Waste streams generated in residential and commercial settings are treated in WWTPs or sent to disposal facilities such as landfills, which in turn can re-emit PFAS to the environment.

PFAS in municipal and industrial wastewater entering WWTPs may partition to different media (for example, solids and liquids) and transform into terminal PFAS compounds.

Decomposing domestic and industrial waste containing PFAS and rainfall can create leachate that contains PFAS released from disposed products. Older un-lined landfills can release leachate to groundwater. Leachate produced in lined landfills is typically transferred to WWTPs for further treatment. Both of these management methods have the potential to release PFAS to the environment.

Biosolids produced in WWTPs where PFAS are present can in turn be contaminated with PFAS. Fundamental PFAS concentration data to characterize Washington biosolids is lacking. Toxicity, concentration, and pathway of exposure determine the risks that PFAS in biosolids pose to human health and the environment.

[18] https://apps.leg.wa.gov/wac/default.aspx?cite=173-334-130

4.1 Evaluate PFAS in wastewater treatment

Recommendation

Ecology should evaluate PFAS in WWTP influent and effluent to better understand PFAS discharges in Washington state.

- Ecology should develop a study design to sample PFAS in three different types of plants: WWTPs with secondary treatment, nutrient removal, and advanced solids removal. Sampling should include products of selected WWTP unit processes (for example primary and secondary clarifiers or dechlorination) to help differentiate removal efficiencies of the different treatment types.
- The study design should ensure that the sampled WWTPs either receive industrial discharges that are likely to contain PFAS or have drinking water sources with known PFAS contamination.
- Ecology should identify industries that are likely to generate wastewater containing PFAS.
- Based on the information from the study, Ecology should consider additional monitoring requirements for WWTP dischargers. This should include consideration of whether EPA has developed approved analytical methods for PFAS suitable for WWTP effluent and a regulatory target (a nationally recommended water quality criterion for PFAS) for waters of the state.
- Based on this evaluation, Ecology should require possible PFAS monitoring for some or all domestic and industrial WWTPs.

Cost

Ecology received $235,000 to conduct a WWTP sampling study by June 30, 2021. This includes costs for sample analysis, which can range from $1,000 to $1,500 per sample, as well as project staff salaries.

The cost of establishing additional monitoring requirements based on the sampling study has not been determined. More funding sources may be needed to complete this work.

4.2 Evaluate landfill PFAS emissions

Recommendation

Ecology will develop a sampling program at selected landfills across the state. The sampling will test for PFAS in leachate, groundwater, and air emissions.

Leachate

The Solid Waste Management program (SWM) developed Phase I of the program, involving leachate sampling. This phase is funded and approved. Landfill leachate sampling was completed in November 2020.

Ecology developed the study to better characterize landfill leachate. The study will:

- Sample leachate at selected landfills in the state.
- Determine the range of values for 33 PFAS substances in leachate, and compare to landfills throughout the country.

- Arrive at an estimate of the total PFAS materials in the landfill leachate through Total Oxidized Precursor (TOP) analyses.
- Determine if differences in amount of PFAS occurs in landfill cells of different ages.
- Determine if specific types of waste streams lead to higher PFAS values.
- Identify disposed wastes that are likely to generate PFAS releases to leachate.
- Perform a one-time testing of leachate from approximately 23 landfills.
- Consider additional sampling of leachate for landfills not yet sampled after the initial Phase I is completed. This second step of Phase I may include landfills that are undergoing MTCA cleanups, or landfills that contain specific refuse streams that have been shown to have high PFAS values from the Phase I sampling.

If warranted, Ecology would manage PFAS in landfill leachate long-term by:

- Considering additional monitoring requirements for landfills to test leachate for PFAS using information from the study above.
- Potentially updating the rules (Chapters 173-350[19] and 351[20] WAC) to require PFAS testing of leachate during landfill monitoring.

Groundwater and gaseous emissions

Phase II of the program will sample groundwater and gas emissions at landfills for PFAS. This phase of the program is in the conceptual stage. Landfills to be sampled will be based on the results of the Phase I leachate study. Groundwater will be sampled from existing monitoring wells.

The Solid Waste Management program (SWM), in conjunction with the Air Quality Program (AQ), will develop the gas emissions sampling portion of the program. Ecology will also consider landfill gas emissions monitoring being conducted by North Carolina State University and Oregon State University.

Landfill waste makeup

In parallel to landfill gas emission sampling above, Ecology will continue to research the makeup of PFAS waste entering and potentially currently stored in landfills.

Cost

The Phase I testing of leachate from 23 landfills received $34,500 of funding. It is estimated that the groundwater sampling portion of Phase II will cost approximately $60,000. An estimate for the sampling of gaseous emissions has not yet been developed.

Adding PFAS monitoring requirements to Chapter 173-350 WAC could take two and a half years and cost up to $1.1 million. Less complex rulemaking could take two years and cost up to $260,000. These cost estimates include employee time and expenses, but will vary based on the degree of consultation with Ecology's Assistant Attorneys General.

[19] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350
[20] https://apps.leg.wa.gov/wac/default.aspx?cite=173-351

4.3 Evaluate Washington biosolids management

The information gaps regarding biosolids are significant and currently prevent assessment of risk from PFAS in biosolids that are land applied in Washington. Any regulatory changes should be founded on defensible data and science-based risk assessments. If Ecology uses scientific modeling to assess potential PFAS transfer from biosolids to soil or groundwater, realistic model parameters must be used.

Washington biosolids regulation in the near term should ensure sound agronomic land application practices on permitted sites where human exposure is limited. It is premature to add or change regulatory limits given the absence of data from Washington biosolids and problems identified with models and their input parameters.

Recommendation

We recommend the following key steps to address the current data gaps:

- Establish biosolids and soil sample collection and handling methods for PFAS analysis.
- Accredit Washington labs for EPA-validated analysis methods.
- Use EPA-validated analysis methods for biosolids and soils.
- Conduct credentialed third-party review of raw mass spectrometer PFAS data.
- Investigate land application sites where procedures mimic rates and practices under current state rule (Chapter 173-308[21] WAC).
- Evaluate realistic exposure pathways.
- Evaluate risk modeling using realistic input values.
- Collaborate with stakeholders to get accurate and precise biosolids data. Initial results should remain anonymous.
- Compile analysis data with statistical review.

To conduct this work, Ecology will collaborate with municipalities managing WWTPs.

Cost

As of the date of this CAP, it is not possible to precisely estimate costs for implementing this recommendation—based on the cost of sample analysis and the need to sample multiple municipal WWTPs, an initial round of biosolids sampling statewide is preliminarily estimated at $100,000. Ecology will recruit a senior employee to lead the biosolids data gathering process. Ecology will also submit program funding requests for both sampling and analysis to help with expenses.

[21] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308

What else are we doing about PFAS?

This section outlines other activities Ecology and Health are conducting in addition to developing this CAP. For the most part, the activities described below implement legislation which has been adopted. Some of these activities also respond to earlier CAP recommendations, for example reducing AFFF releases to the environment, and further assessing certain products which contain PFAS (e.g., carpeting) as priority PFAS sources.

Rulemaking

State drinking water rulemaking

The SBOH initiated two rulemaking activities[22] to address PFAS in drinking water. The SBOH is considering establishing state action levels for PFAS in drinking water. The proposed revisions to Chapter 246-290[23] WAC intend to improve public health protection by requiring Group A water systems to test for PFAS, and providing health-based action levels for five common PFAS: PFOS, PFOA, PFNA, PFHxS and PFBS. The proposed revisions would require monitoring, recordkeeping and reporting, and follow-up actions for PFAS. The SBOH is also considering amendments to the drinking water laboratory certification and data reporting rules (Chapter 246-390[24] WAC) to align laboratory data reporting requirements with the anticipated changes to Chapter 246-290 WAC outlined above. Health's overall timeline[25] and lab rule timeline[26] anticipates draft rules will be issued for comment in August 2021, and the rulemaking completed in 2021.

Law implementation

Firefighting Agents and Equipment

Chapter 70A.400[27] RCW establishes restrictions on Class B firefighting foam that contains intentionally added PFAS chemicals:

- As of July 1, 2018, prohibits use of Class B firefighting foam for training.
- As of July 1, 2020, prohibits the manufacture, sale, and distribution of Class B firefighting foam.
  - Interim exemptions include federally required users, petroleum storage and distribution facilities, or certain chemical plants.
- Requires manufacturers to notify Washington purchasers about the presence and purpose of PFAS in firefighting personal protective equipment.
- Two years after amendment of federal regulations (prohibiting the use of PFAS-containing foam), requires federal facilities to use non-PFAS foams that comply with the new federal regulation.

[22] https://www.doh.wa.gov/CommunityandEnvironment/DrinkingWater/RegulationandCompliance/RuleMaking
[23] https://apps.leg.wa.gov/wac/default.aspx?cite=246-290
[24] https://apps.leg.wa.gov/wac/default.aspx?cite=246-390
[25] https://www.doh.wa.gov/Portals/1/Documents/4200/PFAS-Timeline.pdf
[26] https://www.doh.wa.gov/Portals/1/Documents/4200/LabRuleTimeline.pdf
[27] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

- Airports must inform Ecology about their ability to switch to non-PFAS foams within 18 months of the change in federal regulations.
- Beginning 2024, restricts the purchase of PFAS-containing foams by oil terminals, oil refineries, and chemical plants.

Update: Ecology completed—or is conducting—the following activities to implement the law.

- Developed an agency website to provide more information and outreach materials regarding the requirements of the law.[28] Ecology updates this website with additional information as new implementation activities are initiated.
- Conducted outreach to manufacturers to explain the requirements and ensure compliance with the restrictions.
- Collaborated with firefighting foam users on the restriction of PFAS-containing firefighting foam use in training, and on the purchase restriction taking effect in 2020. Ecology will continue to provide technical assistance in this area as purchase and use restrictions continue to take effect.
- Provided technical assistance to state and local governments and other jurisdictions to help them purchase PFAS-free Class B firefighting foam. This activity will continue as purchase restrictions continue to take effect.
- Provided guidance to municipal fire departments on how to safely use and correctly store their AFFF stockpiles while Ecology completes its AFFF environmental impact statement (EIS) under the State Environmental Policy Act (SEPA).
- Launched an input-based test equipment reimbursement program. This program will provide Washington State Part 139 airports with funding to purchase equipment which will allow them to test their firefighting equipment without having to run PFAS foam through the system.
- Informed firefighting personal protective equipment manufacturers of the requirement to notify purchasers about the presence of PFAS—and requested copies of the notification. An initial round of such requests was completed in 2019—additional similar requests may be re-initiated in the future.
- Surveyed state and local governments and other jurisdictions about stocks of Class B firefighting foam through Ecology's Product Replacement Program.[29]
- In July of 2020, in response to receiving information that PFAS-containing firefighting foam products were still being sold in Washington after July 1, 2020, Ecology communicated with sellers and manufacturers of such products that such sales were prohibited by Chapter 70A.400.020[30] RCW. Enforcement resolution included changes in foam formulations and the recall of banned foam products.
- In January 2021, issued a Determination of Significance and Scoping Notice[31] to prepare for an EIS review of an AFFF collection and disposal program. The EIS will

[28] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals/PFAS/Toxics-in-firefighting
[29] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Product-Replacement-Program
[30] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400.020&full=true
[31] https://www.ezview.wa.gov/Portals/_1962/Documents/FirefightingFoam/01.19.2020_DS_EIS_Issuance.pdf)

consider the collection and disposal program's impact upon the environment, public health, disadvantaged communities, wildlife including endangered species, and other resources still to be determined. The EIS will also investigate potential disposal methods. Those disposal methods are likely to include options such as landfill, deep-well injection, emerging technologies such as supercritical water oxidation, and incineration. No decision regarding the preferred destruction method has been made. Ecology expects to issue the EIS by the end of 2021 or early 2022. Ongoing activity related to this review is updated via the project webpage.[32]

Packages Containing Metals and Toxic Chemicals

The Packages Containing Metals and Toxic Chemicals law (Chapter 70A.222[33] RCW) includes the following restrictions:

- Effective January 2022, prohibits PFAS in plant fiber-based food packaging.
- Requires Ecology to conduct an AA to identify safer alternative products. This assessment must consider chemical hazard, performance, cost and availability, and exposure.
  - Ecology must submit the findings for external peer review and publish the results in the Washington State Register.
- Requires Ecology to report results to the Legislature before a ban on PFAS in food packaging can take effect.

Update: Ecology has completed—or is conducting—the following work to implement the law.

- Our analysis focused on single-use food paper (such as wraps), dinnerware (such as plates), and takeout containers used to serve and transport freshly prepared food.
- Ecology and Health submitted the PFAS in Food Packaging Alternatives Assessment (AA) Report to the Legislature,[34] and published the PFAS in Food Packaging AA[35] in February 2021.
- Ecology and Health initiated the second PFAS AA cycle in 2021, considering the following types of products: closed containers, flat service ware, open-top containers, bags and sleeves, and bowls. These products include several types of products where no alternatives that met all the criteria in the law were identified. We expect to submit a report to the legislature by the end of 2021.
- We are working on a pilot program to help users of PFAS-containing food packaging test out safer alternatives in their businesses or institutions.

[32] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals/PFAS/Toxics-in-firefighting#foam-replacement
[33] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222&full=true
[34] https://apps.ecology.wa.gov/publications/summarypages/2104007.html
[35] https://apps.ecology.wa.gov/publications/summarypages/2104004.html

The Pollution Prevention for Healthy People and Puget Sound Act

The Pollution Prevention for Healthy People and Puget Sound Act (Chapter 70A.350[36] RCW) creates a process for Ecology, in consultation with Health, to regulate classes of chemicals in consumer products. Ecology is implementing the law through the Safer Products for Washington[37] program. It identifies PFAS as priority chemicals and requires Ecology to:

- Designate priority chemicals and identify products that contain these chemicals.
- Consider safer, feasible and available alternatives to use instead of the priority chemicals.
- Determine needed regulatory actions and adopt rules to implement regulatory actions.
- Conduct stakeholder consultation, legislative reporting, and rulemaking.

Update: Under the implementation program, Ecology submitted the final version of the report[38] identifying priority products with PFAS to the Legislature on July 6, 2020. Since the summer of 2020, Ecology and Health have developed draft criteria to identify safer, feasible, and available alternatives and used the criteria to determine whether potential alternatives to PFAS are safer, feasible for use in the priority products identified, and available on the market. Following this work, Ecology will determine whether regulatory actions are necessary and report this to the Legislature by June 1, 2022.

Children's Safe Products Act

The Children's Safe Products Act (CSPA), Chapter 70A.430[39] RCW, requires manufacturers to annually report the presence of certain chemicals (including PFOS and PFOA) in children's products sold in Washington state.

Update: Ecology implements the law as follows:

- Ecology receives manufacturer reports and conducts compliance activities.
- Manufacturer reports are published online.[40]

Other activities

Landfill leachate sampling

One of the 2019 Preliminary Recommendations addressed gathering more information about PFAS in landfill leachate. Ecology has begun this work. Ecology's Solid Waste Management Program (SWM) developed Phase I of a landfill leachate sampling program. This phase is funded and approved. Landfill leachate sampling was completed in November 2020. Ecology received the PFAS laboratory analytical data in the Spring of 2021 and the data is currently undergoing review and analysis. A final report on Phase I of the PFAS leachate study is expected to be

[36] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350&full=true
[37] https://ecology.wa.gov/safer-products-wa
[38] https://apps.ecology.wa.gov/publications/summarypages/2004019.html
[39] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.430&full=true
[40] https://hpcds.theic2.org/Search

completed by the end of 2021. The study sampled leachate at selected landfills from across the state to estimate a range of values for 40 PFAS substances as well as 20 total oxidizable precursor compounds. Values will be compared to landfills across the country, and the data will be used to:

- Evaluate potential differences in amount of PFAS across landfill cells of different ages.
- Investigate whether specific waste streams lead to higher PFAS values. This will identify disposed waste that is likely to release PFAS to leachate.
- Help determine if any follow-up studies may be needed to evaluate potential impacts to groundwater, soil-gas vapor, and air emissions that are associated with landfill operations.

WWTP sampling

One of the 2019 Preliminary Recommendations addressed gathering more information about PFAS in WWTP influent and effluent. Ecology received funding to develop and conduct sampling of PFAS in influent, effluent, and biosolids at three municipal WWTPs receiving industrial discharges. This data would help inform how PFAS move through a WWTP and which treatment processes are potentially more effective at transforming and removing PFAS. Ecology sampled three WWTPs in February 2021 and will complete the report in Fall 2021.

Fish consumption advisory

Health is developing fish consumption advisories for PFOS in freshwater fish based on Ecology fish sampling data. Health received additional data from Ecology in 2019 to provide an adequate basis for a fish consumption advisory. Health is reviewing these data and re-evaluating screening levels in consideration of recent changes in recommended oral intake.

Introduction

A Chemical Action Plan (CAP) "identifies, characterizes, and evaluates uses and releases" for individual, or groups of, PBTs, and "recommends actions to protect human health or the environment" WAC 173-333-400(1).[41] Chapter 173-333 WAC identifies perfluorooctane sulfonates (PFOS), a type of per- and polyfluoroalkyl substances (PFAS), as a chemical group that requires further action because they persist in the environment for long periods of time, where they can bioaccumulate to levels that pose threats to human health and the environment in Washington.

The Washington State Department of Ecology (Ecology) and the Washington State Department of Health (Health), jointly "we," prepared this PFAS CAP to identify, characterize, and evaluate PFAS uses, releases, and current PFAS management approaches in Washington state. Based on these considerations, we recommend actions to reduce PFAS exposure, use, and release in Washington. The recommendations address urgent public health and environmental concerns while considering feasibility, social impacts, and economic costs. As described in detail in the PFAS CAP Requirements section below, the CAP considers the family of PFAS as a whole.

The CAP includes the following sections:

- A PFAS Assessment Summary section reviewing the findings of our analysis.
- The CAP Recommendations stemming from these assessments and a discussion of PFAS-related activities Ecology and Health are conducting in addition to preparing this CAP.
- A description of the PFAS CAP Requirements guiding the preparation of the CAP and next steps in the CAP process.

A series of ten appendices then assess current scientific knowledge and impacts of PFAS in Washington, each identifying the recommendations it informed. The appendices are organized as follows:

- Appendix 1: Chemistry—reviews the chemical characteristics of PFAS.
- Appendix 2: Analytical Methods—outlines analytical standards available to identify PFAS in environmental media.
- Appendix 3: Sources and Uses—summarizes commercial use of PFAS and how this use results in environmental releases.
- Appendix 4: Fate and Transport—describes how PFAS enter and behave in the environment.
- Appendix 5: Environmental Occurrence—describes how PFAS are distributed throughout Washington state's environment.
- Appendix 6: Ecological Toxicology—reviews toxicological impacts of PFAS to environmental media and their inhabitants.

[41] https://app.leg.wa.gov/wac/default.aspx?cite=173-333-400

- Appendix 7: Health—reviews the potential for human exposure and health impacts for several PFAS and summarizes PFAS occurrence in state drinking water.
- Appendix 8: Biosolids—reviews the impacts of PFAS in biosolids generated from wastewater treatment.
- Appendix 9: Regulations—reviews state and federal regulations that apply to PFAS in Washington state.
- Appendix 10: Economic Analysis—presents qualitative and quantitative estimates of costs to implement recommendations, as well as costs and benefits from reducing PFAS in Washington's environment.
- Appendix 11: Response to Comments—presents responses to comments received on the Draft PFAS CAP.[42]

[42] https://apps.ecology.wa.gov/publications/summarypages/2004035.html

PFAS Assessment Summary

This section summarizes the major findings from our assessment of PFAS, their presence in our environment, and their potential impacts. In order to make this summary accessible, we did not include the citations that support each statement. Each appendix includes detailed assessment findings and associated references to scientific and other sources. Readers should consider the information below in the context of and in combination with the full analysis presented in each appendix.

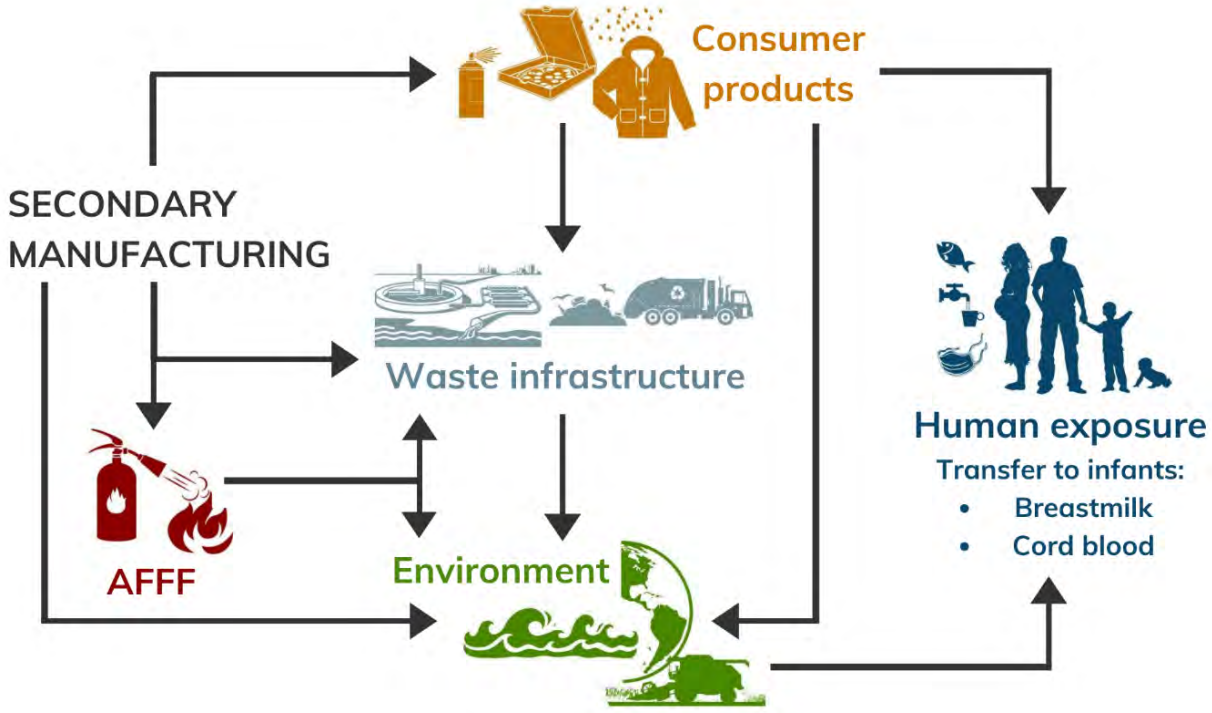
PFAS are used in many applications for consumer, commercial, and industrial products. Even though PFAS were not manufactured in Washington, they may be used in certain manufacturing and industrial processes in our state. PFAS can enter the environment and different types of waste streams as a result of product use. Some waste stream pathways can result in PFAS being cycled from one waste stream into another. Many PFAS—such as those used for firefighting foam—degrade in the environment to form perfluoroalkyl acids (PFAAs). No known natural mechanisms can break these PFAAs down.

PFAS have been detected in Washington state's environment. They are also expected to occur in several types of waste streams produced throughout our state. PFAS have been detected in Washington surface waters, groundwater, wastewater treatment plant (WWTP) effluent, freshwater and marine sediments, freshwater and marine fish tissue, and wildlife. They are expected to occur in landfills and biosolids produced at WWTPs.

National surveys show that most people tested have some PFAS in their blood. Many sources lead to exposure. Workers in jobs related to PFAS-containing products have the highest exposures. People consuming PFAS-contaminated drinking water or food can also be highly exposed. For most people, exposure occurs through food, drinking water, and contact with things like disposable packaging or treated textile products, to name a few.

Figure 1 illustrates the "PFAS cycle" adapted to the presence of PFAS in Washington state outside of occupational settings. The various pathways through which PFAS enters the environment, cycles through the environment and waste streams, and resulting routes of exposure for humans and the environment are show in Figure 1.

Figure 1. PFAS cycle adapted to presence of PFAS in Washington state outside of occupational settings.



Note: Figure was adapted from an article by Elise M. Sunderland et al., published in 2019.[43]

Chemistry (Appendix 1)

More than 4,730 PFAS are registered in the Chemical Abstract Service. As of November 2019, U.S. Environmental Protection Agency's (EPA) master list of PFAS includes 9,252 chemical compounds. EPA identified approximately 600 PFAS which are actively used in U.S. commerce. The large chemical family of PFAS is subdivided into non-polymer and polymer classes.

In their manufactured form, PFAS can be gases, liquids, and high-molecular weight polymer solids. Individual PFAS can be raw materials, compounds used in products, or environmental transformation products. One of the important chemical characteristics of PFAS is their resistance to extreme environments. This characteristic makes certain PFAS completely resistant to natural degradation.

Due to their well-established properties, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) dominate the literature on PFAS. Much of the regulatory interest on PFAS in the environment focuses on PFOS and PFOA. Both of these chemicals are long-chain fluorine and carbon atoms. The number of carbon atoms distinguishes long-chain PFAS from

[43] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6380916/

short-chain PFAS. Since 2002, voluntary stewardship efforts eliminated PFOS and PFOA production in the U.S., Japan, and Europe.

Below are some examples of how PFAS chemical characteristics are used in products:

- Carpet and textile treatments to impart stain and water resistance.
- Paper and packaging treatment to provide water, oil, and grease resistance as well as non-stick performance.
- Surfactants to impart water, oil, and dirt resistance to painted walls, sealed grout, or polished floors.
- Hydraulic fluids resistant to high temperature or reactive environments.
- PFAS-based aqueous film forming foams (AFFF) to extinguish Class B (flammable liquid fuel) fires.
- Durable and heat-stable fluoropolymer surfaces that create non-stick cookware.
- Durable water-resistant layer for outdoor clothing that creates breathable but waterproof fabric.

Analytical Methods (Appendix 2)

A variety of analytical methods are available to analyze PFAS in consumer products and the environment, and the methods are still evolving. Currently, few methods are formally validated and published. Appendix 2: Analytical Methods reviews the standard and non-standard analytical methods for analyzing PFAS.

In November 2018, EPA published a multi-laboratory validated method, EPA Method 537.1 version 1.0, for analyzing 18 PFAS analytes in drinking water. EPA later updated this method with Revision 2.0. In December 2019, EPA announced a new validated method for testing additional PFAS in drinking water, EPA Method 533. This method focuses on PFAS with carbon chain lengths of four to twelve, and complements EPA Method 537.1 version 1.0.

Methods 537.1 Revision 2.0 and 533 are intended to analyze PFAS in drinking water. As a result, they are not effective for additional PFAS compounds or other sample types without modifying the method.

EPA is tentatively scheduled to issue Draft Method 8328 in 2021. The Draft Method 8328 will make use of solid-phase extraction to sample water not used for drinking. Additional methods EPA is developing and validating to detect and quantify PFAS in air, water, and soil include:

- Clean Water Act Method 1600.
- OTM Method 45.
- Standard Operating Procedures for Total Organic Fluorine.
- Analytical Model to Identify Novel PFAS Using Non-Targeted Analysis Data.

Most of the available standard methods for PFAS analysis do not account for all known PFAS. Human exposures to PFAS are generally not from individual PFAS, but from complex mixtures. Analytical techniques are limited in determining which PFAS are in those mixtures. Non-specific methods for PFAS analysis assessed in Appendix 2 include:

- Combustion ion chromatography.
- Particle-induced gamma ray emission.
- Total oxidizable precursors assay.

Analysis of PFAS is progressing, but challenges remain because the complete list of PFAS relevant to environmental and human exposure is unknown. As more studies identify novel PFAS, an effective, comprehensive technique that is capable of quantitative, non-target analysis remains elusive.

Ecology's analysis of analytical methods does not include specific recommendations. Ecology supports the use of approved validated methods as recommended by EPA for specific targeted PFAS analysis. Implementation of several CAP recommendations requires PFAS sampling in environmental media, which would benefit from improved analytical approaches that can characterize unknown PFAS.

Sources and Uses (Appendix 3)

PFAS contamination is widespread. As of April 2020, in the U.S., 300 sites and 390 water systems in more than 40 states have known PFAS contamination. AFFF use during emergency response, equipment testing, and training exercises contributes to PFAS groundwater contamination. AFFF has been stored and used throughout Washington. Ecology estimates that 1.4 million liters may have been stored statewide in 2004, and 606,000 liters in 2011.

PFAS releases from manufacturing are linked to approximately 60 contaminated sites across the U.S. We do not know of any PFAS manufacturing which has occurred, or continues to occur, in Washington state. We estimate that the range of industry sectors (mining, paper products, resins, surfactants, etc.) that potentially use PFAS—as raw material or as a product component—represent approximately 1,200 manufacturing businesses. However, we do not yet know whether any of these operations have used, or currently use PFAS.

People are exposed to PFAS in their homes when they use contaminated products and through contact with house dust that contains PFAS. For example, textile-related products that use fluorinated chemicals include carpeting and upholstery, outer garments, tents, car seat covers, leather articles, etc. Studies have also identified a variety of PFAS in a range of cosmetics. Between 2014 and 2019, PFOS was reported in 112 children's products sold in Washington. High levels of PFAS have been reported in occupational settings (such as carpet shops and industries that use products containing PFAS), where we estimate that 269,278 Washington workers could be exposed.

PFAS may be entering the state's ambient environment as a result of waste disposal, landfill leachate (liquid that drains from a landfill), land application of industrial sludge, and discharges of municipal and industrial wastewater. Numerous products that contribute to waste streams contain PFAS. Some municipal wastewater treatment plant (WWTP) effluent sampling in Washington found PFAS levels similar to publicly owned WWTPs in other areas of the U.S.

Privately and publicly operated landfills, which receive and store wastes, are likely to receive products containing PFAS. Uncontrolled leachate can migrate into groundwater, resulting in contamination if the landfill contains materials containing PFAS. Controlled leachate, which may

also contain PFAS, is typically sent to publicly owned WWTPs, potentially increasing PFAS in WWTP influent.

Data suggest that 51.66 to 17,043 metric tons of PFAS are landfilled in consumer products in Washington each year. From 1960 – 2002, we estimate Washington state's average annual contribution of six PFAS emissions (the sum of perfluoro-carboxylic acid [PFCA], fluorotelomer alcohol [FTOH], perfluorooctane sulfonyl fluoride [POSF], PFOS, PFHxS, and perfluorodecane sulfonate [PFDS]) resulting from product use and waste streams is approximately 29.5 metric tons per year.

Fate and Transport (Appendix 4)

Manufacturing processes can use and emit PFAS directly into the environment. Once emitted into the environment, certain short-chain and long-chain PFAS—called "precursors"—can degrade to perfluoroalkyl acids (PFAAs), which are very stable in the environment and are referred to as terminal substances. The timeframe for the transformation from precursor to terminal substance depends on the compounds present and the surrounding environmental conditions. Transformation processes include:

- Abiotic (without living organisms).
- Biotic aerobic (by organisms with access to oxygen).
- Biotic anaerobic (by organisms without oxygen).

Even though U.S. production of PFOS and PFOA was phased out by 2002 and 2015 respectively, levels of certain PFAAs have continued to increase in wildlife because of these transformation processes. Manufacturers continue to make other precursor compounds, which transform into PFAAs in the environment. Surface waters and wildlife have measurable levels of both precursors and PFAAs. This shows that exposure to precursors can be significant.

During direct or secondary manufacturing, PFAS can be released to the air through stack emissions. Once in the air, certain PFAS can travel large distances before deposition, as shown by their occurrence across the globe, far from all manufacturing sites.

Environmental release to bodies of water results from secondary manufacturing activities. Neither the state nor federal Clean Water Act (CWA) establish numeric standards for discharge of PFAS in industrial wastewater discharges. PFAS-containing product use and disposal in domestic wastewater can result in PFAS presence in sewage. Similarly, PFAS can also be present in domestic wastewater effluents, which are released to on-site wastewater systems, and typically discharge to groundwater.

Some PFAS compounds, as a result of their high solubility, may be susceptible to leaching from landfills or contaminated biosolids, compost, and soils when exposed to water. PFAS will often localize at phase interfaces, such as soil and water or water and air boundaries.

Individual PFAS will adsorb to organic carbon in soil to varying degrees. How long PFAS remain in soil depends on site-specific factors. However, evidence shows that desorption is often incomplete. As such, soil contaminated with PFAS may remain as a low-volume source of contamination for ground and surface water for a long time.

Environmental Occurrence (Appendix 5)

In Washington, PFAAs have been detected in fresh and marine surface waters, stormwater in urban industrial catchments, municipal WWTP effluent (treated water leaving the treatment plant), freshwater and marine sediments, catch basin sediments, freshwater and marine fish, mussels, and osprey eggs. Environmental concentrations of PFAAs in Washington state surface waters, WWTP effluent, and freshwater fish tissue sampled in 2016 were consistent with PFAS levels in other parts of the U.S. not impacted by PFAS manufacturing facilities.

Beyond Washington, PFAS have been detected in other wildlife, with PFOS generally detected at the highest frequency and in the greatest amount.

Monitoring suggests that stormwater, municipal WWTP effluent, and uncontrolled releases of AFFF are primary ways that PFAAs are delivered to water bodies. PFOS (and to a lesser extent, perfluorodecanoic acid [PFDA], perfluorododecanoic acid [PFDoA], perfluoroundecanoate [PFUnA], and perfluorooctane sulfonamide [PFOSA]) are widespread in freshwater fish tissue found in Washington state's water bodies. Samples of urban lake fish tissue had PFOS levels that are above Department of Health's initial screening levels and may trigger consumption advisories to protect human health. Sampling in 2018 confirmed that PFAS concentrations in freshwater fish collected from Washington urban lakes are consistent with other urban water bodies in North America.

Environmental monitoring in 2016 suggested that PFAA levels in surface waters and municipal WWTP effluent had decreased since the last round of sampling in 2008. A shift was evident in WWTP effluent samples: short-chain PFAAs were replacing PFOA as the most dominant compounds.

At sites affected by urban sources and WWTP effluent discharge locations, PFOS and other long-chain PFAAs are detected in osprey eggs at concentrations that are high enough to reduce hatchability. PFAS concentrations (primarily PFOS) in osprey eggs remained unchanged between 2008 and 2016.

Ecological Toxicology (Appendix 6)

PFOA and PFOS are the major PFAS contaminants found in oceanic waters. A variety of wildlife across the globe have measurable PFCA (perfluorooctanoate [PFO], perfluorononanoate [PFN], or perfluorodecanoate [PFD]) concentrations. Stability and water solubility allow some PFAS to transport through marine environments, concentrate in marine organisms, and easily accumulate throughout all trophic levels.

Both short- and long-chain PFAS are environmentally persistent. Long-chain PFAS tend to be more bioaccumulative and produce adverse toxicological effects, even at relatively low contaminant levels. While resistant to degradation, short-chain PFAS appear to be less bioaccumulative and to have fewer significant toxicological effects. Though short-chain PFAS are less bioaccumulative, high mobility and bioavailability lead to relatively high levels in fish tissues.

Bioaccumulation or biomagnification has been confirmed in marine and terrestrial species, zooplankton and other invertebrates, and fish. PFAS have been shown to be taken up by plants from soil, with different PFAS presenting in different portions of the plant.

Biomagnification results in greater levels of PFAS in animals higher on the food chain (e.g., seals, polar bears), relative to animals at lower trophic levels. PFAS are persistent and able to transport long distances, and bioaccumulation is not required for sustained internal exposure. Therefore, animals do not need to be near sources of PFAS releases to the environment to show bioaccumulation, and exposure will continue regardless of accumulation.

Scientific literature supports the association between PFOA exposure and reduced antibody response in animals. Animal studies with both PFOS and PFOA show that they are well-absorbed orally, but poorly eliminated. PFAAs bind to proteins (rather than fats, like other bioaccumulating compounds), and are found mostly in the liver and blood. Documented toxicological effects of PFAS include:

- Inhibited growth and detrimental effects on photosynthesis on green algae and floating macrophyte, L. gibba (P. subcapitata, S. capricornutum, and C. vulgaris).
- Slight to moderate toxicity to aquatic invertebrates.
- Impacted fertility in adult fish.
- Risks for impacted development in Arctic marine food webs.
- Reduced plant root elongation.
- Induction of liver tumors in Wistar rats.
- Significantly stunted mammary epithelial growth and ultrastructural liver changes in mice.
- Reduced hatchability and pathological liver changes in chickens.

Health (Appendix 7)

We are still learning about potential human health risks of PFAS. Much of what we know is from toxicity testing in laboratory animals. The evidence base is strongest for PFOA and PFOS, but is expanding for other PFAAs.

Animal studies provide strong evidence that some PFAAs produce liver and kidney toxicity, immune toxicity, reproductive and developmental toxicity, endocrine disruption (altered hormones), and certain tumors. Epidemiological studies link higher exposures to PFAAs with reduced antibody response to childhood vaccines, increased cholesterol and liver enzymes, and slightly reduced birth weights, among others.

It takes years for human bodies to excrete PFOS, PFOA, PFNA, PFHxS, and other long-chain PFAS—some are strongly bioaccumulative in people. Other PFAAs such as perfluorobutanoic acid (PFBA), PFBS, and perfluorohexanoic acid (PFHxA) are more rapidly cleared. For most PFAS, absorption, distribution, and clearance in humans have not been studied.

Since 1999, Centers for Disease Control and Prevention (CDC) surveys of the U.S. population detected PFOS, PFOA, PFHxS, and PFNA in the blood of nearly every participant. Levels have

declined since phase-outs of these PFAS from domestic production and use, but current analysis methods cannot identify all PFAS in human blood, underestimating occurrence.

People can be exposed to PFAS from contaminated drinking water and other dietary sources, from indoor dust and air containing PFAS released from consumer products, and from use of PFAS-containing consumer products. Although difficult to assess, studies identify food and drinking water as the likely main routes of non-occupational exposure for people.

Several Washington drinking water sources have been contaminated near sites of AFFF release:

- City of Issaquah.
- Naval Air Station, Whidbey Island—with off-base impacts to the Town of Coupeville, plus adjacent public and private drinking water supplies.
- Naval Base Kitsap Bangor—with off-base impacts to private wells.
- Joint Base Lewis McChord, and the Fort Lewis and McChord field water systems—with off-base impacts to city drinking water systems in Dupont, Lakewood, Tacoma, and Parkland.
- Fairchild Air Force Base—with off-base impacts to the City of Airway Heights and private well owners.

In each area, the sum of PFOA and PFOS in at least one drinking water well exceeded EPA's lifetime health advisory level (70 parts per trillion [ppt]). AFFF is the suspected contamination source in all of these areas. Ongoing site investigations may identify other sources.

Biosolids (Appendix 8)

Chapter 173-308[44] WAC, Biosolids Management, divides wastewater solids into two classes. Those that meet the regulatory standards to allow land application are classified as biosolids, whereas those that do not meet the regulatory standards are classified as sewage sludge. Washington law requires that biosolids are land applied (i.e., applied to agricultural fields as fertilizer) to the greatest extent possible, but sewage sludge is disposed in landfills. Currently, about 85 – 90% of biosolids generated in Washington are land-applied.

Some U.S. labs are analyzing biosolids using modified procedures based on EPA's Method 537. However, guidelines are inconsistent and results are not validated. For PFAS analysis using modified 537 methods, Ecology's lab accreditation unit at Manchester Environmental Laboratory recognizes the National Environmental Laboratory Accreditation Program (NELAP) for a few other Washington labs. EPA is in the process of validating a different procedure for analyzing PFAS in biosolids and soil—SW-846.

Most studies assessing contamination impacts from biosolids application sample publicly owned WWTPs receiving influent directly from industries using fluorinated compounds. Although some industrial discharge in Washington is possible, we anticipate that the majority of perfluorinated compounds in Washington municipal wastewater originate from domestic sources.

[44] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308

Worldwide monitoring data show that PFOA and PFOS concentrations in biosolids are trending downward, likely due to less production of the compounds. Studies with high loading rates to agricultural soils showed bioaccumulative effects in some vegetables or diminished growth of spring wheat. However, the PFOS and PFOA application rates in these studies were likely far higher than the PFOS and PFOA present in Washington biosolids. The lack of potential industrial contamination in Washington means these negative impacts on crop growth are not likely to be representative of biosolids applications in Washington state.

Adoption of extremely low regulatory limits for soil PFAS could have adverse consequences for organics and residual recycling, and may not provide demonstrated risk-reduction for human health and the environment.

Regulations (Appendix 9)

Regulatory action to restrict the production and use of PFAS has been enacted at both state and federal levels. The best understood long-chain PFAS (such as PFOS and PFOA) were voluntarily withdrawn from commercial use in the U.S. However, specialized uses are still permitted.

Washington state is considering developing drinking water standards for several PFAS. Regulatory activity in Washington includes, for example:

- Manufacturer reporting requirements under for children's products (Chapter 70A.430[45] RCW).
- Restrictions for use, and eventual bans of AFFF (Chapter 70A.400[46] RCW).
- Assessments of safer alternatives for PFAS used in carpets and rugs, textile and leather furnishings, aftermarket textile treatment products (Chapter 70A.350[47] RCW), and food contact packaging (Chapter 70A.222[48] RCW).

At the federal level, the Food and Drug Administration regulates PFAS use in food packaging. The ATSDR advises local, state, federal, and tribal agencies regarding human health effects. DOD enacted requirements to decrease PFAS use—such as in AFFF in food packing for military rations, for example. DOD will also continue with initiatives to address PFAS contamination resulting from its activities.

Under the Toxic Substances Control Act (TSCA), EPA has minimized and regulated the manufacture and use of certain long-chain PFAS. Data on PFAS use nationally will soon be collected via EPA's Toxics Release Inventory (TRI). EPA is coordinating these and other activities under its 2019 PFAS Action Plan.

[45] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.430&full=true
[46] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true
[47] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350&full=true
[48] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222&full=true

Economic Analysis (Appendix 10)

Statewide costs for PFAS mitigation in drinking water will not be fully understood until further testing to characterize the occurrence in drinking water is complete. Currently, a few examples are available to consider the costs of drinking water mitigation for PFAS. Some examples do not separate investigation costs.

- The City of Issaquah spent more than $600,000 (plus ongoing maintenance costs) to install a filter on one PFAS-contaminated city well.
- The Sammamish Plateau Water and Sewer District has incurred testing and modeling costs in excess of $510,000. The District is funding an $800,000 project to design a PFAS treatment plant in response to the proposed SBOH State Action Levels (SAL). Ultimate construction of a PFAS removal treatment plant is estimated to be $6 – $7 million dollars. The District has also incurred additional costs to replace water supply from wells that were removed from production due to PFAS contaminant levels.
- The Department of Navy (DON) spent $9.8 million to add granular activated carbon treatment to the Town of Coupeville's water system and connect impacted private well owners to the Town's water system near Naval Air Station Whidbey Island, Outlying Landing Field (OLF) Coupeville. The DON has also spent over $14 million (as of January 2021) for PFAS investigation and other drinking water mitigation efforts.
- In 2017, Airway Heights public water system shut down PFAA-contaminated wells. Using the City of Spokane water system, Airway Heights used an emergency intertie (to flush their system with clean water) and added another connection (to supply water while they pursue treatment options). The water purchase (439 million gallons) could cost $687,000 in the first year. The Air Force has agreed to pay the city.
- The Lakewood Water District anticipates capital costs of $21 million to provide treatment for well systems. The District estimates that operating costs and treatment media replacement costs of $340 million and $1.1 billion respectively will be incurred over the 50-year life of the treatment system.
- At Joint Base Lewis McChord, McChord Field System, activated carbon filtration treatment of water from three wells is estimated to cost $10.3 million for initial capital investments, and $830,000 per year for ongoing maintenance.

These costs are in line with similar drinking water remediation activities in other states. The total cost of remediation for PFAS-contaminated groundwater remains unknown, because there are no completed cleanups of PFAS contamination in the U.S.

Based on Washington state Model Toxics Control Act (MTCA) remediation ratios, we have estimated that overall remediation costs could range between $5.3 million and $62.8 million for a site where AFFF release results in groundwater contamination. Interim solutions such as filtering or alternative sources of drinking water could result in ten-year costs of $6.5 million to $10 million.

Response to Comments (Appendix 11)

This appendix provides our response to comments received on the Draft PFAS CAP,[49] which was issued for public review in October 2020. The response is organized into 299 Issues, addressing topics presented in the CAP. The responses also identify changes made to the CAP as a result of the comments received.

[49] https://apps.ecology.wa.gov/publications/summarypages/2004035.html

PFAS CAP Recommendations

Our CAP recommendations address a broad range of concerns. Figure 2 provides an overview of the four main categories of recommendations proposed.

Figure 2. Recommendations found in the PFAS Chemical Action Plan and associated sub-efforts to support implementation.

We based these recommendations on our assessment of scientific information—presented in the appendices—and Advisory Committee input (see section PFAS CAP Requirements below). These broad categories were first identified in the 2018 Interim Chemical Action Plan for Per- and Polyfluorinated Alkyl Substances[50] (Interim CAP). Over time, as we improved our knowledge of PFAS, and as several pieces of legislation were passed and implemented, some of our earlier recommendations were acted upon and further refined in our May 2019 Preliminary CAP Recommendations[51] (Preliminary Recommendations). Our activity to address PFAS has continued since May 2019, resulting in additional evolution of our recommendations, described below.

For each of the four main recommendations, this section provides a summary of how the recommendations have evolved since they were first considered in 2018, and identifies implementation activities that have already begun. Most of the activities described below implement legislation that has been adopted. Some of these activities also respond to Interim CAP or Preliminary Recommendations, for example reducing AFFF releases to the environment, and further assessing certain PFAS-containing products.

[50] https://apps.ecology.wa.gov/publications/SummaryPages/1804005.html
[51] https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PrelimRecommendations-2019-PFAS-CAP.pdf

Implementing the CAP recommended actions would require additional resources and funding. We include agency cost estimates for some actions. Appendix 10: Economic Analysis addresses economic impacts to other entities for some actions.

1.0 Ensure drinking water is safe

Protecting public health by ensuring safe drinking water is a fundamental responsibility of the Health Office of Drinking Water (ODW).

There are three types of drinking water systems in Washington:

- Group A water systems serve 85% of state residents.[52] They service more than 15 connections or more than 25 people. There are 4,105 Group A systems in the state. ODW primarily regulates these public water systems.
- Group B water systems are smaller and serve 1.5% of state residents. The local health department usually oversees these systems. Group B systems have few testing requirements for continued operation.
- Private wells serve 13.5% of state residents. Private wells are only regulated in their design and installation, and regulatory overview is by local health departments. Chemical testing is not usually required.

Less than 10% of all Group A systems in the state have been tested for PFAS. This includes water testing done by the DOD, voluntary testing by public water systems, and testing done under EPA's third unregulated contaminant monitoring rule (UCMR3). However, those that have been tested serve most water customers in the state. The percentage of Group B and private wells tested for PFAS is even lower. A water test is required to determine whether PFAS are in drinking water, because PFAS are tasteless and odorless at levels of public health concern.

Because testing and treating for PFAS in drinking water is expensive, exposures to PFAS-contaminated water may be disproportionately borne by populations who do not have the financial means to test for and remove these contaminants.

[52] https://www.doh.wa.gov/DataandStatisticalReports/EnvironmentalHealth/DrinkingWaterSystemData/DataDownload

Previous CAP Recommendations

Interim CAP

The Interim CAP[53] proposed three areas of action pertaining to drinking water protection.

First, it proposed supporting rulemaking for state drinking water standards. This recommendation is being implemented. The SBOH initiated two rulemaking activities[54] to address PFAS in drinking water. The SBOH is considering establishing state action levels for five PFAS in drinking water. The proposed revisions intend to improve public health protection by setting a PFAS regulatory standard for Group A public water systems in Washington. Proposed revisions to Group A Public Water Supplies (Chapter 246-290[55] WAC) include:

- Required testing for PFAS by most Group A water systems.
- Health protective levels in drinking water for PFOS (15 ppt), PFOA (10 ppt), PFNA (9 ppt), PFHxS (65 ppt), and PFBS (345 ppt).
- Required monitoring, recordkeeping and reporting, and follow-up actions for PFAS and other unregulated contaminants with established state advisory levels.
- Technical and editorial changes as needed.

The SBOH is also considering amendments to the drinking water laboratory certification and data reporting rules, Chapter 246-390[56] WAC. These amendments would align laboratory data reporting requirements with the anticipated changes to Chapter 246-290 WAC outlined above.

The SBOH issued draft rules for comment in August 2021; the rulemaking timeline[57] anticipates rule adoption to be completed in 2021. Health is absorbing costs to conduct PFAS rulemaking with existing resources. As part of the rulemaking process, Health will assess costs for water systems to comply with testing requirements and to act when drinking water exceeds state action levels.

Second**,** the Interim CAP proposed to expand voluntary testing for PFAS to include drinking water sources and PFAS chemicals that have not yet been evaluated. It sought to prioritize water systems at high risk for contamination for early testing, such as those near airports or firefighter training centers. Health estimated a range of $235,000 to $8 million in costs to implement this recommendation based on the scope of water systems (Group A, Group B, or both) included. Health was unable to secure commercial laboratory services or sufficient funding for this initiative in 2018 – 2019. The drinking water rulemaking activity described above proposes a statewide requirement for public water systems to test for PFAS at least once. This would essentially implement the testing recommendation. Health is looking to use set-aside funding from the capitalization grant of the State Revolving Fund, funding from EPA

[53] https://apps.ecology.wa.gov/publications/SummaryPages/1804005.html
[54] https://www.doh.wa.gov/CommunityandEnvironment/DrinkingWater/RegulationandCompliance/RuleMaking
[55] https://apps.leg.wa.gov/wac/default.aspx?cite=246-290
[56] https://apps.leg.wa.gov/wac/default.aspx?cite=246-390
[57] https://www.doh.wa.gov/Portals/1/Documents/4200/PFAS_Timeline_PublicComment.pdf

for unregulated contaminants, and money from the Wellhead Protection Grant to help subsidize costs for utilities willing to sample earlier than the rule requirements.

Third, the Interim CAP proposed to implement methods to reduce PFAS in drinking water. This recommendation sought to encourage water systems to implement options to meet EPA's health advisory level for PFOA and PFOS of 70 ng/L until state rulemaking is complete. It also proposed providing technical assistance to public water systems for talking to the public about contamination, mitigation options, and monitoring. As described in Appendix 7, Health is working closely with public drinking water systems currently known to be affected by PFAS releases.

The remainder of this recommendation was further developed in the Preliminary Recommendations, described below.

Preliminary Recommendations

The Preliminary Recommendations identified three activities aimed at providing support to public water systems adversely affected by PFAS releases into the environment:

- Identify funding for PFAS drinking water mitigation.
- Provide technical support for site characterization, source investigation, and mitigation at contaminated sites.
- Seek funding for biomonitoring to support impacted residents and help answer important health questions.

Draft CAP

The above three recommendations were included in the Draft CAP. The third recommendation was refined to emphasize finding opportunities for Washington residents to participate in exposure and health studies. These recommendations are incorporated into the CAP below. The goals of the recommendations have not been substantively revised since the Draft CAP. However, they were updated to acknowledge certain response costs not included in the Draft CAP, and that privately owned systems regulated by the Washington State Utilities and Transportation Commission have limited funding options.

1.1 Identify funding for PFAS drinking water mitigation

Recommendation

State agencies, the Washington State Legislature, and water systems should work together to fund PFAS drinking water mitigation. These costs should be reimbursed by responsible parties under applicable laws. Once PFAS water contaminants are classified as hazardous substances by the federal government or meet the definition of hazardous substance under the state of Washington's statutes or rules, they can be addressed under the state Model Toxics Control Act (MTCA) framework.

Existing resources

Drinking Water State Revolving Fund is an EPA-funded loan program administered by Health. The loans are used to:

- Improve drinking water infrastructure.
- Finance the cost of installing treatment or other infrastructure improvements over a number of years.

Drinking Water State Revolving Fund can provide emergency loans in the event a water system is issued a "Do Not Use" order by the Department of Health as a result of PFAS contamination. The program recently funded a reservoir project for City of Spokane to allow Spokane to provide reliable water service to Airway Heights. Airway Heights has PFAS in their wells and is now relying on City of Spokane for its water.

EPA provides funding to Health's Office of Drinking Water for set-aside activities and source water protections. Health can use these funds in limited circumstances to defray costs of additional water testing.

Other funding programs in the state could be tapped for loans or grants to help with costs of new infrastructure in response to PFAS contamination:

- Public Works Assistance Account overseen by Public Works Board.
- Community Development Block Grant overseen by Department of Commerce.
- Rural Development loans and grants overseen by U.S. Department of Agriculture.

Public water systems can pursue reimbursement from potentially liable parties under the state MTCA when PFAS are concluded to be hazardous substances under MTCA. Even under MTCA, water systems may have to carry costs long-term or permanently because:

- The process of identifying responsible parties and being reimbursed can take years.
- Responsible parties may be difficult, if not impossible, to determine.
- The potentially liable party could be a local entity under the same public administration as the water utility (for example, a local fire station).
- Legal costs to the affected water system operator to pursue liable parties can also be significant.

Privately owned water systems regulated by the Washington State Utilities and Transportation Commission (defined in Chapter 80.04.010(30)[58] RCW and having 100 or more connections or charging more than $557 per year per customer) may have fewer options to secure funding, being primarily limited to the Drinking Water State Revolving Fund.

In each of these cases, the costs borne by the water system would be long-term or permanent.

[58] https://app.leg.wa.gov/rcw/default.aspx?cite=80.04.010

Why?

Without funding, public water systems and their ratepayers must absorb what can be a costly response. Funding would support water systems when they:

- Continue providing water or alternate water supplies while incurring costs to implement necessary mitigation actions.
- Investigate contamination sources.
- Find an alternative water source and/or design and install expensive treatment systems on contaminated water sources.
- Maintain and monitor new treatment systems.
- Replace and dispose of used treatment system media.

When PFAS concentrations in drinking water supplies exceed health advisory levels, timely mitigation may be needed to protect human health. This can create immediate costs to water systems.

The water system must explore ways to mitigate the problem, both immediately and long-term. Mitigation planning should aim to minimize cost burdens for lower-income and overburdened communities who are less able to absorb ratepayer cost increases.

Cost

Initial investigation and mitigation costs at PFAS-contaminated sites are reported in the millions of dollars. These costs have been borne by DOD, the water systems or local governments impacted, and the agency programs at Health and Ecology that support water systems and contaminated site cleanup.

For example, the Issaquah PFAS Pilot Project received $400,000 through the State Building Construction Account for groundwater assessment work to be conducted during the 2019 – 2021 biennium. An additional $750,000 was allocated as part of the 2021 – 2023 state Capital Budget[59] for additional groundwater investigation and pilot project design.

Funding of $450,000 was also provided for the West Plains PFAS Groundwater Fate and Transport study. Modeling will assist with geochemical fingerprinting PFAS sources across the West Plains area. The Spokane Regional Health District—in collaboration with Fairchild AFB, Spokane County, and Eastern Washington University—will undertake the study. These allocations were focused on very specific activities, but the 2021 – 2023 Capital Budget included several much larger appropriations to help address PFAS-contaminated drinking water, such as:

- $5,950,000 to the Department of Commerce to provide assistance with PFAS treatment at the City of DuPont water wells.
- $5,569,000 to the Department of Health (as a drinking water construction loan) for treatment of PFAS-contaminated groundwater at the Lakewood Water District.

With mitigation measures identified, implementation funds are sought from granting sources as described above. In addition to costs for investigating the source of the contamination, filter

[59] http://lawfilesext.leg.wa.gov/biennium/2021-22/Pdf/Bills/Session%20Laws/House/1080-S.SL.pdf

maintenance and monitoring also require ongoing expenditures. Such costs could also be covered under grants, but may require additional resources from water supply systems.

Each contaminated drinking water site has specific needs, which complicates cost estimation. Without knowing the number of impacted systems in the state, we are unable to estimate total costs to implement this recommendation.

1.2 Provide technical support for site characterization, source investigation, and mitigation at contaminated sites

Recommendation:

Ecology and Health will continue to develop expertise and provide technical assistance and guidance to drinking water purveyors, local jurisdictions, and responsible parties in order to address PFAS contamination and conduct cleanup actions.

Those actions include:

- Ecology will continue to collaborate with involved parties at PFAS contamination sites in the state. These efforts will help to better understand the sources, composition, and distribution of PFAS contamination in soil and water. Identification and evaluation of appropriate cleanup actions and their costs will be informed by this work. This work is being done within Ecology's existing resources.
- Health will continue to provide water systems with advice and assistance to understand the mitigation options and guide voluntary action on unregulated PFAS until the rulemaking for PFAS in drinking water is complete. To-date, technical assistance has focused on public water systems near military bases with PFAS detections in groundwater. Department of Health continues to include local health departments in outreach and guidance. This work is being done within Health's existing resources.
- Ecology will look at using Safe Drinking Water Action Grants (a category of Remedial Action Grants for Local Governments) to help address PFAS-contaminated drinking water, once Maximum Contaminant Levels (MCLs) have been promulgated for the PFAS compounds of concern or site specific cleanup levels have been established.
- Ecology plans to investigate PFAS contamination in groundwater and surface water. These efforts would support local health departments, cities, counties, and other public entities in Washington when PFAS contamination is discovered. Initial investigation efforts could identify areas at high risk of contamination. This could include areas where trainings or firefighting activities used large quantities of PFAS-containing AFFF, or where spills released the foam. Ecology could prioritize funding for site-specific assessments and groundwater testing. Funding for this action is estimated below.
- Ecology plans to consider the number of people impacted, the concentration of the PFAAs in the drinking water, and vulnerable populations present when prioritizing mitigation and cleanup activities. Ecology may use mapping tools such as Environmental Justice (EJ) screen and Information by Location (IBL) in the

Washington Tracking Network (WTN) portal to characterize the demographics of the population served by impacted drinking water.

- Ecology may seek to obtain chemical identities from products and at contaminated sites to find chemical "fingerprints" useful in identifying source locations. Analytical methods may not yet be developed to obtain all the required data.

Why?

Technical assistance helps people understand the advantages and disadvantages of various options to reduce levels of PFAS in water and soil.

Variation in environmental conditions and contamination sources makes site characterization difficult. Site-specific conditions should inform the selection of appropriate actions. Evolving cleanup methods, plus the differences unique to a site, lead to difficulty estimating costs.

PFAS have unusual properties and research into their movement through soils and aquifers is ongoing. Further, PFAS contamination sources need to be investigated. To recover mitigation costs, Ecology must identify the party or parties responsible for the source of contamination. Local water districts and governments often lack the expertise and resources to investigate sources of PFAS contamination.

Cost

To support PFAS investigations as needed, Ecology requested resources from the Legislature to:

- Provide monitoring assistance to local jurisdictions when PFAS contamination is discovered.
- Assist with investigations, including researching potential sources, collecting samples, conducting laboratory analysis, and installing monitoring wells.

This type of environmental monitoring work was funded in 2020 and 2021 through the approved state 2020 supplemental budget.[60]

1.3 Support biomonitoring and other health studies to answer important health questions

Recommendation:

Health should continue to find opportunities for Washington residents to participate in exposure and health studies. These studies help answer important community and public health questions about PFAS exposure and health outcomes. For example, Health requested and supports inclusion of Airway Heights as one of eight sites in the ATSDR's PFAS Exposure Assessment study. Health also applied for but was not awarded a cooperative agreement to include a Washington site in the ATSDR Multisite PFAS Health Study.

State agencies should also support investigations into pathways of PFAS contamination in food, drinking water, and indoor environments. They should pursue policies to mitigate and reduce these sources of human exposure over time.

[60] https://ofm.wa.gov/sites/default/files/public/budget/statebudget/20supp/Z-0776.2Operating.pdf

Why?

Biomonitoring can help us understand how best to reduce human exposure to PFAS. Biomonitoring helps people compare their PFAS exposure level to national averages, and could connect residents to health information as it becomes available. Further health studies are needed to better understand the impacts of PFAS on human health.

Cost

Biomonitoring studies are expensive and the state would need funding to support these types of investigations. Additional funding could be secured through competitive grants for such activities. Benchmark costs have been estimated based on reports from several sites in the U.S. where biomonitoring testing has been conducted for residents near areas of PFAS contamination. Costs averaged up to $1,000 per person tested.

2.0 Manage environmental PFAS contamination

PFAS have contaminated soil, groundwater, and surface water in certain Washington locations. To reduce exposure and protect human health, these contaminated areas may require a variety of responses. In Washington, PFAS-containing Class B firefighting foam used in firefighter training seems to be the primary source of drinking water supply contamination. Nationally, in addition to firefighting foam use, certain manufacturing and industrial processes (and improper waste disposal from such industries) have been identified as sources of PFAS contamination.

Previous CAP Recommendations

Interim CAP

The Interim CAP proposed several areas of action pertaining to managing environmental PFAS contamination.

First, the Interim CAP recommended developing PFAS cleanup levels for soil and groundwater. This recommendation was reiterated in the Preliminary Recommendations, and is presented again in this CAP, as Recommendation 2.1 below.

Second, the Interim CAP recommended identifying methods to reduce exposure to contamination. The recommendation focused on developing expertise, providing technical assistance and guidance to parties that address PFAS contamination, and collaborating with parties to better understand the sources, composition, and distribution of PFAS contamination in soil and water. This recommendation was also reiterated in the Preliminary Recommendations, and is included as Recommendation 2.1 below.

The Interim CAP recommended reducing risks to drinking water from firefighting foam. This included implementing AFFF notification and restrictions, surveying firefighting foam users to identify high-risk sites, developing outreach on responsible AFFF use, and replacing PFAS containing AFFF in non-exempt uses. It also recommended providing assistance for firefighting personal equipment notifications.

These recommendations focused on the future implementation of the Firefighting Agents and Equipment Toxic Chemical Use law (Chapter 70A.400[61] RCW), passed in 2018. This law establishes restrictions on Class B firefighting foam, which contain intentionally added PFAS chemicals:

- As of July 1, 2018, prohibits use of Class B firefighting foam for training.
- As of July 1, 2020, prohibits the manufacture, sale, and distribution of Class B firefighting foam.
  - Interim exemptions include federally required users, petroleum storage and distribution facilities, or certain chemical plants.
- Requires manufacturers to notify Washington purchasers about the presence and purpose of PFAS in firefighting personal protective equipment.
- Two years after amendment of federal regulations (prohibiting the use of PFAS-containing foam), requires federal facilities to use non-PFAS foams that comply with the new federal regulation.
  - Airports must inform Ecology about their ability to switch to non-PFAS foams within 18 months of the change in federal regulations.
- Beginning 2024, restricts the purchase of PFAS-containing foams by oil terminals, oil refineries, and chemical plants.

Finally, the Interim CAP identified use of PFAS in industry or manufacturing as a potential source of release or environmental exposure. It recommended identifying potential industrial point sources of PFAS in the state and considering outreach on best management practices for handling and disposing of PFAS-containing wastes. This recommendation was also included in the Preliminary Recommendations.

Preliminary Recommendations

In addition to establishing cleanup levels and identifying methods to reduce exposure to contamination noted above, the Preliminary Recommendations proposed partnering with local organizations in communities with contamination, and providing them funding to lead messaging, consultation, and solution identification for PFAS contamination issues. This represents Recommendation 2.2 below.

The Preliminary Recommendations continued to focus on implementation of Chapter 70A.400[62] RCW, and future work is identified in Recommendation 2.3 below.

[61] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true
[62] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

Upon enactment of Chapter 70A.400 RCW, Ecology received funding[63] of approximately $215,000 for fiscal years 2017 through 2019 to implement the Law. Since the summer of 2019, Ecology has conducted the following activities to implement the law:

- Developed an agency website to provide more information and outreach materials regarding the requirements of the law.[64]
- Conducted outreach to manufacturers to explain the requirements and ensure compliance with the restrictions.
- Collaborated with firefighting foam users on the restriction of PFAS-containing firefighting foam use in training, and on the purchase restriction taking effect in 2020.
- Provided technical assistance to state and local governments and other jurisdictions to help them purchase PFAS-free Class B firefighting foam.
- Consulted with the Department of Enterprise Services to develop procurement preferences for state and local governments and other jurisdictions to purchase PFAS-free Class B firefighting foam alternatives.
- Informed firefighting personal protective equipment manufacturers of the requirement to notify purchasers about the presence of PFAS—and requested copies of the notification.
- Surveyed state and local governments and other jurisdictions about stocks of Class B firefighting foam through Ecology's Product Replacement Program.[65]

Ecology also received funding through its Product Replacement Program to collect, transport, and dispose of PFAS-containing firefighting foam owned by the state's municipal fire departments by June 2021. This program intends to dispose of 30,000 to 40,000 gallons of foam. Ecology expects this activity to cost between $300,000 and $500,000.

Ecology is conducting a review of this collection and disposal activity under SEPA. In September 2020, Ecology issued a Determination of Non-Significance (DNS)[66] and associated checklist[67] documenting this review.[68] In January 2021, Ecology withdrew the DNS and issued a Determination of Significance and Scoping Notice to prepare for an EIS review of the AFFF collection and disposal program.

The Preliminary Recommendations also addressed identifying industry sectors in Washington that also carry AFFF stocks or use commercial quantities of PFAS and finding opportunities to reduce such usage. These recommendations are also represented in Recommendation 2.3 below.

---

[63] https://fnspublic.ofm.wa.gov/FNSPublicSearch/GetPDF?packageID=53000
[64] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals/PFAS/Toxics-in-firefighting
[65] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Product-Replacement-Program
[66] https://apps.ecology.wa.gov/separ/Main/SEPA/Document/DocumentOpenHandler.ashx?DocumentId=97538
[67] https://apps.ecology.wa.gov/separ/Main/SEPA/Document/DocumentOpenHandler.ashx?DocumentId=97539
[68] https://apps.ecology.wa.gov/separ/Main/SEPA/Record.aspx?SEPANumber=202004521

Draft CAP

The preliminary recommendations were included in the Draft CAP. In addition, Recommendation 2.3 acknowledged new sources of information, namely EPA's TRI, which can supplement our knowledge of PFAS used in industry in the state.

Since issuance of the Draft CAP, Ecology further defined its proposal to use its existing authority under MTCA to develop cleanup standards for PFOA, PFOS, PFNA, PFHxS, and PFBS. Recommendation 2.1 has been refined to reflect this future activity.

Health is pursuing activities to protect human health from adverse impacts of environmental PFAS contamination based on data collected since PFAS CAP development began. Health is currently developing fish consumption advisories for PFOS in freshwater fish based on Ecology fish sampling data. Health received additional data from Ecology in 2019 to provide an adequate basis for a fish consumption advisory. Health is reviewing these data and re-evaluating screening levels and considering recent changes in recommended oral intake.

2.1 Establish PFAS cleanup levels for soil and groundwater

Recommendation

- Using existing authority under MTCA, Ecology plans to develop cleanup levels for PFOA, PFOS, PFNA, PFHxS, and PFBS, the five PFAS for which the SBOH is planning to promulgate state action levels in 2021. Ecology will use SBOH drinking water standards or action levels adopted in rule to develop these cleanup levels.
- Ecology will explore methods for investigation and cleanup of PFAS contamination.
- Ecology will conduct monitoring for PFAS compounds in environmental media (soils, surface water, and sediment) and wildlife tissue to identify sources of contamination and assess exposure.
- Once sufficient supporting data are available, Ecology plans to develop cleanup levels for individual or mixtures of PFAS in soil, sediment, freshwater, and saltwater to protect ecological receptors.
- In this context, the following activities will be implemented to support activity under the recommendations above:
    - Trophic transfer and bioaccumulation of PFAS compounds should be further evaluated in aquatic and terrestrial food webs to further understand exposure.
    - Selected individual PFAS compounds, as well as common PFAS mixtures, should be evaluated for ecotoxicity in aquatic and terrestrial biota, using both laboratory and field methods.
    - Ecological risk assessment should be performed for PFAS compounds by detailing exposure and effects in order to estimate risks to nonhuman biota.
    - An uncertainty analysis should accompany PFAS ecorisk assessment to promote transparency in the risk assessment and communication processes and to more clearly identify data gaps.

    - Results of these risk assessments should support potential interventions (for example, species protections) and characterization of potential impacts on ecological services.
- Ecology will provide information to interested parties about cleanup efforts.

Why?

Ecology establishes cleanup levels for hazardous substances in the environment. The cleanup level concentrations, under specific exposure conditions, are considered sufficiently "protective of human health and the environment." Cleanup levels are expected to protect people, overburdened populations, animals, and plants from potentially harmful exposures to chemicals in the environment. They determine which geographic areas and environmental media have enough contamination to need further evaluation and potential cleanup actions.

Currently, no enforceable federal or Washington state regulatory standards exist to determine whether a site with PFAS contamination requires cleanup or to regulate cleanup of PFAS at contaminated sites. Further, best practices for conducting such a cleanup are not established. Ecological receptors contribute to Washington state's health and economy overall. Collecting additional data and extending cleanup levels to other environmental media is crucial to protecting them.

Ecology supported PFAS groundwater contamination investigation of the Lower Issaquah Valley Aquifer, by developing investigatory levels for PFOS and PFOA. These were advisory values, not regulatory cleanup levels. Based on information available at the time, the values were expected to be protective of human health and the environment. Formulation of these advisory levels cost Ecology approximately $42,000. In order to develop regulatory cleanup levels, Ecology will need to continue evaluating the rapidly expanding body of scientific information related to PFAS.

Cost

The cost to develop cleanup standards is being funded out of Ecology's Toxics Cleanup Program operating budget, and is expected to be similar to the cost of developing the advisory levels described above. This estimate does not include work to collect additional exposure data, nor to develop cleanup levels for other environmental media (sediment and surface water).

Costs to develop and evaluate methods for addressing PFAS contamination are difficult to estimate due to significant uncertainties around:

- How (and in what concentrations) most PFAS affect people, animals, and plants.
- How best to measure the types and amounts of PFAS in the environment.
- How PFAS move through the environment and change over time.
- How to effectively clean up environmental PFAS contamination—including factors like protectiveness, feasibility, and cost.

Ecology is planning to conduct additional environmental monitoring in 2020 and 2021 funded through the approved state 2019 – 2021 supplemental budget,[69] however specific projects have not yet been selected.

2.2 Partner with local organizations in communities with contaminated water or contaminated sites

Recommendation

Department of Health will identify local health departments or community-based organizations to address health equity related to contaminated sites in public communications. Health will coordinate with Ecology to distribute funding to those organizations selected for assistance. Health's new Community Engagement Guide[70] may support this effort.

Funded organizations would:

- Address potential health equity issues through culturally and linguistically informed engagement.
- Find trusted messengers or platforms to deliver audience-tested risk communication messages to engage historically overburdened and higher risk populations.
- Support impacted populations in finding their own solutions through collective action and decision-making.
- Engage the community throughout the course of the public health response, source investigation, and site cleanup.
- Invite area residents to actively participate on advisory committees, in site information meetings, and in public decision-making about remediation.
- Aim to remove participation barriers by providing child care, reducing transportation costs, and planning for convenient meetings times at familiar locations.
- When possible, appropriately compensate community advisors for participation—particularly in areas with low-income populations.

Why?

When testing identifies PFAS in drinking water in a new community, it can be challenging to communicate effectively with area residents.

Communities are unique, and there may be:

- Cultural and language barriers to effective communication.
- Economic, systemic, and social barriers to acting on public health advice.

These barriers disproportionately affect low-income and other historically overburdened communities, including communities of color. During PFAS investigation and mitigation, state agencies should collaborate with local leadership and organizations to strengthen community awareness and engagement.

[69] https://ofm.wa.gov/sites/default/files/public/budget/statebudget/20supp/Z-0776.2Operating.pdf
[70] https://www.doh.wa.gov/Portals/1/Documents/1000/CommEngageGuide.pdf

Community-based and community-led organizations (that are rooted in and that directly serve these communities) can offer meaningful engagement support. For example:

- A recent $120,000 two-year grant funded a local organization providing educational materials and conducting outreach in a community impacted by industrial activities.
- In one affected community, a local church group volunteered to distribute bottled water to elderly and disabled residents.

Cost

If PFAS are classified as hazardous substances under MTCA, community-led public engagement would be eligible for funding through Ecology's Public Participation Grant program (in the Contaminated Site Project category). Designated PFAS funds should be allocated specifically to PFAS-related impacts to communities.

Local outreach efforts depend on the extent and type of community outreach required for a specific contamination concern. As such, at this time, it is not possible to estimate the funding needed for these efforts.

2.3 Work to prevent PFAS releases from firefighting foam use and manufacturing

Recommendation

Ecology will continue to work proactively with industry, manufacturers, and businesses to eliminate releases to the environment from the use of PFAS-containing AFFF or other manufacturing processes using PFAS.

To address PFAS in AFFF, Ecology would continue implementing the Firefighting Agents and Equipment Toxic Chemical Use law (Chapter 70A.400[71] RCW), as follows:

- Collaborate with users of firefighting foam to develop and share outreach materials and best management practices that address the proper use, storage, and disposal of PFAS-containing AFFF.
- Ensure that industrial use of PFAS-containing AFFF provides for containment procedures along with collection of this foam and contaminated soil or sediment for proper designation and disposal. Costs to industrial users to collect and dispose of released PFAS-containing AFFF include plan development, employee training, methods for containment, and disposal of waste.
- Continue identifying organizations and industries, which store and use AFFF in training and emergency firefighting, including use of AFFF in highway tunnels.
- Assist state and local governments, airport, industry, and fire districts with prioritizing the quantification, disposal and replacement of PFAS-containing AFFF, especially in communities with cumulative impacts, health disparities, and environmental justice considerations.

[71] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

- Share information about PFAS-free Class B firefighting foam with users of firefighting foam as information or research is available, including GreenScreen® certifications.
- Provide funding to airports to purchase equipment to test their firefighting capabilities without the use of PFAS foam.
- Conduct compliance and enforcement actions to ensure the law is being followed.

Ecology will work proactively with industry, manufacturers, and businesses to eliminate releases to the environment from the use of PFAS in manufacturing or other processes.

- Ecology will review data from other states and countries to identify industrial or manufacturing uses of PFAS. To identify potential industrial and manufacturing PFAS dischargers, Ecology will also consider data collected under activities conducted through other CAP recommendations. Ecology will use this information to identify industries in Washington that have used or continue to use commercial quantities of PFAS. Ecology will also track future TRI reports (starting 2021) for industries.
- Ecology will evaluate PFAS release potential from those industries which may have, or continue to, use PFAS.
- Ecology will reach out to these industries to discuss their use of PFAS, identify opportunities to switch to safer alternatives, implement best practices, and ensure proper waste management.

Why?

PFAS-containing Class B firefighting foam has been associated with drinking water contamination in Washington state. In their risk-based efforts to identify and mitigate PFAS in drinking water, both the military and Health focus on firefighting foam release sites. However, firefighting foam is not the only likely source of PFAS in state drinking water. Other states that are expanding testing for PFAS in drinking water have identified manufacturing and commercial sources such as:

- Manufacture of waterproof leather shoes.
- Manufacture of parchment paper.
- Taxidermy.
- Textile coating.
- Metal plating and finishing.
- Car washes.
- Pulp and paper mills.

In addition to the manufacturing processes themselves, wastes generated during some manufacturing processes can result in releases of PFAS to the environment if they are improperly managed. More work is needed to understand PFAS use, sources, pathways of exposure, and effects on human health and the environment resulting from industrial use or manufacturing.

Cost

Ecology identified additional foam stockpiles managed by commercial airports, manufacturing, and transportation facilities that represent a large pollution source, but do not currently qualify for the disposal program established under Chapter 70A.400[72] RCW. Ecology estimates that it will cost between $500,000 and $1,500,000 to collect, transport, and dispose of such foam, including 0.25 FTE to manage this program. Ecology has included this cost in its FY 2021 – 2023 budget request.

Ecology has requested approximately $36,000 for monitoring and compliance activities to be conducted under Chapter 70A.400 RCW in FY 2021 – 2023.

Ecology estimates that supporting industry with investigation and reduction of non AFFF-related PFAS use would require the resources of 0.25 FTE for one year, at the cost of approximately $50,000. This funding has not yet been budgeted or requested.

3.0 Reduce PFAS in products

A wide variety of industrial, commercial, and consumer products use PFAS. People can be exposed to the PFAS in consumer products when they use products, or as PFAS accumulate in indoor air and dust. Although PFOA and PFOS are not readily absorbed through skin, residues on hands can be absorbed if swallowed.

Previous CAP Recommendations

Interim CAP

The Interim CAP proposed several areas of action pertaining to reducing exposures from products (other than AFFF and firefighting turnout gear, already discussed above):

- Identifying sources of PFAS exposure in the home resulting from PFAS present in carpets, textiles, cosmetics, waxes, and cleaning agents.
- Conducting alternatives assessments for uses of PFAS with the highest potential for human exposure.
- Completing an alternatives assessment of PFAS-containing food contact materials.

Within the timeframe of the issuance and revision of the Interim CAP, the Washington State Legislature adopted the Pollution Prevention for Healthy People and Puget Sound Act (Chapter 70A.350[73] RCW), creating a process for Ecology, in consultation with Health, to regulate classes of chemicals in consumer products. The Legislature also adopted the Packages Containing Metals and Toxic Chemicals law (Chapter 70A.222[74] RCW) restricting PFAS in food packaging materials.

[72] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true
[73] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350&full=true
[74] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222&full=true

Ecology is implementing Chapter 70A.350[75] RCW through the Safer Products for Washington program. The law directs us to work with stakeholders, report to the Legislature, and do four things on a repeating, five-year cycle:

- Identify at least five priority chemicals, based on hazard, exposure, and impacts.
  - The first priority chemicals identified are bisphenols, organohalogen flame retardants, phthalates, polychlorinated biphenyls, and PFAS.
- Identify consumer products that are significant sources of exposure to the priority chemicals for people and sensitive species.
- Determine needed regulatory actions to reduce exposure to people and sensitive species.
- Adopt rules to implement regulatory actions, which could include reporting requirements or restrictions on the use of a chemical in a product.

Under the law, we will identify products that are significant sources of PFAS exposure and determine whether regulatory actions are needed to reduce exposures.

Chapter 70A.222[76] RCW includes the following restrictions:

- Effective January 2022, prohibits PFAS in plant fiber-based food packaging.
- Requires Ecology to conduct an assessment to identify safer alternative products. This assessment must consider chemical hazard, performance, cost and availability, and exposure.
  - Ecology must submit the findings for external peer review and publish the results in the Washington State Register.
- Requires Ecology to report results to the Legislature before a ban on PFAS in food packaging can take effect.

Preliminary Recommendations

The Preliminary Recommendations moved the consideration of PFAS in products into its own main recommendation, focused on future implementation of Chapter 70A.350[77] RCW.

Draft CAP

The Draft CAP[78] reflected the re-organization of recommendations presented in the Preliminary Recommendations, focusing on implementation of the Safer Products for Washington program as of late summer 2020:

- Recommendation 3.1 recommended that Ecology determine whether safer alternatives are feasible and available for carpets, water and stain resistance treatments, and leather and textile furnishings. Such determinations would be made by June 2022 and would be accompanied by proposed regulatory actions to reduce exposure.

[75] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350&full=true
[76] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222&full=true
[77] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350&full=true
[78] https://apps.ecology.wa.gov/publications/summarypages/2004035.html

- Recommendation 3.2 focused on continuing research to better understand how additional products contribute to PFAS concentrations in homes, workplaces, and the environment and determining whether any of these products should be considered as priority products in the second cycle of Chapter 70A.350 RCW implementation.
- Recommendation 3.3 focused on Ecology's future activity to propose restrictions of PFAS in priority consumer products when a safer alternative is feasible and available, and the restriction will reduce a significant source of PFAS or protect sensitive populations or species. This recommendation also identified other actions that could be taken outside of the Safer Products for Washington program activity:
  - Gathering input from low-income and other historically overburdened communities, including communities of color.
  - Establishing purchasing preference for products free of intentionally added PFAS.
  - Proposing a ban on the import or sale of products containing phased-out long-chain PFAAs.

Since issuing the Preliminary Recommendations in 2019, we also continued implementing these product laws as follows:

- Under the Safer Products for Washington program Ecology submitted a report to the Legislature[79] in July 2020, identifying carpets and rugs, aftermarket water and stain resistance treatments and leather and textile furnishings with PFAS as priority products. Since the summer of 2020, Ecology and Health have developed draft criteria to identify safer, feasible, and available alternatives and used the criteria to determine whether potential alternatives to PFAS are safer, feasible for use in the priority products identified, and available on the market. Following this work, Ecology will determine whether regulatory determinations are necessary and report this to the Legislature by June 1, 2022.
- The Children's Safe Products Act (CSPA), Chapter 70A.430[80] RCW, requires manufacturers to annually report the presence of certain chemicals (including PFOS and PFOA) in children's products sold in Washington state. Ecology implements the law as follows:
  - Ecology receives manufacturer reports and conducts compliance activities.
  - Manufacturer reports are published online.[81]
- Ecology has completed—or is conducting—the following work under Chapter 70A.222 RCW:
  - Our analysis has focused on single-use food paper (such as wraps), dinnerware (such as plates) and takeout containers used to serve and transport freshly prepared food.

[79] https://apps.ecology.wa.gov/publications/summarypages/2004019.html
[80] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.430&full=true
[81] https://hpcds.theic2.org/Search

- The Departments of Ecology and Health submitted the PFAS in Food Packaging AA Report to the Legislature[82] and published the PFAS in Food Packaging AA[83] in February 2021. The report found safer alternatives to PFAS in four types of food packaging: wraps and liners, plates, food boats, and pizza boxes.
- The second AA is being completed in 2021. It is considering whether alternatives exist for PFAS used in flat serviceware, open-top containers, closed containers, bags and sleeves, and bowls. These products include several types of products where no alternatives that met all the criteria in the law were identified.
    - A scope and timeline are available on the PFAS in food packaging AA website.[84]
    - We are working on a pilot program to help users of PFAS-containing food packaging to test out safer alternatives in their businesses and institutions.

3.1 Reduce PFAS exposure from carpets and rugs, water and stain resistance treatments, and leather and textile furnishings

Under Chapter 70A.350 RCW, Ecology identified carpets, water and stain resistance treatments, and leather and textile furnishings as significant sources and uses of PFAS. As required by the law, Ecology is evaluating whether safer alternatives are available and feasible. If such alternatives are available, Ecology could then make regulatory determinations to restrict PFAS in these products, and report these determinations to the Legislature by June 2022.

Beyond the work being conducted under Chapter 70A.350 RCW, we can also propose actions to reduce legacy PFAS-containing carpet and carpet care products remaining in homes, especially in low-income households, where items may be retained past the typical product lifespan.

Recommendation

We recommend that as part of the work conducted under Chapter 70A.350 RCW, the following regulatory actions be considered:

- Requesting that manufacturers:
    - Identify products that contain PFAS.
    - Disclose their use of priority chemicals in product ingredients.
    - Release information on exposure and chemical hazard.
    - Describe the amount and function of PFAS in products.

In addition to the work conducted under Chapter 70A.350 RCW above, we recommend the following actions:

- Implement a purchasing preference policy for PFAS-free carpet. Work with vendors on the state flooring contract to offer PFAS-free carpet on all state master contracts

[82] https://apps.ecology.wa.gov/publications/summarypages/2104007.html
[83] https://apps.ecology.wa.gov/publications/summarypages/2104004.html
[84] https://www.ezview.wa.gov/site/alias__1962/37610/pfas_in_food_packaging_alternatives_assessment.aspx

and all agency contracts. Purchasing PFAS-free carpet could result in increased costs to the state.

- If safer alternatives are available, include them in Ecology's Product Replacement Program[85] to replace legacy PFAS-containing carpet in community centers, low-income housing, libraries, daycares, and other environments where children may be disproportionately exposed.

Why?

According to EPA, some of the most significant sources of human exposure to nine PFAS in the U.S. are carpets and commercial carpet-care liquids. Treated carpet in homes and offices can contribute to PFAS in indoor environments. Infants and children have higher exposure due to inhalation and ingestion of house dust. California DTSC identified PFAS in carpet as a priority product[86] under the Safer Consumer Products program. San Francisco adopted a comprehensive carpet regulation[87] prohibiting the use of PFAS.

Cost

The Legislature funds these efforts under the Safer Products for Washington program. As a result of appropriations for the 2019 – 2021 biennium, the 2020 supplemental budget, and the 2021 – 2023 biennium, Ecology received approximately $1.5 million to implement the program as a whole through 2026. As described in the July 2020 report to the Legislature,[88] Ecology identified eleven priority products, of which three were PFAS-related (carpets, water and stain resistance treatments, and leather and textile furnishings).

Because Ecology conducts program activities as a whole, it is not possible to distinguish program costs attributed to only the PFAS-related priority products. However, one could approximate the PFAS-related costs as a proportion of entire program costs based on the number of priority products identified (i.e., three of eleven). Thus, the cost of activities associated with PFAS-related priority products under Chapter 70A.350 RCW would be approximately $409,000.

At this time, Ecology has not estimated the cost of additional actions (i.e., implementing a purchasing preference policy and replacing PFAS-containing carpet under the Product Replacement Program). Ecology is already funding a staff position to coordinate the identification of viable purchasing preference policies with the Washington State Department of Enterprise Services for a number of products, including PFAS-containing carpet.

Establishing the cost of replacing carpet in community centers, low-income housing, libraries, daycares, and other environments where children may be disproportionately exposed would require an estimate of the number of facilities, and the square footage of carpet to be replaced. Funding could then be requested by Ecology's Product Replacement Program.

---

[85] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Product-Replacement-Program
[86] https://www.dtsc.ca.gov/SCP/carpets_and_rugs_containing_pfas.cfm
[87] https://sfenvironment.org/sites/default/files/policy/regulation_sfe-2018-01-ppo_gbrcbo.pdf
[88] https://apps.ecology.wa.gov/publications/summarypages/2004019.html

3.2 Identify additional sources and uses of PFAS to consider in the second Safer Products for Washington cycle

The priority products identified in 2020 under the Safer Products for Washington program do not account for all sources and uses of PFAS. Ecology will continue research to better understand how other products contribute to PFAS concentrations in homes, workplaces, and the environment. These include PFAS in:

- Water resistant clothing and gear.
- Nonstick cookware and kitchen supplies.
- Personal care products (e.g., cosmetics and dental floss).
- Cleaning agents.
- Automotive products.
- Floor waxes and sealants.
- Ski waxes.
- Car waxes.

Recommendation

Ecology should engage with overburdened communities regarding consumer products that may contain PFAS. Communities use consumer products differently. Ecology should identify consumer products which might be disproportionately exposing overburdened communities.

Ecology should conduct preliminary investigations into the availability and feasibility of safer alternatives, prior to Phase 2 of Cycle 2 of Safer Products for Washington, for the products listed above. If safer alternatives are identified in the preliminary investigations, outreach should be conducted to increase voluntary adoption in the marketplace.

Ecology should determine if the products listed above are significant sources or uses of PFAS If so, they should be evaluated during Phase 2 of Cycle 2 of Safer Products for Washington to determine if they should be recommended as priority products. If identified as a priority product in the report to the Legislature, the product will be evaluated to determine if safer alternatives are feasible and available. If they are, Ecology may determine that a restriction or ban is appropriate.

Why?

People are exposed to PFAS in their homes when they use products, and via exposure to house dust that contains PFAS. Ingesting contaminated food and drinking water leads to the greatest portion of chronic exposure to PFAS (specifically to PFOS and PFOA) for the general population.

PFAS-containing products in the home and in some occupations can be additional sources of exposure. High PFAA levels were identified in ski waxes, leather samples, outdoor textiles, and some baking supplies. Studies of indoor air and house dust indicate that PFAS exposure occurs from products in the home, such as carpet care liquids, nonstick cookware, food packaging, and waterproof clothing. Many other consumer products may contain PFAS ingredients (see the list above). Research is needed to understand how these products contribute to human exposure.

Cost

Ecology will make budget requests to fund future cycles of the Safer Products for Washington Program, including consideration of the products listed above.

Ecology estimates that the costs of future cycles of product consideration under Safer Products for Washington would be similar to those incurred to-date (see Recommendation 3.1 above), but could vary based on the complexity and the number of chemical-product combinations considered.

3.3 Implement other reduction actions for PFAS in products

Ecology should investigate uses and regulatory actions to further reduce exposures and releases to the environment from the priority consumer products containing PFAS.

Recommendation

Actions should include:

- Gather input from low-income and other historically overburdened communities, including communities of color. Develop a list of ways to reduce exposure that include low cost and subsidized approaches. These may be particularly important measures to employ in communities with higher exposure from drinking water. No cost estimate is provided to conduct this evaluation or to develop exposure reduction recommendations.
- Establish a purchasing preference policy for products free of intentionally added PFAS. Work with vendors to offer PFAS-free textiles, furniture, and paints. If possible, select products that do not have stain or water resistance or use safer alternatives. Apply this policy to all state master contracts and all agency contracts.
- Consider PFAS as a class when the list of chemicals of high concern to children, WAC 173-334-130,[89] is updated.
- Propose a ban on the import or sale of all products in Washington containing phased-out long-chain PFAAs. Long-chain PFAAs include perfluorinated carboxylates (PFCAs) with seven or more fully fluorinated carbons (for example, PFOA) and perfluorinated sulfonates (PFSAs) with six or more fully fluorinated carbons (for example, PFHxS and PFOS), their salts, and precursor compounds capable of forming long-chain PFAAs.

[89] https://apps.leg.wa.gov/wac/default.aspx?cite=173-334-130

Why?

Actions need to be implemented to remove or reduce levels of PFAS from products that contribute to human or environmental exposure. Removing chemicals from consumer products can reduce chemicals in indoor air and dust. These actions directly impact human and environmental exposures.

PFOS, PFOA, and related long-chain PFAS compounds are mostly phased-out of U.S. production, but are still produced in other countries. Rather than bans, EPA used voluntary phase-outs and Significant New Use Rules (40 Code of Federal Regulations [CFR] 721.9582) under TSCA to reduce their use. It appears to be legal to import long-chain substances into Washington state for commercial uses, and to distribute and sell products containing them.

Cost

No cost estimate is provided to conduct the evaluation of low-income or overburdened communities or to develop exposure reduction recommendations. Exposure reduction actions would be specific to the needs expressed by specific communities.

The costs for banning the import and sale of certain PFAS cannot be estimated. This activity would require legislative action; an estimate for implementing such an action can only be completed once the specifics of any enacted legislation are known.

The costs for considering PFAS as a class when the CHCC is next updated would be included in the staff and agency resources allocated to such an update. Such funding requests have not yet been made.

4.0 Understand and manage PFAS in waste

PFAS are released from products people use in their homes and businesses. These releases travel to municipal wastewater treatment plants (WWTPs) and disposal facilities. PFAS entering and passing through these facilities could impact the environment. Investigating PFAS in Washington's wastewater, landfills, and biosolids is needed to determine PFAS concentrations and inform development of appropriate control actions.

Previous CAP Recommendations

Interim CAP

The Interim CAP identified that handling and disposal of PFAS-containing wastes (including landfilling) required outreach on best management practices.

Preliminary Recommendations

The Preliminary Recommendations explored further evaluation of waste streams that could contain PFAS, creating a dedicated recommendation for evaluating wastewater treatment plant, landfill, and biosolids streams for PFAS contamination.

Preliminary Recommendation 4.1 addressed gathering more information about PFAS in publicly owned WWTP influent and effluent. Ecology received funding to develop and conduct sampling of PFAS in influent and effluent at three municipal WWTPs receiving industrial discharges. This

data would help inform which treatment processes are more effective at transforming and removing PFAS.

Preliminary Recommendation 4.2 addressed gathering more information about PFAS in landfill leachate. The study will sample leachate at selected landfills in the state to determine the range of values for 33 PFAS substances. Values will be compared to landfills across the country, and the data will be used to:

- Evaluate potential differences in amount of PFAS across landfill cells of different ages.
- Determine whether specific waste streams lead to higher PFAS values. This will identify disposed waste that is likely to release PFAS to leachate.

Draft CAP

The Preliminary Recommendations 4.1 through 4.3 were included in the Draft CAP and are carried forward in the CAP below.

Ecology began implementation of the WWTP and landfill leachate studies in 2020:

- As part of Recommendation 4.1, sampling of WWTPs was completed—in response to comments on the Draft CAP, the sampling included facilities that also produce reclaimed water. A report is expected to be completed by the end of 2021.
- Phase I of the landfill leachate sampling program was planned and samples taken in 2020. Ecology received the PFAS laboratory analytical data in the Spring of 2021 and the data is currently undergoing review and analysis. A final report on Phase I of the PFAS Leachate Study is expected to be completed by the end of 2021. The study sampled leachate at selected landfills from across the state to estimate a range of values for 40 PFAS substances as well as 20 total oxidizable precursor compounds. Values will be compared to landfills across the country, and the data will be used to:
    - Evaluate potential differences in amount of PFAS across landfill cells of different ages.
    - Investigate whether specific waste streams lead to higher PFAS values. This will identify disposed waste that is likely to release PFAS to leachate.
    - Help determine if any follow-on studies may be needed to evaluate potential impacts to groundwater, soil-gas vapor, and air emissions that are associated with landfill operations.

4.1 Evaluate PFAS in wastewater treatment

Recommendation

Ecology should evaluate PFAS in WWTP influent and effluent to better understand PFAS discharges in Washington state.

- Ecology should develop a study design to sample PFAS in three different types of WWTPs: those with secondary treatment, nutrient removal, and advanced solids removal. Sampling should include products of selected WWTP unit processes (for example, primary and secondary clarifiers or dechlorination) to help differentiate removal efficiencies of the different treatment types.
- The study design should ensure that the WWTPs that are sampled receive industrial discharges that are likely to contain PFAS, or that have drinking water sources with known PFAS contamination.
- Ecology should identify industries that are likely to generate wastewater containing PFAS.
- Based on the information from the study, Ecology should consider additional monitoring requirements for WWTP dischargers. This should include consideration of whether EPA has developed approved analytical methods for PFAS suitable for WWTP effluent and a regulatory target (a nationally recommended water quality criterion for PFAS) for waters of the state.
- Based on this evaluation, Ecology should require possible PFAS monitoring for some or all domestic and industrial WWTPs.

Why?

PFAS travel from homes, businesses, and industry sources to publicly owned WWTPs. Once they enter the WWTP, PFAS may partition to different media (for example, solids and liquids). PFAS are subject to aerobic and anaerobic biological processes, and transform into terminal PFAS compounds that resist further natural breakdown. Future WWTP design and operation would benefit from a greater understanding of how different wastewater treatment technologies transform PFAS or remove them from the effluent stream.

Cost

Ecology received $235,000 to conduct a WWTP sampling study by June 30, 2021. Influent, effluent, and biosolids at three municipal WWTPs receiving industrial discharges will be sampled and analyzed. This includes costs for sample analysis, which can range from $1,000 to $1,500 per sample, as well as project staff salaries.

The cost of establishing additional monitoring requirements based on the sampling study has not been determined. More funding sources may be needed to complete this work.

4.2 Evaluate landfill PFAS emissions

Recommendation

Ecology will develop a sampling program at selected landfills across the state. The sampling will test for PFAS in leachate, groundwater, and air emissions.

Leachate

The Solid Waste Management program developed Phase I of the program, involving leachate sampling, which has been funded and approved.

Ecology developed the study to better characterize landfill leachate. The study will:

- Sample leachate at selected landfills in the state.
- Determine the range of values for 33 PFAS substances in leachate, and compare to landfills throughout the country.
- Arrive at an estimate of the total PFAS materials in the landfill leachate through Total Oxidized Precursor (TOP) analyses.
- Determine if differences in amount of PFAS occurs in landfill cells of different ages.
- Determine if specific types of waste streams lead to higher PFAS values.
- Identify disposed wastes that are likely to generate PFAS releases to leachate.
- Perform a one-time testing of leachate from approximately 23 landfills.
- Consider additional sampling of leachate for landfills not yet sampled after the initial Phase I is completed. This second step of Phase I may include landfills that are undergoing MTCA cleanups, or landfills that contain specific refuse streams that have been shown to have high PFAS values from the Phase I sampling.

If warranted, Ecology would manage PFAS in landfill leachate long-term by:

- Considering additional monitoring requirements for landfills to test leachate for PFAS using information from the study above.
- Potentially updating the rules (Chapters 173-350[90] and 351[91] WAC) to require PFAS testing of leachate during landfill monitoring.

Groundwater and Gaseous Emissions

Phase II of the program will sample groundwater and gas emissions at landfills for PFAS. This phase of the program is in the conceptual stage. Landfills to be sampled will be based on the results of the Phase I leachate study. Groundwater will be sampled from existing monitoring wells.

The Solid Waste Management program, in conjunction with the Air Quality program, will develop the gas emissions sampling portion of the program. Ecology will also monitor landfill gas emissions monitoring being conducted by North Carolina State University and Oregon State University.

[90] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350
[91] https://apps.leg.wa.gov/wac/default.aspx?cite=173-351

Landfill waste makeup

In parallel to landfill gas emission sampling above, Ecology will continue to research the makeup of PFAS waste entering and potentially currently stored in landfills.

Why?

Landfills contain a variety of waste including inert materials (like wood or ash), disposed consumer products, and various organic wastes and solvents. Decomposing waste and rainfall can create leachate that contains water, metallic ions, acids, and other contaminants including PFAS. Landfills manage these liquids differently, but they can be a point of release of PFAS to the environment if leachate containing PFAS is not collected in a lined system, or when leachate from lined landfills is sent to wastewater treatment.

Cost

The Phase I testing of leachate from 23 landfills has received $34,500 of funding. It is estimated that the groundwater sampling portion of Phase II will cost approximately $60,000. An estimate for the sampling of gaseous emissions has not yet been developed.

Adding PFAS monitoring requirements to Chapter 173-350[92] WAC could take two and a half years and cost up to $1.1 million. Less complex rulemaking could take two years and cost up to $260,000. These cost estimates include employee time and expenses, but will vary based on the degree of consultation with Ecology's Assistant Attorneys General.

4.3 Evaluate Washington biosolids management

The information gaps regarding biosolids are significant and currently prevent assessment of risk from PFAS in biosolids land applied in Washington. Any regulatory changes should be founded on defensible data and science-based risk assessments. If scientific modeling is used by Ecology to assess potential PFAS transfer from biosolids to soil or groundwater, realistic model parameters must be used.

Washington biosolids regulation in the near term should ensure sound agronomic land application practices on permitted sites where human exposure is limited. It is premature to add or change regulatory limits given the absence of data from Washington biosolids and problems identified with models and their input parameters.

Recommendation

We recommend the following key steps to address the current data gaps:

- Establish biosolids and soil sample collection and handling methods for PFAS analysis.
- Accredit Washington labs for EPA-validated analysis methods.
- Use EPA-validated analysis methods for biosolids and soils.
- Conduct credentialed third-party review of raw mass spectrometer PFAS data.

[92] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350

- Investigate land application sites where procedures mimic rates and practices under current state rule (Chapter 173-308[93] WAC).
- Evaluate realistic exposure pathways.
- Evaluate risk modeling using realistic input values.
- Collaborate with stakeholders to get accurate and precise biosolids data. Initial results should remain anonymous.
- Compile analysis data with statistical review.

To conduct this work, Ecology will collaborate with municipalities managing WWTPs.

Why?

Toxicity, concentration, and pathway of exposure determine the risks contaminants pose to human health and the environment. Fundamental PFAS concentration data to characterize Washington biosolids is lacking. This prevents accurate assessment of PFAS risk resulting from land application under the state biosolids program. The recommendations work toward securing representative PFAS concentration data that is specific to Washington biosolids. Such data supports models that evaluate human health and environmental risks from contamination.

Cost

As of the date of this CAP, it is not possible to precisely estimate costs for fully implementing this recommendation. Based on the cost of sample analysis and the need to sample multiple municipal WWTPs, an initial round of biosolids sampling statewide is preliminarily estimated at $100,000. Ecology will recruit a senior employee to lead the biosolids data gathering process. Ecology will also submit program funding requests for both sampling and analysis to help with expenses. As indicated under Recommendation 4.1, a limited biosolids sampling and analysis effort will occur as part of funding approved to sample WWTP influent and effluent by 2021.

How health equity and environmental justice goals informed the CAP recommendations

As the recommendations were drafted, agency staff, including health equity and environmental justice (EJ) specialists, considered how the response to PFAS contamination can be equitably focused. Our approach aims to incorporate an EJ framework as we identify and address environmental contamination pathways and types of human exposure considered in the CAP. Appendix 7, Section 7.6, Health Equity and Environmental Justice, reviews the limited information we have related to the intersection of exposure to PFAS and vulnerable and historically overburdened communities. We also recognize that generally speaking, communities who are more exposed to toxic chemicals are not often the same communities with expendable resources to get involved with CAPs, or with environmental policy in general.

As a result of these considerations, we incorporated health equity and EJ elements into the CAP recommendations:

[93] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308

- Certain communities may not have the financial resources to address high costs of response to PFAS contamination of drinking water supplies, and funding must support an equitable PFAS response. This is included in Recommendation 1.1. Supporting information to this recommendation identifies that "Mitigation planning should aim to minimize cost burdens for lower-income and overburdened communities who are less able to absorb ratepayer cost increases."
- Recommendation 1.2 includes determining whether vulnerable or overburdened populations may be impacted as a result of PFAS contamination when response resources are prioritized.
- Supporting information for Recommendation 2.1 acknowledges that, "cleanup levels are expected to protect people, overburdened populations, animals, and plants from potentially harmful exposures to chemicals in the environment."
- Effective communication channels should engage and inform the communities who benefit from tailored outreach. Recommendation 2.2 proposes relying on local community resources to perform effective and equitable outreach to typically underserved populations. Involving overburdened communities requires removing barriers to participation unique to these communities. Funding should be included to compensate expert stakeholders for their time and input, and to cover expenditures for items such as food, childcare, translation and interpretation, and transportation services.
- PFAS contamination resulting from use of AFFF can result in additional health and environmental burdens in communities with cumulative impacts, health disparities, and EJ considerations, and such communities can be prioritized when PFAS-containing AFFF is quantified, disposed, or replaced (Recommendation 2.3).
- Recommendation 3.2 identifies that certain communities use products differently, and that we need to identify those products which might be disproportionately exposing overburdened communities.
- In addition to involving historically overburdened and underserved communities in response to drinking water contamination, we aim to gather input from these communities to address PFAS in products and empower people with information to purchase safer products. Recommendation 3.3 focuses on building these relationships so that low-cost and subsidized approaches can be tailored to community needs.

Future CAP implementation activities will also continue to be informed by and consistent with the requirements of Engrossed Second Substitute Senate Bill 5141.[94]

[94] http://lawfilesext.leg.wa.gov/biennium/2021-22/Pdf/Bills/Session%20Laws/Senate/5141-S2.SL.pdf?q=20210713132200

PFAS CAP Requirements

We prepared this CAP to meet the requirements of Chapter 173-333[95] Washington Administrative Code (WAC): Persistent Bioaccumulative Toxins (PBTs). An advisory process and the requirements of Chapter 173-333 WAC informed our CAP. We conducted public comment on a Draft CAP and considered input received to prepare this CAP.

Advisory committee

Ecology created an external advisory committee to provide stakeholder input and expertise (WAC 173-333-430(3)).[96] Beginning in 2016, we convened committee members from large and small business sectors, federally recognized tribal governments, community organizations, environmental and public health advocacy groups, local governments, and public health agencies. The following organizations, government agencies, and tribal governments were represented on the advisory committee:

- American Chemistry Council*
- Agency for Toxic Substances and Disease Registry
- Association of Washington Business
- Carpet and Rug Institute**
- City of Issaquah
- Clean Production Action
- Green Science Policy Institute
- Institute of Neurotoxicology & Neurological Disorders
- Island County Public Health
- King County Department of Natural Resources and Parks
- Washington State Patrol, Fire Training Academy
- Naval Facilities Engineering Command Northwest
- Outdoor Industry Association
- Port Gamble S'Klallam Tribe
- Port of Seattle Aviation
- Port of Seattle Fire Department
- Toxic-Free Future
- University of Washington
- Whidbey Island Water Systems Association
- Whitman College***
- Zero Waste Washington

*The American Chemistry Council took over representation for FluoroCouncil in August 2020.

**The Carpet and Rug Institute did not participate on the committee after March 2020.

[95] https://app.leg.wa.gov/wac/default.aspx?cite=173-333
[96] https://app.leg.wa.gov/wac/default.aspx?cite=173-333-430

***A professor from Whitman College is representing academia.

Beginning in January 2016, we convened meetings of the advisory committee and hosted several webinars. These meetings were open to the public. An Interim CAP was published in April 2018, and was revised in January 2019.[97] We issued Preliminary CAP Recommendations[98] with supporting documentation for advisory committee review in July 2019. Their comments, available on Ecology's PFAS CAP website,[99] were considered while preparing this CAP.

We conducted public outreach via Ecology's PFAS CAP website (where CAP documents are available), Ecology's PFAS website[100] and Health's PFAS website, [101] and by maintaining a CAP email list,[102] through which we distribute information to nearly 400 subscribers.

CAP requirements

In addition to the advisory process, the requirements of WAC 173-333-420[103] informed the CAP scope. A CAP considers chemical information, production, uses, releases, human health and environmental impacts, and current management approaches. We evaluated the necessary steps and costs of implementing CAP recommendations.

A CAP is advisory in nature. Chapter 173-333-120(1)[104] WAC "does not impose new requirements on persons using or releasing PBTs, and it does not create new authorities." A CAP does not implement new requirements or mandates on production or use of PFAS. We identify which requirements the Washington State Legislature has enacted and signed into law regarding management of certain PFAS since our process began (see the section PFAS CAP Recommendations or Appendix 9: Regulations).

A CAP considers "other chemicals or products that are known or suspected to degrade to the chemical included on the PBT list," such as PFAS precursors (WAC 173-333-420(1)(b)). Expanding knowledge of PFAS as a class shapes the current regulatory environment in Washington, which views PFAS as "a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom" (Chapters 70A.222,[105] 70A.400,[106] and 70A.350[107] Revised Code of Washington (RCW)).

A CAP must consider "the use of available substitutes" (WAC 173-333-420(1)(d)). Our assessment reviews the rapid development of short-chain PFAS to substitute for certain long-chain PFAS. To meet regulatory requirements, we must assess both the opportunities and

[97] https://apps.ecology.wa.gov/publications/documents/1804005.pdf
[98] https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PrelimRecommendations-2019-PFAS-CAP.pdf
[99] https://www.ezview.wa.gov/site/alias__1962/37105/pfas_chemical_action_plan.aspx
[100] https://ecology.wa.gov/PFAS
[101] https://www.doh.wa.gov/CommunityandEnvironment/Contaminants/PFAS
[102] http://listserv.ecology.wa.gov/scripts/wa-ECOLOGY.exe?A0=CHEMICAL-ACTION-PLAN
[103] https://app.leg.wa.gov/wac/default.aspx?cite=173-333-420
[104] https://app.leg.wa.gov/wac/default.aspx?cite=173-333-120
[105] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222&full=true
[106] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true
[107] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350&full=true

constraints that substitutes pose. Therefore, we evaluated the body of research on short-chain PFAS as well as long-chain PFAS.

A CAP must consider recommendations for "switching to (iv)" and "encouraging the development of (v)" safer alternatives (WAC 173-333-420(f)). Evaluation of the "availability and effectiveness of safer substitutes (v)(D)" for PFAS uses must form the basis for recommendations. As such, the CAP considers whether substitutes for long-chain PFAS—primarily short-chain PFAS—are safer.

Finally, WAC 173-333-420(i) allows us to include "other information that Ecology determines is necessary to support the decision-making process." Commercially available PFAS—even those intended to be long-chain—often contain a mix of PFAS, including short-chain. Therefore, evaluating how only long-chain PFAS behave would result in a partial understanding of the impacts of commercial products and how PFAS degrade.

Research on the safety of short-chain PFAS is ongoing. Human and environmental health implications of short-chain PFAS are uncertain. EPA has acknowledged the need to finalize draft toxicity assessments and develop additional toxicity values for several PFAS.

Short-chain PFAS tend to be more water soluble and more mobile than long-chain PFAS. This means they can move more easily through soil to contaminate groundwater or surface water, and are harder to remove. For example, due to the persistence of even short-chain perfluoroalkyl acids (PFAAs), exposure to these substances will continue regardless of accumulation because bioaccumulation is not required for sustained internal exposure (see Appendix 6: Ecotoxicology, Section 6.2 Bioaccumulation). If future scientific research finds that exposure to short-chain PFAS poses health risks to people or the environment, mitigation may be more difficult or expensive.

We need to understand the combinations of PFAS in waste streams and how they degrade. Studies note the importance of evaluating exposure to precursors and PFAAs separately when considering toxicological risk. Over time, PFAS released to the environment from manufacturing operations transform into a variety of chemical products. The lifetimes and toxicity of transformation and degradation products contribute to uncertain environmental impacts.

Public comment

A Draft CAP[108] was issued for review by the advisory committee and the public in October 2020 under WAC 173-333-430(6).[109] Comments were accepted through January 21, 2021. During the public review period, we also conducted webinars to inform stakeholders about the updated version of the CAP and to receive verbal comments. Appendix 11 details the public comments received and presents how we considered this input in preparing this CAP.

CAP issuance

This CAP is issued in accordance with WAC 173-333-430(7).[110] In addition to notification published in the Washington State Register and sent to persons who submitted comments on the Draft CAP, this document is available on the Ecology PFAS webpage[111] and found at publication number 21-04-048.

[108] https://apps.ecology.wa.gov/publications/summarypages/2004035.html
[109] https://apps.leg.wa.gov/wac/default.aspx?cite=173-333-430
[110] https://apps.leg.wa.gov/wac/default.aspx?cite=173-333-430
[111] https://ecology.wa.gov/PFAS

Acronyms

List of acronyms

General acronyms

Table 1. Acronyms found in the CAP summary.

Acronym	Definition
AA	Alternatives assessment
AWB	Association of Washington Business
AFFF	Aqueous film forming foam
ATSDR	Agency for Toxic Substances and Disease Registry
CAA	Clean Air Act
CAP	Chemical Action Plan
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
CHCC	Chemicals of High Concern to Children
COVID-19	Coronavirus disease 2019
CSPA	Children's Safe Products Act
CWA	Clean Water Act
DEPA	Danish Environmental Protection Agency
DOD	United States Department of Defense
DNRP	Department of Natural Resources and Parks
DNS	Determination of non-significance
DON	United States Department of the Navy
DTSC	Department of Toxics Substances Control, California
ECHO	United States Environmental Protection Agency Enforcement and Compliance History
Ecology	Washington State Department of Ecology
EFSA	European Food Safety Authority
EIS	Environmental Impact Statement
EJ	Environmental justice
EPA	United States Environmental Protection Agency
EWG	Environmental Working Group
FTE	Full-time equivalent
FY	Fiscal year
Health	Washington State Department of Health
HEPA	Heads of EPAs Australia and New Zealand
IARC	International Agency for Research on Cancer
IBL	Information by location
INND	Institute of Neurotoxicology & Neurological Disorders
ITRC	Interstate Technology & Regulatory Council
MTCA	Washington State Model Toxics Control Act

Acronym	Definition
NELAP	National Environmental Laboratory Accreditation Program
NWGA	National Ground Water Association
ODW	Washington State Department of Health Office of Drinking Water
OECD	Organisation for Economic Co-operation and Development
OIA	Outdoor Industry Association
OLF	Outlying Landing Field
ppt	Part per trillion
PBT	Persistent bioaccumulative toxin
RCW	Revised Code of Washington
SAL	State action level
SAEPA	South Australia Environment Protection Authority
SBOH	Washington State Board of Health
SEPA	State Environmental Policy Act
SSEHRI	Social Science Environmental Health Research Institute
SWM	Ecology Solid Waste Management Program
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
UCMR3	Third unregulated contaminant monitoring rule
UNEP	United National Environment Programme
WAC	Washington Administrative Code
WTN	Washington Tracking Network
WWTP	Wastewater treatment plant

Chemical Names

Table 2. Chemical name acronyms used in the CAP summary, excluding the general acronyms listed in the table above.

Acronym	Chemical Name
FTOH	Fluorotelomer alcohol
PFAA	Perfluoroalkyl acid
PFAS	Per- and poly-fluorinated alkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonic acid
PFCA	Perfluoro-carboxylic acid
PFD	Perfluorodecanoate
PFDA	Perfluorodecanoic acid
PFDS	Perfluorodecane sulfonate
PFDoA	Perfluorododecanoic acid
PFHpA	Perfluoroheptanoic acid
PFHpS	Perfluoroheptane sulfonic acid
PFHxA	Perfluorohexanoic acid

Acronym	Chemical Name
PFHxS	Perfluorohexane sulfonic acid
PFN	Perfluorononanoate
PFNA	Perfluorononanoic acid
PFO	Perfluorooctanoate
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOSA	Perfluorooctane sulfonamide
PFPeA	Perfluoropentanoic acid
PFPeS	Perfluoropentane sulfonic acid
PFSA	Perfluorooctane sulfonic acid
PFUnA	Perfluoroundecanoate
POSF	Perfluorooctane sulfonyl fluoride

Appendix 1: Chemistry

1.0 Overview

1.0.1 Findings

PFAS are a class of fluorine-containing chemicals with broad application in commercial products. More than 4,730 PFAS have been registered in the Chemical Abstract Service. The Environmental Protection Agency's (EPA) Master List of PFAS Substances includes 9,252 compounds.

Fluorosurfactants are used for their effectiveness in reducing surface energy (of solids) and surface tension (of liquids). Side-chain fluorinated polymers and polyether products help impart oil and grease resistance or soil resistance to food packaging or other substrates. The unique properties of PFAS arise from the strength of the carbon-fluorine bond.

Fluorosurfactants and side-chain polymer PFAS are manufactured from raw materials made by either electrochemical fluorination (ECF) or the telomerization process. Both processes produce end-mixtures of variable composition. The ECF process produces mixtures of various structural shapes (branched or linear chains) and lengths (odd and even). Conversely, telomerization produces a homologous mixture of even chain lengths. Per- and polyfluorinated ethers can be manufactured by several diverse processes, however, comparatively little has been published on the by-products or composition of polyether technical mixtures.

The production and use of long-chain PFAS was voluntarily curtailed in the U.S., Japan, and Western Europe starting in 2002. Following additional regulatory restrictions and voluntary withdrawal campaigns regarding long-chain PFAS, manufacturers in the U.S., Western Europe, and Japan shifted manufacture primarily to shorter-chain PFAS by the end of 2015.

Global PFAS production includes both newer short-chain chemistries and ongoing production of long-chain chemistries in some countries. The transition from legacy products to new chemistries has led to a concurrent increase in what was an already large number of PFAS substances.

This large number of substances—coupled with the fact that products may contain mixtures of target substances, residuals, and contaminants—complicates efforts to understand and characterize PFAS uses, emissions, and impacts.

1.0.2 Introduction

This appendix provides an overview of per- and polyfluoroalkyl substances (PFAS) and a background on their manufacture, and identifies select physical and chemical properties of PFAS relative to their uses. PFAS and their properties have been thoroughly described by others (Buck et al., 2011; Interstate Technology & Regulatory Council [ITRC], 2020a, 2020b; Korzeniowski & Buck, 2019a, 2019b, 2019c).

PFAS are a class of fluorine-containing chemicals with broad application in commercial products. More than 4,730 PFAS have been registered in the Chemical Abstract Service (Organisation for Economic Co-operation and Development [OECD], 2018; Wang et al., 2017).

As of November 2019, EPA's Master List of PFAS includes 9,252 chemical compounds (EPA, 2020).

1.1 Subclasses of per- and polyfluoroalkyl substances (PFAS)

1.1.1 PFAS terminology

This section provides a basic definition of PFAS and establishes how these compounds will be described in this appendix.

Definition of PFAS

Buck et al. (2011) and others have provided thorough discussion of PFAS classification (ITRC, 2020b; Knepper & Lange, 2012). Buck et al. (2011) provides the following definition of PFAS:

> …the highly fluorinated aliphatic substances that contain one or more C atoms on which all the H substituents (present in the nonfluorinated analogues from which they are notionally derived) have been replaced by F atoms, in such a manner that they contain the perfluoroalkyl moiety C_nF_{2n+1}–.

The definition and terminology surrounding this large group of substances continues to evolve, with the OECD proposing the following definition in 2021 (OECD, 2021):

> PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS.

Ordinary **hydrocarbons** contain mostly hydrogen (H) and carbon (C) atoms. However, when the H atoms are completely replaced by fluorine (F) atoms, the substance is described as **perfluorinated**. Figures 3 and 4 provide an example of such perfluorination.

Figure 3 illustrates a non-fluorinated hydrocarbon, octane sulfonic acid. When the hydrogen atoms are replaced by fluorine, one obtains its perfluorinated cousin, perfluorooctane sulfonic acid (PFOS), illustrated in Figure 4.

Figure 4 illustrates the structure of PFOS with all the individual atoms shown. As indicated, PFOS is made up of a chain of carbon (C) and fluorine (F) atoms, with a sulfonic acid tail composed of sulfur (S), oxygen (O), and hydroxyl (OH) components.

Figure 5 simplifies these illustrations. It does not show the C atoms located at the intersection of the straight lines (which represent bonds between the atoms), nor the hydrogens that are attached to carbons. This simplified style will be used throughout the remainder of this appendix.

It is also customary to abbreviate carbon chain-length using the term Cx, where x is replaced by a number indicating the number of carbon atoms in the chain. For example, C6 would represent a chain length of six carbon atoms.

Figure 3. Non-fluorinated hydrocarbon, octane sulfonic acid.

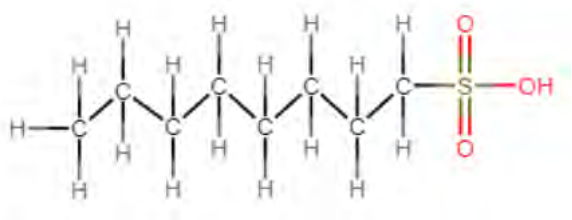
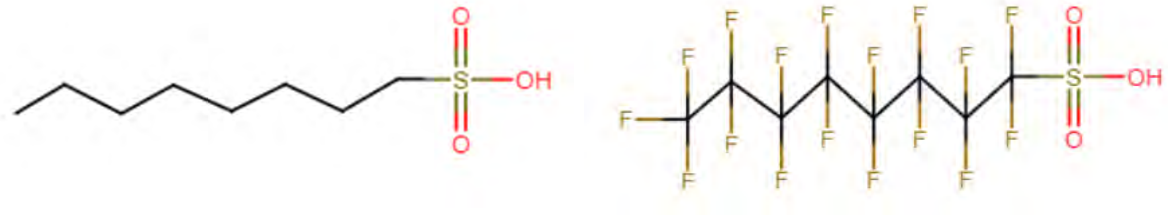


Figure 4. Fluorinated hydrocarbon, PFOS.

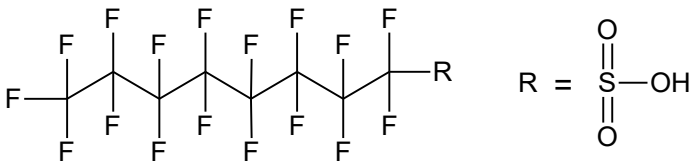
Figure 5. Simplified illustration of octane sulfonic acid (left) and PFOS (right) chemical structure where C and H are not shown.



Moiety (R-group)

A moiety (or R-group) is a part of a molecule that can be found in other types of molecules, and is given a typical name. For convenience, structure illustrations often use R to represent a "functional group" add-on to the main carbon chain. R may represent a single atom or a group of atoms. For the PFOS example used in Figures 3, 4, and 5 above, the sulfonic acid group (SO_3H) is the R-group in PFOS. Figure 6 illustrates the relationship of the R-group (SO_3H) to the remainder of the PFOS chemical structure. Chemical manufacturers may alter the R-group in PFAS to achieve desired properties, such as solubility in a formulation solvent.

Figure 6. PFOS in which the SO_3H functional group is represented by R.



Long-chain versus short-chain PFAS

Much of the regulatory interest around PFAS in the environment has focused on PFOS and PFOA. Both of these chemicals are long-chain assemblages of fluorine and carbon atoms. In scientific literature, researchers distinguish between long-chain and short-chain PFAS as follows (ITRC, 2020b; OECD, 2013).

Long-chain refers to:

- Perfluoroalkyl carboxylic acids (PFCAs) with eight or more carbons (seven or more carbons are perfluorinated).
- Perfluoroalkane sulfonates (PFSAs) with six or more carbons (six or more carbons are perfluorinated).

Short-chain refers to:

- Perfluoroalkyl carboxylic acids with seven or fewer carbons (six or fewer carbons are perfluorinated).
- Perfluoroalkane sulfonates with five or fewer carbons (five or fewer carbons are perfluorinated).

Regardless of the chain length distinction described above, and although some PFAS exhibit similarities based on chain length, PFAS behavior is not entirely based on chain length (ITRC, 2020b).

1.1.2 Overview of PFAS

PFAS are a large family of compounds with varying physical and chemical properties. In their manufactured form they can be gases (for example, perfluorobutane), liquids (for example, fluorotelomer alcohols), surfactants (for example, perfluorooctane sulfonate), and high-molecular weight polymer solids (for example, polytetrafluoroethylene [PTFE]) (ITRC, 2020a). The family of PFAS has been subdivided into two primary classes (Buck et al., 2011; ITRC, 2020a). These include polymers and non-polymer substances. Table 3, adapted from Buck et al. (2011), describes this classification and identifies substance types within each subclass.

Each of these PFAS classes is described in additional detail below, and illustrates the class based on example "characteristic" properties, substances, and uses. It is important to note that individual PFAS can be raw materials, compounds used in products, or environmental transformation products. In many cases, raw materials, final manufactured products, or treated articles may contain a mixture of related structures, impurities, residual raw materials, and other contaminants. Similarly, environmental transformation products may result in a mixture of compounds at the emission source based on the ambient conditions causing degradation to occur. Some of these substances are known and well-characterized, but many are unknown. Appendix 4: Fate and Transport addresses environmental transformation of PFAS in more detail.

Table 3. PFAS classes.

Non-polymers	Polymers
Perfluoroalkyl substances Compounds for which all hydrogen atoms on all carbon atoms (except for carbon atoms associated with functional groups) have been replaced by fluorine atoms, such as: • (Aliphatic) perfluorocarbons. • Perfluoroalkyl acids. • Perfluoroalkane sulfonyl fluorides. • Perfluoroalkane sulfonamides. • Perfluoroalkyl iodides. • Perfluoroalkyl aldehydes. • Perfluoroalkyl ether acids **Polyfluoroalkyl substances** Compounds for which all hydrogen atoms on at least one (but not all) carbon atoms have been replaced by fluorine atoms, such as: • Perfluoroalkane sulfonamido derivatives. • Fluorotelomer-based compounds. • Semifluorinated n-alkanes and alkenes.	**Side-chain fluorinated polymers** Variable composition non-fluorinated polymer backbone with fluorinated side chains, such as: • Fluorinated acrylate and methacrylate polymers. • Fluorinated urethane polymers. • Fluorinated oxetane polymers. **Fluoropolymers** Carbon-only polymer backbone with fluorine atoms directly attached, such as: • Polytetrafluoroethylene. • Polyvinylidene fluoride. • Polyvinyl fluoride. **Perfluoropolyethers** Carbon and oxygen polymer backbone with fluorine atoms directly attached to carbon atoms, such as perfluoropolyethers.

1.1.3 Non-polymer PFAS

Most PFAS of interest at environmental release sites are non-polymers (ITRC, 2020b). Non-polymeric PFAS can be subdivided into two classes: perfluoroalkyl substances and polyfluoroalkyl substances.

Table 4 below provides additional classification of perfluoroalkyl substances, their chemical structures, and their uses. This table is in no way comprehensive. It focuses on those substances which have been more prevalently identified with respect to environmental presence or regulatory control (ITRC, 2020b).

Table 5 presents similar information for polyfluoroalkyl substances.

Perfluoroalkyl substances

Perfluoroalkyl substances are fully fluorinated (perfluoro-) alkane (carbon-chain) molecules. Their basic chemical structure is a chain (or tail) of two or more carbon atoms with a charged functional group "head" attached at one end. The functional groups commonly are carboxylic or sulfonic acids, but other forms have been detected, as indicated in Table 4.

PFOS, illustrated in Figure 4 above, is a perfluoroalkyl substance—where F atoms are attached to all possible bonding sites along the C chain of the tail, except for one bonding site on the last

C where the functional sulfonic acid group head is attached. Perfluoroalkyl chains are often represented in a shorthand form as C_nF_{2n+1}, with n≥2. As noted in Table 4, these PFAS can be present in the form of raw materials, compounds used as commercial products, or intermediate environmental degradation compounds.

As addressed in Appendix 4: Fate and Transport, biotic and abiotic degradation of many polyfluoroalkyl substances may result in the formation of PFAAs. PFAAs are essentially non-degradable, and are the most tested type of PFAS in the environment (ITRC, 2020b). Polyfluoroalkyl substances that degrade to PFAAs are often called "precursors." PFAAs are sometimes referred to as "terminal PFAS," because no further degradation products will form from them.

Short-chain PFAAs have been developed and are currently marketed as replacements to phased-out long-chain PFAAs such as PFOS and PFOA. These are discussed in Section 1.3.4 below.

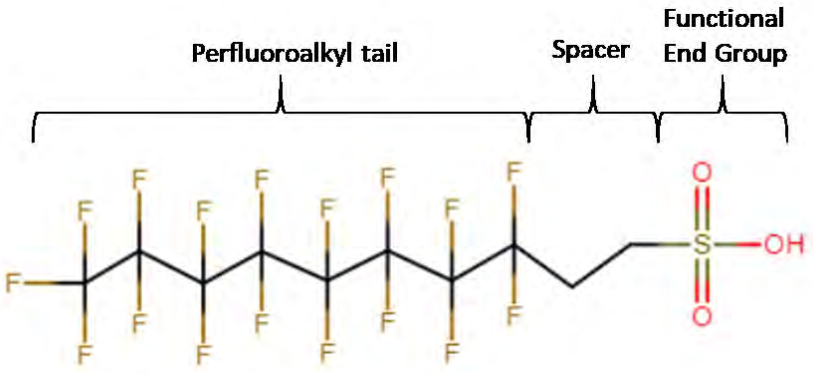
Polyfluoroalkyl substances

Unlike perfluoroalkyl substances, polyfluoroalkyl substances are not fully fluorinated. Instead, they have a non-fluorine atom (typically hydrogen or oxygen) attached to at least one, but not all, carbon atoms, while at least two or more of the remaining carbon atoms in the carbon chain tail are fully fluorinated (ITRC, 2020b).

Fluorotelomer substances are polyfluoroalkyl substances produced by the telomerization process. Perfluoroalkane sulfonamido substances have a fully fluorinated carbon chain tail, but they also contain one or more CH_2 groups in the head of the molecule attached to a sulfonamido spacer (ITRC, 2020b).

In Figure 7, the eight perfluorinated carbons (n=8), could be represented as C_8F_{17}, the hydrocarbon spacer as C_2H_4, and the end group as SO_3H. This mix of a perfluoroalkyl chain and a hydrocarbon spacer results in a **polyfluorinated** carbon chain. The polyfluoroalkyl structures have a numerical prefix based on these structural elements to indicate the number of **perfluorinated** versus **non-fluorinated** C atoms. Figure 7 illustrates the 8:2 fluorotelomer sulfonic acid.

Figure 7. Schematic structure of a polyfluorinated surfactant, the 8:2 fluorotelomer sulfonic acid.



The carbon-hydrogen (or other non-fluorinated) bond in polyfluoroalkyl molecules creates a "weak" point in the carbon chain that is susceptible to biotic or abiotic degradation. As a result, many polyfluoroalkyl substances that contain a perfluoroalkyl C_nF_{2n+1} group are potential precursor compounds that have the potential to be transformed into PFAAs (ITRC, 2020b). See Appendix 4: Fate and Transport for additional discussion of the degradation of these substances.

Table 4. Overview of non-polymer perfluoroalkyl PFAS (Buck et al., 2011).

Class	Sub-class	Functional group $C_nF_{2n+1}R$, where R =	Examples	Uses
Perfluoroalkyl acids (PFAAs)	Perfluoroalkyl carboxylic acids (PFCAs) [a]	-COOH	Perfluorooctanoic acid (PFOA) Perfluorononanoic acid (PFNA) Perfluorohexanoic acid (PFHxA)	Surfactant
PFAAs	Perfluoroalkyl carboxylates (PFCAs) [a]	$-COO^-$	Sodium perfluorooctanoate (Na-PFOA) Ammonium perfluorooctanoate (APFO) Ammonium perfluorononanoate (APFN)	Surfactant
PFAAs	Perfluoroalkane sulfonic acids (PFSAs) [b]	$-SO_3H$	Perfluorooctane sulfonic acid (PFOS) Perfluorohexane sulfonic acid (PFHxS) Perfluorobutane sulfonic acid (PFBS)	Surfactant
PFAAs	Perfluorooctane sulfinic acid (PFSIAs) [b]	$-SO_2H$	Perfluorooctane sulfinic acid (PFOSI)	Intermediate environmental transformation product
PFAAs	Perfluoroalkane sulfonates (PFSAs) [b]	$-SO_3^-$	Tetraethylammonium perfluorooctane sulfonate (NEt_4-PFOS)	Surfactant
PFAAs	Perfluoroalkyl phosphonic acids (PFPAs) [c]	$-P(=O)(OH)_2$	Perfluorooctyl phosphonic acid (C8-PFPA)	Surfactant
PFAAs	Perfluoroalkyl phosphonic acids (PFPIAs) [c]	-P(=O)(OH)	Bis(perfluorohexyl) phosphonic acid (C6/C6-PFPIA)	Surfactant

Class	Sub-class	Functional group $C_nF_{2n+1}R$, where R =	Examples	Uses
PFAAs	Perfluoroalkyl ether carboxylic acids or Perfluoroalkyl ether sulfonic acids (PFECA/PFESA) [c]	Various Example: - $(C_mF_{2m})COOH$	Hexafluoropropylene oxide (HFPO) dimer acid "GenX"	Polymer processing aid
Perfluoroalkane sulfonyl fluorides (PASFs)[b]	N/A	$-SO_2F$	Perfluorooctane sulfonyl fluoride (POSF) Perfluorobutane sulfonyl fluoride (PBSF)	Raw material for surfactant and surface protection products
Perfluoroalkane sulfonamides (FASAs)[b]	N/A	$-SO_2NH_2$	Perfluorooctane sulfonamide (FOSA)	Raw material for surfactant and surface protection products
Perfluoroalkanoyl fluorides (PAFs)[b]	N/A	-COF	Perfluorooctanoyl fluoride (POF)	Raw material for PFOA made by the ECF process; raw material for surfactant and surface protection products
Perfluoroalkyl iodides (PFAIs)[c] (Telomer A)	N/A	-I	Perfluorohexyl iodide (PFHxI) Perfluorooctyl iodide (PFOI)	Raw material for surfactant and surface protection products
Perfluoroalkyl aldehydes and aldehyde hydrates (PFALs)[c]	N/A	-CHO and $-CH(OH)_2$	Perfluorononanal (PFNAL)	Intermediate environmental transformation product

Notes:

- a: Substances originating by either electrochemical fluorination (ECF) or fluorotelomer processes.
- b: Substances originating by the ECF process.
- c: Substances originating by the fluorotelomer process.

Table 5. Overview of non-polymer polyfluoroalkyl PFAS (Buck et al., 2011).

Class	Sub-class	Functional group $C_nF_{2n+1}R$, where R =	Examples	Uses
Perfluoroalkane sulfonamido substances[a]	N-alkyl perfluoroalkane sulfonamides (MeFASAs, EtFASAs, BuFASAs)	$-SO_2NH(R')$ where $R' = C_mH_{2m+1}$ (m=1,2,4)	N-methyl perfluorooctane sulfonamide (MeFOSA) N-ethyl perfluorobutane sulfonamide (EtFBSA) N-butyl perfluorooctane sulfonamide (BuFOSA)	Major raw material for surfactant and surface protection products
Perfluoroalkane sulfonamido substances[a]	Perfluoroalkane sulfonamidoethanols (FASEs) and N-alkyl perfluoroalkane sulfonamidoethanols (MeASEs, EtFASEs, BuFASEs)	$-SO_2N(R')CH_2CH_2OH$ where $R' = C_mH_{2m+1}$ (m = 1,2,4)	N-ethyl perfluorobutane sulfonamidoethanol (EtFBSE) Perfluorooctane sulfonamidoethanol (FOSE)	Raw material for surfactant and surface protection products
Perfluoroalkane sulfonamido substances[a]	N-alkyl perfluoroalkane sulfonamidoethyl acrylates and methacrylates (MeFAS(M)ACs, EtFAS(M)ACs, BuFAS(M)ACs)	$-SO_2N(R')CH_2CH_2OC-(O)CH=CH_2$ and $SO_2N(R')CH_2CH_2OC-(O)C(CH_3)=CH_2$ where $R' = C_mH_{2m+1}$ (m=1,2,4)	N-ethyl perfluorooctane sulfonamidoethyl acrylate (EtFOSAC)	Raw material for surfactant and surface protection products
Perfluoroalkane sulfonamido substances[a]	Perfluoroalkane sulfonamidoacetic acids (FASAAs) and N-alkyl perfluoroalkane sulfonamidoacetic acids (MeFASAAs, EtFASAAs, BuFASAAs)	$-SO_2N(R')CH_2COOH$ where $R' = C_mH_{2m+1}$ (m=0,1,2,4)	N-ethyl perfluorooctane sulfonamidoacetic acid (EtFOSAA)	Intermediate environmental transformation product

Class	Sub-class	Functional group $C_nF_{2n+1}R$, where R =	Examples	Uses
Fluorotelomer substances[b]	Semifluorinated n-alkanes (SFAs) and alkenes (SFAenes)	$-(CH_2)_mH$ and $-CH=CH(CH_2)_mH$, with m = 2–16	(Perfluorooctyl)ethane (F_8H_2)	Ski wax, medical applications
Fluorotelomer substances[b]	n:2 Fluorotelomer iodides (n:2 FTIs)	$-CH_2CH_2I$	8:2 Fluorotelomer iodide (8:2 FTI)	Raw material for surfactant and surface protection products
Fluorotelomer substances[b]	n:2 Fluorotelomer olefins (n:2 FTOs)	$-CH=CH_2$	6:2 Fluorotelomer olefin (6:2 FTO)	Raw material for surfactant and surface protection products
Fluorotelomer substances[b]	n:2 Fluorotelomer alcohols (n:2 FTOHs)	$-CH_2CH_2OH$	4:2 Fluorotelomer alcohol (4:2 FTOH)	Raw material for surfactant and surface protection products
Fluorotelomer substances[b]	n:2 Unsaturated fluorotelomer alcohols (n:2 FTUOHs)	$-CF=CHCH_2OH$	8:2 Unsaturated fluorotelomer alcohol	Intermediate environmental transformation product
Fluorotelomer substances[b]	n:2 Fluorotelomer acrylates (n:2 FTACs) and methacrylates (n:2 FTMACs)	$-CH_2CH_2OC(O)CH=CH_2$ and $-CH_2CH_2OC(O)C(CH_3)=CH_2$	6:2 Fluorotelomer acrylate (6:2 FTAC) 6:2 Fluorotelomer methacrylate (6:2 FTMAC)	Raw material for surfactant and surface protection products
Fluorotelomer substances[b]	n:2 Polyfluoroalkyl phosphoric acid esters, polyfluoroalkyl phosphates, fluorotelomer phosphates (PAPs)	$(-CH_2CH_2O)_x-P(=O)(OH)_{3-x}$ where x = 1 or 2	10:2 Fluorotelomer phosphate monoester (10:2 monoPAP)	Surfactant and surface protection products
Fluorotelomer substances[b]	n:2 Fluorotelomer aldehydes (n:2 FTALs) and unsaturated aldehydes (2 FTUALs)	$-CH_2CHO$ and $-CF=CHCHO$	8:2 Fluorotelomer aldehyde (8:2 FTAL) 8:2 Fluorotelomer unsaturated aldehyde (8:2 FTUAL)	Intermediate environmental transformation product

Class	Sub-class	Functional group $C_nF_{2n+1}R$, where R =	Examples	Uses
Fluorotelomer substances[b]	n:2 Fluorotelomer carboxylic acids (n:2 FTCAs) and unsaturated carboxylic acids (n:2 FTUCAs)	$-CH_2COOH$ and –CF=CHCOOH	8:2 Fluorotelomer carboxylic acid (8:2 FTCA) 8:2 Fluorotelomer unsaturated carboxylic acid (8:2 FTUCA)	Intermediate environmental transformation product
Fluorotelomer substances[b]	n:3 Saturated acids (n:3 Acids) and n:3 Unsaturated acids (n:3 UAcids)	$-CH_2CH_2COOH$ and –CH=CHCOOH	7:3 Acid, 7:3 UAcid	Intermediate environmental transformation product
Fluorotelomer substances[b]	n:2 Fluorotelomer sulfonic acids (n:2 FTSAs)	$-CH_2CH_2SO_3H$	6:2 Fluorotelomer sulfonic acid (6:2 FTSA)	Surfactant and environmental transformation products
Miscellaneous	Polyfluoroalkyl ether carboxylic acids & others Perfluoropolyethers	e.g.,—$O(C_mF_{2m})$-$OCHF(C_pF_{2p})$COOH e.g.,—$O(C_mF_{2m}O-)_nCF_3$	4,8-Dioxa-3H-perfluorononanoic acid	Perfluoro-polyether oils and lubricants Alternative fluoropolymer processing aid (as ammonium salt)

Notes:

- a: Substances originating by electrochemical fluorination (ECF) process.
- b: Substances originating by fluorotelomer process.

Table 6. Overview of polymeric PFAS (Buck et al., 2011).

Class	Sub-class	Examples	Uses
Fluoropolymers: Carbon-only polymer backbone with F directly attached to backbone C atoms	N/A	$-(CF_2CF_2)_n-$ Polytetrafluoroethylene (PTFE) $-(CH_2CF_2)_n-$ Polyvinylidene fluoride (PVDF) $-(CH_2CHF)_n-$ Polyvinyl fluoride (PVF) $-(CF_2CF_2)_n-(CF(CF_3)CF_2)_m-$ Fluorinated ethylene propylene (FEP)	Plastics
Perfluoropolyethers: Ether polymer backbone with F atoms directly attached (PFPEs)	N/A	Examples: $F-(C_mF2mO-)nCF_3$ $HOCH_2O-[CmF_{2m}O-]nCH_2OH$ -where $C_mF_{2m}O$ represents $-CF_2O-$, $-CF_2CF_2O-$, and/or $-CF(CF_3)CF_2O-$ units distributed randomly along the polymer backbone	Functional fluids, surfactants, and surface protection products
Side-chain–fluorinated polymers: Nonfluorinated polymer backbone with fluorinated side chains, ending in $-C_nF_{2n+1}$	Fluorinated acrylate and methacrylate polymers	Acrylate: Backbone-CH-C(O)O-X-C_nF_{2n+1} Methacrylate: Backbone-$C(CH_3)$-C(O)O-X-C_nF_{2n+1} -where X is $-CH_2CH_2N(R')SO_2-$ with R' = $-C_nH_{2n+1}$ (n=0,1,2,4) or $-CH_2CH_2-$	Surfactants and surface protection products
Side-chain–fluorinated polymers	Fluorinated urethane polymers	Backbone-NHC(O)O- X-C_nF_{2n+1} -where X is either $-CH_2CH_2N(R'0)SO_2-$ with R' = C_nH_{2n+1} (n=0,1,2,4) or $-CH_2CH_2-$	Surfactants and surface protection products
Side-chain–fluorinated polymers	Fluorinated oxetane polymers	Backbone-CH_2OCH_2-R -where R = $-CF_3$, $-C_2F_5$ or $-CH_2C_4F_9$	Surfactants and surface protection products

1.1.4 Polymeric PFAS

Polymers are large molecules formed by combining many identical smaller molecules (monomers) in a repeating pattern (ITRC, 2020b). Polymeric substances in the PFAS family include fluoropolymers, polymeric perfluoropolyethers, and side-chain fluorinated polymers. Table 6 provides an overview of polymeric PFAS, their chemical structures, and their uses.

In general, polymeric PFAS are currently believed to pose less immediate human health and ecological risk relative to some non-polymer PFAS (ITRC, 2020b). However, some polymeric PFAS incorporate one or more PFAS monomer(s) during their synthesis. Any degradation of these polymers, during or after their useful lifetime, may lead to release of PFAS to the environment (Buck et al., 2011).

Fluoropolymers

Fluoropolymers contain F bound to one or both of the olefinic C atoms, to form a perfluorinated C-only polymer backbone with F atoms directly attached to it (Buck et al., 2011).

Fluoropolymers have been found to have thermal, chemical, photochemical, hydrolytic, oxidative, and biological stability (Henry et al., 2018; Korzeniowski & Buck, 2019a). They are almost insoluble in water and not subject to long-range transport. With very high molecular weight (greater than 100,000 Da), fluoropolymers cannot cross the cell membrane. They are neither bioavailable nor bioaccumulative. Clinical studies of their use in medical devices has demonstrated lack of chronic toxicity or carcinogenicity and no reproductive, developmental, or endocrine toxicity.

Fluoropolymers can only be destroyed or degraded to HF and CO_2 under municipal waste incineration conditions. The manufacture of some fluoropolymers may require use of PFAS monomers as a processing aid, added in very small levels, and traditionally composed of PFOA or PFNA. Although the manufacturing process intends to remove the fluorosurfactants by drying or high cure temperatures, residual surfactants may remain on the product (Guo et al., 2009). U.S. manufacturers have discontinued the use of PFOA (see Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency) and PFNA salts.

Pefluoropolyethers

Perfluoropolyethers (PFPEs) are polymers in which the backbone $-CF_2-$, $-CF_2CF_2-$, and possibly $-CF(CF_3)CF_2-$ units are separated by O atoms (Buck et al., 2011). Because the repeating units of these PFPEs contain only two or three perfluorinated C atoms per O atom, their degradation cannot lead to the formation of long-chain PFCAs.

Perfluoropolyether polymers have thermal, chemical, photochemical, hydrolytic, oxidative, and biological stability. They are practically insoluble in water and hydrocarbons, and not subject to long-range transport (Korzeniowski & Buck, 2019a).

Side-chain fluorinated polymers

Unlike fluoropolymers and perfluoropolyethers, side-chain fluorinated polymers do not have perfluorinated or polyfluorinated polymer backbones, but are composed of variable composition backbones with polyfluoroalkyl (and possibly perfluoroalkyl) side chains (Buck et al., 2011). In particular, three groups of side-chain fluorinated polymers (acrylate or methacrylate, urethane, and oxetane) may be able to sever from the polymer chain to form PFAS shown in Tables 4 and 5.

Buck et al. (2011) notes that this transformation process can occur over periods greater than 1,000 years and may result in small amounts of PFAS—meaning a small overall contribution of long-chain PFAS to the environment relative to other sources. However, other studies have shown degradation of these polymers in shorter time frames (Rankin et al., 2014; Washington & Jenkins, 2015; Washington et al., 2015). This topic is discussed further in Appendix 4: Fate and Transport.

1.2 Select physical and chemical properties of PFAS

Physical and chemical properties of PFAS have been extensively described in scientific literature (for example, but not limited to, Buck et al., 2011). PFAS have some unique and valuable properties when compared with non-fluorinated hydrocarbon chemicals of similar structure (Krafft & Riess, 2015). The purpose of this section is to identify significant PFAS characteristics relevant to their commercial use and significant characteristics impacting how they may enter the environment. Appendix 4: Fate and Transport addresses specific PFAS degradation pathways in detail.

1.2.1 Resistance to extreme environments

Fluorine forms an extraordinarily strong bond with carbon, and when fluorine completely replaces hydrogen in an alkyl chain of carbons, the resulting substance is much more resistant to thermal or chemical attack than a similar fluorine-free hydrocarbon. As a result, PFAS are often preferred for use in extreme environments (high temperatures, strongly reactive conditions, etc.). These same characteristics are responsible for the extreme environmental persistence of perfluorinated substances—they are completely resistant to naturally occurring breakdown mechanisms. See more on this in Appendix 4: Fate and Transport.

1.2.2 Surfactants and emulsifiers

PFAS treatments or polymer coatings are often used to create low surface energy materials, preventing the spread of water or oils on their surface. Fluoropolymers, such as polytetrafluoroethylene (PTFE), are un-wettable in that both oil and water will “bead-up” on PTFE surfaces. Common applications include thin fluoropolymer linings in hydraulic tubing, linings for chemical and pharmaceutical processing equipment, and breathable membranes for garments. Side-chain polymers or perfluoropolyethers derived from PFAS can be used to coat surfaces on a molecular scale, imparting oil and water (i.e., stain) resistance at the individual fiber level in textiles, fabrics, or carpets.

Other PFAS are added to liquid formulations and function mostly as surface-active agents (surfactants) or emulsifiers. Surfactants are commonly used to affect wetting and spreading of liquids (Knepper & Lange, 2012). When a surfactant is added to water, the normally high surface tension is reduced, and droplets behave more like oil droplets, spreading on the polyethylene surface. Fluorinated surfactants are effective at reducing surface tension in both oil- and water-based products to promote wetting and spreading. These properties are important in many applications, for example paints which must cover surfaces uniformly and completely, or inks which need to achieve full coverage on printing plates.

When surfactant properties are combined with a need for chemical inertness or resistance to high temperature, PFAS can have distinct advantages over traditional hydrocarbon surfactants or materials (Krafft & Riess, 2015).

1.2.3 Modifications for PFAS chemical function

Formulating a product from a mixture of chemical ingredients and solvents is complex. A surfactant may play multiple roles and needs to meet other functional requirements (color, temperature, stability, etc.). In a floor polish, the surfactant improves wetting and spreading, but also helps achieve a smooth, glossy finish through its effect on surface tension as the polish dries. Several surfactants may be used in a single product, with hydrocarbon surfactants used to keep ingredients dispersed and fluorinated surfactants used to promote wetting. The individual constituents must work well together in the complete system of ingredients for the product to function as intended. PFAS products are therefore carefully designed to achieve multiple characteristics upon their intended use.

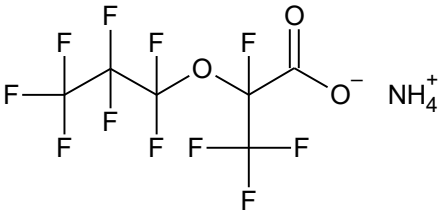
Hydrocarbon surfactants are often described as having a head and a tail. The tail is often a long alkyl chain and relatively insoluble in water (hydrophobic). In contrast to the tail, the head is typically more compact, and often hydrophilic, or water-loving. Most surfactants for water-based applications orient at the surface of the liquid, with the tail portion extending out and over the surface at the molecular level and the head-only immersed in liquid. The head is equivalent to the R-group described in Section 1.1.1 above.

As described in Section 1.1.1 above, many fluorosurfactants have a similar design, but the fluorocarbon tail is insoluble in both oil and water (both oleophobic and hydrophobic). Most often, the tail is a perfluorinated carbon chain. The head varies more widely and is chosen so that surfactants will perform certain functions in each product application. For example, a fluorinated surfactant for a water-based paint application usually has an R-group that is hydrophilic (water-loving). Sulfonic acid or carboxylic acid R-groups work well in these applications, so both PFOS and PFOA were used for water-based applications.

In some applications, heteroatoms, like oxygen (O), may be introduced into the fluorinated tail. The resulting perfluoroalkyl ether surfactants are currently used as processing aids in emulsion polymerization, where they replace legacy processing aids like ammonium perfluorooctanoate (APFO), the ammonium salt of PFOA. One example is the ammonium salt of perfluoro-2-propoxypropanoic acid (PFPrOPrA), also called hexafluoropropylene oxide dimer acid (HPFO-DA) and known by the trade name used for this process, called GenX. Perfluoroalkyl ether carboxylic acids (PFECAs) and perfluoroalkyl ether sulfonic acids (PFESAs) contain O-atoms

interspersed among (typically) short perfluorinated chains (Sun et al., 2016). Figure 8 provides an illustration of the structure of PFPrOPrA.

Figure 8. The ammonium salt of PFPrOPrA/HPFO-DA (also known as GenX).

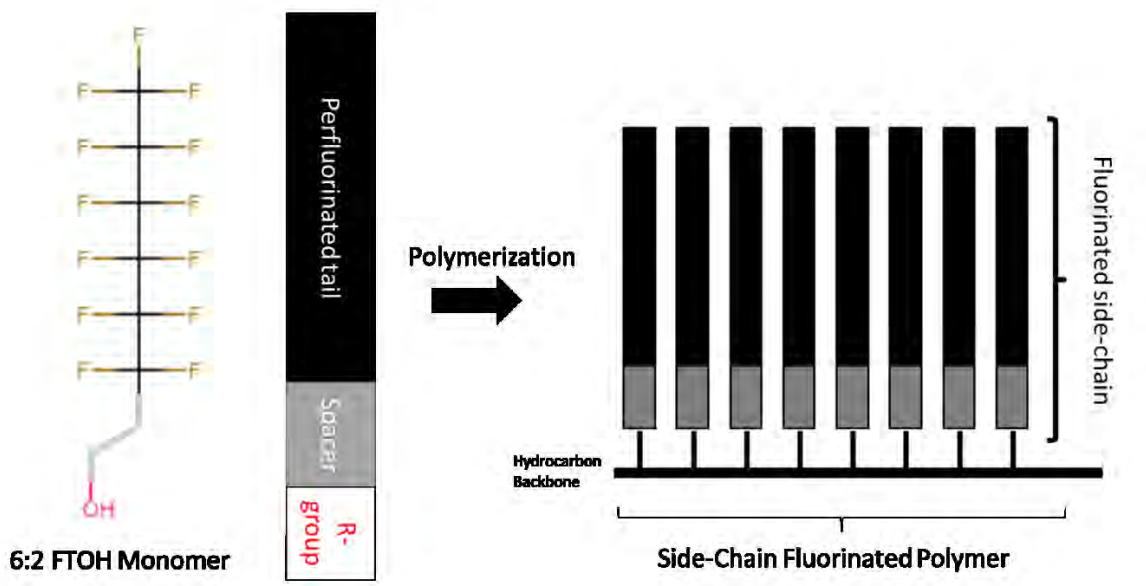


The basic head and tail concept is a bit different in polyfluorinated surfactant design. As illustrated in Figure 9, using 6:2 FTOH as an example, manufacturers have introduced a hydrocarbon spacer (grey portion in center) between the perfluorinated tail (black portion, left) and the head-group (white portion, right). The hydrocarbon "spacer," often a two-carbon group, extends the combined surfactant tail length. Some reports suggest that the use of a spacer helps to balance function and toxicity as manufacturers have moved to shorter perfluorinated chains (Renner, 2006).

Very similar fluorinated monomer structures as those used in surfactants are used in the production of polymeric surface treatment or impregnation products for textiles and paper. R-groups such as acrylate or methacrylate form fluoroalkyl acrylate and methacrylate monomers. These may be combined with non-fluorinated monomers. The monomers are polymerized to form a non-fluorinated hydrocarbon backbone with fluorinated side-chains, like teeth on a comb. These are commonly called "side-chain polymers." Side-chain polymers are often sold as aqueous dispersions and used for surface treatment or impregnation of textiles, carpets, and paper products, among other uses. Side-chain polymers are not themselves considered surfactants.

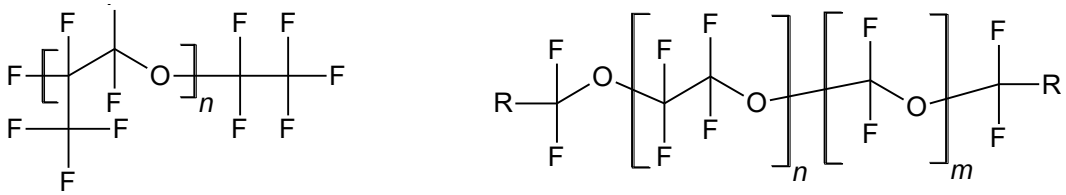
Figure 9 provides an illustration of a side-chain polymer. In the schematic (right), the solid line at the base represents the main, non-fluorinated polymer backbone. Fluorinated side-chains (black bars) are bonded to the backbone through reactions with the hydrocarbon spacer group (gray bar). The treated surface is at the bottom of the figure with the air interface at the top. The structure on the right is a typical example of one "tooth" of the comb.

Figure 9. Fluorinated side-chain polymer, typical of stain-resistant surface treatments for textiles.



Another example of substance tailoring is that of perfluoropolyether (PFPE) substances, which include repeating structural ether units, as illustrated in Figure 10 by the bracketed structures with subscripts. Depending on the number of repeating ether-units, these will vary in molecular weight and in their physicochemical properties. PFPE includes different length ether units that repeat ("n" or "m" times) and variable R groups that can be tailored by application requirements (Solvay Company, 2015). One manufacturer reports that "n" can vary from 10 to 60 (Krytox, 2020). PFPEs are used as surfactants, functional fluids, and to modify properties of other polymers such as polyurethane.

Figure 10. Possible chemical structure of perfluoropolyether (PFPE).



The expertise to fine-tune these surfactant, side-chain fluoroalkyl polymer, and perfluoro-polyether structures is highly valued intellectual property and may be one reason why the details of these structures are often not publicly disclosed. The first chapter in Knepper and Lange (2012) contains many examples of fluorinated chemicals, their associated applications, and relevant literature citations.

1.2.4 Solubility in water

PFAS can have varying solubility in water (Ross & Hurst, 2019). Pancras et al. (2016) compiled solubility data for a variety of PFAS. PFCAs (PFBA, PFPeA, PFHxA, PFHpA, and PFOA) and PFSAs (PFBS, PFPeS, PFHxS, PFHpS, and PFOS), in general, have high solubility, with decreasing solubility as chain length increases. This is one reason why these PFAS have been transported throughout the environment. On the other hand, fluorotelomer alcohols (FTOHs) are, in general, more hydrophobic than PFAAs, and also have decreasing solubility as chain length increases.

Solubility of PFAS is further affected by the chemical composition of the water medium where they are located. The environment determines the protonation state of PFAS, which in turn affects physical and chemical properties, including solubility. For example, PFAAs are anionic, dissociating in water under most environmentally relevant pHs to form a negatively charged version of the acid along with a dissociated proton. However, under conditions of very low pHs, PFAAs will not dissociate (Johansson, 2017), which changes their properties, such as greatly decreasing their solubility.

In this report, we will most often be discussing anionic PFAS under environmental conditions, since they are the chemicals most often studied and used. However, some PFAS are cationic, zwitterionic, or non-ionic, which can lead to different behavior. As described in Appendix 4: Fate and Transport, for example, cationic PFAS are much more likely to associate with soils and sediment (ITRC, 2020c).

1.3 Manufacturing

Complex chemicals like PFAS generally require several sequential manufacturing steps and utilize multiple chemical raw materials, catalysts, and other additives too numerous to detail here. However, the principle perfluoroalkyl building blocks used for making fluorosurfactants and side-chain fluorinated polymers are manufactured using two main processes: electrochemical fluorination (ECF) and telomerization (Buck et al., 2011; Keppner & Lange, 2012). ECF was licensed for use by 3M in the 1940s; telomerization was developed in the 1970s (Lindstrom et al., 2011; ITRC, 2020a).

As addressed in Appendix 3: Sources and Uses, Section 3.1.1 Primary Manufacturing, PFAS were not, nor are they currently, manufactured in Washington state.

1.3.1 Electrochemical fluorination (ECF)

When a hydrocarbon raw material is combined with hydrofluoric acid (HF), application of a strong electric current can break the H – F bond and create reactive fluoride species. These reactive species replace the hydrogens in the hydrocarbon one-by-one with fluorine resulting in a perfluorinated molecule. ECF produces odd and even numbered chains as well as branched and linear mixtures. ECF was the dominant global method of production (principally by the 3M Company) for both PFOS and PFOA from the late 1940s until their U.S. phase-out beginning around the year 2000, and subsequent 2006 – 2015 stewardship program (De Voogt, 2010; EPA, 2000, 2018).

ECF related production of short-chains PFAS products became available in the 2000s, and ECF production of long-chains was started in Asian countries such as China to fill the void left by the major global manufacturers who exited production (ITRC, 2020a). ECF is still used in both the U.S. and abroad, especially in China, India, and Russia (OECD, 2015).

Perfluorooctane sulfonyl fluoride (POSF) from the ECF process was the basic building block for a wide variety of surfactant and polymer products, including PFOS. Figure 11 illustrates the reaction that produces POSF through ECF.

Figure 11. A schematic of the ECF reaction that forms PFOS.

1.3.2 Telomerization

Following the phase-out of PFOS and PFOA production by ECF, telomerization has become the more dominant process for producing perfluorinated alkyl chain raw materials. Telomerization is a polymerization reaction that results in products with even-numbered carbon chain lengths and a terminal iodide (I) functional group. PFOA can be subsequently made by oxidizing PFI with sulfur trioxide. Insertion of the hydrocarbon ethylene instead of fluorocarbon reactants converts a perfluorinated molecule to a linear polyfluorinated alkyl chain, such as the 8:2 fluorotelomer iodide (8:2 FTI). Figures 12 and 13 respectively illustrate each of these reactions.

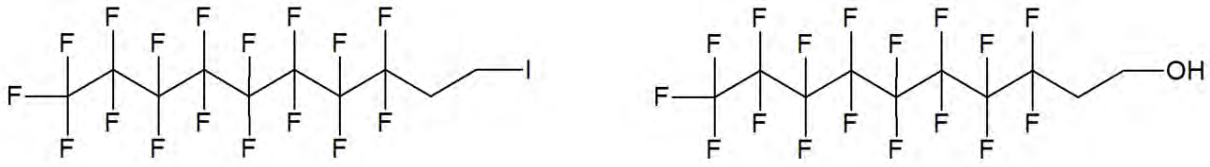
Figure 12. Schematic of telogen (perfluoroethyl iodide) reacting with three taxogen units (tetrafluoroethene) to form a perfluorinated product, perfluorooctyl iodide (PFI).

Figure 13. Schematic of PFI further reacting with the hydrocarbon ethene to form the polyfluorinated 8:2 fluorotelomer iodide (FTI).

FTI can be converted to alcohols (FTOHs) and further functionalized for use as fluorotelomer surfactants. Figure 14 provides the example of an 8:2 fluorotelomer iodide shown on the left, and its alcohol counterpart shown on the right. In the case of this fluorotelomer, the “8” refers to the eight perfluorinated carbons, and the “2” refers to the two hydrogenated carbons (Hs not shown) adjacent to the end group. A significant share of the fluorotelomer market is for side-chain fluorinated polymers (Grand View Research Inc., 2020) such as the fluorotelomer acrylates (FTACs), which are made from FTOH monomers, but can also made via ECF (Rankin, 2015).

Because FTOH have been manufactured more recently, their presence in environmental media can be an indication of more recent contamination sources.

Figure 14. An 8:2 fluorotelomer iodide (left) can be converted to an 8:2 fluorotelomer alcohol (right).



1.3.3 Other processes

As identified in Tables 4 and 5, the per- and polyfluoroalkyl substances described in the previous sections can be used as raw materials or intermediates for commercial products. Some of the main manufacturing processes used to modify these intermediates, such as the addition of functional groups, are well described in Knepper and Lange (2012).

Since the 1970s, several manufacturers have developed independent production paths to produce the many per- and polyfluorinated ether surfactants and perfluoropolyether products available on the market today (Dams & Hinzter, 2016; Knepper & Lange, 2012). Literature has only recently begun to identify and assess these substances (Sun et al., 2016; Wang et al., 2013).

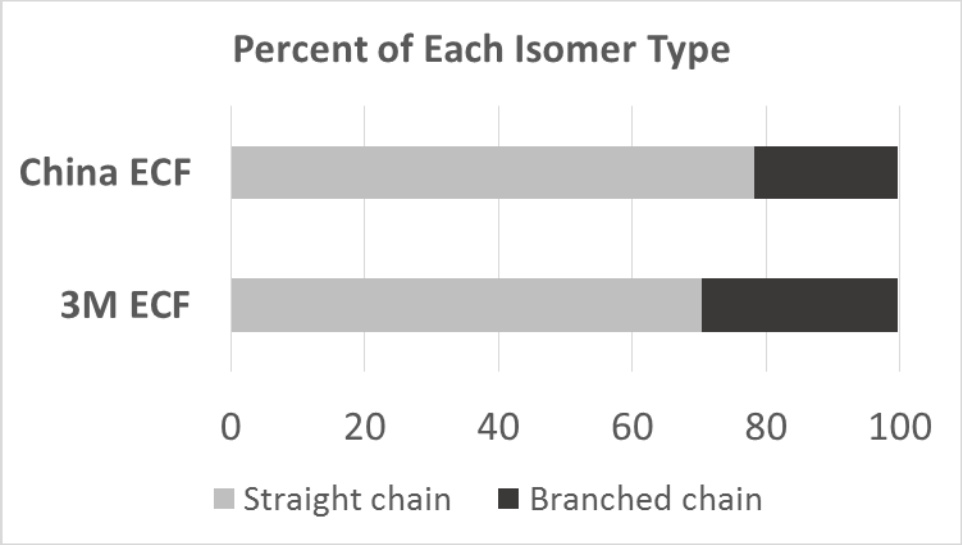
As identified in Appendix 3, Section 3.1.2 Secondary Manufacturing, although several thousand distinct PFAS may have been used worldwide in manufacturing processes since their inception, approximately 200 to 600 PFAS are currently commercially active in the U.S. (Naturvårdsverket, 2016, as cited by Banzhaf et al., 2017; EPA, 2019; Buck et al., 2021).

1.3.4 Technical quality and implications for environmental impacts

While discrete substances, like PFOS or PFOA, are the focus of the discussion of environmental impacts, the ECF and telomerization processes produce a complex mixture of substances rather than pure one-component products. For example, the harsh conditions of the ECF process lead to a variety of unwanted side-reactions. The resulting product mixture may contain both linear and branched chains with both odd and even chain lengths. ECF production targeting PFOA (C8) includes 70 – 80% linear substances (of differing carbon chain lengths) with 20 – 30% branched substances, including even cyclic compounds (De Voogt, 2010).

While ECF mixtures randomly vary, they are sufficiently consistent for forensic application. PFAS environmental contaminants collected in China matched the chain-length profile expected for ECF products, suggesting that nearby manufacturing facilities employ the ECF process (Jiang, 2015). Figure 15 illustrates the isomer composition of two ECF products (adapted from Jiang, 2015). As one would expect, the majority of these ECF products are “normal” or straight-chain isomers, but may contain 20 – 30% of various branched isomers. The top bar represents Chinese ECF production (Defu PFOSK, China). The bottom bar is typical of a 2000-era 3M PFOS. The similarity of the composition confirms that both were manufactured using ECF.

Figure 15. Comparison of two-carbon tetrafluoroethene taxogens manufactured using ECF (Jiang et al., 2015).



The telomerization process also produces a mixture of substances, typically a series of straight chains varying in length by even numbers. For example, production targeting the 6:2 FTI may include minor quantities of 8:2 and 4:2 chain lengths. The two-carbon tetrafluoroethene taxogen (shown in Figure 12) adds about 100 grams per mole (g/mol) in each addition step. The change in properties between the C_n to C_{n+2} homologue allows for purification by distillation (Krafft & Riess, 2015). The extent to which manufacturers purify their products or otherwise control for by-product content is not well understood.

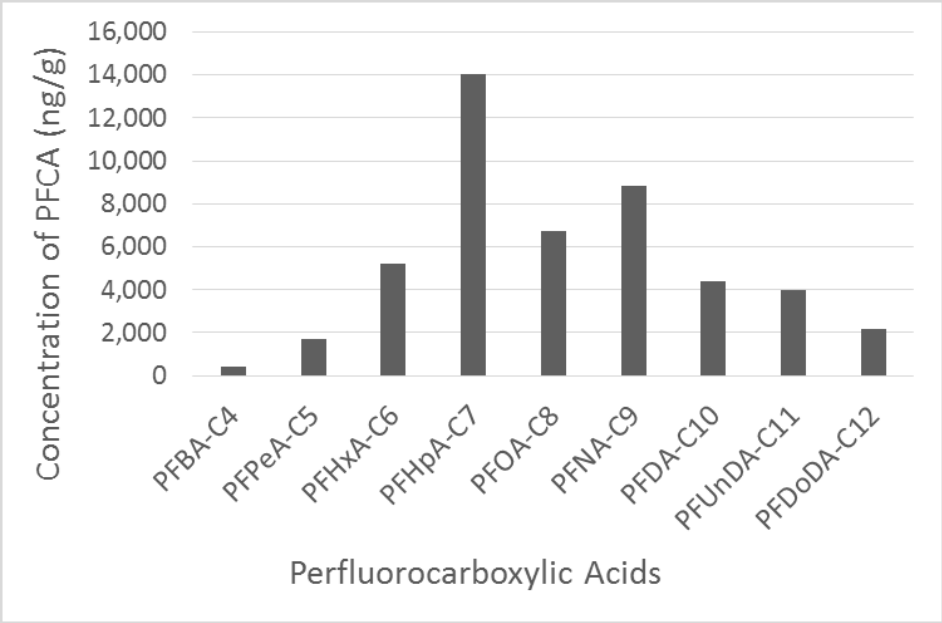
Products have been marketed as mixtures of PFAS isomers or homologues (KEMI, 2015). For example, Surflon® S-111, a now-discontinued surfactant produced by telomerization, contained primarily 9-C perfluorononanoic acid (PFNA), but also significant quantities of 11-C perfluoroundecanoic acid (PFUnDA) (20%) and 13-C perfluoro-tridecanoic acid (PFTrDA) (5%) (Prevedouros et al., 2006). Chemical analysis of "articles of commerce" shows that many formulated products have been composed of complex PFAS mixtures (Figure 15) (Liu et al., 2012).

Products may also be contaminated with residual raw materials, polymerization aids, and unintended by-products. PFOA, higher molecular weight homologues, and PFOA precursors have all been found in fluorotelomer and fluoropolymer products. Similarly, FTOHs and fluorotelomer olefins (FTOs) have been identified in fluorotelomer acrylate and methacrylate products (Lassen et al., 2013).

Figure 16 provides an illustrative example of the various PFAS making up a single commercial product—in this case, a carpet or upholstery protector concentrate. As indicated in the figure, the sample contains a wide distribution of chain lengths. Many other commercial PFAS-based products may also be composed of multiple PFAS. This shows that PFAS manufacturing and the use of PFAS in products can lead to emission of a multitude of PFAS. As further explained in Appendix 4: Fate and Transport, environmental transformation of manufactured PFAS may lead to an even larger variety of contaminants. Appendix 2: Analytical Methods further addresses

the fact that analytical methods approved by EPA and other agencies are not able to detect all PFAS present in a sample, but only those targeted by the analytical method.

Figure 16. Analytical chemistry data for the PFCA content (C4 – C12) of a U.S. carpet or upholstery protector concentrate (Liu et al., 2012).



1.3.5 Trends in per- and polyfluorinated substance design

PFOS and PFOA, both which are characterized as long-chains, dominate the literature on PFAS due to their well-established PBT properties. These substances are associated with workhorse technologies of the first decades of PFAS development and use. PFOS is both a directly manufactured product and a highly stable degradation product of many legacy POSF-based surfactants. PFOS can also occur as an impurity in derivative products. The ammonium salt of PFOA, APFO, was widely used as a polymerization aid in fluoropolymer manufacture (Buck et al., 2011). PFOA emissions have historically been linked to releases from these manufacturing operations (Prevedouros et al., 2006), but also occur as breakdown products of PFOA-precursors like the fluorotelomer alcohols. Production of PFOS- and PFOA-associated chemistries has continued in China, India, and Russia. Figure 17 illustrates historical estimated emissions based on manufacturing location. Based on these estimates, production-related PFCA emissions were expected to be substantively eliminated in Japan, Western Europe, and the U.S. by 2002, but have continued in China, India, and Russia (ITRC, 2020a). Articles treated with long-chain PFAS are still imported from these countries to the U.S.

Due to regulatory restrictions and voluntary withdrawal campaigns regarding long-chain PFAS (see Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency), manufacturers in the U.S., Western Europe, and Japan have shifted manufacture primarily to replacement shorter-chain PFAS. Shorter-chain alternatives include (OECD, 2013):

- Perfluorobutane sulfonyl fluoride (PBSF)-based derivatives.
- Shorter-chain (i.e., 6:2) fluorotelomer-based chemicals.

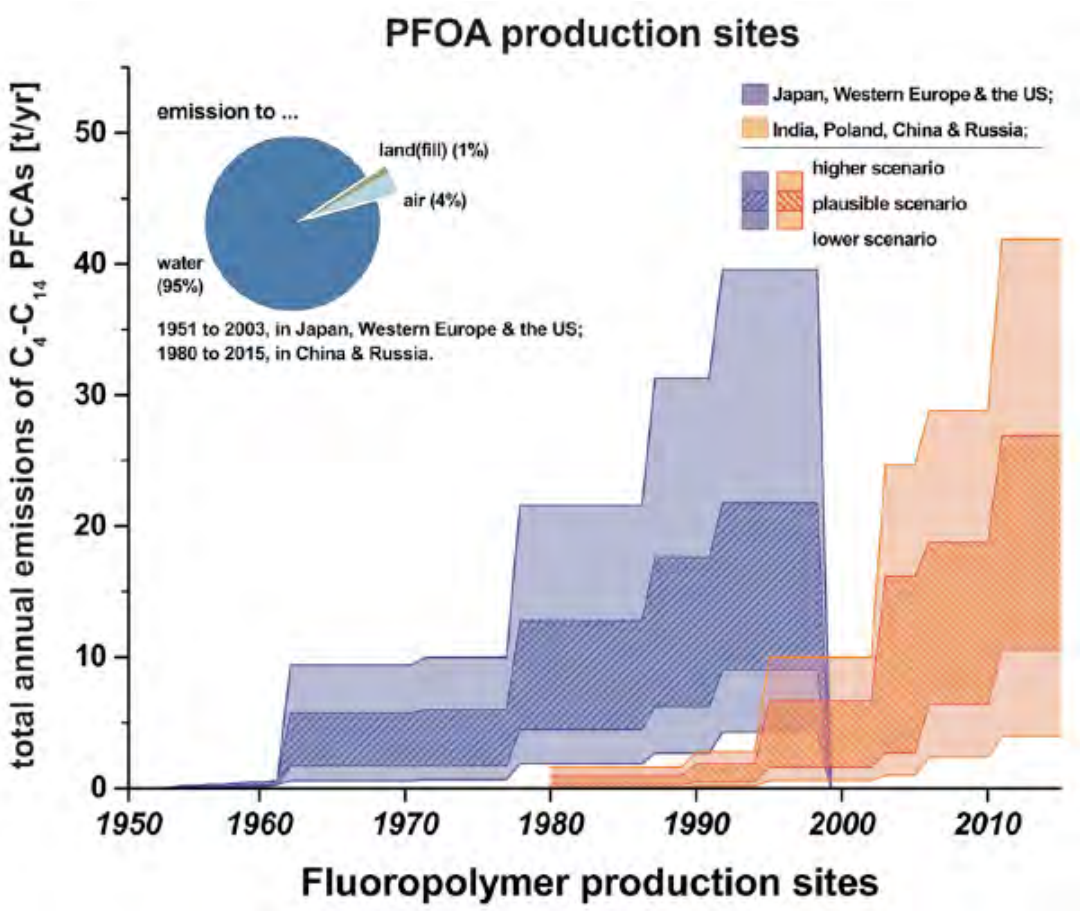
- Mono- and polyfluorinated-ether compounds.
- Fluorinated oxetanes.
- Other fluorinated polymers.

Both legacy products (which are responsible for much of current-day emissions) and newer chemistries of so-called alternative or replacement products are included in the discussion of commercially used products in Section 1.4 below. It is important to remember that PFOA may be present as a manufacturing impurity in shorter-chain products made by telomerization. If non-target isomers and homologues are not removed by further processing, they will end up in the final product formulation or treated articles.

Information is lacking regarding the effects and fate of short-chain PFAS in general, in the environment, and their toxicological profiles. Ateia et al. (2019) reviewed the information available regarding short-chain PFAS and identified the following challenges in characterizing and quantifying their long-term effects once released in the environment:

- These substances can persist in the environment.
- Few of them have been identified because they remain proprietary.
- Their release may continue indefinitely into the future.

Figure 17. Manufacturing emissions estimates from the OECD (Wang et al., 2014).



1.4 Characteristic product uses of PFAS

Poulsen (2005) discussed legacy product designs in detail. In addition to legacy products, current-use products have also been addressed by OECD (2013), Buck et al. (2011), and Knepper and Lange (2012). Appendix 3: Sources and Uses discusses commercial PFAS uses in detail.

This section focuses on better-known product types and substances more commonly discussed in the environmental literature, as well as their relationships to specific PFAS chemistries and characteristics. While fluoropolymers dominate the market for fluorinated materials, this section will limit the polymer discussion primarily to side-chain polymers and perfluoropolyethers used as surface treatments.

Example substances for both legacy and current-use PFAS in some selected use categories are presented in Table 7. While the term "legacy" suggests an old or outdated use, the terminology is used more loosely here because:

- Some of the identified legacy substances may still be manufactured in foreign markets and imported to the U.S. (as discussed above in Section 1.3.4).
- Some legacy substances were recently withdrawn from the U.S. market and may still be in use or stockpiled, such as long-chain PFAS in treated carpets or firefighting foams.
- Some otherwise widely banned substances have permitted (exempt) uses, such as long-chain PFAS in mist suppressants for chrome-plating operations. This use of PFOS has been phased out by industry in the U.S. (NASF, 2019).

Table 7. Typical examples of legacy and current-use products for selected use categories (Danish Environmental Protection Agency (DEPA), 2015; United Nations Environmental Programme (UNEP), 2013). (See Tables 4, 5, and 6 for definitions of abbreviations.)

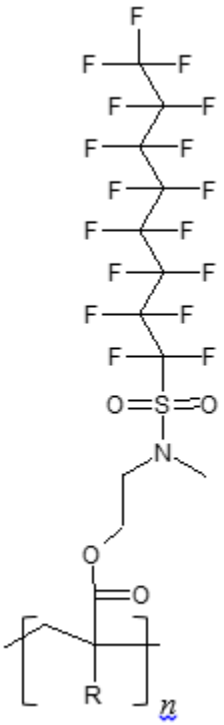
Use category	Example legacy products	Example current-use product
Carpet, textile, leather, stone and tile, paints and coating additives and treatments	PFOS, N-ethyl perfluorooctane sulfonamidoethanol (EtFOSE)-based acrylate, FTOH-based acrylate, methacrylate and urethane side-chain polymers	≤C6 FTI/FTOH- and PBSF-based acrylate, methacrylate and urethane side-chain polymers
Paper and packaging treatment	EtFFOSE phosphate esters, N-methyl perfluorooctane sulfonamido-ethanol (MeFOSE) acrylate polymers	Perfluoropolyethers, ≤C6 Side-chain fluorinated polymers
Specialty chemicals used in oil production	Potassium salt of glycine, N-ethyl-N-[(heptadecafluorooctyl)sulfonyl] (PFOS-based surfactant)	FTOH- and PBSF-based surfactants, perfluoropolyethers
Fire-fighting chemicals	Perfluoroalkyl sulfonamido amine derivatives and other PFOS-based products	6:2 FTAB (FTalkyl iodide-based surfactant) and 6:2 thiol derivatives (6:2-SH)
Polymer processing aids	PFOA, PFNA	Ammonium salts of PFOA, perfluoroalkyl ether carboxylates (PFECA's)
Metal plating	PFOS	6:2-Fluorotelomer sulfonate (6:2 FTS)

1.4.1 Carpet and textile surface treatment

Surface treatments for carpets, upholstery, leather, apparel, and other textiles are the largest market for fluorinated side-chain polymers. Carpeting and upholstery involve large treated areas and stain-resistance treatment is a frequent specification among institutional purchasers (DTSC, 2017).

POSF is a manufacturing precursor for the perfluoroalkane sulfonamido alcohols. These alcohols are converted to acrylates and methacrylates used as monomers in the production of polymeric surface protection products. Acrylates of N-methyl or N-ethyl perfluorooctane sulfonamido ethanol (MeFOSE and EtFOSE) and related precursors have been phased-out among U.S., Western Europe, and Japanese manufacturers over the last decade. A single MeFOSE-derived side-chain "tooth" is shown in Figure 18. These products were no longer produced in the U.S. after the early 2000s.

Figure 18. Legacy carpet treatment chemistry.



Similarly, fluorotelomer alcohols and ethyl iodides are the basis for acrylate, methacrylate, or urethane substances that are polymerized to form fluorinated side-chain polymers as illustrated previously in Figure 9. Early versions of these telomer-based products contained broad ranges of chain lengths (e.g., recall Figure 16 analytical results) (Dinglasan-Panlilio & Mabury, 2006). Fluorotelomer products (4:2 or 6:2) have replaced the longer chain legacy products in the U.S., Western Europe, Japan, and elsewhere globally.

1.4.2 Paper and packaging treatment

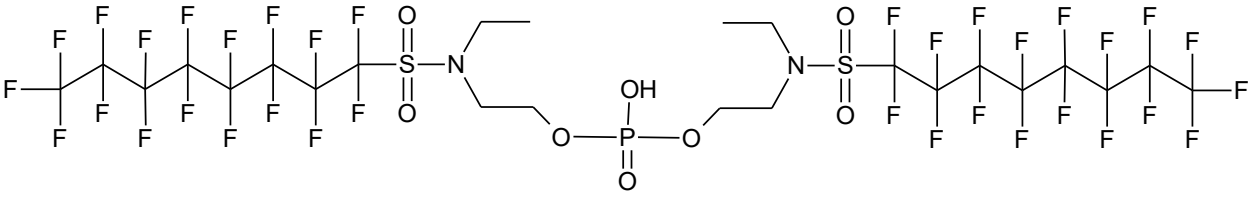
Surface treatment and impregnation products provide water, oil, and grease resistance and non-stick performance for paper and packaging. These include both food-contact materials, like popcorn bags, pizza boxes, and fast-food wrappers, and non-food applications, such as masking papers and folding cartons.

Legacy products include variants of perfluorooctane sulfonamido alcohols (like EtFOSE) in perfluoroalkyl phosphoric acid products, also called SAmPAPs (D'eon et al., 2009; Geueke, 2016). As an example, Figure 19 provides a schematic of a phosphate di-ester formed from EtFOSE. These and related mono- and tri-esters are also called SAmPAPs and are among the first perfluorinated substances widely commercialized for food packaging. Prior to their removal from commerce in the U.S., SAmPAPs were reportedly the largest source of PFOS precursors in the commercial market (Benskin et al., 2012).

The MeFOSE-based acrylate polymers similar to those used in textiles were also used for paper protection. PFOS-based and other long-chain chemistries are still used for food-contact materials in Thailand and China (Benskin et al., 2012; Geueke, 2016; Yuan et al., 2016). A very

recent review from the Nordic Council of Ministers includes a broad survey of PFAS food packaging chemicals worldwide (Trier et al., 2018).

Figure 19. A phosphate di-ester formed from EtFOSE.



Current-use alternatives in food-contact materials may be based on:

- Short-chain replacements for the FOSE-like products, such as N-ethyl perfluorobutane sulfonamidoethanol (EtFBSE) (Geueke, 2016).
- Fluorotelomer acrylate and methacrylate side-chain polymers made with short-chain fluorotelomer intermediates. It should be noted that fluorotelomer-based PAPs are not listed as approved products on the U.S. Food and Drug Administration's (FDA) current Food Contact Notification (FCN) listing.
- Fluorotelomer-based mono-, di-, and triPAPs (such as tri-polyfluoroalkyl phosphoric acid) (Zabaleta et al., 2017).
- Perfluoropolyethers (Wang et al., 2013).

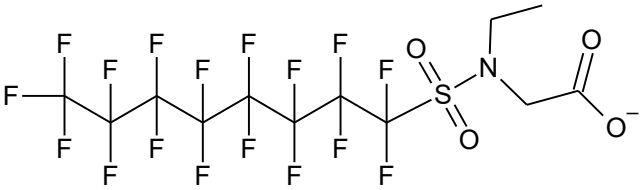
1.4.3 Specialty chemicals

Fluorinated surfactants are used in innumerable industrial and consumer products, where they provide advantages both during application and in the final product performance. Paints, coatings, and sealants need to wet the solid substrate and penetrate into crevices or other imperfections. The final finish should be smooth and level. These performance characteristics are all facilitated by the very low surface tension obtained using fluorosurfactants. When appropriately formulated, the same or related surfactants can impart water, oil, and dirt resistance to painted walls, sealed grout, or polished floors.

PFAS are also used in a wide-range of functional fluids. These include lubricants for use in harsh or reactive environments such as space applications, vacuum pump fluids, and heat transfer fluids. Other specialty applications include friction reduction, anti-adhesion products, and anti-squeak products used in automotive applications. Certain PFAS are also used as polymer processing aids (as illustrated in Section 1.4.5 below).

Liquid-applied products vary substantially by type, and the specialty chemical market requires a broad range of surfactant designs. Knepper and Lange (2012) provides a number of examples with supporting literature references. A study of commercial products purchased around 2010 (such as the carpet protector in Figure 16 above) often contained a mix of PFAA chain-lengths (4-C to 12-C PFAAs were quantified) (Liu et al., 2012). The potassium salt of glycine, N-ethyl-N-[(heptadecafluorooctyl)sulfonyl] (Chemical Abstract Services Registration Number [CASRN] 2991-51-7, also marketed as Fluorad 129, now discontinued) is a typical legacy POSF-based substance used in cleaning agents and polishing products (Poulsen et al., 2005). Figure 20 provides an illustrative schematic of this compound.

Figure 20. Typical legacy POSF-based surfactant used in liquid-applied products.



As for the applications described above, current-use surfactant products can be similar in structure to the legacy products, but with shorter perfluorinated chains. Product brochures from major manufacturers identify 4-C (PFBS) and 6-C (6:2 FTOH) chemistries for a wide-range of product types (3M, 2016; DuPont, 2008).

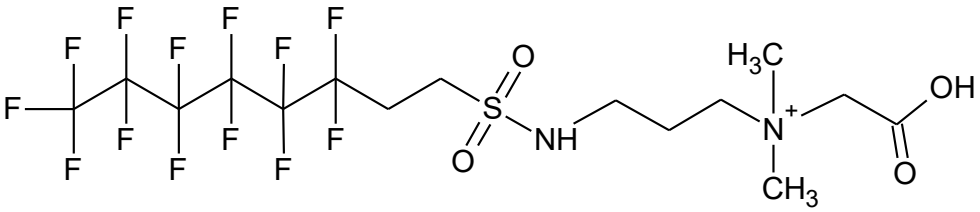
1.4.4 Fire-fighting chemicals

PFAS-based AFFF (aqueous film forming foams) were developed in the 1960s to extinguish Class B flammable liquid fuel fires. After extinguishing the fire, the foam-surfactant film acts as a radiation barrier and vapor-sealant to prevent re-ignition of the fuel or "burnback." Impacts of AFFF use are discussed in additional detail in Appendix 3: Sources and Uses, Section 3.2 Aqueous film forming foam.

While PFCAs were used only in the earliest AFFF formulations, POSF-based products dominated the market in the 1970s and later (Prevedouros et al., 2006). Many 1970 – 2000-era AFFF products were PFSA-based, with derivatives of perfluoroalkylsulfamido amines and PFOS as "major presence(s)" (Favreau et al., 2017).

Formulations for the military produced in the 1980s to early 2000s contained perfluorinated chains up to 8-, 9-, and 10-C in some cases (Place & Field, 2012). Starting in the 1970s, fluorotelomer-based AFFF products with shorter perfluorinated chains (such as the 6:2 fluorotelomer sulfonamide alkylbetaine) were placed into use (6:2 FTAB, Figure 21) (Wang et al., 2013). Higher purity versions of these products continue to be used today. Figure 21 provides a schematic of the structure of a 6:2 FTAB surfactant typical of fire-fighting foam products. These can also carry a three-digit prefix indicating three types of carbons: X:Y:Z (perfluorinated-polyfluorinated-non-fluorinated) carbons (Place & Field, 2012). Foam concentrates may contain additional surfactants (PFAS and non-PFAS) as well as other adjuvants.

Figure 21. 6:2 FTAB surfactant typical of fire-fighting foam products.



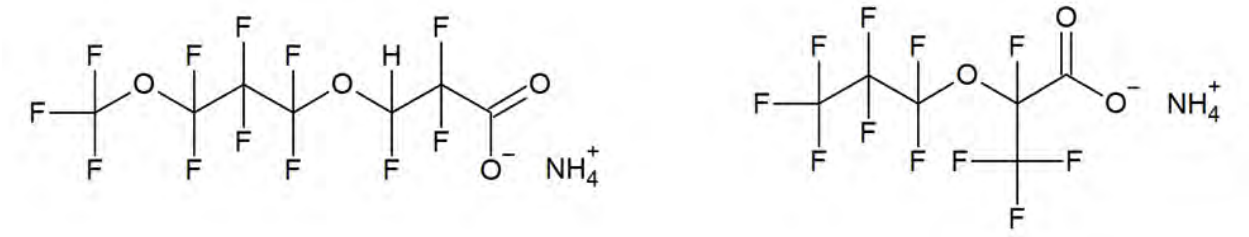
1.4.5 Polymer processing aids

Fluorinated surfactants are used as emulsifiers in aqueous reaction systems, for example, the emulsion polymerization of PTFE. Sodium and ammonium salts of PFOA and PFNA were widely used in the U.S. and Europe, and their use continues in developing and transitional economies.

Newer processing aids identified in the literature are functionalized ethers or polyethers, which contain single or multiple ether O-atoms. Among these are (Wang et al., 2013):

- Ammonium 3H-perfluoro-3-[(3-methoxy-propoxy)propanoic acid], CASRN 958445-44-8 (illustrated in Figure 22 to the left).
- Ammonium perfluoro-2-propoxypropanoic acid (PFPrOPrA), CASRN 62037-80-3 (illustrated in Figure 22 to the right).

Figure 22. Two processing aids used in fluoropolymer production.



1.5 Data gaps and recommendations

1.5.1 Data gaps

While much of the discussion of PFAS focuses on well-known substances like PFOA, PFOS, and perfluorohexanoic acid (PFHxA), as stated in the introduction, there are hundreds of different PFAS in use in the U.S. In many cases, the specific applications where they are used remain proprietary, and there is little publicly available information regarding the properties and fate of manufactured products after product use is discontinued.

1.5.2 Recommendations

Proper understanding of PFAS structures and characteristics is necessary to inform recommended activities described in the PFAS Chemical Action Plan (CAP) recommendations.

References

3M. (2016). 3M TM Fluorosurfactants for Paints and Coatings. St. Paul. Retrieved from http://multimedia.3m.com/mws/media/624307O/3m-fluorosurfactants-for-paints-and-coating.pdf

Ateia, M., Maroli, A., Tharayil, N., & Karanfil, T. (2019). The overlooked short- and ultrashort-chain poly- and perfluorinated substances: A review. *Chemosphere*, *220*, 866–882. https://doi.org/10.1016/j.chemosphere.2018.12.186

Benskin, J. P., Ikonomou, M. G., Gobas, F. A. P. C., Woudneh, M. B., & Cosgrove, J. R. (2012). Observation of a Novel PFOS-Precursor, the Perfluorooctane Sulfonamido Ethanol-Based Phosphate (SAmPAP) Diester, in Marine Sediments. *Environmental Science & Technology*, *46*, 6505–6514. https://doi.org/10.1021/es300823m

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., de Voogt, P., Jensen, A. A., Kannan, K., Mabury, S. A., & van Leeuwen, S. P. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environmental Assessment and Management*, *7*, 513–541. https://doi.org/10.1002/ieam.258

Buck, R., Korzeniowski, S., Laganis, E., & Adamsky, F. (2021). Identification and Classification of Commercially Relevant Per-and Poly-fluoroalkyl Substances (PFAS). *Integrated Environmental Assessment and Management, 00,* 1 – 11. https://doi.org/10.1002/ieam.4450

Chapter 173-333 WAC: PERSISTENT BIOACCUMULATIVE TOXINS

Chemours. (2017). Capstone™ Fluorosurfactants: For high value-in-use applications that require maximum performance. Retrieved from https://www.chemours.com/en-/media/files/capstone/capstone-surfactants-brochure.pdf

Dams, R., & Hintzer, K. (2016). Chapter 1. Industrial Aspects of Fluorinated Oligomers and Polymers. In B. Ameduri & H. Sawada (Eds.), *Fluorinated Polymers: Volume 2: Applications* (pp. 1–31). https://doi.org/10.1039/9781782629368-00001

D'eon, J. C., Crozier, P. W., Furdui, V. I., Reiner, E. J., Libelo, E. L., & Mabury, S. A. (2009). Observation of a Commercial Fluorinated Material, the Polyfluoroalkyl Phosphoric Acid Diesters, in Human Sera, Wastewater Treatment Plant Sludge, and Paper Fibers. *Environmental Science & Technology*, *43*, 4589–4594. https://doi.org/10.1021/es900100d

De Voogt, P. (2010). Reviews of Environmental Contamination and Toxicology Volume 208 (Vol. 208). Springer New York. https://doi.org/10.1007/978-1-4419-6880-7

Dinglasan-Panlilio, M. J. A., & Mabury, S. A. (2006). Significant residual fluorinated alcohols present in various fluorinated materials. *Environmental Science & Technology*, *40*, 1447–1453. https://doi.org/10.1021/es051619+

DTSC. (2017). Safer Consumer Products - PFAS Public Workshop: Jan 31, 2017 - YouTube. Retrieved from https://www.youtube.com/watch?v=MryvxUSlxbA&feature=youtu.be

Favreau, P., Poncioni-Rothlisberger, C., Place, B. J., Bouchex-Bellomie, H., Weber, A., Tremp, J., Field, J. A., & Kohler, M. (2017). Multianalyte profiling of per- and polyfluoroalkyl substances (PFASs) in liquid commercial products. *Chemosphere*, *171*, 491–501. https://doi.org/10.1016/j.chemosphere.2016.11.127

Geueke, B. (2016). Dossier - Per- and polyfluoroalkyl substances (PFASs). Zurich. https://doi.org/10.5281/zenodo.57198

Grand View Research Inc. (2020). Fluorotelomers Market Size, Share & Trends Analysis Report, By Product (Fluorotelomer Alcohol, Fluorotelomer Acrylate, Fluorotelomer Iodide), By Application (Fire Fighting Foams, Food Packaging, Stain Resistance, Textiles) And Segment Forecasts To 2020. Retrieved July 13, 2020 from https://www.grandviewresearch.com/industry-analysis/fluorotelomers-market

Guo, Z., Liu, X., Krebs, K. A., & Roache, N. F. (2009). Perfluorocarboxylic Acid Content in 116 Articles of Commerce. In US Environmental Protection Agency. Retrieved from https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=206124

Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., Seed, J., & Hernandez, O. (2018). A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integrated Environmental Assessment and Management*, *14*(3), 316–334. https://doi.org/10.1002/ieam.4035

Heydebreck, F., Tang, J., Xie, Z., & Ebinghaus, R. (2015). Alternative and Legacy Perfluoroalkyl Substances: Differences between European and Chinese River/Estuary Systems. *Environmental Science & Technology*, *49*, 8386–8395. https://doi.org/10.1021/acs.est.5b01648

Hopkins, Z. R., Sun, M., DeWitt, J. C., & Knappe, D. R. U. (2018). Recently Detected Drinking Water Contaminants: GenX and Other Per- and Polyfluoroalkyl Ether Acids. *American Water Works Association*, *110*, 13–28. https://doi.org/10.1002/awwa.1073

Hu, X. C., Andrews, D. Q., Lindstrom, A. B., Bruton, T. A., Schaider, L. A., Grandjean, P., Lohmann, R., Carignan, C. C., Blum, A., Balan, S. A., Higgins, C. P., & Sunderland, E. M. (2016). Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Military Fire Training Areas, and Wastewater Treatment Plants. *Environmental Science & Technology Letters*, *3*, 344–350. https://doi.org/10.1021/acs.estlett.6b00260

Interstate Technology & Regulatory Council (ITRC). (2020a). History and Use of Per- and Polyfluoroalkyl Substances (PFAS). Retrieved from https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_History_and_Use_April2020.pdf

Interstate Technology & Regulatory Council (ITRC). (2020b). Naming Conventions and Physical and Chemical Properties of Per- and Polyfluoroalkyl Substances (PFAS). Retrieved from https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_Naming_Conventions_April2020.pdf

Interstate Technology & Regulatory Council (ITRC). (2020c). *PFAS — Per- and Polyfluoroalkyl Substances: 4 Physical and Chemical Properties*. Retrieved from https://pfas-1.itrcweb.org/4-physical-and-chemical-properties/

Jiang, W., Zhang, Y., Yang, L., Chu, X., & Zhu, L. (2015). Perfluoroalkyl acids (PFAAs) with isomer analysis in the commercial PFOS and PFOA products in China. *Chemosphere*, *127*, 180–187. https://doi.org/10.1016/j.chemosphere.2015.01.049

Johansson, J. (2017). Sources, Transport and Fate of Perfluoroalkyl Acids in the Atmosphere. *Department of Environmental Science and Analytical Chemistry Stockholm University*. Retrieved from https://www.diva-portal.org/smash/get/diva2:1090949/FULLTEXT01.pdf

Knepper, T. P., & Lange, F. T. (2012). Polyfluorinated Chemicals and Transformation Products (Vol. 17). *Springer Berlin Heidelberg*. https://doi.org/10.1007/978-3-642-21872-9

Korzeniowski, S. H., & Buck, R. C. (2019a). The PFAS Universe: Uses, Classes & Degradation; Webinar for IC2 & MA TURI*. Interstate Chemicals Clearinghouse.* Retrieved from http://theic2.org/ic2_webinar_the_pfas_universe

Korzeniowski, S. H., & Buck, R. C. (2019b). The PFAS Universe: Uses, Classes & Degradation; Webinar for IC2 & MA TURI. [PowerPoint Slides]. *Interstate Chemicals Clearinghouse.* Retrieved from http://theic2.org/article/download-pdf/file_name/2019-01-28_The PFAS Universe Webinar 30Jan2019_FINAL_1p.pdf

Korzeniowski, S. H., & Buck, R. C. (2019c). The PFAS Universe: Uses, Classes & Degradation; Webinar for IC2 & MA TURI. [Questions & Answers Sheet]. *Interstate Chemicals Clearinghouse.* Retrieved from http://theic2.org/article/download-pdf/file_name/20190312_ACC Fluorocouncil Webinar 30JAN2019 QA Answers.pdf

Krafft, M. P., & Riess, J. G. (2015). Selected physicochemical aspects of poly- and perfluoroalkylated substances relevant to performance, environment and sustainability—Part one. *Chemosphere*, *129*, 4–19. https://doi.org/10.1016/j.chemosphere.2014.08.039

Krytox. (2020). Frequently Asked Questions About Krytox™ Lubricants. *Chemours*. Retrieved from https://www.krytox.com/en/sales-support/faq

Lassen, C., Jensen, A. A., Potrykus, A., Christensen, F., Kjølholt, J., Jeppesen, C. N., Mikkelsen, S. H., & Innanen, S. (2013). Survey of PFOS, PFOA and other perfluoroalkyl and polyfluoroalkyl substances Part of the LOUS-review Environmental Project No. 1475. *The Danish Environmental Protection Agency*. Retrieved from https://www2.mst.dk/Udgiv/publications/2013/04/978-87-93026-03-2.pdf

Lindstrom, A. B., Strynar, M. J., & Libelo, E. L. (2011). Polyfluorinated Compounds: Past, Present, and Future. *Environmental Science & Technology*, *45*, 7954–7961. https://doi.org/10.1021/es2011622

Liu, X., Guo, Z., Krebs, K. A., Pope, R. H., & Roache, N. F. (2012). Trends of Perfluoroalkyl Acid Content in Articles of Commerce — Market Monitoring from 2007 through 2011. Retrieved from https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EUF3.txt

National Association for Surface Finishing (NASF). (2019). Per- and Polyfluoroalkyl Substances: PFAS – Regulatory Landscape. Retrieved from https://nasf.org/wp-content/uploads/2019/04/PFAS-REGULATORY-LANDSCAPE.pdf

Naturvårdsverket. (2016). Highly fluorinated substances (PFAS) and pesticides—An aggregative picture of the occurrence in the environment (in Swedish). Retrieved from https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6709-0.pdf?pid=17835

Organisation for Economic Cooperation and Development (OECD). (2013). OECD/UNEP Global PFC Group, Synthesis paper on per- and polyfluorinated chemicals (PFCs). Retrieved from http://www.oecd.org/env/ehs/risk-management/PFC_FINAL-Web.pdf

Organisation for Economic Cooperation and Development (OECD). (2015). OECD/UNEP Global PFC Group, Working Towards a Global Emission Inventory of PFASs: Focus on PFCAs - Status Quo and the Way Forward. Retrieved from https://www.oecd.org/chemicalsafety/risk-management/Working Towards a Global Emission Inventory of PFASs.pdf

Organisation for Economic Co-operation and Development (OECD). (2018). Toward a New Comprehensive Global Database of Per-and Polyfluoroalkyl Substances (PFASs): Summary Report on Updating the OECD 2007 List of Per-and Polyfluoroalkyl Substances (PFASs). Retrieved from http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en

Organisation for Economic Co-operation and Development (OECD). (2021). Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance, OECD Series on Risk Management, No. 61, OECD Publishing, Paris. Retrieved from https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/terminology-per-and-polyfluoroalkyl-substances.pdf

Pan, Y., Zhang, H., Cui, Q., Sheng, N., Yeung, L. W. Y., Sun, Y., Guo, Y., & Dai, J. (2018). Worldwide Distribution of Novel Perfluoroether Carboxylic and Sulfonic Acids in Surface Water. *Environmental Science & Technology*, *52*, 7621–7629. https://doi.org/10.1021/acs.est.8b00829

Pancras, T., Schrauwen, G., Held, T., Baker, K., Ross, I., & Slenders, H. (2016). Environmental fate and effects of poly and perfluoroalkyl substances (PFAS). *Concawe Soil and Groundwater Taskforce*. Retrieved from https://www.concawe.eu/wp-content/uploads/2016/06/Rpt_16-8.pdf

Place, B. J., & Field, J. A. (2012). Identification of Novel Fluorochemicals in Aqueous Film-Forming Foams Used by the US Military. *Environmental Science & Technology*, *46*, 7120–7127. https://doi.org/10.1021/es301465n

Poulsen, P. B., Jensen, A. A., & Wallström, E. (2005). More environmentally friendly alternatives to PFOS-compounds and PFOA. In *The Danish Environmental Protection Agency*. http://www2.mst.dk/udgiv/publications/2005/87-7614-668-5/pdf/87-7614-669-3.pdf

Prevedouros, K., Cousins, I. T., Buck, R. C., & Korzeniowski, S. H. (2006). Sources, Fate and Transport of Perfluorocarboxylates. *Environmental Science & Technology*, *40*, 32–44. https://doi.org/10.1021/es0512475

Rankin, K. (2015). *Fluorotelomer-Based Acrylate Polymers as an Indirect Source of Perfluoroalkyl Carboxylates*. [Doctoral dissertation, University of Toronto.] Retrieved from https://tspace.library.utoronto.ca/bitstream/1807/69457/3/Rankin_Keegan_201501_PhD_thesis.pdf

Rankin, K., Lee, H., Tseng, P. J., & Mabury, S. A. (2014). Investigating the Biodegradability of a Fluorotelomer-Based Acrylate Polymer in a Soil–Plant Microcosm by Indirect and Direct Analysis. *Environmental Science & Technology*, *48*, 12783–12790. https://doi.org/10.1021/es502986w

Renner, R. (2006). The long and the short of perfluorinated replacements. *Environmental Science & Technology*, *40*, 12–13. https://doi.org/10.1021/es062612a

Ross, I., & Hurst, J. (2019). Technical Bulletin: Managing Risks and Liabilities associated with Per and Polyfluoroalkyl Substances (PFASs). *CL:AIRE*.

Solvay Company. (2015). Technical Data Sheet - Solvera PT 5045 PG. Retrieved from https://www.solvay.com/sites/g/files/srpend221/files/2018-10/Solvera-PT-5045-PG_EN-v1.1_0.pdf

Sun, M., Arevalo, E., Strynar, M., Lindstrom, A., Richardson, M., Kearns, B., Pickett, A., Smith, C., & Knappe, D. R. U. (2016). Legacy and Emerging Perfluoroalkyl Substances Are Important Drinking Water Contaminants in the Cape Fear River Watershed of North Carolina. *Environmental Science & Technology Letters*, *3*, 415–419. https://doi.org/10.1021/acs.estlett.6b00398

The Danish Environmental Protection Agency (DEPA). (2015). Short-chain Polyfluoroalkyl Substances (PFAS): A literature review of information on human health effects and environmental fate and effect aspects of short-chain PFAS Environmental project No. 1707, 2015. Retrieved from https://www2.mst.dk/Udgiv/publications/2015/05/978-87-93352-15-5.pdf

The Swedish Chemicals Agency (KEMI). (2015). Occurrence and use of highly fluorinated substances and alternatives. Retrieved from https://www.kemi.se/global/rapporter/2015/report-7-15-occurrence-and-use-of-highly-fluorinated-substances-and-alternatives.pdf

Trier, D. X., Taxvig, C., Rosenmai, A. K., & Pedersen, G. A. (2018). PFAS in Paper and Board for Food Contact. *Nordic Council of Ministers*. https://doi.org/10.6027/TN2017-573

United Nations Environmental Programme (UNEP). (2013). Guidance on alternatives to perfluorooctane sulfonic acid, its salts, perfluorooctane sulfonyl fluoride and their related chemicals: UNEP/POPS/POPRC.9/INF/11/Rev.1. Retrieved from http://chm.pops.int/Implementation/IndustrialPOPs/PFOS/Guidance/tabid/5225/Default.aspx

U.S. Environmental Protection Agency (EPA). (2019). EPA's Per- and Polyfluoroalkyl Substances (PFAS) Action Plan. Retrieved from https://www.epa.gov/sites/production/files/2019-02/documents/pfas_action_plan_021319_508compliant_1.pdf

U.S. Environmental Protection Agency (EPA). (2000). *EPA and 3M Announce Phase Out of PFAS*. Retrieved from https://archive.epa.gov/epapages/newsroom_archive/newsreleases/33aa946e6cb11f35852568e1005246b4.html

U.S. Environmental Protection Agency (EPA). (2020). PFAS Master List of PFAS Substances (Version 2). Retrieved from https://comptox.epa.gov/dashboard/chemical_lists/PFASMASTER

Wang, Z., Cousins, I. T., Scheringer, M., & Hungerbühler, K. (2013). Fluorinated alternatives to long-chain perfluoroalkyl carboxylic acids (PFCAs), perfluoroalkane sulfonic acids (PFSAs) and their potential precursors. *Environment International*, *60*, 242–248. https://doi.org/10.1016/j.envint.2013.08.021

Wang, Z., Cousins, I. T., Scheringer, M., Buck, R. C., & Hungerbühler, K. (2014). Global emission inventories for C4–C14 perfluoroalkyl carboxylic acid (PFCA) homologues from 1951 to 2030, Part I: production and emissions from quantifiable sources. *Environment International*, *70*, 62–75. https://doi.org/10.1016/j.envint.2014.04.013

Wang, Z., DeWitt, J. C., Higgins, C. P., & Cousins, I. T. (2017). A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? *Environmental Science & Technology*, *51*, 2508–2518. https://doi.org/10.1021/acs.est.6b04806

Yuan, G., Peng, H., Huang, C., & Hu, J. (2016). Ubiquitous Occurrence of Fluorotelomer Alcohols in Eco-Friendly Paper-Made Food-Contact Materials and Their Implication for Human Exposure. *Environmental Science & Technology*, *50*, 942–950. https://doi.org/10.1021/acs.est.5b03806

Zabaleta, I., Negreira, N., Bizkarguenaga, E., Prieto, A., Covaci, A., & Zuloaga, O. (2017). Screening and identification of per- and polyfluoroalkyl substances in microwave popcorn bags. *Food Chemistry*, *230*, 497–506. https://doi.org/10.1016/j.foodchem.2017.03.074

List of acronyms

General acronyms

Table 8. Acronyms found in the chemistry appendix.

Acronym	Definition
CAP	Chemical Action Plan
ECF	Electrochemical fluorination
EPA	United States Environmental Protection Agency
FCN	Food contact notification
FDA	United States Food and Drug Administration
g	grams
g/mol	Grams per mole
ITRC	Interstate Technology & Regulatory Council
mol	Mole
OECD	Organisation for Economic Co-operation and Development

Chemical names

Table 9. Chemical name acronyms found in the chemistry appendix, excluding general acronyms listed only in the table above.

Acronym	Chemical name
6:2 FTAB	6:2 fluorotelomer sulfonamide alkylbetaine
8:2 FTI	8:2 fluorotelomer iodide
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
APFO	Ammonium perfluorooctanoate
Br	Bromium
C	Carbon
Cl	Chlorine
diPAPs	Per- or polyfluoroalkyl phosphate di-esters
EtFBSE	N-ethyl perfluorobutane sulfonamidoethanol
EtFOSE	N-Ethyl perfluorooctane sulfonamidoethanol
F	Fluorine
FTAC	Fluorotelomer acrylate
FTI	Fluorotelomer iodide
FTO	Fluorotelomer olefin
FTOH	Fluorotelomer alcohol
H	Hydrogen
HFPO	Hexafluoropropylene oxide
HFPO-DA(GenX)	Hexafluoropropylene oxide dimer acid

Acronym	Chemical name
I	Iodine
MeFOSE	N-Methyl perfluorooctane sulfonamido-ethanol
monoPAPs	Per- or polyfluoroalkyl phosphate esters
O	Oxygen
OH	Hydroxyl
PAP	Per- or polyfluoroalkyl phosphate ester
PBSF	Perfluorobutane sulfonyl fluoride
PFAA	Perfluorinated alkyl acid
PFAS	Per- and poly-fluorinated alkyl substances
PFCA	Perfluoro-carboxylic acid
PFECA	Perfluoroalkyl ether carboxylic acid
PFHxA	Perfluorohexanoic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFPE	Perfluoropolyether
PFPrOPrA	Perfluoro-2-propoxypropanoic acid
PFSA	Perfluoro- sulfonic acid
PFTrDA	Perfluorotridecanoic acid
PFUnDA	Perfluoroundecanoic acid
POSF	Perfluorooctane sulfonyl fluoride
PTFE	Polytetrafluoroethylene
S	Sulfur
SAmPAPs	Perfluorooctane sulfonamidoethanol-based phosphate esters
triPAPs	Per- or polyfluoroalkyl phosphate tri-esters

Appendix 2: Analytical Methods

2.0 Overview

2.0.1 Findings

A variety of analytical methods are available for the analysis of per- and polyfluoroalkyl substances (PFAS) in the environment and consumer products. Analytical methods for PFAS analysis are still evolving. Currently, few methods are formally validated and published.

A multi-laboratory validated method, U.S. Environmental Protection Agency (EPA) Method 537.1 version 1.0 (EPA, 2018), was published in November 2018 for the analysis of 18 PFAS analytes in drinking water. Method 537.1 is a solid phase extraction (SPE) liquid chromatography/tandem mass spectrometry (LC/MS/MS). Surrogate and internal standards are used to monitor for analyte loss due to sample preparation, instrument drifts, or matrix effects. This method is limited to the analysis of selected PFAS in drinking water samples.

In March 2020, EPA updated Method 537.1. Method 537.1 Revision 2.0 is an editorial update to Method 537.1 Revision 1.0 that includes method flexibility to improve the method performance. Method 537.1 measures PFAS in drinking water using solid phase extraction and LC/MS/MS at low ng/L concentrations.

In December 2019, EPA announced a new validated method for testing additional PFAS in drinking water, EPA Method 533. EPA's Method 533 focuses on those PFAS with carbon chain lengths of 4 – 12. This method complements EPA Method 537.1 Revision 1.0, and can be used to test for 11 additional PFAS. Both methods (537.1 and 533) can measure a total of 29 PFAS in drinking water.

In June 2019, EPA published a validated SW-846 Method 8327—Per- and polyfluoroalkyl substances (PFAS) Using External Standard Calibration and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS). This method conducts a two-phase study for 24 PFAS analytes and 19 isotopically-labeled PFAS surrogates in four aqueous matrices of reagent water, surface water, groundwater, and wastewater effluent, three of which were intended to represent non-potable water matrices.

Draft Method 8328 is tentatively scheduled to be issued by EPA in 2021. The draft Method 8328 will make use of solid-phase extraction (SPE) for non-drinking water aqueous samples and solvent extraction for solid matrices. Isotope dilution (ID) will also be incorporated into Method 8328.

Other published standard methods for PFAS analysis that have not been multi-laboratory validated include the American Society for Testing and Materials International (ASTM) D7979-17 (ASTM, 2017). This method is a direct injection method that requires very little sample preparation. The method can be applied for wide range of liquid environmental samples such as surface water, groundwater, and wastewater influent and effluent. Another method, ASTM D7968-17a (ASTM, 2017a), was developed for analyzing PFAS in soil matrices.

The importance of a multiplatform approach for accurately characterizing PFAS is discussed in this appendix. The multiplatform approach comprises a novel workflow combining target analysis and non-target screening analysis (NTA), in addition to extractable organic fluorine with combustion ion chromatography (EOF/CIC) for the determination of total fluorine (TF), and inorganic fluoride (IF) analysis to characterize the chemical composition of both known and unknown PFAS. This approach resulted in the identification of more PFAS chemicals that were not included in the targeted analysis, but were prioritized samples from EOF for suspect screening and quantification. By using these approaches, the sum of the targeted PFAS and total organic organofluorine concentration were determined, as well as a mass balance of known and unknown organofluorine.

A specific multiplatform approach could be used to identify and quantify multiple PFAS chemicals, and provide data on PFAS presence in varying types of environmental media. Ecology supports the use of approved validated methods as recommended by EPA for specific targeted PFAS analysis.

An important shortcoming of the multiplatform non-target approach is that these methods are not standardized or multi-laboratory validated. For regulatory purposes, standard validated methods such as EPA-validated PFAS analytical methods are recommended. Non-targeted analysis techniques are not validated, and may not be used for regulatory purposes. The uses of these methods are limited to research and investigation.

2.0.2 Introduction

The objective of this appendix is to evaluate the current available analytical methods for the analysis of PFAS in the environment and consumer products. This review includes an assessment of the standard and non-standard analytical methods for the analysis of PFAS. The performance challenges with current standard methods for PFAS analysis and suggested analytical techniques for measuring PFAS are also discussed.

Buck et al. (2011) provides an expanded overview of PFAS in the environment, terminology, classification, and their contributory sources. EPA has an online resource for PFAS (EPA, 2019). The Interstate Technology & Regulatory Council (ITRC) has developed a series of fact sheets that summarize the latest science and emerging technologies regarding PFAS (ITRC, 2018).

The ITRC fact sheet describes methods for evaluating PFAS in the environment, including laboratory analytical methods for PFAS (ITRC, 2018). There are several published papers and literature reviews on analytical methods or techniques for the determination of PFAS in various matrices (Berger et al., 2011; De Voogt et al., 2006; Jahnke et al., 2009). The analytical methods used for PFAS determination are dominated by chromatography, mostly in combination with mass spectrometric detection.

High performance liquid chromatography (HPLC) hyphenated with conductivity or fluorimetric detection and gas chromatography combined with flame ionization or electron capture detection have been used for PFAS analysis (Mahmoud et al., 2009; Moody et al., 2001; Schultz et al., 2004; Trojanowicz et al., 2013). These methods are used for the analysis of specific, targeted PFAS analytes. Most PFAS fractions are quantified during targeted liquid chromatography mass spectrometric (LC/MS/MS) analysis. Commercially relevant internal

standards are available for most of the method analytes, however many of the branch isomers are unknown and standards are not available. As the list of PFAS analytes grows, corresponding isotopically labeled internal standards for these analytes may become available. Otherwise, definitive identification and quantitative analysis are difficult or impossible.

2.1 Published standard methods for PFAS analysis

The following standard methods have been used for PFAS analysis. For detailed procedure and quality control requirements for each method, see the referenced standard methods.

2.1.1 Drinking water methods

The following drinking water methods have been tested and validated. Tested and validated methods are important for ensuring that government and private laboratories can accurately and consistently measure PFAS in the environment, which is critical for estimating exposure and risk.

Method 537.1

EPA Method 537—Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS)—was first published in 2009 for the determination of 14 PFAS in drinking water using SPE and LC-MS/MS (Shoemaker et al., 2008). Table 10 lists the original 14 PFAS determined using Method 537.

A multi-laboratory validated method, EPA method 537.1 version 1.0, was published in November 2018 for the analysis of 18 PFAS analytes in drinking water, including the 14 originally determined using Method 537 and four additional PFAS (Shoemaker & Tettenhorst, 2018). New analytes in the updated method, also shown in Table 10, include for example the GenX (hexafluoropropylene oxide dimer acid [HFPO-DA]) and 4, 8-Dioxa-3H-Perfluorononoic acid (ADONA) (Kato et al., 2008; Strynar et al., 2015). However, non–targeted liquid chromatography with high-resolution mass spectrometer (LC-HRMS) can be applied to identify additional suspected or uncharacterized PFAS if analytical standards are available for PFAS identification and quantification (McDonough et al. 2019).

In March 2020, EPA further updated Method 537.1. Method 537.1 Revision 2.0 is an editorial update to Method 537.1 Revision 1.0 that includes method flexibility to improve the method performance. Method 537.1 measures PFAS in drinking water using solid phase extraction and LC/MS/MS at low ng/L concentrations (Shoemaker & Tettenhorst, 2020). The method flexibility incorporated into revision 2.0 permits laboratories to modify the techniques in the method such as the evaporation and separation techniques. However, changes may not be made to sample collection and preservation, sample extraction steps, or to quality control requirements. EPA recommends that method modifications should be considered only to improve method performance. Modifications that are introduced in the interest of reducing cost or sample processing time, but result in poorer method performance, should not be used.

Analysis of short-chain PFAS using Method 533

In December 2019, EPA announced a new validated method for testing additional PFAS in drinking water, EPA Method 533. EPA's Method 533 focuses on those PFAS with carbon chain lengths of four to twelve, and complements EPA Method 537.1 version 1.0. It can be used to test for 11 additional PFAS, as shown in Table 10. Used together, Methods 537.1 and 533 can measure a total of 29 PFAS chemicals in drinking water.

EPA Method 533 is a SPE LC/MS/MS method for the determination of select PFAS in drinking water. Method 533 requires the use of MS/MS in Multiple Reaction Monitoring (MRM) mode to enhance selectivity. Method 533 incorporates ID, which can minimize sample matrix interference and improve data quality (Rosenblum et al., 2019).

Table 10. EPA validated Methods 537, 537.1 and 533 analyte list.

Analyte	Abbreviation	CASRN	Method 537	Method 537.1	Method 533
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS	763051-92-9	no	yes	yes
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS	756426-58-1	no	yes	yes
4,8-Dioxa-3H-perfluorononanoic acid	ADONA	919005-14-4	no	yes	yes
Hexafluoropropylene oxide dimer acid	HFPO-DA	13252-13-6	no	yes	yes
Perfluorobutanesulfonic acid	PFBS	375-73-5	yes	yes	yes
Perfluorodecanoic acid	PFDA	335-76-2	yes	yes	yes
Perfluorododecanoic acid	PFDoA	307-55-1	yes	yes	yes
Perfluoroheptanoic acid	PFHpA	375-85-9	yes	yes	yes
Perfluorohexanoic acid	PFHxA	307-24-4	yes	yes	yes
Perfluorohexanesulfonic acid	PFHxS	355-46-4	yes	yes	yes
Perfluorononanoic acid	PFNA	375-95-1	yes	yes	yes
Perfluorooctanoic acid	PFOA	335-67-1	yes	yes	yes
Perfluorooctanesulfonic acid	PFOS	1763-23-1	yes	yes	yes
Perfluoroundecanoic acid	PFUnA	2058-94-8	yes	yes	yes
1H,1H, 2H, 2H-Perfluorohexane sulfonic acid	4:2FTS	757124-72-4	no	no	yes

Analyte	Abbreviation	CASRN	Method 537	Method 537.1	Method 533
1H,1H, 2H, 2H-Perfluorooctane sulfonic acid	6:2FTS	27619-97-2	no	no	yes
1H,1H, 2H, 2H-Perfluorodecane sulfonic acid	8:2FTS	39108-34-4	no	no	yes
Nonafluoro-3,6-dioxaheptanoic acid	NFDHA	151772-58-6	no	no	yes
Perfluorobutanoic acid	PFBA	375-22-4	no	no	yes
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	113507-82-7	no	no	yes
Perfluoroheptanesulfonic acid	PFHpS	375-92-8	no	no	yes
Perfluoro-4-methoxybutanoic acid	PFMBA	863090-89-5	no	no	yes
Perfluoro-3-methoxypropanoic acid	PFMPA	377-73-1	no	no	yes
Perfluoropentanoic acid	PFPeA	2706-90-3	no	no	yes
Perfluoropentanesulfonic acid	PFPeS	2706-91-4	no	no	yes
N-ethyl perfluorooctane-sulfonamidoacetic acid	NEtFOSAA	2991-50-6	yes	yes	no
N-methyl perfluorooctane-sulfonamidoacetic acid	NMeFOSAA	2355-31-9	yes	yes	no
Perfluorotetradecanoic acid	PFTA	376-06-7	yes	yes	no
Perfluorotridecanoic acid	PFTrDA	72629-94-8	yes	yes	no

Notes:

- “Yes” denotes that the method can be used to test for the specified analyte.
- “No” denotes that it cannot be used to test for the specified analyte.

These methods (533 and 537.1) measure all forms of the analytes as anions while the identity of the counterion is inconsequential. Method 533 could be used for a variety of environmental monitoring applications, which include the analysis of multiple short-chain PFAS that cannot be measured by Method 537.1 (Rosenblum et al., 2019).

In Method 533, the concentration of each analyte is calculated using the Isotopic Dilution (ID) technique. For quality control (QC) purposes, the percent recoveries of the ID analogues (added to samples prior to sample extraction to function as isotope dilution standards) are calculated using the integrated peak areas of isotope performance standards, which are added to the final extract and function as traditional internal standards, exclusively applied to the ID analogues.

Quantitation of linear and branch isomers of PFAS with drinking water methods

Accurate quantification of PFAS that are mixtures of linear isomers and branched isomers in environmental matrices is useful in understanding both the sources of PFAS and the age of the source, since the production of isomers varies by manufacturing processes. However, such quantification of PFAS can be difficult (Riddell et al., 2009).

With EPA Method 537, laboratories had difficulty in quantifying both linear and branch isomers of perfluorooctanoic acid (PFOA) (Shoemaker & Tettenhorst, 2018). To account for linear and branched isomers of PFOA, EPA recommends that integration and quantitation of drinking water samples include peaks that represent both linear and branched isomers. EPA notes that the correct application of the method is to calibrate using a certified quantitative standard that includes both the linear and branched isomers of each analyte, if available. As of the release of EPA's (2016) technical advisory, there is no certified quantitative mixed standard for PFOA, and the available PFOA standards can be used to account for mixed isomers.

Since there is currently no certified quantitative PFOA standard that contains both linear and branched isomers that can be used to quantitate in the traditional manner, EPA recommends that until such standards are available, labs use the following approach (EPA, 2016):

- Calibrate instrumentation using a certified quantitative standard containing only the linear isomer.
- Identify the branched isomers by analyzing a qualitative or semi-quantitative PFOA mixed standard that includes both linear and branched isomers (Wellington Laboratories, cat#: T-PFOA or equivalent), and compare retention times and tandem mass spectrometry transitions.
- Quantitate PFOA by integrating the total response (i.e., accounting for peaks that are identified as linear and branched isomers) and relying on the initial calibration with the linear-isomer quantitative standard.

Method 533 includes procedures for summing the contribution of multiple isomers to the final reported concentration. Where standard materials containing multiple isomers are commercially available, laboratories are encouraged to obtain the standards for the method analytes. The technical grade standards are used to identify retention times of branched and linear isomers of method analytes (Rosenblum et al., 2019).

2.1.2 Non–drinking water sample methods

Methods 537.1 Revision 2.0 and 533 are specified for analyzing PFAS in drinking water. As a result, they are not amenable to an expanded list of PFAS compounds or to analysis of other sample matrices without modification of the method. Method 537.1 Revision 2.0 only permitted modification to the method techniques for application to drinking water analysis. For

example, it would not work well for the determination of PFAS in consumer products or non-water matrices. Proprietary non-standard methods based on modifications of Method 537 are used by various commercial laboratories for the determination of PFAS in non-drinking water samples. The U.S. Department of Defense (DOD), Environmental Laboratory Accreditation Program (ELAP) maintains a list of laboratories for the determination of PFAS in various environmental media other than drinking water on the Defense Environmental Network Information Exchange (DENIX) server.[112]

With lack of standardization among laboratories performing Method 537 modified, Ecology recommends, as part of the laboratory selection process for non-drinking water analysis (e.g. consumer product), the laboratory analytical procedure should be evaluated based on the DOD Quality Systems Manual (QSM) to ensure all parameters meet acceptance criteria for all analytical QC elements. The QC elements should be evaluated to ensure that they are set at levels that meet the project's measurement quality objectives (MQOs). The laboratories are required to provide an initial demonstration of capability (IDC) consistent with the DOD QSM for Ecology bid evaluation. The QC criteria should not be less stringent than the criteria found in the DOD QSM, Version 5.3, Appendix B, Table B-15 (DOD, 2019) or later version.

Currently, DOD QSM for Environmental Laboratories, Version 5.3, Table B-15 provides the most current and comprehensive set of quality standards for PFAS analysis. These performance-based standards outline specific quality processes for sample preparation, instrument calibration and analysis when working with PFAS. The DOD QSM, Version 5.3, Table B-15, criteria currently require ID quantitation of PFAS. The ID method accounts for interferences caused by complex sample matrices and bias introduced by sample preparation and instrumental issues.

EPA SW-846 Method 8327

In June 2019, EPA published a validated SW-846 Method 8327—Per- and Polyfluoroalkyl Substances (PFAS) Using External Standard Calibration and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS) (EPA, 2019). This method consists of a two-phase study for 24 PFAS analytes and 19 isotopically-labeled PFAS surrogates in four aqueous matrices of reagent water, surface water, groundwater, and wastewater effluent, three of which were intended to represent non-potable water matrices. As identified in Tables 11, 12, and 13 below, the PFAS targets included sulfonic acids (e.g., perfluorooctane sulfonic acid [PFOS]) (Table 11), fluorotelomer sulfonic acids (e.g., 6:2 fluorotelomer sulfonate [FTS]) (Table 11), carboxylic acids (e.g., PFOA) (Table 12), and sulfonamides and sulfonamidoacetic acids (e.g., N-methyl perfluorooctanesulfonamidoacetic acid [N-MeFOSAA]) (Table 13).

Target compounds are identified by comparing multiple reaction monitoring (MRM) transitions in the sample to MRM transitions in the standards. The retention time (RT) and qualifier ion ratio are compared to a mid-level standard to support qualitative identification. Target compounds are quantitated based on the response of their quantifier MRM transitions utilizing external standard calibration. See reference for method detail (EPA, 2019).

[112] https://www.denix.osd.mil/edqw/accreditation/accreditedlabs/

Standards for some target analytes may consist of mixtures of structural isomers. However, the Chemical Abstracts Service Registry Number (CASRN) listed in the tables below is for the normal-chain isomer. All CASRNs in the table are for the acid form. Sulfonic acids in stock standard mixes are typically received as the sodium or potassium salt form. CASRNs for the salt form are not included (EPA, 2019).

Analytes marked with an asterisk (*) in the tables exhibit known difficulties with reproducibility, response, recovery, stability, and/or chromatography that may reduce the overall quality or confidence in the result when using this method. This analyte may require special care to ensure analytical performance will meet the needs of the project and, where necessary, may also require the use of appropriate data qualification. See Section 1.3 of the referenced method for specific information regarding these analytes (EPA, 2019). The final version of Method 8327 was published in the SW-846 Compendium in July 2021 and is available for public use (EPA, 2021a). Section 8.2 of the final version recommends a maximum holding time of 14 days from sample collection to preparation and refrigerated (0 – 6 degrees C) storage as a guideline—it recommends frozen storage to extend sample holding times beyond 14 days.

Table 11. Method 8327 PFAS analytes: PFAS sulfonic acids.

Analyte	CASRN
Perfluoro-1-butanesulfonic acid (PFBS)	375-73-5
Perfluoro-1-pentanesulfonic acid (PFPeS)	2706-91-4
Perfluoro-1-hexanesulfonic acid (PFHxS)	355-46-4
Perfluoro-1-heptanesulfonic acid (PFHpS)	375-92-8
Perfluoro-1-octanesulfonic acid (PFOS)	1763-23-1
Perfluoro-1-nonanesulfonic acid (PFNS)	68259-12-1
Perfluoro-1-decanesulfonic acid (PFDS)	335-77-3
1H, 1H, 2H, 2H-perfluorohexane sulfonic acid (4:2 FTS)	757124-72-4
1H, 1H, 2H, 2H-perfluorooctane sulfonic acid (6:2 FTS)*	27619-97-2
1H, 1H, 2H, 2H-perfluorodecane sulfonic acid (8:2 FTS)*	39108-34-4

Table 12. Method 8327 PFAS analytes: PFAS carboxylic acids.

Analyte	CASRN
Perfluorobutanoic acid (PFBA)*	375-22-4
Perfluoropentanoic acid (PFPeA)*	2706-90-3
Perfluorohexanoic acid (PFHxA)*	307-24-4
Perfluoroheptanoic acid (PFHpA)	375-85-9

Analyte	CASRN
Perfluorooctanoic acid (PFOA)	335-67-1
Perfluorononanoic acid (PFNA)	375-95-1
Perfluorodecanoic acid (PFDA)	335-76-2
Perfluoroundecanoic acid (PFUdA)*	2058-94-8
Perfluorododecanoic acid (PFDoA)*	307-55-1
Perfluorotridecanoic acid (PFTrDA)*	72629-94-8
Perfluorotetradecanoic acid (PFTeDA)*	376-06-7

Table 13. Method 8327 PFAS analytes: PFAS sulfonamides and sulfonamidoacetic acids.

Analyte	CASRN
N-ethylperfluoro-1-octanesulfonamidoacetic acid (N-EtFOSAA)*	2991-50-6
N-methylperfluoro-1-octanesulfonamidoacetic acid (N-MeFOSAA)*	2355-31-9
Perfluoro-1-octanesulfonamide (FOSA)	754-91-6

EPA SW-846 Method 8328

Draft Method 8328 is tentatively scheduled to be issued by EPA in 2021. Draft Method 8328 will make use of solid-phase extraction (SPE) for non-drinking water aqueous samples and solvent extraction for solid matrices. ID will also be incorporated into this method (Mills & Impellitteri, 2019).

It is a more complex method relative to direct injection. The method will account for matrix effects (e.g., sorption) through isotopically marked standard recoveries, and the options to meet DOD requirements. The method is amenable to the same 24 PFAS as in Method 8327 plus GenX in matrices consisting of non-drinking water sources (surface water, groundwater, wastewater) and solids (soils, sediments, biosolids). Two-lab internal validation is ongoing, and an additional ten-lab external validation study is planned. EPA is exploring collaborative efforts with DOD on external validation. The target quantitation limit for Method 8328 is 10 nanograms (ng)/liter(L).

EPA Methods for Source (Air) Emissions

EPA identified three test methods for measuring PFAS source emissions (EPA, 2021b). Sources can include chemical manufacturers, commercial applications, and thermal treatment incineration processes.

Other Test Method (OTM)-45 is an EPA method that measures PFAS air emissions from stationary sources (EPA, 2021c). OTM-45 can currently be used to test for 50 specific PFAS and can be used to help identify other PFAS that may be present in the sample. EPA is collecting

feedback on this method from the scientific community in consideration of future method improvements.

SW-846 Test Method 0010: Modified Method 5 Sampling Train is a performance-based method that uses an isotope dilution train approach for GC/MS targeted and non-targeted analysis (EPA, 2018). This method is used for semi-volatiles and non-volatiles. Modified Method TO-15 uses SUMMA canisters for GX/MS targeted and non-targeted analysis (EPA, 1999). This method is used for volatiles.

Other EPA methods in development

Table 14 below summarizes the description and status of additional methods EPA is developing and validating to detect and quantify selected PFAS in air, water, and soil (EPA, 2021b).

Table 14. EPA method development and validation to detect and quantify selected PFAS in air, water, soil and other environmental media (EPA, 2021b).

Title	Media	Description	Status
SW-846 Isotope Dilution Method	Non-potable water and other environmental media (e.g., soil, biosolids, sediment)	An isotope dilution method for non-drinking water aqueous matrices (surface water, groundwater, wastewater influent/effluent, landfill leachate), fish tissues, biosolids, soils, and sediments.	Developed in collaboration with DOD. A draft method will be posted after validation studies are complete.
Ambient/Near-Source	Ambient air	Field deployable Time of Flight/Chemical Ionization Mass Spectrometer for real time detection and measurement.	In development by EPA.
Semivolatile PFAS	Ambient air	A performance-based method guide by EPA TO-13a.	In development by EPA.
Volatile PFAS	Ambient air	Uses SUMMA canisters and sorbent traps for GC/MS targeted and non-targeted analysis.	In development by EPA.
Total Organic Fluorine (TOF)	Environmental samples	EPA is developing a potential rapid screening tool to identify total PFAS presence and absence. This eventual standard operating procedure will be used to quantify TOF.	EPA is working to develop this method in 2021.

Title	Media	Description	Status
Total Organic Precursors (TOP)	Environmental samples	EPA is considering the development of a method, based on existing protocols, to identify PFAS precursors that may transform to more persistent PFAS.	TOP methods are commercially available. EPA will consider the need for a thorough multi-laboratory validation study in 2021.
Draft CWA Method 1633	Wastewater, surface water, soils, biosolids, landfill leachate and fish tissue	Analysis of 40 PFAS by LC-MS/MS	Draft laboratory analytical method issued in August 2021.

International Organization for Standardization (ISO) Method 25101:2009: SPE in water

ISO 25101:2009 specifies a method for the determination of the linear isomers of PFOS and PFOA in unfiltered samples of drinking water, groundwater, and surface water (fresh water and sea water) using high-performance liquid chromatography-tandem mass spectrometry (HPLC-MS/MS) (ISO 2009, reviewed 2014). Analytes are extracted from water samples by solid phase extraction (SPE) followed by solvent elution and determined by HPLC-MS/MS. Other isomers may be reported separately as non-linear isomers and qualified as such. The method is applicable to a concentration range of 2 – 10,000 ng/L for PFOS and 10 – 10,000 ng/L for PFOA. Depending on the matrix, the method may also be applicable to higher concentrations ranging from 100 – 200,000 ng/L after suitable dilution of the sample or reduction in sample size.

ASTM D7979: Direct injection—surface and wastewater

ASTM D7979 have been successfully used in the determination of selected PFAS in water matrices (e.g., sludge and wastewater influent and effluent) using liquid chromatography (LC) and detection with tandem mass spectrometry (MS/MS) (ASTM 2017). This method adheres to a technique known as selected reaction monitoring (SRM) or sometimes referred to as multiple reaction monitoring (MRM). This is not a drinking water method—performance of this test method has not been evaluated on drinking water matrices. ASTM D7979 is a performance-based method, and alternative operating conditions can be used to perform this method provided data quality objectives are attained. It is a direct injection method that does not require sample preparation.

ASTM D7979 (2017) currently covers the analysis of 21 PFAS compounds, with ten additional compounds listed for consideration in the appendix of the method. Eight additional PFAS compounds, including three emerging PFAS compound of interest (11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid [11Cl-PF3OUdS], 9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid [9Cl-PF3ONS], and 4,8-dioxa-3H-perfluorononanoic acid [ADONA]), have been determined by the method to a total of 39 PFAS analytes (Waters, 2018).

Since the publication of this international standard, there have been many comments regarding the method, ranging from applicability to matrices, detection limits, lack of solid phase extraction, and calibration model.

ASTM D7968: Solids (soil)

This method was developed by EPA Region 5 Chicago Regional Laboratory, and has been successfully used for the determination of selected PFAS in a soil matrix (ASTM, 2017a). It is similar in scope to ASTM D7979-17 and uses solvent extraction and filtration, followed by LC/MS/MS to qualitatively and quantitatively determine PFAS in soil. Thirty analytes can be detected with this method, including but not limited to:

- Eleven perfluoroalkyl carboxylic acids.
- Three perfluoroalkyl sulfonates.
- Decafluoro-4- (pentafluoroethyl) cyclohexanesulfonate.
- Six fluorotelomers.

This is also a performance-based method, and alternative operating conditions can be used to perform this method, provided that all data quality objectives defined in the method are attained. It is recommended that QC and quality assurance requirements, if not well defined in the standard methods, must not be less stringent than the PFAS requirement found in DOD QSM (2019), Version 5.3 or later, Appendix B, and Table B-15, for media types.

2.2 Non–specific methods for PFAS analysis

Many of the available standard methods for PFAS analysis do not account for all known PFAS. Human exposures to PFAS are generally not from individual PFAS, but from a complex mixture (Schaider et al., 2017), and analytical techniques are limited for determining which PFAS constituents are in a given mixture. Hence, the full extent of PFAS contamination could be underestimated when targeted analytical methods are used to quantify PFAS concentration. The complexity of PFAS, the production of commercial mixtures, and the tendency to generate intermediate transformation products (Guelfo et al., 2018) present a performance challenge for current targeted methods.

Targeted analytical methods have been used successfully in quantitation of known PFAS chemicals (Lacorte et al., 2006), but they may not be feasible in the quantitation of more than 9,000 PFAS that are recognized today (EPA, 2020; Thermofisher, 2018). Unknown PFAS—including new alternatives or legacy substances, their transformation products, and residual impurities—may contribute to a substantial proportion of unknown organic fluorine in the environment.

These unknowns represent a great source of uncertainty for ascertaining environmental and human health risks (Liu et al., 2019). Analytical approaches that can discover and characterize such unknown PFAS are a first step to facilitating knowledge on the hazards and environmental behaviors of these unknown chemicals. Studies have indicated that scientists are using techniques that focus on measuring the total exposure of all PFAS instead of one or a limited

set of PFAS. This is important to gain a better understanding of exposures to PFAS as a class (Hartmann et al., 2107; Poothong et al., 2017).

In a published study by the Nordic Council of Ministers analyzing PFAS and TOF in products, comparison between analyzed individual PFAS and TOF concentration showed that individual PFAS constitute a small proportion of the TOF (Borg et al., 2017). It indicates a data gap relative to the unknown or potentially uncharacterized PFAS by conventional analytical techniques. The TOF method is capable of measuring TOF at ultra-trace levels and checking the mass balance, but cannot trace the individual analytes present in the sample (Ateia et al., 2019).

Schultes et al. (2019) also compared combustion ion chromatography (CIC) based EOF to target PFAS measurement in food packaging samples by LC/MS/MS. The study revealed large amounts of unidentified organic fluorine not captured by compound-specific analysis.

Liu et al. (2019), in their literature review of HRMS for non-targeted analysis, reported unknown PFAS discovery in commercial products, surfactant concentrates in environmental samples, sediment, soil, airborne particulate matter, and concrete, as well as in biological matrices, polar bears, and human serum.

2.2.1 Non-standard analytical techniques for measuring PFAS

McDonough et al. (2019) evaluated analytical techniques for measuring total (bulk) organo-fluorine developed for the study and quantification of unidentified fractions of PFAS in environmental and biological samples. These methods or techniques vary in applicability to different sample matrices, and in their selectivity and sensitivity. Description of each technique follows.

Combustion ion chromatography (CIC) methods

Combustion ion chromatography mineralizes and then measures organic fluorine from the EOF and absorbable organic fluorine (AOF) assay. Samples are combusted at a temperature of 900 – 1,000 degree Celsius (C) to convert organic fluorine to hydrofluoric acid, which is then absorbed into a solution of sodium hydroxide (McDonough et al., 2019). The total concentration of the fluoride is subsequently measured by ion chromatography (IC) after calibration with sodium fluoride. The choice of sample preparation is important in isolating organic fluorine from fluoride prior to CIC analysis, since CIC will not differentiate between organic and inorganic fluorine, and does not identify individual PFAS.

In EOF, the organic fluorine fraction is isolated by ion pairing methods and TOF is measured by CIC. The EOF assay is the most commonly used assay found in literature for total organic fluorine measurement in different environmental matrices, in human blood (Miyake et al., 2007, Yeung et al., 2013), and in marine mammals (Yeung et al., 2009).

Wagner et al. (2013) described the AOF assay, which differs in the way the organo-fluorine is extracted from the sample matrix. In AOF, the sample is passed through cartridges containing synthetic polystyrenedivinylbenzene-based activated carbon (AC). Residual fluoride is removed with a sodium nitrate washing solution, and the AC absorbent is then analyzed by CIC. AOF has only been applied to waters and wastewater (Dauchy et al., 2017; Wagner et al., 2013).

Particle-induced gamma ray emission (PIGE)

PIGE is a non-destructive analytical technique that takes advantage of the unique gamma-ray wavelength emission of fluorine when impacted with a proton ion beam. The technique is not compound specific, but it is able to assess total fluorine content of a variety of materials isolated on a thin surface. Fluorine can be detected to a depth of approximately 200 micrometers (ųm), but the precise value varies by substrate type (Ritter et al., 2017).

The sample is secured in the instrument and bombarded ex vacuo under a 3.4 Mega electron-volt (MeV) beam with an intensity of 10 nanoampere (nA) for approximately 180 seconds. Two gamma rays characteristic of the decay of the F nucleus (110 kiloelectron volt (keV) and 197 keV) are measured and the responses integrated. PIGE has recently been quantitatively applied to the measurement of PFAS-impacted samples by creating calibration standards consisting of textiles soaked in solution of a known organofluorine (Ritter et al., 2017).

PIGE has primarily been used for solid-phase samples such as textiles, paper, and food packaging (Lang et al., 2016, Robel et al., 2017, Schaider et al., 2017). PIGE is a rapid screening technique to measure fluoride, PFAS, and other fluorine-containing compounds in the samples. PIGE does not differentiate between inorganic fluorine and organic fluorine. It is important to understand whether there are significant sources of both organic and inorganic fluorine in a sample. There are techniques to remove inorganic fluorine that can make it specific for organofluorine if the sample does not contain a significant amount of fluoride or if the inorganic fluoride has been removed from the sample.

PIGE can detect a wide range of fluorine treatment chemicals including polymeric fluorine treatments such as polytetrafluoroethylene (PTFE), side-chain fluorinated polymers, and small molecule products.

Total oxidizable precursors (TOP) assay

Houtz and Sedlak (2012) developed the TOP assay method. The TOP assay was developed to infer and indirectly quantify the total amount of chemical precursors to perfluorinated alkyl acids (PFAA) in a sample by comparing the concentrations of specific PFAAs before and after oxidation of the sample by an excess of hydroxyl radicals (Houtz & Sedlak, 2012). It is the most selective of PFAS surrogate analytical methods, in that it selects only PFAS compounds that can be oxidized to form targeted PFAAs (McDonough et al., 2019). The same procedure of sample preparation is followed as traditionally used for targeted LC/MS/MS analysis. The assay is useful with compounds that oxidize to form LC-amenable hydroxyl radical resistant PFAS, however, these oxidation products must then also be detectable by LC/MS/MS. Some oxidation products, such as very short-chain PFAS, will not be detected by standard post-assay detection approaches such as EPA Method 537.

The assay is subject to low and variable recoveries that may lead to false negatives, especially in samples that have very low levels of PFAS (Robel et al., 2017). The limitation of the TOP assay is that it does not easily differentiate between precursors that contain telomer or sulfonamide functionalities, as all of these precursors are chemically oxidized primarily to perfluoroalkyl carboxylates. The TOP assay has not been demonstrated on large molecular weight polymer

compounds or newer ether-linked PFAS like GenX. It is unknown if the oxidative process would liberate PFAAs from these types of compounds.

The TOP assay process converts fluorotelomer-based compounds including PFAA precursors into a mixture of PFAA products (Houtz & Sedlak, 2012). The increase in PFAAs measured after the TOP assay, relative to before, is a conservative estimate of the total concentration of PFAA precursors present in a sample, because not all PFAS present will be subject to quantitation or reaction, and will remain as undetected PFAS. The PFAAs generated have perfluoroalkyl chain lengths equal to or shorter than the perfluoroalkyl chain lengths present in the precursors (Dauchy et al., 2017; Houtz et al., 2013; Houtz & Sedlak, 2012; Weber et al., 2017).

The TOP assay has been applied to a number of environmental matrices such as effluent wastewater, stormwater runoff, river water and groundwater, and soil. Houtz and Sedlak (2012), Houtz et al. (2013, 2016), McGuire et al. (2014), and Harding-Marjanovic et al. (2015) have published applications of the TOP assay.

The paper published by Zhang et al. (2019) on the fate of per- and polyfluoroalkyl ether acids (PFEAs), including fluorinated replacements such as GenX and ADONA and manufacturing byproducts, found that PFEAs containing the -O-CFH- moiety were readily oxidized in the TOP assay.

GenX, in their study, was among the ten perfluoroalkyl ether acids and one chlorinated polyfluoroalkyl ether acid (F-53B) that were stable of the 15 PFEAs in the TOP assay. Prior to the Zhang et al. (2019) paper, PFEAs were not in the TOP assay analyte list—the paper recommended that adding PFEAs will capture a higher percentage of the total PFAS concentration in environmental samples. The polyfluoroalkyl ether acids with a -O-CFH- moiety were mostly oxidized to products that could not be identified by targeted liquid chromatography and high-resolution mass spectrometry.

Although, GenX may not appreciably degrade in the environment, other PFEAs may degrade as described in Zhang et al. (2019). It has been demonstrated that polyfluoroalkyl ether acids with a -O-CFH- moiety such ADONA are amenable to TOP assay. Application of TOP assay to PFEAs showed the presence of precursors that form perfluoroalkyl carboxylic acids.

2.3 Challenges of analytical method selection

Detailed descriptions of the non-standard analytical techniques for measuring PFAS are referenced in TOP (Houtz & Sedlak, 2012), PIGE (Ritter et al., 2017), EOF (Miyake et al., 2007), and AOF (Wagner et al., 2013). These methods enable measurement of total precursors, TF, and TOF, respectively. Method choice depends on the selectivity and inclusivity of individual or cumulative PFAS needed for a given application. McDonough et al. (2019) indicated that methods that are highly inclusive—such as PIGE, which does not differentiate between organic and inorganic fluorine—are impractical for measuring PFAS-related organofluorine.

However, EOF has a unique advantage over other methods as its selectivity can be adjusted depending on the sample preparation and fractionation method, and it can be used to measure PFAS-related organofluorine present in a sample. EOF and AOF may have sufficient sensitivity to

measure total PFAS in water (Miyake et al., 2007), while the sensitivity of PIGE may be limited by fluoride interferences.

Among these methods, the TOP assay is the most sensitive for individual PFAS (Houtz & Sedlak, 2012), as it utilizes LC/MS/MS of targeted precursors. However, it is limited in its ability to account for emerging PFAS of concern, such as GenX and ADONA, that do not oxidize. It is also prone to selectivity concerns with reverse phase liquid chromatography, meaning that compounds that are not retained by the LC columns (for example, short-chain PFAS) are lost.

Although analysis of PFAS is progressing, significant challenges remain from the fact that the complete list of PFAS relevant to environmental and human exposure scenarios is still unknown. As more research and studies identify novel PFAS and precursor transformation products, an effective, comprehensive technique that is capable of quantitative non-target analysis remains elusive (Nakayama et al., 2019).

Targeted analyses with sensitive and highly specific analytical methods have made great contributions to PFAS discovery and to quantification of concentrations in human and environmental samples (Liu et al., 2019). However, the full extent of PFAS contamination may be underestimated unless non-targeted methods are used for PFAS analysis. The lack of available analytical standards means that precursors, degradation products, and transformation products will not be quantified (D'Agostino & Mabury, 2018).

Recent development in HRMS has made the discovery of unknown or suspected PFAS possible without the need for an authentic standard (Liu et al., 2019). HRMS, using technology such as quadrupole time of flight (QTOF), generates high mass accuracy data that can be used to identify unknown compounds (Barzen-Hanson et al., 2017b; Strynar et al., 2015).

McDonough et al. (2019) recommended combining total organofluorine measurements by EOF and/or TOP assay with HRMS and with targeted analytical methods (LC/MS/MS) to obtain a full characterization of PFAS composition and sources. Although this recommendation may be specific to water, TOF measurement has been applied to other matrices (Schultes et al., 2019). Guelfo et al. (2018) suggested that coupling AOF/EOF, TOP, or PIGE with LC/MS/MS could help provide a better understanding of the total PFAS load present in a sample, but will not result in identification of all individual PFAS present.

The availability of these techniques (EOF, PIGE, and HRMS—except TOP assay) is mostly limited to non-commercial research facilities or laboratories. The quantification of PFAS that lack standards remains a challenge.

Due to the limitation of available standard methods, non-targeted analytical techniques that can measure the total PFAS concentration in multiple matrices are preferred. The selection of any non-targeted method depends on the selectivity and inclusivity for a given application.

Spaan et al. (2020) highlighted the importance of a multiplatform approach for accurately characterizing PFAS. To assess whether PFAS exposure is underestimated in marine mammals, Spaan et al. (2020) performed a combination of targeted ultra performance liquid chromatography analysis tandem mass spectrometry (UPLC-MS/MS) and suspect screening (UPLC-Orbitrap-MS)—in addition to EOF/CIC for the determination of TF. This approach

resulted in the identification of 63 more PFAS that were not included in the targeted analysis, but were prioritized samples from EOF for suspect screening and quantification. EOF/CIC remains a tool in determining the total PFAS as TF (except where suspect screening is required to identify the unknown PFAS from the mass balance).

In their study, Dubocg et al. (2020) also used a multiplatform approach comprising of a novel workflow combining target analysis, non-target screening analysis (NTA), TF analysis, and inorganic fluoride (IF) analysis to characterize the chemical composition of 24 firefighting foams marketed as containing PFAS as well as fluorine-free foams. By using these approaches, the study determined the sum of the targeted PFAS and total organofluorine concentration, as well as a mass balance of known and unknown organofluorine. In this study, five fluorinated substances were tentatively identified, and non-fluorinated zwitterionic betaine compounds, which are considered to be replacement substances for PFAS, were tentatively identified in the organofluorine-free foams.

Miaz et al. (2020) developed a combined method for quantitative analysis, along with suspect and non-target screening of PFAS using ultra-high pressure liquid chromatography and ultra-high resolution (Orbitrap) mass spectrometry as reported in Spaan et al. (2020). The method was applied together with measurements of TF and EOF to pooled serum samples. This study found that targeted PFAS accounted for a smaller fraction of the EOF in the serum, indicating an increased contribution from unidentified PFAS. Non-targeted screening found three unidentified features with neutral masses, but the authors could not confirm if they are fluorinated without structural elucidation and NTA data base mining confirmation (Miaz et al., 2020).

A multiplatform approach allows for the comparison of the sum PFAS concentrations from targeted analysis to EOF and total fluorine (Miaz et al., 2020; Spaan et al., 2020). An important shortcoming of the non-targeted methods is that they are not standardized or multi-laboratory validated. The use of these methods is limited to research and investigation. Their results cannot be used for estimating toxicological effects, preventing the use of these methods, or for regulatory purposes.

2.4 Data gaps and recommendations

2.4.1 Data gaps

Progress has been made in the targeted analysis of PFAS. However, significant challenges remain, in that the complete list of PFAS relevant to environmental and human exposure scenarios is still unknown. It is estimated that there are more than 9,000 known registered PFAS compounds (Miaz et al., 2020). Targeted PFAS analysis can only quantify a limited amount of known PFAS, and most of the targeted analytical techniques only address the anionic forms of PFAS, unable to identify cationic, zwitterionic, and neutral forms of PFAS.

These unknown PFAS represent a great source of uncertainty for ascertaining environmental and human health risks (Liu et al., 2019). Analytical approaches that can discover and characterize such unknown PFAS are a first step to facilitating knowledge on the hazards and environmental behaviors of these unknown substances.

Addressing these challenges requires analytical tools that are both selective and inclusive (analytical methods that are able to detect thousands of known and unknown PFAS). Targeted analysis using LC with either HRMS (e.g., quadrupole time-offlight; Q-TOF) or MS/MS can capture many known PFAS. Non-targeted analysis using HRMS could also be used to identify many additional suspected or previously uncharacterized PFAS.

Using LC/MS/MS or LC-HRMS for PFAS identification and quantification requires analytical standards, and standards are currently only available for about 100 of the more than 3,000 potentially relevant PFAS (Liu et al., 2019). HRMS can be used with a number of techniques for measuring TOF to study and quantify the unidentified portion of PFAS in environmental samples. CIC and PIGE can be used to identify samples with high organic fluorine content, which can then be selected for non-target HRMS analysis**.**

CIC has been used to measure the TF in firefighting foams, and when combined with HRMS, can quantify the unidentified fraction of the PFAS that were unaccounted in targeted analysis (Dubocq et al., 2020). Although useful, CIC and PIGE have low sensitivity, limiting their direct application to many environmental samples (Liu et al., 2019). EOF/CIC remains a tool in determining the total PFAS as TF (except where suspect screening is required to identify the unknown PFAS from the mass balance).

Spaan et al. (2020), Dubocq et al. (2020), and Miaz et al. (2020) highlighted the importance of multiplatform approaches for accurately characterizing PFAS. The multiplatform approach combines target analysis, non-target screening analysis (NTA), EOF/CIC for the determination of total fluorine (TF), and inorganic fluoride (IF) analysis to characterize the chemical composition of both known and unknown PFAS. This approach resulted in the identification of more PFAS chemicals that were not included in the targeted analysis but were prioritized samples from EOF for suspect screening and quantification. By using these approaches, the sum of the targeted PFAS and total organic organofluorine concentration were determined, as well as a mass balance of known and unknown organofluorine.

The multiplatform approach has been used in the study of fluorinated substances that were tentatively identified, and non-fluorinated zwitterionic betaine compounds (which are considered to be replacement substances for PFAS) that were tentatively identified in the organofluorine-free foams (Dubocq et al., 2020).

Non-targeted screening techniques are semi-quantitative and require structural elucidation and NTA data base mining confirmation. Sample pre-treatment and data analysis are not standardized. A multiplatform approach allows for the comparison of the sum PFAS concentrations from targeted analysis to EOF and total fluorine. Although these approaches are used in the discovery of unidentified PFAS, they are also useful for screening fluorinated substances in the environment and other matrices. For regulatory purposes, standard validated methods such as EPA-validated PFAS analytical methods are recommended. Non-targeted analysis techniques are not validated, and may not be used for regulatory purposes.

A specific multiplatform approach could be used to identify and quantify multiple PFAS chemicals, and provide data on PFAS presence in varying types of environmental media. Ecology supports the use of approved validated methods as recommended by EPA for specific

targeted PFAS analysis. Modification of an approved standard analytical method will require Ecology approval, provided such modification is consistent with the DOD QSM.

2.4.2 Recommendations

There are no specific recommendations resulting from our analysis of analytical methods, neither of those available now nor those in process of development. Implementation of several recommendations in the CAP will require sampling and assessment of PFAS in various environmental media. This includes but is not limited to the following:

- 1.2 Technical support for site characterization, source investigation, and mitigation at contaminated sites.
- 4.1 Evaluate PFAS in wastewater treatment.
- 4.2 Evaluate PFAS in landfill leachate and air emissions.
- 4.3 Evaluate Washington biosolids management.

References

Ateia, M., Maroli, A., Tharayil, N., & Karanfil, T. (2019). The overlooked short- and ultrashort-chain poly- and perfluorinated substances: A review. *Chemosphere*, *220*, 866–882. https://doi.org/10.1016/j.chemosphere.2018.12.186

ASTM. (2017a). D7979-17: Standard Test Method for Determination of Per- and Polyfluoroalkyl Substances in Water, Sludge, Influent, Effluent and Wastewater by Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS). Retrieved from https://www.astm.org/

ASTM. (2017b). D7968-17a: Standard Test Method for Determination of Polyfluoroalkyl Compounds in Soil by Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS). Retrieved from https://www.astm.org/

Barzen-Hanson, K. A., Roberts, S. C., Choyke, S., Oetjen, K., McAlees, A., Riddell, N., McCrindle, R., Ferguson, P. L., Higgins, C. P., & Field, J. A. (2017). Discovery of 40 Classes of Per- and Polyfluoroalkyl Substances in Historical Aqueous Film-Forming Foams (AFFFs) and AFFF-Impacted Groundwater. *Environmental Science & Technology*, *51*, 2047–2057. https://doi.org/10.1021/acs.est.6b05843

Berger, U., Kaiser, M. A., Kärrman, A., Barber, J. L., & van Leeuwen, S. P. J. (2011). Recent developments in trace analysis of poly- and perfluoroalkyl substances. *Analytical and Bioanalytical Chemistry*, *400*, 1625–1635. https://doi.org/10.1007/s00216-011-4823-8

Borg, D., & Ivarsson, J. (2017). *Analysis of PFASs and TOF in products*. Nordic Council of Ministers. https://doi.org/10.6027/TN2017-543

Brendel, S., Fetter, É., Staude, C., Vierke, L., & Biegel-Engler, A. (2018). Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. *Environmental Sciences Europe*, *30*, 9. https://doi.org/10.1186/s12302-018-0134-4

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., de Voogt, P., Jensen, A. A., Kannan, K., Mabury, S. A., & van Leeuwen, S. P. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environmental Assessment and Management*, *7*, 513–541. https://doi.org/10.1002/ieam.258

D'Agostino, L. A., & Mabury, S. A. (2017). Aerobic biodegradation of 2 fluorotelomer sulfonamide-based aqueous film-forming foam components produces perfluoroalkyl carboxylates. *Environmental Toxicology and Chemistry*, *36*, 2012–2021. https://doi.org/10.1002/etc.3750

Dauchy, X., Boiteux, V., Bach, C., Colin, A., Hemard, J., Rosin, C., & Munoz, J.-F. (2017). Mass flows and fate of per- and polyfluoroalkyl substances (PFASs) in the wastewater treatment plant of a fluorochemical manufacturing facility. *Science of the Total Environment*, *576*, 549–558. https://doi.org/10.1016/j.scitotenv.2016.10.130

Department of Toxic Substances Control (DTSC). (2019). Product – Chemical Profile for Carpets and Rugs Containing Perfluoroalkyl or Polyfluoroalkyl Substances. Retrieved from https://dtsc.ca.gov/wp-content/uploads/sites/31/2020/02/Final_Product-Chemical_Profile_Carpets_Rugs_PFASs_a.pdf

De Voogt, P., & Saez, M. (2006). Analytical chemistry of perfluoroalkylated substances. *TrAC Trends in Analytical Chemistry*, *25*, 326–342. https://doi.org/10.1016/j.trac.2005.10.008

Department of Defense (DOD). (2019). DOD Quality Systems Manual Version 5.3 DOE Quality Systems Manual (QSM) for Environmental Laboratories. Retrieved from https://denix.osd.mil/edqw/documents/manuals/qsm-version-5-3-final/

Dubocq, F., Wang, T., Yeung, L. W. Y., Sjöberg, V., & Kärrman, A. (2019). Characterization of the Chemical Contents of Fluorinated and Fluorine-Free Firefighting Foams Using a Novel Workflow Combining Nontarget Screening and Total Fluorine Analysis. *Environmental Science & Technology*, acs.est.9b05440. https://doi.org/10.1021/acs.est.9b05440

Guelfo, J. L., & Adamson, D. T. (2018). Evaluation of a national data set for insights into sources, composition, and concentrations of per- and polyfluoroalkyl substances (PFASs) in U.S. drinking water. *Environmental Pollution*, *236*, 505–513. https://doi.org/10.1016/j.envpol.2018.01.066

Guelfo, J. L., Marlow, T., Klein, D. M., Savitz, D. A., Frickel, S., Crimi, M., & Suuberg, E. M. (2018). Evaluation and Management Strategies for Per- and Polyfluoroalkyl Substances (PFASs) in Drinking Water Aquifers: Perspectives from Impacted U.S. Northeast Communities. *Environmental Health Perspectives*, *126*, 065001. https://doi.org/10.1289/EHP2727

Harding-Marjanovic, K. C., Houtz, E. F., Yi, S., Field, J. A., Sedlak, D. L., & Alvarez-Cohen, L. (2015). Aerobic Biotransformation of Fluorotelomer Thioether Amido Sulfonate (Lodyne) in AFFF-Amended Microcosms. *Environmental Science & Technology*, *49*, 7666–7674. https://doi.org/10.1021/acs.est.5b01219

Hartmann, C., Raffesberg, W., Scharf, S., & Uhl, M. (2017). Perfluoroalkylated substances in human urine: results of a biomonitoring pilot study. *Biomonitoring*, *4*, 1–10. https://doi.org/10.1515/bimo-2017-0001

Houtz, E. F., Higgins, C. P., Field, J. A., & Sedlak, D. L. (2013). Persistence of Perfluoroalkyl Acid Precursors in AFFF-Impacted Groundwater and Soil. *Environmental Science & Technology*, *47*, 8187–8195. https://doi.org/10.1021/es4018877

Houtz, E. F., Sutton, R., Park, J.-S., & Sedlak, M. (2016). Poly- and perfluoroalkyl substances in wastewater: Significance of unknown precursors, manufacturing shifts, and likely AFFF impacts. *Water Research*, *95*, 142–149. https://doi.org/10.1016/j.watres.2016.02.055

International Organization for Standardization (ISO). (2009). ISO 25101:2009(en) Water quality — Determination of perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) — Method for unfiltered samples using solid phase extraction and liquid chromatography/mass spectrometry. Retrieved from https://www.iso.org/obp/ui/#iso:std:iso:25101:ed-1:v1:en

Interstate Technology & Regulatory Council (ITRC). (2018). Site Characterization Considerations, Sampling Precautions, and Laboratory Analytical Methods for Per- and Polyfluoroalkyl Substances (PFAS).

Jahnke, A., & Berger, U. (2009). Trace analysis of per- and polyfluorinated alkyl substances in various matrices—How do current methods perform? *Journal of Chromatography A*, *1216*, 410–421. https://doi.org/10.1016/j.chroma.2008.08.098

Kato, K., Wong, L.-Y., Jia, L. T., Kuklenyik, Z., & Calafat, A. M. (2011). Trends in Exposure to Polyfluoroalkyl Chemicals in the U.S. Population: 1999−2008 †. *Environmental Science & Technology*, *45*, 8037–8045. https://doi.org/10.1021/es1043613

Lang, J. R., Allred, B. M., Peaslee, G. F., Field, J. A., & Barlaz, M. A. (2016). Release of Per- and Polyfluoroalkyl Substances (PFASs) from Carpet and Clothing in Model Anaerobic Landfill Reactors. *Environmental Science & Technology*, *50*, 5024–5032. https://doi.org/10.1021/acs.est.5b06237

Lilienthal, H., Dieter, H. H., Hölzer, J., & Wilhelm, M. (2017). Recent experimental results of effects of perfluoroalkyl substances in laboratory animals – Relation to current regulations and guidance values. *International Journal of Hygiene and Environmental Health*, *220*, 766–775. https://doi.org/10.1016/j.ijheh.2017.03.001

Liu, Y., D'Agostino, L. A., Qu, G., Jiang, G., & Martin, J. W. (2019). High-resolution mass spectrometry (HRMS) methods for nontarget discovery and characterization of poly- and per-fluoroalkyl substances (PFASs) in environmental and human samples. *TrAC Trends in Analytical Chemistry*, *121*, 115–420. https://doi.org/10.1016/j.trac.2019.02.021

Mahmoud, M. A. M., Kärrman, A., Oono, S., Harada, K. H., & Koizumi, A. (2009). Polyfluorinated telomers in precipitation and surface water in an urban area of Japan. *Chemosphere*, *74*, 467–472. https://doi.org/10.1016/j.chemosphere.2008.08.029

McDonough, C. A., Guelfo, J. L., & Higgins, C. P. (2019). Measuring total PFASs in water: The tradeoff between selectivity and inclusivity. *Current Opinion in Environmental Science & Health*, *7*, 13–18. https://doi.org/10.1016/j.coesh.2018.08.005

McGuire, M., Schaefer, C., Richards, T., Backe, W., Field, J., Houtz, E., Sedlak, D., Guelfo, J., Wunsch, A., & Higgins, C. (2014). Evidence of Remediation-Induced Alteration of Subsurface Poly- and Perfluoroalkyl Substance Distribution at a Former Firefighter Training Area. *Environmental Science & Technology*, *48*, 6644–6652. https://doi.org/10.1021/es5006187

Miaz, L., Plassmann, M. M., Gyllenhammar, I., Bignert, A., Sandblom, O., Lignell, S., Glynn, A., & Benskin, J. (2020). Temporal trends of suspect- and target-per/polyfluoroalkyl substances (PFAS), extractable organic fluorine (EOF) and total fluorine (TF) in pooled serum from first-time mothers in Uppsala, Sweden, 1996–2017. *Environmental Science: Processes & Impacts*, *22*, 1071–1083. https://doi.org/10.1039/C9EM00502A

Mills, M., & Impellitteri, C. (2019). EPA Method Development Update: Per- and Polyfluoroalkyl Substances (PFAS). Retrieved from https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=345654

Miyake, Y., Yamashita, N., So, M., Rostkowski, P., Taniyasu, S., Lam, P., & Kannan, K. (2007). Trace analysis of total fluorine in human blood using combustion ion chromatography for fluorine: A mass balance approach for the determination of known and unknown organofluorine compounds. *Journal of Chromatography A*, *1154*, 214–221. https://doi.org/10.1016/j.chroma.2007.03.084

Moody, C. A., Kwan, W. C., Martin, J. W., Muir, D. C. G., & Mabury, S. A. (2001). Determination of Perfluorinated Surfactants in Surface Water Samples by Two Independent Analytical Techniques: Liquid Chromatography/Tandem Mass Spectrometry and 19 F NMR. *Analytical Chemistry*, *73*, 2200–2206. https://doi.org/10.1021/ac0100648

Nakayama, S. F., Yoshikane, M., Onoda, Y., Nishihama, Y., Iwai-Shimada, M., Takagi, M., Kobayashi, Y., & Isobe, T. (2019). Worldwide trends in tracing poly- and perfluoroalkyl substances (PFAS) in the environment. *TrAC Trends in Analytical Chemistry*, *121*, 115–410. https://doi.org/10.1016/j.trac.2019.02.011

Poothong, S., Thomsen, C., Padilla-Sanchez, J. A., Papadopoulou, E., & Haug, L. S. (2017). Distribution of Novel and Well-Known Poly- and Perfluoroalkyl Substances (PFASs) in Human Serum, Plasma, and Whole Blood. *Environmental Science & Technology*, *51*, 13388–13396. https://doi.org/10.1021/acs.est.7b03299

Ritter, E. E., Dickinson, M. E., Harron, J. P., Lunderberg, D. M., DeYoung, P. A., Robel, A. E., Field, J. A., & Peaslee, G. F. (2017). PIGE as a screening tool for per- and polyfluorinated substances in papers and textiles. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, *407*, 47–54. https://doi.org/10.1016/j.nimb.2017.05.052

Robel, A. E., Marshall, K., Dickinson, M., Lunderberg, D., Butt, C., Peaslee, G., Stapleton, H. M., & Field, J. A. (2017). Closing the Mass Balance on Fluorine on Papers and Textiles. *Environmental Science & Technology*, *51*, 9022–9032. https://doi.org/10.1021/acs.est.7b02080

Rosenblum, L., & Wendelken, S. C. (2019). Method 533 Determination of Per- and Polyfluoroalkyl Substances (PFAS) in drinking water by isotope dilution anion exchange solid phase extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS). *U.S. Environmental Protection Agency (EPA)*. Retrieved from https://www.epa.gov/sites/production/files/2019-12/documents/method-533-815b19020.pdf

Schaider, L. A., Balan, S. A., Blum, A., Andrews, D. Q., Strynar, M. J., Dickinson, M. E., Lunderberg, D. M., Lang, J. R., & Peaslee, G. F. (2017). Fluorinated Compounds in U.S. Fast Food Packaging. *Environmental Science & Technology Letters*, *4*, 105–111. https://doi.org/10.1021/acs.estlett.6b00435

Schultes, L., Peaslee, G. F., Brockman, J. D., Majumdar, A., McGuinness, S. R., Wilkinson, J. T., Sandblom, O., Ngwenyama, R. A., & Benskin, J. P. (2019). Total Fluorine Measurements in Food Packaging: How Do Current Methods Perform? *Environmental Science & Technology Letters*, *6*, 73–78. https://doi.org/10.1021/acs.estlett.8b00700

Schultz, M. M., Barofsky, D. F., & Field, J. A. (2004). Quantitative Determination of Fluorotelomer Sulfonates in Groundwater by LC MS/MS. *Environmental Science & Technology*, *38*, 1828–1835. https://doi.org/10.1021/es035031j

Shoemaker, J. A., Grimmett, P., & Boutin, B. (2008). Determination of Selected Perfluorinated Alkyl Acids in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS). Retrieved from https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&direntryid=198984

Shoemaker, J. A., & Tettenhorst, D. R. (2018). Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS). *U.S. Environmental Protection Agency (EPA)*. Retrieved from https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=343042

Shoemaker, J. A., & Tettenhorst, D. R. (2020). Method 537.1 Rev 2.0 Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS). *U.S. Environmental Protection Agency (EPA)*. Retrieved from https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=348508&Lab=CESER

Spaan, K. M., van Noordenburg, C., Plassmann, M. M., Schultes, L., Shaw, S., Berger, M., Heide-Jørgensen, M. P., Rosing-Asvid, A., Granquist, S. M., Dietz, R., Sonne, C., Rigét, F., Roos, A., & Benskin, J. P. (2020). Fluorine Mass Balance and Suspect Screening in Marine Mammals from the Northern Hemisphere. *Environmental Science & Technology*, *54*, 4046–4058. https://doi.org/10.1021/acs.est.9b06773

Strynar, M., Dagnino, S., McMahen, R., Liang, S., Lindstrom, A., Andersen, E., McMillan, L., Thurman, M., Ferrer, I., & Ball, C. (2015). Identification of Novel Perfluoroalkyl Ether Carboxylic Acids (PFECAs) and Sulfonic Acids (PFESAs) in Natural Waters Using Accurate Mass Time-of-Flight Mass Spectrometry (TOFMS). *Environmental Science & Technology*, *49*, 11622–11630. https://doi.org/10.1021/acs.est.5b01215

Trojanowicz, M., & Koc, M. (2013). Recent developments in methods for analysis of perfluorinated persistent pollutants. *Microchimica Acta*, *180*, 957–971. https://doi.org/10.1007/s00604-013-1046-z

U.S. Department of Defense Environmental Laboratory Accreditation Program (U.S. DOD ELAP). (n.d.). Environmental Data Quality Workgroup: Accredited Labs Search. *Defense Environmental Network Information Exchange (DENIX)*. Retrieved from https://www.denix.osd.mil/edqw/accreditation/accreditedlabs/

U.S. Environmental Protection Agency (EPA). (1999). Compendium Method TO-15 Determination Of Volatile Organic Compounds (VOCs) In Air Collected In Specially-Prepared Canisters And Analyzed By Gas Chromatography/ Mass Spectrometry (GC/MS). January 1999. Retrieved from https://www3.epa.gov/ttnamti1/files/ambient/airtox/to-15r.pdf

U.S. Environmental Protection Agency (EPA). (2018). SW-846 Test Method 0010: Modified Method 5 Sampling Train. August 2018. Retrieved from https://www.epa.gov/sites/default/files/2020-04/documents/method_0010_0.pdf

U.S. Environmental Protection Agency (EPA). (2019). EPA PFAS Data and Tools. Retrieved from www.epa.gov/pfas/epa-pfas-data-and-tools

U.S. Environmental Protection Agency (EPA). (2020). PFAS Master List of PFAS Substances (Version 2). Retrieved from https://comptox.epa.gov/dashboard/chemical_lists/PFASMASTER

U.S. Environmental Protection Agency (EPA). (2021a). Method 8327. Per- and Polyfluoroalkyl Substances (PFAS) by Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS). Retrieved from https://www.epa.gov/system/files/documents/2021-07/8327.pdf

U.S. Environmental Protection Agency (EPA). (2021b). PFAS Analytical Methods Development and Sampling Research. Retrieved from https://www.epa.gov/water-research/pfas-analytical-methods-development-and-sampling-research

U.S. Environmental Protection Agency (EPA). (2021c). Other Test Method 45 (OTM-45) Measurement of Selected Per- and Polyfluorinated Alkyl Substances from Stationary Sources. January 13, 2021. Retrieved from https://www.epa.gov/sites/default/files/2021-01/documents/otm_45_semivolatile_pfas_1-13-21.pdf

Wagner, A., Raue, B., Brauch, H.-J., Worch, E., & Lange, F. T. (2013). Determination of absorbable organic fluorine from aqueous environmental samples by adsorption to polystyrene-divinylbenzene based activated carbon and combustion ion chromatography. *Journal of Chromatography A*, *1295*, 82–89. https://doi.org/10.1016/j.chroma.2013.04.051

Wang, Z., DeWitt, J. C., Higgins, C. P., & Cousins, I. T. (2017). A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? *Environmental Science & Technology*, *51*, 2508–2518. https://doi.org/10.1021/acs.est.6b04806

Yeung, L. W. Y., De Silva, A. O., Loi, E. I. H., Marvin, C. H., Taniyasu, S., Yamashita, N., Mabury, S. A., Muir, D. C. G., & Lam, P. K. S. (2013). Perfluoroalkyl substances and extractable organic fluorine in surface sediments and cores from Lake Ontario. *Environment International*, *59*, 389–397. https://doi.org/10.1016/j.envint.2013.06.026

Yeung, L. W. Y., Miyake, Y., Wang, Y., Taniyasu, S., Yamashita, N., & Lam, P. K. S. (2009). Total fluorine, extractable organic fluorine, perfluorooctane sulfonate and other related fluorochemicals in liver of Indo-Pacific humpback dolphins (Sousa chinensis) and finless porpoises (Neophocaena phocaenoides) from South China. *Environmental Pollution*, *157*, 17–23. https://doi.org/10.1016/j.envpol.2008.08.005

Zhang, C., Hopkins, Z., McCord, J., Strynar, M., & Knappe, D. (2019). Fate of Per- and Polyfluoroalkyl Ether Acids in the Total Oxidizable Precursor Assay and Implications for the Analysis of Impacted Water. *Environmental Sciences and Technology Letters, 6*, 662–668. doi: 10.1021/acs.estlett.9b00525.

List of acronyms

General acronyms

Table 15. Acronyms found in the analytical methods appendix.

Acronym	Definition
AC	Activated carbon
AOF	Absorbable organic fluorine
ASTM	American Society for Testing and Materials International
CAS	Chemical Abstracts Service
CIC	Combustion ion chromatography
CWA	Clean Water Act
DENIX	Defense Environmental Network Information Exchange
DOD	Department of Defense
EOF	Extractable organic fluorine
ELAP	Environmental Laboratory Accreditation Program
EPA	United States Environmental Protection Agency
HPLC	High performance liquid chromatography
HPLC-MS/MS	High-performance liquid chromatography-tandem mass spectrometry
HRMS	High-resolution mass spectrometer
IC	Ion chromatography
ID	Isotopic dilution
IDC	Initial demonstration of capability
IF	Inorganic fluoride
ISO	International Organization for Standardization
ITRC	Interstate Technology & Regulatory Council
keV	Kiloelectron volt
L	liter
LC	Liquid chromatography
LC-HRMS	Liquid chromatography with high-resolution mass spectrometer
LC/MS/MS	Liquid chromatography/tandem mass spectrometry
MeV	Mega electron-volt
MQO	Measurement quality objective
MRM	Multiple reaction monitoring
MS	Mass spectrometry
MS/MS	Tandem mass spectrometry
nA	Nanoampere
ng	nanogram
NTA	Non-targeted screening analysis

Acronym	Definition
PIGE	Particle Induced Gamma Ray Emission
QC	Quality Control
QSM	Quality Systems Manual
QTOF	Quadrupole time of flight
QTOF-MS	Quadrupole Time of Flight-Mass Spectroscopy
RN	Registry Number
RT	Retention time
s	second
SPE	Solid phase extraction
SRM	Selected reaction monitoring
TF	Total fluorine
TOF	Total organic fluorine
TOP	Total Oxidizable Precursors
UPLC	Ultra performance liquid chromatography
ųm	micrometer

Chemical names

Table 16. Chemical name acronyms found in the analytical methods appendix, excluding the general acronyms listed in the table above.

Acronym	Chemical name
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
4:2FTS	1H,1H, 2H, 2H-Perfluorohexane sulfonic acid
6:2FTS	1H,1H, 2H, 2H-Perfluorooctane sulfonic acid
8:2FTS	1H,1H, 2H, 2H-Perfluorodecane sulfonic acid
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid
ADONA	4,8-dioxa-3H-perfluorononanoic acid
FTS	Fluorotelomer sulfonate
Gen X	Hexafluoropropylene oxide dimer acid
HFPO-DA (GenX)	Hexafluoropropylene oxide dimer acid
NFDHA	Nonafluoro-3,6-dioxaheptanoic acid
NEtFOSAA	N-ethyl perfluorooctanesulfonamidoacetic acid
NMeFOSAA	N-methyl perfluorooctanesulfonamidoacetic acid
PFAA	Perfluorinated alkyl acid
PFAS	Per- and poly-fluorinated alkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonic acid

Acronym	Chemical name
PFDA	Perfluorodecanoic acid
PFDoA	Perfluorododecanoic acid
PFEA	Per- and polyfluoroalkyl ether acid
PFEESA	Perfluoro(2-ethoxyethane)sulfonic acid
PFHpA	Perfluoroheptanoic acid
PFHpS	Perfluoroheptane sulfonic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFMBA	Perfluoro-4-methoxybutanoic acid
PFMPA	Perfluoro-3-methoxypropanoic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFPeA	Perfluoropentanoic acid
PFPeS	Perfluoropentanesulfonic acid
PFTA	Perfluorotetradecanoic acid
PFTrDA	Perfluorotridecanoic acid
PFUnA	Perfluoroundecanoic acid
PTFE	Polytetrafluoroethylene

Appendix 3: Sources and Uses

3.0 Overview

3.0.1 Findings

Primary manufacturing of per- and polyfluoroalkyl substances (PFAS), involving wastewater discharges, waste disposal, and air emissions, can release PFAS into the environment. There are no known primary PFAS manufacturing operations in Washington state.

Secondary manufacturing, where PFAS are used as part of the manufacturing or industrial process, manufacturing emissions, or waste management could result in PFAS releases. These operations can include aerospace, automotive, aviation, building and construction, cable and wiring, electronics, energy, food processing, paper production, leather and textile, oil and mining, medical products, and metal plating. An estimated 1,200 Washington businesses could use PFAS or a PFAS-containing product in their operations.

Firefighting foam can release PFAS to the environment during use, storage, training, and annual testing. We estimate that as of 2011, an estimated 389,000 liters of aqueous film forming foam (AFFF) was maintained in Washington state by fire departments, civilian airports, military installations, and petroleum-related facilities. As part of the implementation of Chapter 70A.400[113] Revised Code of Washington (RCW), Ecology is collecting additional information regarding current AFFF stocks.

Waste management activities can result in pathways whereby PFAS present in waste streams enters the environment. Studies in other states document such pathways via industrial and municipal wastewater treatment plant (WWTP) effluent discharges, landfill air and leachate emissions, and land application of industrial sludges. However, limited data is available regarding releases of PFAS from such activities in Washington state.

Household products that are sources of PFAS include:

- Cosmetics and personal care products.
- Treatments on textiles, upholstery, carpets, and leather.
- Coatings and floor finishes.
- Cleaning agents.
- Automobile and ski waxes.
- Nonstick cookware.

Occupational exposure to PFAS has been documented at retail stores where products containing PFAS are sold, and service industries that use products containing PFAS.

Historic releases in Washington are estimated based on global estimates published in the literature.

[113] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

3.0.2 Introduction

This appendix presents information about PFAS in Washington, and estimates historical PFAS releases to the environment.

As presented in Appendix 1: Chemistry, PFAS describes a class of more than 4,730 chemicals (Organisation for Economic Co-Operation and Development (OECD), 2018). This appendix provides information on the variety of consumer products that are known to contain PFAS. This appendix also addresses the main sources of PFAS in the environment resulting from manufacturing, consumer use, and product disposal. Past PFAS production, use, and disposal have resulted in PFAS contamination of soil, surface water, and groundwater (see Appendix 4: Fate and Transport).

As of April 2020, known PFAS contamination in the U.S. includes approximately 339 sites and 393 water systems in more than 40 states (Social Science Environmental Health Research Institute (SSEHRI), 2020; Walker, 2018). These compilations identify three impacted sites (City of Issaquah, Fairchild Air Force Base, Joint Base Lewis McChord) and three water systems (City of Dupont, Fort Lewis Cantonment, City of Issaquah) in Washington state. However, as discussed in Section 3.2.3 below, several other locations are being investigated.

Nationwide, groundwater contamination sites are impacted by firefighting foam use and training at military installations, civilian airports or fire stations, as well as use during a few fire events. Other activities reported to impact groundwater include manufacturing of PFAS and secondary manufacturing use of PFAS. Impacts to groundwater are also reported from waste disposal, landfill leachate, land application of industrial sludge, and discharges of wastewater to treatment facilities or septic systems—discussed in more detail in Section 3.4, Waste Management, below.

3.1 Manufacturing

3.1.1 Primary manufacturing

Appendix 1: Chemistry, Section 1.3 Manufacturing, addresses the methods used to manufacture PFAS compounds. Although raw and intermediate PFAS compounds have been, and continue to be, manufactured in the U.S. (see Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency), we do not know of manufacture which was conducted in Washington state.

3.1.2 Secondary manufacturing

Release of PFAS can occur at manufacturing sites where PFAS are used as part of the manufacturing or industrial process. More than 3,000 PFAS may have been commercially used since their inception (Naturvårdsverket, 2016, as cited by Banzhaf et al., 2017). EPA has identified approximately 600 PFAS which are currently commercially active in the U.S. (EPA, 2019a, 2019b) and EPA's Significant New Use Rules still allow use of certain long-chain PFAS in specific low-volume applications where substitute chemicals are limited or absent (for example, but not limited to, photographic imaging and semiconductor manufacturing) (See Appendix 9:

Regulations, Section 9.2.1). U.S. PFAS industry reported that as of 2021, approximately 200 PFAS compounds are currently in commerce in the U.S. (Buck et al., 2021) Recent studies have also more thoroughly identified the variety of manufacturing and other industries where PFAS are still being used (Glüge et al., 2020).

However, use of PFAS in secondary manufacturing operations is not typically reported to regulatory agencies. Its presence in air and aqueous industrial waste streams is not regulated with numeric standards under the Clean Air Act (CAA) or the Clean Water Act (CWA) respectively. However, certain solid wastes may qualify for reporting if they meet the threshold of state designation as dangerous waste (Section 3.4.4 below).

Fourteen investigated contaminated sites across the U.S. indicate PFAS releases from automobile, carpet, cable or wire, footwear, metal plating, paper, plastics, and textiles manufacturing (SSEHRI, 2018). PFAS releases and release mechanisms differ among the manufacturing processes. Appendix 4: Fate and Transport provides additional information about release mechanisms to the environment. PFAS releases during manufacturing operations could result from industrial air emissions, wastewater discharges, stormwater runoff, or waste disposal. Starting in 2021, release data for 172 PFAS will become available through Toxics Release Inventory (TRI) reporting (EPA, 2021).

Examples of secondary manufacturing using PFAS include (Gaines, 2017; Interstate Technology & Regulatory Council (ITRC), 2020a; SSEHRI, 2018; United Nations Environment Programme (UNEP), 2012, 2015a, 2015b, 2016):

- **Automotive**: Coatings on mechanical components, surface treatments for textiles, upholstery, carpets, and leather and automobile surface protectants and finishes.
- **Aviation and aerospace**: Coatings on mechanical components; hydraulic fluids.
- **Electroplating and etching**: Corrosion prevention; mechanical wear reduction; aesthetic enhancement; surfactant; wetting agent/fume suppressant for chrome, copper, nickel and tin electroplating; and postplating cleaner.
- **Industrial surfactants, resins, molds, and plastics**: Manufacture of plastics and fluoropolymers, rubber, and compression mold release coatings; plumbing fluxing agents; fluoroplastic coatings, composite resins, and flame retardants for polycarbonate.
- **Medical products**: Coatings on surgical products and medical fabrics.
- **Oil and mining**: Surfactants; evaporation inhibitors; solvents; fire suppression.
- **Paper products and packaging**: Surface coatings to repel grease and moisture. Uses include non-food paper packaging (for example, cardboard, carbonless forms, masking papers) and food-contact materials (for example, pizza boxes, fast food wrappers, microwave popcorn bags, baking papers, pet food bags).
- **Semiconductor industry**: Top anti-reflective coatings; bottom anti-reflective coatings; etchants, with other uses including surfactants, wetting agents, and photo-acid generation.
- **Textiles and leather treatments**: Factory or consumer-applied coatings to repel water, oil, and stains. Examples include protective clothing and outerwear, umbrellas, tents, sails, architectural materials, carpets, footwear, and upholstery.

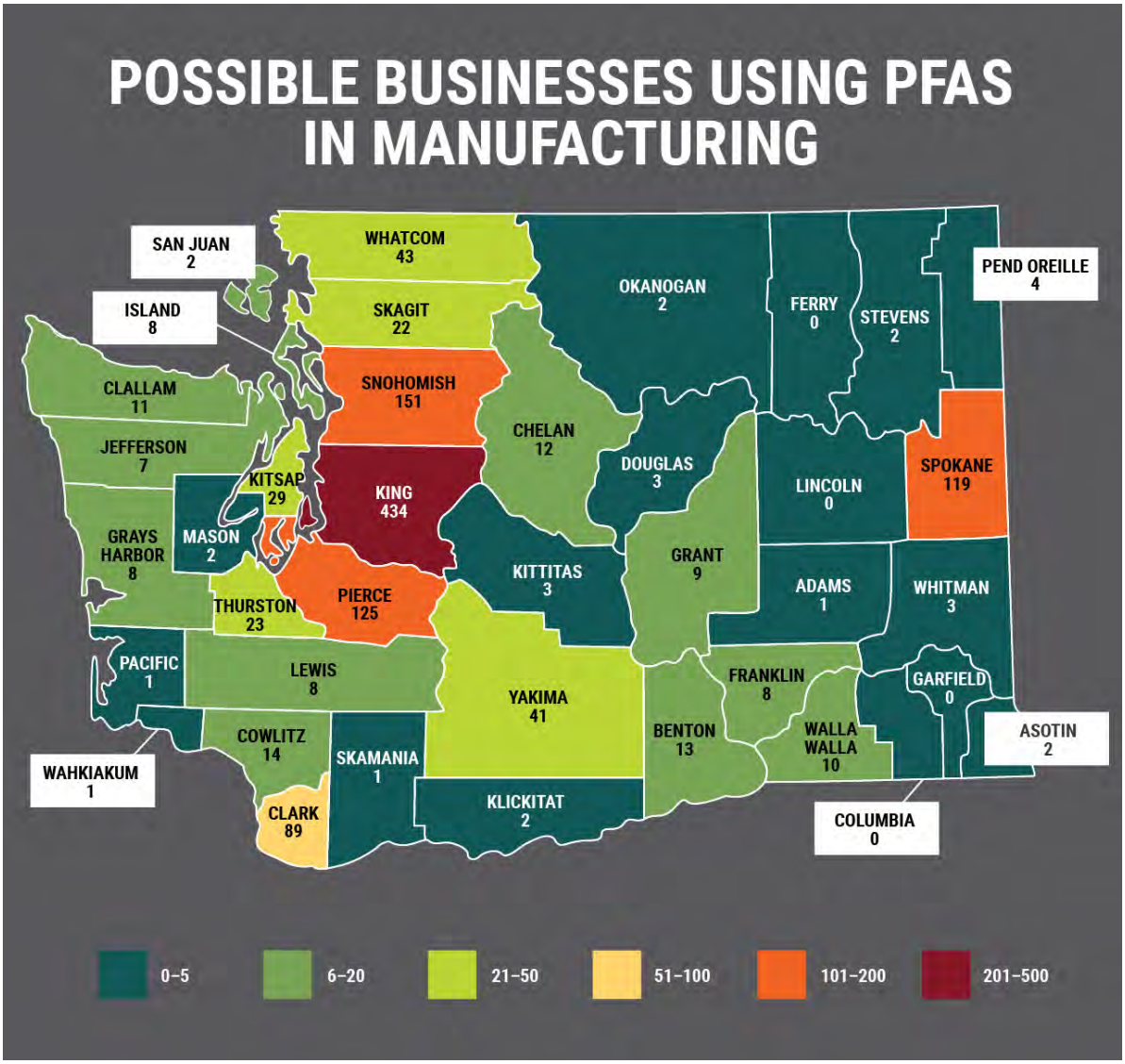
- **Wire manufacturing**: Coating; insulation.

Ecology collected information to estimate how many businesses in Washington state might be operating in a sector known to employ PFAS in the manufacturing process. The U.S. Census Bureau listed 577,445 businesses in Washington state in 2015 (U.S. Census, 2015). Table 17 lists the number of Washington businesses in selected North American Industry Classification System (NAICS) codes that include potential PFAS use (Infogroup, 2012). Figure 23 shows the general location of the businesses in Table 17 in each county of the state. There is no evidence that any of these operations use PFAS or have released PFAS during their operations. Also, PFAS use is not an indication that a release could have occurred.

Table 17: Secondary manufacturing in Washington.

NAICS code name	Count of businesses
All other plastics product manufacturing	241
Automobile manufacturing (plating activity)	13
Aviation and Aerospace	165
Carpet rug mills	13
Corrugated solid fiber box manufacturing	28
Electroplating, plating, polishing, anodizing	60
Leather hide tanning finishing	12
Medical products	249
Other fabricated wire product manufacturing	74
Oil (petroleum) and mining	128
Paper mills (except newsprint)	54
Paper bag coated treated paper manufacturing	69
Paperboard mills	10
Pulp mills	18
Semiconductors related devices manufacturing	33
Textile fabric finishing mills	46
Total of secondary manufacturing by NAICS code	**1,213**

Figure 23. Count of secondary manufacturing facilities by county based on NAICS code.



EPA has also compiled the typical industry sectors which may produce or employ PFAS in manufacturing processes or components in its Enforcement and Compliance History (ECHO) database (EPA, 2020). The facility data presented within displays a subset of the universe of facilities subject to CAA, CWA, or Resource Conservation and Recovery Act (RCRA) regulations. EPA identified these industry sectors from literature reviews and other investigations.

Inclusion in the compilation, however, is not an indication that a business has ever used any PFAS component, or if it has, that any emissions have occurred. For Washington, ECHO identifies 1,095 businesses across 20 industry categories including airports and defense installations. The industry categories are similar to those listed in Table 17. Of the businesses identified, ECHO categorizes them against activity status: 508 are listed as active, 603 inactive, and seven with unknown activity status. Some facilities may be listed in multiple industry categories.

In addition to the manufacturing businesses in Table 17, use of PFAS-containing products like car polishes have been identified in one case as a source of groundwater contamination (Kernan, 2018). A variety of products containing polytetrafluoroethylene (PTFE) are marketed in the automobile washing and detailing industry, as well as to individual consumers. There are more than 700 car washes listed in Washington state, however the extent of use of such PFAS products in the state is unknown. Car washes are not included in Table 17 or Figure 23.

3.2 Aqueous film forming foam

Appendix 1: Chemistry, Section 1.4.4 Fire-fighting chemicals, describes the chemical characteristics of PFAS used in the manufacture of AFFF.

AFFF, while not a large use category, is often used in uncontrolled circumstances with little or no barrier to direct environmental release. PFAS-containing firefighting foams have been implicated in many cases of groundwater contamination (Hu et al., 2016). Environmental releases of firefighting foam can occur during emergency response, mandatory firefighting equipment testing, emergency activation of fire suppression systems, and training exercises. These releases can occur at airports, refineries, bulk storage terminals, and other facilities handling large volumes of flammable liquid hydrocarbons (Heads of EPAs Australia and New Zealand (HEPA), 2018). Drinking water contamination by PFOS and PFOA has also been confirmed as a result of the historical use of AFFF to suppress tire fires (EnviroTrac, Ltd., 2020; Michigan Department of Environment, Great Lakes and Energy, 2021).

Typical facilities that could store AFFF for use at the facility are listed below. Listing of these categories does not imply that PFAS releases have occurred from such activities in Washington, with the exception of specific sites that are discussed below.

- Electrical power generation from coal, diesel, or gas.
- General chemical storage.
- Military installations, civilian airports, or fire departments.
- Mineral, oil, or gas extraction.
- Mining for coal or minerals.
- Petroleum production, exploration, storage, or refining.
- Production of aluminum, batteries, bitumen, brewing and distilling, coal works, dangerous goods, explosives, paints, polishes, or adhesives.

As identified in Appendix 9: Regulations, Section 9.1.1 Washington state laws, the Firefighting Agents and Equipment Toxic Chemical Use Law, Chapter 70A.400[114] RCW, now applies restrictions to the use of PFAS-containing firefighting foam and PFAS use in firefighting personal protective equipment.

The following subsections describe our estimates of AFFF held in the state. The data below was derived from the following sources:

- Information gathered directly by Ecology.

[114] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

- Data estimated based on Ecology's regulatory requirements.
- Estimates based on a compilation of AFFF use by Darwin (2004).
- An update to Darwin's 2004 data completed in 2011.

3.2.1 Fire departments and fire training

According to the Washington Fire Chiefs Association, there are approximately 350 public fire agencies within the state (Senter, 2019). Fire agencies are better known as fire departments, fire districts, regional fire authorities, and port fire departments. In addition to these public agencies, there also exists U.S. Department of Defense (DOD) and private or industrial firefighting forces. Each fire agency has one or more fire stations to serve their community. Fire agencies typically have training facilities located at one of their facilities for in-service training. Fire agencies frequently create regionalized training centers where resources are pooled for multi-agency out-of-service training.

Use of AFFF for fire training has occurred both locally and at regional fire training sites across the state. The following list includes some of the larger and frequently used regional training facilities, however we have not identified all fire training centers at this time:

- Big Bend Community College Air Rescue Firefighting Training, Moses Lake.
- City of Seattle Joint Training Facility, Seattle.
- Kitsap County Regional Training Center, Bremerton.
- Mark Noble Regional Fire Training Center, Olympia.
- North Bend Fire Training Academy, North Bend.
- Puget Sound Regional Fire Authority Fire Training Center.
- Spokane Regional Training Center, Spokane.
- Tacoma Fire Department Training Center, Tacoma.
- Yakima Fire Department Training Center, Yakima.

Other uses of AFFF include portable and wheeled fire extinguishers available for DOD, residential, commercial, and industrial users. Estimates of this type of fire extinguisher availability or use are currently not available.

In early 2018, the Washington Fire Chiefs Association polled its membership to begin to quantify impacts of the proposed legislation that would eliminate PFAS-containing AFFF from training exercises and curtail sales a year later. Feedback, while limited, indicated that most large fire agencies had moved away from using PFAS-containing AFFF. Other feedback related to the availability of reasonable alternatives and how to safely dispose of PFAS-containing AFFF. In response, the Washington Fire Chiefs Association held presentations on the subject at its annual conference and raised awareness through its newsletter and other various mediums.

In 2019, as part of the implementation of Chapter 70A.400[115] RCW (see Appendix 9: Regulations, Section 9.1.1 Washington state laws), Ecology surveyed municipal fire departments, fire districts, fire authorities, port authority fire departments, and fire training facilities about volumes of AFFF currently stored and interest in state-funded AFFF disposal

[115] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

options (Ecology, 2020a). As of February 2020, Ecology received 61 responses. A summary of responses is expected to be completed by fall 2020 (Smith, 2020). Ecology is currently identifying locations where these AFFF stocks can be safely disposed, and will be conducting a State Environmental Policy Act review[116] of the disposal activity (Smith, 2020).

Pending the compilation of statewide survey information, Ecology estimated fire agency storage of AFFF in Washington from the 2004 and 2011 Darwin reports. In 2004, Darwin estimated U.S. public fire departments (excluding airports) possessed 5.14 million liters of AFFF (all measurements are reported in metric units—Darwin reported 1,360,000 gallons of AFFF). This estimate included a 35% margin of error. Adjusting the national estimate in Darwin's study to Washington state (2.3% of the U.S. by population), the fire service possessed 118,577 liters of fluorinated and non-fluorinated firefighting foam in 2004 (the margin of error represents a range from 77,075 to 160,078 liters of foam).

Darwin's (2011) estimate took into account two factors. First, Darwin estimated total 2014 holdings by fire departments nationally to be lower, at 120,000 gallons. Second, Darwin estimated that by 2011, holdings were reduced by 50%. Applying these same reductions to Washington's 2004 estimate above results in 52,240 liters held in 2011.

3.2.2 Civilian airports

U.S. airports have been required to procure and use AFFF that meets the standards set by the Federal Aviation Administration (FAA), which currently requires the use of AFFF that meets military specifications (required to be fluorinated). In October 2018, the U.S. Congress passed legislation directing the FAA to stop requiring airports to use non-fluorinated firefighting foam by October 4, 2021. The change is required to be implemented within three years using the latest version of the National Fire Protection Association (NFPA) 403 Standard for aircraft rescue and firefighting services at airports. NFPA 403 includes a fluorine-free synthetic foam option. There are fluorine-free foams that have been certified by GreenScreen®. These products meet the bronze standard, indicating that their ingredients are not found on any restricted substances lists (GreenScreen®, 2020).

The FAA issues operating certificates to airports that comply with certain operational and safety standards. Current regulatory requirements related to firefighting at airports are found in 14 Code of Federal Regulations (CFR) Aeronautics and Space, Part 139: Certification of Airports, specifically 139.317: Aircraft rescue and firefighting: Equipment and agents. FAA provides guidance in Advisory Circulars. The most recent, on Aircraft Fire Extinguishing Agents (AC 150/5210-6D), states that foam concentrates must meet the performance test requirements of U.S. Military Specification (MIL-SPEC) MIL-F-24385F, which includes the requirement that the foam be fluorinated (FAA, 2004).

The eleven airports in Washington certified by the FAA to handle aircraft rescue and firefighting are listed below (FAA, 2018). In addition to airports listed below, there are 124 general aviation,

[116] https://apps.ecology.wa.gov/separ/Main/SEPA/Record.aspx?SEPANumber=202100276

reliever, and private airports and airstrips around the state (Washington State Department of Transportation (WSDOT), 2017).

WSDOT Aviation has reached out to several larger general aviation airports that do not have a requirement for AFFF under the FAA Part 139 requirement and have found that they do not possess any firefighting foam or personal protective equipment (PPE) that contained PFAS (Wright, 2019).

The amount of AFFF at airports is based on the amount carried on aircraft rescue and firefighting vehicles as well as the reserve available at the airport. Aircraft rescue and firefighting indexes (established at 14 CFR Part 139:315: Aircraft Rescue and Firefighting: Index Determination) indicate ascending order of aircraft length: A for aircraft less than 18 meters in length, and up to E for aircraft longer than in 60 meters in length. Estimated quantities of AFFF stored at civilian airports based on each aircraft rescue and firefighting index are as follows (Darwin, 2004):

- Index A: 2,101 liters.
- Index B: 4,088 liters.
- Index C: 11,564 liters.
- Index E: 25,434 liters.

The following list identifies the index classification of larger civilian airports in Washington.

- Bellingham International, Bellingham, Index B.
- Boeing Field/King County International, Seattle, Index A.
- Grant County International, Moses Lake, Index A.
- Pangborn Memorial, Wenatchee, Index A.
- Pullman/Moscow Regional, Pullman, Index B.
- Seattle-Tacoma International, Seattle, Index E.
- Snohomish County (Paine Field), Everett, Index A.
- Spokane International, Spokane, Index C.
- Tri-Cities, Pasco, Index B.
- Walla Walla Regional, Walla Walla, Index A.
- Yakima Air Terminal (McAllister Field), Yakima, Index A.

Table 18 summarizes the volumes of AFFF held by civilian airports in Washington based on Darwin's (2004) assumptions.

Darwin re-estimated volumes of AFFF held by airports in 2004 based on volumes of 3M concentrate only, and also determined rate of usage drawing down the amounts held through 2011. Darwin's national 2004 estimate was only 37% of the 2011 estimate (i.e., a total of 26,824 gallons). Darwin determined that between 2004 and 2011, national civilian airport AFFF stocks were further reduced by approximately 85% (i.e., a total of 3,992 gallons). Darwin also received confirmation that SeaTac airport no longer held any AFFF with perfluorooctane sulfonic acid (PFOS). Table 19 provides a conservative update for Washington AFFF holdings based on an 85% reduction of 2004 volumes by index and excluding SeaTac. Based on these assumptions, civilian airports in Washington would have held 5,465 liters.

AFFF is also used in airplane hangars, according to NFPA standard 409 "Standard on Aircraft Hangars." Aircraft hangars require overhead foam sprinkling for the entire hangar if the floor area exceeds 1,858 square meters (m^2): 11,356 liters of AFFF concentrate. Foam capacity increases for a hangar floor greater than 3,716 m^2: 22,712 liters of AFFF concentrate. Darwin estimated hangar AFFF storage for airport index categories C and E at 43,721 and 289,205 liters per airport respectively (Darwin, 2004). These totals assumed AFFF storage in hangars were proportional to the FAA index estimates. Estimated AFFF stored in hangars in Washington in 2004 is summarized in Table 18. Darwin estimated that by 2011, volumes previously provided in 2004 were reduced by 37% overall. This same assumption is applied to AFFF maintained in hangars in Washington state in 2011, resulting in 123,183 liters, as shown in Table 19.

FAA regulations (14 CFR Part 139) establish the minimum aircraft firefighting capability for each index. AFFF quantities stored at FAA certified airports are estimated from Darwin (2004) using the estimates for A, B, C, and E aircraft rescue and firefighting indexes and for associated storage for hangars. There are additional users that maintain supplies of AFFF, such as airplane manufacturers, overnight shipping aircraft hangars, and fuel storage. Darwin (2004) provided quantities of AFFF stored by Boeing at 217,472 liters and FedEx at 378,541 liters at all U.S. locations.

PFAS-containing AFFF quantities stored at Washington certified airports are listed in Tables 18 and 19 for 2004 and 2011 respectively.

Table 18. 2004 estimated AFFF storage at certified airports and hangars (combined totals).

Airports in each FAA Index code	AFFF storage (liters)	AFFF hangar storage (liters)
A = 6 airports	12,605	-
B = 3 airports	12,265	-
C = 1 airport	11,564	43,721
E = 1 airport	25,434	289,205
TOTAL	**61,868**	**332,926**

Table 19. 2011 Estimated AFFF storage at certified airports and hangars (combined totals).

Airports in each FAA Index code	AFFF storage (liters)	AFFF hangar storage (liters)
A = 6 airports	1,891	-
B = 3 airports	1,840	-
C = 1 airport	1,735	16,177
E = 1 airports	0	107,006
TOTAL	**5,465**	**123,183**

Many airports have instituted best management practices associated with the testing of aircraft rescue and firefighting equipment required for use of AFFF (FAA, 2004; NFPA, 2014; Thalheimer et al., 2017). Certified airports must annually test the AFFF proportioning equipment to maintain their Part 139 Certification. These tests require spraying the foam for 30 seconds and collecting a sample of the foam to verify that the proper concentration of AFFF is dispensed. AFFF best management practices recommend collection and proper disposal of the foam and any impacted soil. Recent FAA guidance allows testing to be performed in a closed system,

some airports may opt to use this system for future annual tests (FAA. 2019). Fire response training can be conducted at the airport or at other fire training locations.

3.2.3 Defense installations

Federal law requires that the Secretary of Defense prohibit the use of fluorinated AFFF for training exercises at military installations by October 2024. (Ginn, 2021). AFFF storage and use at DOD sites includes ships, shore facilities, and firefighting vehicles (Darwin, 2004). We assumed that nationally there are 242 Navy installations, 245 Army installations, 384 Air Force installations, and 400 Coast Guard installations. There are 19 active military installations in Washington state, including ten operated by the U.S. Coast Guard. Ecology calculated Washington AFFF volumes by proportionally reducing Darwin's national data against the number of installations in Washington. PFAS-containing AFFF quantities stored at active Washington military installations estimated from Darwin (2004) are shown in Table 20.

For his 2011 estimate, Darwin focused on 3M AFFF inventories. On this basis, he first revised the national 2004 holdings from 2,836,497 gallons to 2,080,000 gallons. Darwin further estimated various drawdown percentages between 2004 and 2011 for each of the defense branches and for specific types of uses within a branch. Ecology updated its 2004 estimate using national volume totals by installation type determined by Darwin for 2011, proportioned against the number of installations in Washington. These are also presented in Table 20.

Table 20. Military AFFF storage (combined totals) in 2004 and 2011.

Military installations	2004 estimated AFFF concentrate stored (liters)	2011 estimated AFFF concentrate stored (liters)
4 Navy	78,184	19,623
3 Army	3,585	3,121
2 Air Force	26,173	12,442
10 Coast Guard	13,438	7,823
TOTAL	**121,380**	**43,008**

The DOD and Department of the Navy (DON) continue to inventory fire and crash training sites at U.S. installations. The military is assessing the risk of groundwater contamination from firefighting foam at many of its locations including those in Washington state (DOD, 2014, 2018, 2019a, 2019b, 2019c; DON, 2016a). The following is a partial listing of defense installation sites in Washington state where PFAS use or releases may have occurred:

- Four Lakes Communications Air Guard Station (closed), Cheney.
- Fairchild Air Force Base, Spokane (DOD, 2019c).
- Joint Base Lewis-McChord, Tacoma (DOD, 2018).
- Yakima Training Center, Yakima (DOD, 2014).
- Naval Base Kitsap (DON, 2020a, 2020b).
- Naval Air Station Whidbey Island (DON, 2018, 2019).

Appendix 7: Health, Section 7.4 Known areas of PFAS contamination in drinking water aquifers in Washington state, provides additional information regarding impacts of AFFF releases.

3.2.4 Petroleum storage and transport

Petroleum is refined, stored, and transported from and around Washington state. Petroleum products stored at gas stations are not included in this discussion. Transport and storage of fuel from railcar, tanker, pipeline, or refinery has the potential for fire or explosion, requiring the availability and use of fire suppression. Fire suppression systems at these facilities may include PFAS-containing AFFF.

Ecology regulates equipment and oil transfer, storage, and handling at 121 facilities to ensure protection of environmental and public health. There are three facility types, shown in Figure 24. Each facility has different types of requirements, depending on their classification, but all are required to have some type of spill prevention plan. Regulated facilities are trained to prevent, prepare for, and respond to spills when they occur. Ecology does not track the firefighting foam stored at these facilities. Darwin (2004) estimated 59,052 liters (15,600 gallons) of AFFF concentrate per refinery in the U.S. For the five refineries in Washington, that amounts to 295,262 liters of AFFF. The following brands of AFFF have been reported to be stored or used at these refineries:

- 3M Light Water 3X6 AR-AFFF
- Aer-O-Foam XL-3
- Chemguard 3 percent AR-AFFF
- FireAde 2000
- National Foam (Universal Plus 3/6 percent AR-AFFF)
- Thunderstorm 1 X 6, 3 X 6 and 1 X 3 AR-AFFF Ansul/Williams
- Thunderstorm FC601A

Darwin revised the 2004 estimate to 4,724 liters (1,248 gallons) per refinery based on consideration of 3M AFFF holdings in 2004 and a consumption of 86% between the years 2004 and 2011. This resulted in an estimated total of 23,621 liters for the five refineries in Washington state.

Mobile facilities transporting petroleum products into Puget Sound are required by federal shipping regulations to maintain a supply of fire suppressant on the tanker (46 CFR). That volume of foam liquid must be sufficient to provide a minimum of 20 minutes of flow through nozzles across the cargo tank deck. Darwin (2004) estimated 3,785 liters (1,000 gallons) of AFFF are maintained per oil tanker and 189 liters for other merchant ships. Darwin further estimated that holdings associated with mobile facility uses would have been reduced by half from 2004 – 2011. International shipping regulations require fire extinguishing systems adequate for the fire hazard that may exist, but fire extinguishing systems using perfluorocarbons are prohibited (International Maritime Organization, 2007).

In addition to refineries, other petroleum facilities include blending facilities, tank farms, loading and fueling terminals, and other flammable liquid storage. Fire protection at these facilities include AFFF systems constructed according to NFPA standards. AFFF storage at these facility types, in Table 21, are estimates. Ecology regulates these facilities in four categories:

- **Class 1** facilities are large, fixed shore-side facilities such as refineries and refueling terminals. This definition includes facilities that transfer to or from tank vessels and pipelines.
- **Class 2** facilities are mobile facilities, such as tanker trucks and portable tanks.
- **Class 3** facilities are small tank farms and terminals that transfer oil to non-recreational vessels that have a fuel capacity of 39,746 liters (10,500 gallons) or more. This definition does not include facilities that transfer to tank vessels and pipelines, as they are Class 1 facilities.
- **Class 4** facilities are marinas or other small fueling facilities that transfer oil to non-recreational vessels with a total oil capacity of less than 39,746 liters.

In line with Darwin's estimates, we also assumed that from 2004 – 2011, stocks of these AFFF holdings were reduced by half. Tables 21 and 22 summarize AFFF volumes estimated in Washington state for the petroleum refinery sector for years 2004 and 2011 respectively.

Table 21. 2004 AFFF storage at petroleum related facilities.

Description	Count of facilities	AFFF/facility (liters)	Estimated AFFF (liters)
Refineries	5	59,052	295,262
Large refueling terminal, pipeline	20	7,570	151,400
Mobile facility	24	3,785	90,840
Transfer >10,500 gal capacity	5	3,785	18,925
Transfer <10,500 gal capacity	67	1,892	126,764
TOTAL	**121**		**683,191**

Table 22. 2011 AFFF storage at petroleum related facilities.

Description	Count of facilities	AFFF/facility (liters)	Estimated AFFF (liters)
Refineries	5	4,724	23,621
Large refueling terminal, pipeline	20	3,785	75,700
Mobile facility	24	1.893	45,420
Transfer >10,500 gal capacity	5	1,893	9,463
Transfer <10,500 gal capacity	67	946	63,382
TOTAL	**121**		**217,585**

Figure 24. Class 1, 3, and 4 oil transfer, storage, and handling facilities.[117]

Oil spill response can also involve the use of products which may contain PFAS, for example AFFF stored in caches. Oil spill response resources are tracked on the Worldwide Response Resource List (WWRL). Records indicate BNSF holds 2,082 liters (550 gallons) AFFF at each of its Pasco, Seattle, and Vancouver cache locations, for a total of 6,246 liters (Ecology, 2020).

Ecology funds oil spill response equipment located around the state (including AFFF) and provides training to local responders on how to safely and effectively deploy the equipment. Cached equipment has been used a number of times since deployment, and has effectively limited the spreading of and environmental damage from oil spills, and reduced the time and costs associated with oil spill cleanup. AFFF covered under this grant funding is limited to non-fluorinated products.

[117] https://fortress.wa.gov/ecy/coastalatlas/storymaps/spills/spills_sm.html?&Tab=nt3

3.2.5 Transportation

Fire protection systems using AFFF are used in some types of public road and marine transportation, namely where flammable fuels can be present. These include, but may not be limited to, protection of tunnels and ferries.

Tunnels

NFPA standard 502 provides fire protection and fire safety requirements for road tunnels, bridges, and other limited access highways (NFPA, 2011). In Seattle, tunnels using a deluge foam fire suppression system are the I-90 Mercer Island, I-90 Mt. Baker, and the I-5 Convention Center (Cox, 2019). Other Seattle tunnels use a non-PFAS based fixed water firefighting system: Battery Street, downtown Seattle transit for bus and train, and SR99 Replacement Tunnel. Table 23 summarizes estimated volumes of AFFF Seattle area tunnels.

Table 23. Road tunnels with fixed foam firefighting systems in Seattle.

Tunnel	Route	Length (meters)	Lanes	Estimate of AFFF storage (liters)
Mercer Island	I-90	914	8	48,510
Mt Baker	I-90	1067	8	28,334
Convention Center	I-5	167	12	11,735
TOTAL				**88,579**

Ferries

Ferry transportation systems are also required to provide fire protection systems that may be based on Class B firefighting foam. For example, Class B firefighting foam is carried on WSDOT ferries for emergency response purposes in 5-gallon containers, with 8 – 10 such containers on a ferry, depending on its size (Cory, 2021).

3.2.6 Summary of AFFF quantities

Table 24 summarizes the estimates of firefighting foam quantities in Washington state in 2004 and 2011. The table also estimates average annual use over the seven years.

Table 24. 2004 and 2011 estimated AFFF quantities in Washington state.

AFFF use sector	2004 (liters)	2011 (liters)	Estimated annual use
Fire departments	118,577	52,240	8% or 9,477 liters
Fire extinguishers*	Not able to estimate*	Not able to estimate*	Not able to estimate*
Civilian airports	61,867	5,465	13% or 8,057 liters
Airport hangars	332,926	123,183	9% or 29,963 liters

AFFF use sector	2004 (liters)	2011 (liters)	Estimated annual use
U.S. Military installations	121,380	43,008	9% or 11,196 liters
Petroleum refineries	295,262	23,621	13% or 38,806 liters
Other petroleum facilities	387,929	193,965	7% or 27,720 liters
Merchant ships/Oil cargo tankers*	189 to 3,785 per vessel*	189 to 3,785 per vessel*	Not able to estimate*
Oil response storage	76,011**	76,011**	Not able to estimate*
Seattle tunnels	88,579**	88,579**	Not able to estimate*
TOTAL storage	1,482,605	606,702	(11%) or 125,219 liters

Notes:

- * = Not included in total.
- ** = 2004 and 2011 data are not available; data represents 2019 – 2020 storage.

3.2.7 Spill reports

When oil or other hazardous substances are spilled, a report must be submitted to Ecology. Since 2007, Ecology has maintained the Emergency Reporting Tracking System (ERTS) for these reports. Reports entered into that system that refer to releases of firefighting foam are summarized in Table 25. Most of these reports were related to activities that occurred on or near water, or where firefighting foam entered a waterway. These voluntary reports refer to fuel, water, and foam but do not specify if the material released contains PFAS. These reports are shared with local agencies and other response personnel. Information in these reports is not independently verified.

Table 25. Firefighting release incidents voluntarily reported to Ecology's ERTS.

Year	Number of reported incidents	Released fuel, water, AFFF (liters)
2007	1	76
2009	3	30
2010	3	15
2011	4	1,908
2012	2	34,163
2013	3	2,468
2014	2	15
2015	1	38

Year	Number of reported incidents	Released fuel, water, AFFF (liters)
2016	9	1,177,535*
TOTAL	**28**	**1,216,248**

Note: * = One incident in August 2016 reported the use of 1,173,477 liters (310,000 gallons) of water with firefighting foam at an industrial facility.

3.3 Consumer products

3.3.1 PFAS in children's products

As identified in Appendix 9: Regulations, Section 9.1.1 Washington state laws, the Children's Safe Products Act (CSPA—Chapter 70A.430[118] RCW) requires manufacturers to annually report the presence of PFOS or perfluorooctanoic acid (PFOA) in children's products sold in Washington state. Manufacturer reports are available online.[119]

A summary of the PFOS manufacturer data available through 2020 is provided in Table 26. For all products, PFOS was reported to be present at concentrations less than 100 parts per million, except for the artists accessories report from 2014 and dress costumes in 2020, which reported PFOS at 100 to 500 parts per million. PFOA was only reported once in 2019 in the Belts/Braces/Cummerbunds product category, present at less than 100 ppm, with a stain prevention function.

Table 26. Reports of PFOS in children's products, at concentrations below 100 parts per million unless noted.

Product category	2014	2016	2017	2018	2019	2020	Chemical function
Artists Accessories (PFOS reported at 100 to 500 parts per million)	1						UV stabilizer
Baby Feeding – Bibs	1						Contaminant
Belts/Braces/Cummerbunds					1		Protective coating
Blankets/Throws (Non Powered)	1						Contaminant
Board Games/Cards/Puzzles Variety Packs	1						Contaminant
Dresses	1	1					Contaminant
Full Body Wear Variety Packs		1					Manufacturing additive
Fancy Dress Costumes/Accessories Other						1	No function
Indoor Footwear – Fully Enclosed Uppers	1						Contaminant

[118] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.430
[119] https://hpcds.theic2.org/Search

Product category	2014	2016	2017	2018	2019	2020	Chemical function
Jackets/Blazers/Cardigans/Waistcoats	1	1	1				Colorant; Contaminant
Overalls/Bodysuits	1	1	14				Colorant; Flame retardant; Contaminant
Pants/Briefs/Undershorts	1		14				Flame retardant; Contaminant
Pantyhose/Stockings	1						Contaminant
Shirts/Blouses/Polo Shirts/T-shirts	1		22				Colorant; Flame retardant; Contaminant
Shoes – General Purpose	1						Contaminant
Skirts	1		1				Flame retardant; Contaminant
Sleepwear Variety Packs	1						Contaminant
Socks	1						Contaminant
Sportswear – Full Body Wear	1	4					Colorant; Contaminant
Sportswear – Lower Body Wear	1	1	2				Colorant; Flame retardant; Contaminant
Sportswear – Upper Body Wear	1	5	4				Colorant; Flame retardant; Waterproofing
Sweaters/Pullovers	1						Contaminant
Trousers/Shorts	1						Contaminant
Upper Body Wear/Tops Variety Packs		1					Colorant
Total reports	**20**	**15**	**58**	**0**	**1**	**1**	

3.3.2 PFAS in a typical home

PFAS exposure in the home occurs during product use and exposure to house dust containing PFAS. The greatest portion of the chronic exposure to PFAS for the general public, specifically to PFOS and PFOA, results from the intake of contaminated drinking water and foods—more discussion is provided in Appendix 7: Health, Sections 7.3.1 Drinking water and 7.3.2 Food (Trudel et al., 2008). Other sources of exposure could occur from PFAS-containing products in the home and in some occupations (Glüge et al., 2020; Guo et al., 2009; ITRC, 2020a). Studies of indoor air and house dust indicate exposure to PFAS from consumer products in the home such as carpet care liquids, nonstick cookware, packaged fast food, and waterproof clothing (see

Appendix 7: Health, Section 7.3.3 Consumer products). Pets are also exposed to PFAS by many of the same pathways as people (Ma et al., 2020).

In a study published in 2009, EPA evaluated 116 products available in the typical home and tested each product for perfluorocarboxylic acid (PFCA) (Guo et al., 2009). The main goal of that study was to identify and rank potentially important indoor sources based on PFCA content in articles of commerce. In the following tables, the Guo et al. (2009) study data is provided and supplemented with data from more recent consumer products PFAS studies.

The EPA study estimated quantities of product categories present in a typical American home (Guo et al., 2009). For example, in the EPA study, a typical home was assumed to contain 150 m^2 of PFAS-treated carpet and 50 m^2 of PFAS-treated textiles and upholstery.

- Treated carpet: 60% of the U.S. home floor area of 250 m^2 is carpeted.
- Textile and upholstery of 50 m^2: 10 – 20 m^2 of fabric for an upholstered chair or sofa and 2 – 3 m^2 of fabric for a jacket, shirt, or pants.

Carpeting and upholstery involve large treated areas and stain-resistance treatment is a frequent specification among institutional purchasers (Department of Toxic Substances Control, California (DTSC), 2017). Textile-related products that use fluorinated applications include: home furnishings, outer garments, umbrellas, bags, sails, tents, parasols, car seats, covers, leather articles, and shoes.

Investigations indicate a variety of PFAS are present in a wide range of cosmetics, including sunscreen, foundations, concealers, hair spray, eye liners, creams, lotions, and powders. The results varied widely across product types and brands, with highest measured PFAS concentrations in sunscreen and foundation (Danish Environmental Protection Agency (DEPA), 2018). Examples of fluorinated ingredients in cosmetic products include: per/polyfluorinated acrylate polymers, naphthalenes, alkanes/alkenes, alcohols, siloxanes, silanes, sulfonamides, ethers, esters, phosphate esters, acrylates, and acids. According to the European Commission's database on cosmetic ingredients, these substances are used in cosmetic products as emulsifiers, antistatics, stabilizers, surfactants, film formers, viscosity regulators, and solvents (Schultes, 2018).

Using the process developed by EPA, recent product testing study data are added to the 2009 data (Guo et al., 2009; Fujii, 2013; Herzke et al., 2012; Kotthoff, 2015; Liu et al., 2015). Tables 27 and 28 list the top ten products for the sum of PFCA and FTOH/fluorotelomer sulfonate (FTS). Supplement 1 to this appendix provides estimates for more product testing data. The amount of PFAS in the typical home from each product will not directly correlate with exposure. Some PFAS such as fluoropolymers in nonstick cookware have been shown to be relatively heat stable (see Appendix 1: Chemistry, Section 1.1.4 Polymeric PFAS). Stability in the product means that the amount in the product may not directly correlate with exposure. It does not mean that exposure is not possible.

Table 27. Estimated PFCA in consumer products in a typical home.

Category name	Concentration of PFCAs in product	Typical quantity of product used	Total PFCA in typical home (microgram µg)	Reference
Pre-treated carpeting	484 µg/ m^2	150 m^2	72,600	Guo et al., 2009
Treated home textile and upholstery	346 µg/ m^2	50 m^2	17,300	Herzke et al., 2012
Waterproofing agents	29,889 µg/Liter (L)	0.5 L	14,945	Herzke et al., 2012
Pre-treated carpeting	57.2 µg/kilogram (kg)	50 kg	2,860	Kotthoff, 2015
Food contact material (paper)	2,859.9 µg/kg	1 kg	2,860	Kotthoff, 2015
Treated floor waxes and stone/wood sealants	2,430 µg/kg	1 kg	2,430	Guo et al., 2009
Sunscreen	19,000 µg/kg	0.1 kg	1,900	Fujii, 2013
Treated home textile and upholstery	336 µg/kg	5 kg	1,680	Guo et al., 2009
Nonstick cookware	1,234.74 µg/kg	1 kg	1,235	Herzke et al., 2012
Household carpet/fabric-care liquids and foams	953 µg/kg	1 kg	953	Guo et al., 2009
Dental floss and plaque removers	31.3 µg/kg	0.005 kg	0.2	Guo et al., 2009

Table 28. Estimated FTOH or FTS in consumer products in a typical home.

Category	Concentration of FTOH/FTS in product	Typical quantity of product used	Total FTOH/FTS in typical home (microgram µg)	Reference
Cleaning agents	667,700 µg/kg	1 kg	667,700	Kotthoff, 2015
Treated floor waxes and stone/wood sealants	423,000 µg/kg	1 kg	423,000	Liu et al., 2015
Waterproofing agents	464,774 µg/L	0.5 L	232,387	Herzke et al., 2012
Treated home textile and upholstery	42,900 µg/kg	5 kg	214,500	Liu et al., 2015
Carpet	4,010 µg/kg	50 kg	200,500	Liu et al., 2015
Impregnating sprays (waterproofing)	1,857,300 µg/kg	0.1 kg	185,730	Kotthoff, 2015
Treated home textile and upholstery	757 µg/ m^2	50 m^2	37,850	Herzke et al., 2012

Category	Concentration of FTOH/FTS in product	Typical quantity of product used	Total FTOH/FTS in typical home (microgram µg)	Reference
Carpet samples	73.5 µg/kg	50 kg	3,675	Kotthoff, 2015
Membranes for apparel	1,590 µg/kg	1 kg	1,590	Liu et al., 2015
Treated apparel	464 µg/kg	2 kg	928	Liu et al., 2015

Based on the method used by Guo et al. (2009) and Liu (2015), sources in a typical home include:

- PFCA from carpet, carpet care products, textiles and upholstery, and floor waxes and polishes.
- Fluorotelomer alcohols (FTOH) and fluorotelomer sulfonates (FTS) from cleaners, carpet-care products, waterproofing spray, textiles, floor waxes and polishes, and carpet.

3.3.3 Consumer product priorities

We have identified several consumer product categories that merit additional consideration based on their contribution to PFAS in homes, potential human exposure (see Appendix 7: Health, Section 7.3 Sources and pathways for human exposure), and environmental release pathways (see Appendix 4: Fate and Transport). These are summarized in Table 29.

Table 29. Consumer products that have the potential to contribute to human and environmental exposures of PFAS in Washington state.

Product	Contribution to human exposure	Contribution to environmental exposure
Stain resistant carpet	PFAS in carpet is associated with indoor air concentrations of PFAS (Fraser, 2012) and PFAS biomarkers in children (Harris, 2017). Carpet can cover a large portion of home and commercial floor space. Since young children spend more time on or near the floor, they are particularly vulnerable to PFAS exposure from carpet (Tian, 2016; Trudel, 2012).	An estimated 14,300 metric tons of PFAS from carpet end up in Washington landfills annually. This could represent an environmental exposure pathway if landfills do not properly contain and manage leachate. Carpet washing can result in the discharge of PFAS to used wash water, which is then typically discharged to sewer and transferred to WWTP. PFAS are found in WWTP influent and are difficult to remove, resulting in direct environmental releases (Pan, 2016).

Product	Contribution to human exposure	Contribution to environmental exposure
Carpet treatments	Frequent carpet treatments were associated with elevated house dust and blood concentrations of PFHxS, PFOA, and PFOS in a case study (Beesoon, 2012). Once treated, there is similar exposure potential as pretreated stain-resistant carpet. Since application is done in residential settings, the use of protective equipment and ventilation may be insufficient. PFAS are semi-volatile and can be inhaled. Exposures to PFNA is higher in people when they use wax, polish, or water-resistant materials (Lee, 2017).	An estimated 14,300 metric tons of PFAS from carpet end up in Washington landfills annually. Most of this comes from pretreated carpet (50 – 90%), however the use of carpet treatments also contributes to this burden. This could represent an environmental exposure pathway if landfills do not properly contain and manage leachate.
Waterproofing sprays	Waterproofing sprays can have high PFAS concentrations (1,857,300 microgram/kg) (Kotthoff, 2015). Since application is done in residential settings, the use of protective equipment and ventilation may be insufficient. PFAS are semi-volatile and can be inhaled. They also penetrate the skin. Exposures to PFNA is higher in people when they use wax, polish, or water-resistant materials (Lee, 2017).	An estimated 2,066 metric tons of PFAS from textiles end up in Washington Landfills annually. This could represent an environmental exposure pathway if landfills do not properly contain and manage leachate. PFAS used in waterproofing textiles can be released during the laundering process (CEC, 2017). They are found in municipal WWTP influent and are difficult to remove, resulting in direct environmental releases (Pan, 2016).
Furniture	PFAS can be released from furniture over time and accumulate house dust and be inhaled or ingested by babies and children. Women with treated carpets or furniture in their homes had higher concentrations of some PFAS in their bodies (Boronow et al., 2019).	59,842 metric tons of furniture are disposed of in Washington state each year. If furniture (on average) is approximately 2.4 mg/kg PFOS, 0.17 metric tons of PFOS are disposed of each year (KEMI, 2015).

Product	Contribution to human exposure	Contribution to environmental exposure
Waterproof textiles	PFAS in textiles is associated with indoor air and dust concentrations (Wu, 2015). Children who wear waterproof clothing more frequently have higher concentrations of PFOS and PFNA in their serum (Clara, 2008).	An estimated 2,066 metric tons of PFAS from textiles end up in Washington landfills annually. This could represent an environmental exposure if landfills do not properly contain and manage leachate. PFAS can also be released from washable textiles during the laundering process (CEC, 2017). They are found in municipal WWTP influent and are difficult to remove, resulting in direct environmental releases (Pan, 2016).
Cosmetics	PFAS are found in some sunscreen, concealers, hair spray, lotions, shampoo, creams, and powders (DEPA, 2018). These products are applied directly to the skin and body. PFOA can be dermally absorbed, leading to increased serum concentrations (Franko, 2012).	PFAS in rinse-off products can be washed down the drain. PFAS are found in municipal WWTP influent and are difficult to remove, resulting in direct environmental releases (Pan, 2016).

3.3.4 Service and retail settings

Appendix 7: Health, Section 7.2.2 Populations with elevated PFAS exposure, addresses potential occupational PFAS exposure routes. With the exception of firefighter exposure, a primary occupational exposure route in Washington state is exposure to products containing PFAS in retail- and service-oriented occupations.

High levels of PFAS have been reported in some occupational settings, including retail stores where products containing PFAS are sold, and service industries that use products containing PFAS, for example stores selling outdoor equipment, furniture shops, and carpet shops (Langer et al., 2010; Schlummer et. al., 2013). We have estimated that approximately 10,400 and 6,500 retail trade workers are employed in home furnishing and sporting goods stores in Washington respectively (Washington State Employment Security Department (ESD), 2017a).

An estimated 269,798 Washington workers could be exposed at work when using PFAS-containing products, based on 2018 data provided by ESD, unless otherwise noted (ESD, 2019). The estimated number of workers in specific occupations are listed below.

Automotive workers that could use PFAS-containing car polishes or products used on the textiles in the car:

- Automotive & Watercraft Service Attendants: 2,446
- Automotive Body & Related Repairers: 2,545
- Automotive Glass Installers & Repairers: 559

- Automotive Service Technicians & Mechanics: 13,421
- Cleaners of Vehicles & Equipment: 8,116

Carpet and furniture workers that could use PFAS-containing oil, stain, and water repellents:

- Cabinetmakers & Bench Carpenters: 2,330
- Carpet Installers: 1,204
- Floor Layers, Except Carpet, Wood, & Hard Tiles: 291
- Floor Sanders & Finishers: 149
- Upholsterers: 380
- Furniture Finishers: 518

Textile workers that could use PFAS-containing oil, stain, and water repellents:

- Fashion Designers: 495
- Shoe & Leather Workers & Repairers: 68 (2017 data; no data reported for June 2018)
- Textile Cutting Machine Setters, Operators, & Tenders: 114
- Textile Wind/Twist/Draw-Out Machine Setters, Operators, & Tenders: 226
- Fabric & Apparel Patternmakers: 56
- Textile, Apparel, & Furnishings Workers, All Other: 128

Food service workers that could use PFAS-containing food packaging or paper:

- Food Service Managers: 2,297
- Food Preparation & Serving Worker Supervisors: 21,030
- Food Preparation Workers: 20,088
- Combined Food Preparation & Serving Workers, Inc. Fast Food: 80,587
- Counter Attendants, Cafeteria/Concession, & Coffee Shop: 13,766
- Food Servers, Non-restaurant: 4,828
- Dining Room & Cafeteria Attendants & Bartender Helpers: 9,429
- Food Preparation & Serving Related Workers, All Other: 1,646
- Paper Goods Machine Setters, Operators, & Tenders: 2,081

Other workers that could use PFAS-containing cleaning products or cosmetics:

- Janitors/Cleaners, Except Maids & Housekeeping: 45,378
- Maids & Housekeeping Cleaners: 17,617
- Housekeeping & Janitorial Worker Supervisors: 2,421
- Skincare Specialists (cosmetics): 1,301

Workers serving the skiing industry, where fluorinated ski-wax application can occur:

- Athletes and sports competitors (ESD, 2020): 130
- Lifeguards, Ski Patrol, and Other Recreational Protective Service Workers (ESD, 2020): 2,418
- Umpires, Referees, and other Sports Officials (ESD, 2020): 667
- Workers at skiing facilities (U.S. Bureau of Labor Statistics [BLS], 2021a): 1,770

- Workers in sporting and athletic goods manufacturing (BLS, 2020b): 1,874
- Workers in sports and recreation instruction (BLS, 2021c): 4,484

Workers handling waste and recycled materials that may contain PFAS:

- Refuse and Recyclable Material Collectors (ESD, 2020): 2,940

Other occupations may use PFAS-treated clothing or fabric, including but not limited to:

- Medical field and medical emergency responders
- Firefighters
- Retail

3.4 Waste management

3.4.1 Manufacturing waste

Release of PFAS has been shown to occur at manufacturing sites where PFAS are used as part of the industrial process. Approximately 60 contaminated sites across the U.S. are linked to PFAS releases from automobile, carpet, cable or wire, metal plating, paper, plastics, and textiles manufacturing (SSEHRI, 2020). PFAS releases and release mechanisms differ among the manufacturing processes. PFAS releases could result from air emissions, wastewater discharges, stormwater runoff, or waste disposal. SSHERI has not identified any manufacturing-related contaminated sites in Washington. Neither Ecology nor Health have conducted any manufacturing industry surveys in Washington to determine whether PFAS may have been used, and if so, whether discharges of PFAS-contaminated wastes may have occurred.

3.4.2 Wastewater

Wastewater is the water "waste" that results from domestic uses, such as restroom use, bathing, food preparation, and laundry, or industrial uses such as, but not limited to, manufacturing, mining, and commercial businesses. Some wastewaters are treated on site—for example, single-family septic systems or industries that treat their own wastewater prior to disposal to the environment. Others are conveyed via sewage systems for treatment at publicly owned wastewater treatment plants (WWTPs).

Wastewater treatment standards

Different contaminants enter wastewater depending on how and where water is used. Wastewater that contains pollutants (for example, chemicals or organic matter) must be treated before it can be released into the water environment.

Effluent limits for all wastewater discharges are based on technology requirements and water quality-based standards. Neither federal nor state treatment requirements address criteria for PFAS in wastewater discharges. In Washington, industrial and municipal effluent can be discharged to surface waters or to ground, and all WWTPs must meet a minimum pollutant removal threshold known as All Known Available and Reasonable Technology (AKART), WAC

173-201A.[120] In cases where effluent is discharged to ground, it is regulated to meet the Washington Groundwater Quality Standards (Chapter 173-200[121] Washington Administrative Code (WAC)). Effluent discharged to surface waters must meet the state's Surface Water Quality Standards (Chapter 173-201A[122] WAC). Effluent limits for publicly owned WWTPs are also based on meeting secondary treatment standards, AKART, and water quality based requirements. Industrial users who discharge to these publicly owned WWTPs must comply with national and state pre-treatment requirements; however, there are neither state nor federal pre-treatment requirements addressing PFAS in industrial wastewater effluents.

Certain publicly owned WWTPs are designed and permitted to produce reclaimed water. Reclaimed water is secondary effluent from municipal WWTPs that has undergone additional treatment to allow re-use for non-drinking water applications such as landscape watering, flushing toilets in commercial and industrial buildings, dust control, or augmenting natural water resources in streams, wetlands, or groundwater (Ecology, 2021a). Reclaimed water permits, issued under Chapter 90.46[123] RCW and Chapter 173-219[124] WAC, require an extra level of treatment depending on how the reclaimed water will be used, and whether the public may come into contact with it, in addition to meeting surface water discharge standards (WAC 173-219-320[125]).

At this time, EPA has not developed numeric nationally recommended surface water quality criteria for PFAS. States generally adopt EPA's nationally recommended water quality criteria into state surface water quality standards instead of developing state-specific criteria, largely because of the high cost of criteria development, limited resources, and lack of available and adequate toxicological data to calculate criteria.

In the case of PFAS, some states have adopted, or are developing, surface water quality criteria for some PFAS. For example, Michigan adopted a surface water criterion of 12 ng/L for PFOS (Michigan Department of Environment, Great Lakes and Energy, 2019). Washington has not adopted water quality based numeric standards and regulations for PFAS in effluents. In addition, EPA-approved methods for monitoring compliance with effluent limits for PFAS have not yet been developed and adopted by EPA.

Routine wastewater influent and effluent monitoring is required by federal and state regulations and laws—monitoring requirements depend on whether the discharge is industrial or municipal, and on the size and characteristics of the treatment system. The specific pollutants that are generally sampled for under the CWA (for large discharges that reach surface waters) include priority toxic pollutants (126 specific substances), conventional pollutants (five-day biochemical oxygen demand, total suspended solids, pH, fecal coliform, and oil and grease), and non-conventional pollutants (such as ammonia, chlorine, color, iron, and

[120] https://apps.leg.wa.gov/wac/default.aspx?cite=173-218-030
[121] https://apps.leg.wa.gov/wac/default.aspx?cite=173-200
[122] https://apps.leg.wa.gov/wac/default.aspx?cite=173-201A
[123] https://app.leg.wa.gov/rcw/default.aspx?cite=90.46
[124] https://apps.leg.wa.gov/wac/default.aspx?cite=173-219&full=true
[125] https://apps.leg.wa.gov/wac/default.aspx?cite=173-219&full=true#173-219-320

total phenols). State regulations frequently include additional pollutants that must be addressed (e.g., temperature), however PFAS are not included in the lists of pollutants that require water quality monitoring in Washington.

PFAS are also not included in the Washington Groundwater Standards, which sets groundwater quality based requirements for discharges to land.

Industrial wastewater treatment

As identified above, many industries treat their wastewater under state and federal regulatory programs before discharging it. Typically, when industrial wastewater treatment occurs on site, the waste streams produced include both liquids (effluent) and solids (sludge). Treated effluent can be discharged to surface water (direct discharge), at specifically permitted locations (point discharge), or to a publicly owned WWTP (indirect discharge), and on rare occasions to ground. Any PFAS in the effluent, if not removed by, or degraded during, the treatment process enters the environment at the discharge point of the treated effluent (direct discharge), or enters the publicly owned WWTP (indirect discharge). Industries that discharge to publicly owned WWTPs (indirect discharge) must comply with federal and state pre-treatment requirements.

Publicly owned WWTPs

There are approximately 15,500 operational public WWTPs in the U.S., and approximately 72% of these are considered small systems (serving a population of 10,000 or fewer people and an average daily wastewater flow of less than one million gallons per day) (EPA, 2019c). According to Ecology's Water Quality Permitting and Reporting System, there are more than 600 WWTPs in Washington. Twenty-eight WWTPs hold reclaimed water permits (Ecology, 2021b).

PFAS are found in numerous products that contribute to domestic and non-domestic waste streams, as well as in contaminated drinking water supplies. Because PFAS sources are so pervasive, the wastewaters that arrive at WWTPs contain these compounds. As identified above, in addition to sewage, publicly owned WWTPs, in many cases, accept wastewater from local industries and businesses that can contain higher levels of toxic compounds than found in domestic waste. Publicly owned treatment systems that receive wastewater have traditionally been designed and constructed to meet technological requirements to remove solids from the influent (primary treatment) and to further remove some conventional pollutants (secondary treatment) to meet a "technology-based" standard of effluent quality.

These systems did not incorporate specific design considerations for PFAS or other toxics removal. Beyond the technology-based treatment requirements, water quality based toxics regulation is an ongoing process, as WWTPs and others work to reduce levels of toxics entering WWTPs, and as WWTPs work to optimize operations of current infrastructure and to evaluate additional technologies and approaches to reduce toxics. Significant challenges exist in this effort because of the extremely low concentrations that are being targeted for many pollutants, as well as the lack of known technology to assess these concentrations. Because PFAS is a relatively newly identified pollutant, and is gaining attention at the state and national level, some states have begun to sample WWTP effluent for PFAS.

Some WWTP effluents in Washington have been sampled for PFAS compounds as parts of special studies. Appendix 5: Environmental Occurrence, Section 5.1.5 WWTP effluent,

documents such measurements conducted in Washington. Where PFAS compounds have been sampled for, they have been found at levels similar to WWTPs in other areas of the U.S., and at lower concentrations than plants treating wastewater containing AFFF.

When PFAS enter wastewater treatment plants there is a mix of long- and short-chain compounds, as well as a large number of precursor compounds that can form perfluorooctane sulfonic acids (PFAA). This mixture is subject to bacterial degradation during the treatment process (see Appendix 4: Fate and Transport, Section 4.1 Non-polymer PFAS). Prior to the development of improved analytical methods used to identify this phenomenon (see Appendix 2: Analytical Methods), it appeared as though WWTPs were increasing the mass balance of PFAS during the treatment process. However, through a better understanding of a fuller list of measurable PFAS, it has since been confirmed that degradation and transformation of influent PFAS to different individual PFAS are the cause of greater total PFAS concentrations in WWTP effluent. This is especially true with PFAAs such as PFOS and PFOA.

Studies show that conventional activated sludge treatment does not effectively remove most PFAS, though some specialized treatments can remove a large percentage of longer chained compounds (Eschauzier, Beerendonk, Scholte-Veenendaal & De Voogt, 2012; Pan, Liu & Ying, 2016).

Information regarding the presence of PFAS in reclaimed water is limited. Research has shown that WWTPs can remove certain PFAS with specialized technology (Arvaniti et al., 2014). Data for three PFAS has been reported for reclaimed waters produced by the LOTT Clean Water Alliance, indicating very low concentrations of 34.4 ng/l, three times lower than ATSDR's allowable daily dose for a 70 kg adult (King County Department of Natural Resources and Parks, 2019).

Solids that are part of the influent wastewater and also generated during secondary treatment of wastewater are largely removed prior to discharge of the treated effluent. Influent screenings and grit are removed and typically disposed of as solid waste. Solids that remain after wastewater treatment, called sludge, are either treated as waste for disposal or treated as a resource. Sludge from many domestic WWTPs is processed with further digestion, and sometimes additional thermal processing (drying), into the product termed "biosolids." Biosolids are used in agriculture to improve the quality of agricultural lands for crop production. Application of biosolids is regulated under state and federal regulatory programs. PFAS in biosolids is discussed in detail in Appendix 8: Biosolids.

Onsite wastewater treatment systems

Onsite wastewater treatment systems (commonly called septic systems) can release pollutants, including chemical contaminants, to groundwater when such pollutants are discharged into the system. These systems typically produce treated liquid effluent, leachate, that is discharged to ground, and solids that are periodically removed and transferred to publicly owned WWTPs or commercial processing facilities. Leachate from septic systems can contaminate domestic drinking water wells in areas with high septic system density. Incomplete degradation or sorption during treatment in septic tanks and leach fields allow some contaminants to

percolate to the groundwater. PFAS were reported in domestic wells in a Massachusetts study where septic systems were prevalent (Schaider et al., 2016).

3.4.3 Landfilled products

Landfill regulation overview

In Washington state, solid waste landfills are regulated under different administrative codes, depending on the type of landfill. Local health districts directly regulate landfills in Washington under rules authored by Ecology, specifically Chapters 173-350[126] and 173-351[127] WAC. Ecology reviews and approves landfill permits issued by local health districts. Limited Purpose Landfills are regulated under WAC 173-350-100.[128]

Ecology's landfill rules do not require monitoring for PFAS in incoming wastes, or in waste streams generated at landfills (see discussion of leachate and gaseous emissions below). Ecology's rules allow health districts to include stipulations in permits that require landfills to sample for additional constituents.

Waste disposal in Washington includes all waste that goes to landfills or incinerators in the state, including waste brought from out-of-state, but does not include waste sent out-of-state for disposal. Table 30 illustrates typical annual waste tonnages handled in Washington, based on data collected in 2016. A total of 9,540,438 metric tons of waste were disposed in all types of landfills and incinerators in Washington in 2016 (Ecology, 2016).

Table 30. Summary of waste disposed in 2016 in Washington state (Ecology, 2017).

Landfill type	Facilities in Washington	Metric tons disposed
Municipal Solid Waste Landfills	17	8,667,147
Inert Waste Landfills	23	1,570,957
Limited Purpose Landfills	12	521,884
Waste to Energy Facility	1	251,879
TOTAL	**53**	**11,011,867**

As described in Appendix 9: Regulations, Section 9.1.2 Washington state rules, wastes containing halogenated organic compounds, such as PFAS at concentrations above 100 parts per million, are designated and managed as state dangerous waste.

[126] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350
[127] https://apps.leg.wa.gov/wac/default.aspx?cite=173-351
[128] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-100

PFAS in landfilled products

Landfills store wastes containing PFAS representative of items manufactured or in commerce in the state, including but not limited to: industrial wastes, carpeting and upholstery, waterproof clothing, food packaging waste, and—under very specific circumstances—biosolids.

Various types of landfills can be used for long-term storage of wastes that may contain PFAS. For example, privately and publicly operated landfills, which receive and store commercial and residential wastes (regulated under Chapters 173-350[129] and 173-351[130] WAC), are likely to receive products which contain PFAS. Limited Purpose Landfills (see WAC 173-350-100[131]) may store industrial wastes where PFAS occurred in a manufacturing process.

PFAS in landfill leachate

Landfill leachate has been recognized as a potential pathway for PFAS release into the environment under certain circumstances.

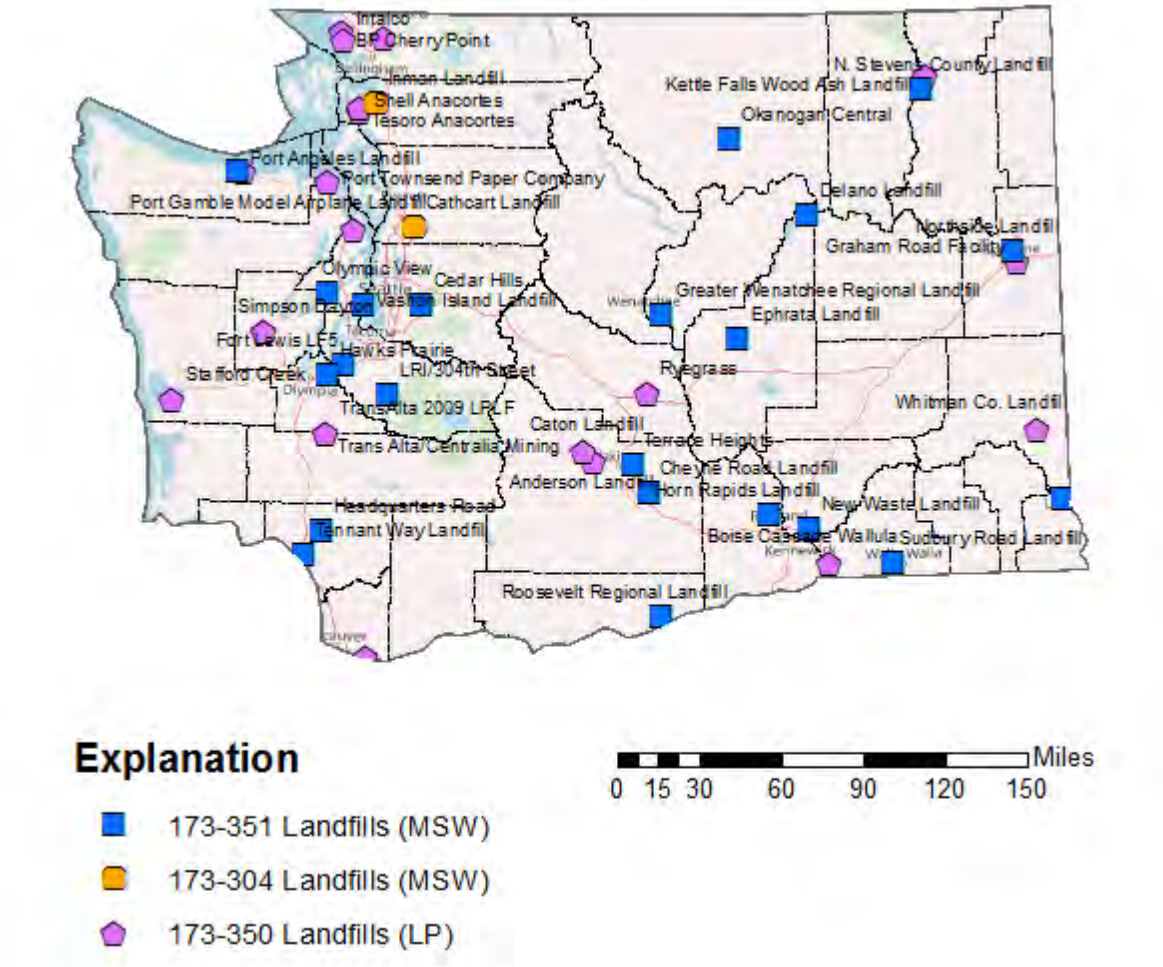
Landfill storage conditions can result in PFAS degradation and mobilization, including migration into landfill leachate (Hamid et al., 2018). In addition to how a landfill is specifically designed and operated (see regulatory requirements above), many factors contribute to whether and how PFAS may mobilize into leachate, including but not limited to (Lang et al., 2017):

- Weather (precipitation rates, climate).
- pH conditions developed within the wastes which affect how chemical species sorb to solids in the waste.
- The age of the landfill and how long it was in operation.
- The types of waste accepted and their age.
- Leachate management systems.

Only Limited Purpose Landfills (Chapter 173-350 WAC) and Municipal Solid Waste Landfills (Chapter 173-351 WAC) are required to have leachate collection systems. This includes most of the active landfills, with the exception of Inert Waste Landfills. A few closed landfills regulated under Chapter 173-304[132] WAC also have leachate collection systems. Older landfills, whether still operating or not, may not have been constructed with liner systems to capture leachate.

[129] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350
[130] https://apps.leg.wa.gov/wac/default.aspx?cite=173-351
[131] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-100
[132] https://apps.leg.wa.gov/wac/default.aspx?cite=173-304

Figure 25. Locations of municipal solid waste (MSW) and limited purpose (LP) landfills in Washington.



Under current State requirements, landfill leachates that are collected are sent either to WWTPs or evaporation ponds. Ecology does not collect data regarding volumes of leachate produced. Ecology staff conducted an informal survey of MSW landfill operators to collect data quantifying the volumes of leachate typically produced (Carter, 2020). Table 31 summarizes the data collected.

Table 31. Landfill leachate production from select landfills located in Washington (Carter, 2020).

Landfill	County	Type	Million liters collected	Collection period covered
Headquarters Road	Cowlitz	MSW	212.48	2018, January through November
LRI/304th Street	Pierce	MSW	30.81	2018, January through March
Tenant Way	Cowlitz	MSW	17.45	2018, January through November
Hawks Prairie	Thurston	MSW	11.85	2018, January through November
Port Angeles	Clallam	MSW	4.73	2017, entire year
Hidden Valley	Pierce	MSW	0.42	2018, January through June
Fort Lewis LF5	Pierce	MSW	0.004	2017, July through December

There is no information regarding the incidence of PFAS in landfill leachate in Washington state. Surveys were conducted in other parts of the U.S. to quantify PFAS contributions to solid waste streams and their contribution to PFAS in landfill leachate in particular (Lang et al., 2017). Additional recent studies have attempted to quantify mass fluxes of certain PFAS entering landfills and exiting in leachate. These studies concluded that though PFAS are present, the amounts in leachate are not major contributors to WWTP influent (Hart & Hickman PC, 2020; Michigan Department of Environment, Great Lakes and Energy, 2021b; Michigan PFAS Action Response Team, Landfills Workgroup, 2021; Michigan Waste & Recycling Association, 2019).

A study conducted in 2019 at the New England Waste Services of Vermont, Inc. Landfill in Coventry, Vermont, sampled waste materials entering the landfill, ranked waste streams with the highest potential to contribute PFAS to landfill leachate, and conducted a mass flux study to evaluate the proportion of PFAS exiting the landfill via leachate (Sanborn, Head & Associates, Inc., 2019). The study identified that, of the wastes considered in the study, bulky waste textiles and carpeting contribute the largest PFAS influx to this landfill, but that municipal solid wastes could also contribute. The study also identified that overall less PFAS exits the landfill via leachate than is input to the landfill—indicating that a significant amount of certain PFAS entering the landfill are sequestered in the landfill, however other PFAS are more susceptible to being mobilized and transferred to leachate.

Others have reported data collected from around the world, including (Hamid et al., 2018):

- A study in Germany which identified 44 PFAS in landfill leachate.
- A study showing a range of PFOA in leachate in U. S. landfills ranging from 0.15 – 9.2 µg/l.
- Measurements in Chinese landfills as high as 214 µg/L.

Uncontrolled leachate can migrate into groundwater, resulting in groundwater contamination. Adverse impacts to drinking water resulting from improperly managed landfill leachate have been documented elsewhere in the U.S., in particular when landfills accepted manufacturing wastes known to contain high levels of PFAS (Michigan PFAS Action Response Team, 2020).

An ongoing study is being conducted in New York state to identify and characterize inactive landfills at high risk of releasing PFAS to the environment, which may be impacting or contaminating drinking water supplies (Fay, 2020). Complete results of this New York study have not yet been reported publicly, though preliminary data has identified locations where groundwater used for drinking water supply has been contaminated as a result of nearby inactive landfills without modern leachate collection and handling practices.

PFAS in landfill gas

Finally, contaminants such as volatile organic compounds (including sufficiently volatile PFAS, which can partition from aqueous solutions) can be transported in landfill gas formed during waste decomposition. As reported by Hamid et al. (2018), studies have demonstrated elevated concentrations of airborne PFAS near certain landfills. EPA plans additional investigation of PFAS in landfill gas emissions via a grant issued to North Carolina State University at Raleigh and Oregon State University (EPA, 2019d).

Waste characterization studies

A waste characterization study involves sampling, sorting, and surveying waste material delivered to landfills over a one year period. Ecology conducted waste characterization studies in 2009 and 2015 (Ecology, 2010, 2016b). Wastes were separated into 130 material types in 2009 and 156 material types in 2015. A few of those material types include products that may contain PFAS: carpet, furniture, textiles, and paper and packaging. The landfilled quantity for those products reported in 2016 are summarized in Table 32.

The amount of PFAS-containing materials landfilled in Washington is unknown. The disposed volumes listed in Table 32 are used to estimate PFAS disposal in Washington.

Table 32. 2015 – 2016 waste characterization data.

Material type	Annual metric ton landfilled	Percent of total disposed
Carpet	64,873	1.4
Furniture	59,842	1.3
Textiles	167,357 *	3.7
Paper packaging	332,543 ^	7.2
TOTAL four types	**624,615**	**12.17**
TOTAL waste landfilled	**4,589,537**	

Notes:

- * = Excludes footwear.
- ^ = Kraft/cardboard that is less likely to contain PFAS.

Carpet

PFAS used in flooring products include carpet and carpet cleaning and treatment products. From 1970 to 2002, carpet applications included perfluorooctanesulfonyl fluoride (POSF)-derived substances, including PFOS (DEPA, 2013). Currently, another PFAS subgroup—termed fluorotelomer-based acrylate polymers—are generally used for carpet stain resistance and carpet care treatments (Bowman, 2018; KEMI, 2015). However, other PFAS can also be present as impurities (for example, PFHxA and PFBA) (Bowman, 2018), or can be formed during environmental degradation (FTOHs and PFCAs) (Washington & Jenkins, 2015).

More than 90% of carpets used in homes and 100% of commercial carpeting is made from plastic. Carpets remain in place for 10 to 12 years or longer before disposal. Between 50% and 90% of carpet is treated for stain resistance with fluorinated substances (DEPA, 2013). Stain resistance treatments are lost each year through vacuuming, steam cleaning, and eventual disposal. Carpet in landfills can take hundreds of years to degrade. Compared to places without carpet, homes and offices with carpet can have higher concentrations of various PFAS in the indoor environment (Fraser et al., 2013; Gewurtz et al., 2009; Kubwabo, Stewart, Zhu, & Marro, 2005).

Based on two reports, a wide range of estimates can be applied to the 65,000 metric tons of carpet annually disposed in Washington landfills:

- One study reported an average concentration of 75 mg/kg (part per million) of PFOS in a mix of treated and untreated carpet (DEPA, 2013). Applying that concentration to the carpet annually disposed results in an estimate of 7 metric tons of PFOS annually disposed in Washington. That would result in a total of 214 metric tons of PFOS over a 30-year period.
- A Swedish estimate reported that treated synthetic carpet contains up to 15% PFAS (KEMI, 2015). That concentration would reflect a total of 14,300 metric tons of PFAS annually disposed in Washington. That would result in a total of 430,000 metric tons of PFAS landfilled over a 30-year period.

There is some uncertainty around the estimated percentage of PFAS in carpet. During our comment period, industry representatives reported PFAS use at around 0.1%, which would lead to a lower estimate of between 90 and 140 metric tons of PFAS being used in Washington carpets each year.

Furniture

PFAS are used to treat leather and upholstered furniture for stain resistance—from 1970 to 2002 using PFOS, and after 2002 using perfluorobutane sulfonyl fluoride-based products (PFBS). The U.S. imports 70% of its upholstered furniture from China—other imports come from Vietnam, Mexico, Canada, and Italy (World Furniture Online, 2017). Furniture usually remains in use for more than 15 years before landfilling.

Based on data from a Danish study, the following are estimates for landfill disposal of PFOS in the 71,424 metric tons of upholstered furniture disposed annually (DEPA, 2013):

- Using an average concentration of 80 mg/kg of PFOS in treated leather amounts to an annual disposal of 5.7 metric tons of PFOS. That would result in a total of 171 metric tons landfilled over a 30-year period.
- Based on a concentration of 2.4 mg/kg in a mix of treated and non-treated furniture amounts to an annual disposal of 0.17 metric tons of PFOS. That would result in a total of 5 metric tons of PFOS over a 30-year period.

Textiles

In 2015, the Swedish Chemicals Agency (KEMI) reported treatments or membrane construction of textiles, including:

- Fluoropolymer dispersions (like polytetrafluoroethylene or PTFE) used in industrial fabrics and professional apparel as well as highly porous fabrics like outdoor clothing and camping equipment.
- Side-chain fluorinated polymers (like PASF or fluorotelomer-based acrylate polymers) used as surface treatments on textiles and leather.

Current polymer chemistry used for textiles includes polyfluorinated (meth) acrylate polymers (C2 – 20). However, in the U.S., C8 – C20 polymers have been discontinued since 2015 under

voluntary stewardship programs, being largely replaced by C6 based acrylate products. Other polymers include fluorinated urethanes (C4 – C18). Other raw materials include various polyfluorinated or perfluorinated substances. These are alkyl sulfonamide derivatives (C4 – 9), alkyl ammonium compounds (C4 – C7), alkyl alcohols (C3 – C14), and a smaller number of alkyl sulfonic acids/sulfinic acids (C8), alkyl thiols (C8 – C20), alkyl sulfonamides (C8), alkyl esters (C8 – 14), alkanes/alkenes (C6), and alkanoyl/sulfonyl chlorides or fluorides (C8). Protective clothing uses surface treatments of side-chain fluoropolymers or woven fluoropolymer textiles. Examples include fire retardant clothing used for medics, pilots and firemen. As indicated in Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency, U.S. manufacturers have voluntarily discontinued production and use PFOS and PFOA, however products entering from other countries may still contain long-chain PFAS.

Table 33 lists 137,755 metric tons of textiles annually disposed—not all of these textiles are PFAS-treated. For the purpose of this estimate, 50% of that total is assumed to be PFAS-treated, which represents 68,877 metric tons of textiles disposed annually:

- 43 metric tons of PFAS annually landfilled based on 627.3 mg/kg perfluoro-carboxylic acid (PFCA) in textiles (Khotoff et al., 2013). Over a 30-year period, this represents 1,300 metric tons of PFCA.
- 2,066 metric tons of PFAS annually landfilled based on 3% by weight of PFAS in treated textiles (KEMI, 2015). Over a 30-year period, this represents 62,000 metric tons of PFAS.

Food packaging

Surface treatment and impregnation products provide water, oil, and grease resistance, and nonstick performance for paper and packaging. These include both food-contact materials (e.g., popcorn bags, pizza boxes, and fast-food wrappers) and non-food applications (e.g., masking papers and folding cartons). Paper, cardboard, and packaging has a very short lifespan from use to disposal. Treated food contact material is generally limited to a one-time use.

In 2015, the Swedish Chemicals Agency (KEMI) reported fluorinated applications in paper packaging, including mainly side-chain fluorinated polymers and polyfluoroalkyl phosphonic acids (PAPs and diPAPs). Other major substance groups were poly- or perfluorinated alkyl thiols (C4 – 20), poly- or perfluorinated alkyl sulfonamide derivatives (C4 – C9), and poly/perfluorinated alkyl phosphorus compounds (C8), as well as smaller number in the substance groups alkyl esters (C6 – 14), alkyl silicones/siloxanes (C6), and alkyl sulfonic/sulfinic acids (C8). As discussed in Appendix 9: Regulations, Section 9.2.2 Food and Drug Administration, FDA regulates the use of PFAS in food packaging. FDA revoked its food additive regulations for use of three long-chain perfluorinated compounds in 2015 (FDA, 2015). Current products on the FDA food contact notification (FCN) list are short-chain fluorotelomer-based polymers and perfluoropoly ethers—however those that contain 6:2 fluorotelomer alcohol (6:2 FTOH) are being voluntarily phased out (FDA, 2019, 2020a, 2020b).

An estimated 17% of disposed paper products and packaging are treated (Trier et al., 2011). For this estimate, 20% of 223,771 metric tons of paper and packaging was used to estimate impacts from landfilled textiles. An estimated 44,751 metric tons of PFAS-treated textiles are used for the estimates below:

- 1.13 metric tons of PFAS annually landfilled based on 25.2 mg/kg fluorotelomer alcohol (FTOH) in treated paper and packaging (Liu et al., 2015). Over a 30-year period, this amounts to 33.83 metric tons of FTOH.
- 671 metric tons of PFCA annually landfilled based on the conservative upper end of 1.5% by weight of PFCA in treated paper products (KEMI, 2015; UNEP, 2015b). Over a 30-year period, this amounts to 20,139 metric tons of PFCA.

Summary

The low and high PFAS disposal estimates are based on limited information from the waste sort data and available product testing data. The greatest sources of PFAS disposal appears to come from carpet and textiles. These estimates are based on the information available in the literature. It is important to note that we received input that the KEMI estimation of 15% is too high, and industry representatives report use at around 0.1%, which would lead us to estimate that between 90 and 140 metric tons of PFAS are used in Washington carpets each year.

Table 33. Annual PFAS disposal estimates by material type.

Material type	Low estimate of PFAS disposal	High estimate of PFAS disposal
Carpet	7.15 metric ton/year (PFOS)	14,300 metric ton/year (PFAS)
Textiles	43.21 metric ton/year (PFCA)	2,066 metric ton/year (PFAS)
Furniture	0.17 metric ton/year (PFOS)	5.71 metric ton/year (PFOS)
Compostable paper, packaging	1.13 metric ton/year (FTOH)	671 metric ton/year (PFCA)
TOTAL	**51.66 metric ton/year**	**17,043 metric ton/year**

3.4.4 Dangerous waste disposal reports

Washington's Dangerous Waste Regulation requires businesses to properly manage, store, and dispose of hazardous waste (Chapter 173-303[133] WAC). This regulation identifies halogenated organic compounds as a state-only "dangerous waste" due to persistence. Fluorine is a halogen, therefore PFAS are halogenated organic compounds. PFAS present in a waste above 100 ppm must be properly managed and disposed as dangerous waste (WAC 173-303-040[134]).

Dangerous waste disposal must be reported to Ecology. Since 2010, those reports have been entered into the TurboWaste database. PFAS is not specifically reported to the database. Waste data entered into TurboWaste that may contain PFAS include wastes described as AFFF, fire debris, and suppressant. Those reports are summarized in Table 34—the submitted reports do not all indicate the presence of PFAS.

TurboWaste data is reported in pounds. For consistency throughout this appendix, the data was converted to kilograms.

[133] https://apps.leg.wa.gov/wac/default.aspx?cite=173-303
[134] https://apps.leg.wa.gov/wac/default.aspx?cite=173-303-040

Table 34. Dangerous waste disposal reports from 2010 to 2016 (kilograms).

Waste	2010	2011	2012	2013	2014	2015	2016
AFFF	1,252	6,762	877	931	1,528	5,640	40,632
Fire debris	1,316	722	784	8,634	6,378	504	1,555
Suppressant	1,946	6,112	2,445	25,908	96,272	2,867	0
TOTAL	**4,514**	**13,596**	**4,105**	**35,473**	**104,179**	**9,010**	**42,187**

3.4.5 Compost

Testing for the presence of PFAS chemicals in the environment has been primarily directed at water and biosolids. According to EPA guidance, the threshold for concern in drinking water is 70 parts per trillion (ppt). Currently, there is no national PFAS threshold for soils or compost. The general consensus is that inclusion of food scraps, food packaging, and biosolids in composting operations will introduce some amount of PFAS, but testing has shown the levels to be low (Croker, 2020; Beecher & Brown, 2018; Choi et al., 2019). Recent studies have confirmed that PFAS may transfer to contact water generated at composting operations (Wood Environment & Infrastructure Solutions, Inc., 2019).

Some concern has been expressed that PFAS in compost may be taken up by plants, but research to date suggests that the concern for plant uptake is minimal (Beecher & Brown, 2018). There is currently minimal regulatory concern with regard to inhalation, ingestion, dermal contact, or other possible routes of exposure related to organic residuals (NEBRA, 2019).

Recognizing the impact that PFAS in food packaging is having on human and environmental health, in 2018 the Washington State Legislature passed a bill that prohibits the use of PFAS in paper food packaging (Ecology, 2018). These efforts are considered to be good steps toward reducing the amount of PFAS in biosolids and composts, but additional research specific to compost will add to this understanding.

3.5 Global estimate: Washington proportion

PFAS emissions have not been tracked in Washington state. We neither know historical emission rates nor current emission rates statewide. We reviewed available assessments of historical global emission rates to estimate historical emission rates in Washington.

Global releases of PFAS are estimated in Prevedouros et al. (2006), Wang et al. (2014a), Paul et al. (2009), and Boucher et al. (2019). Others have also summarized global emission inventories (OECD, 2015). We used a proportion of the global use and disposal estimates to determine historic releases of PFAS in Washington. Global estimates related to manufacture of PFAS are not applicable to Washington because no primary PFAS manufacturing occurred in the state. As such, we have excluded these from our estimates below. A brief summary of each estimate and its associated Washington proportion is provided in the subsections that follow.

To calculate the Washington state proportion of global emissions, we assumed that the U.S. represents 25% of worldwide consumption and Washington represents 2.6% of the U.S. by population. Therefore, the state's emissions would represent 0.65% of global emissions.

These estimates do not reflect all PFAS that may have been present in the global market or released to the environment. The OECD indicated that, "Identifying and understanding production, use, releases, and environmental presence of the various PFAS on the global market has been limited due to the complexity of the issue, data scarcity and fragmentation, and data confidentiality" (OECD, 2018). Researchers have recognized the lack of available information and have only been able to qualitatively assess the emissions of certain PFAS (Wang et al., 2014b).

Wang et al. (2014a) and Boucher et al. (2019) also estimated emissions of certain PFAS following the voluntary stewardship reductions in the U.S. and other countries. These are presented in Section 3.5.5 below.

3.5.1 Estimate of PFCA and FTOH emissions

Prevedouros et al. (2006) described the sources, fate, and transport of PFCA in the environment. Prevedouros estimated PFCA and FTOH releases to the environment from direct (manufacture, use, consumer products) and indirect (impurities, precursors) sources. These estimates were based on total emissions from 1960 – 2002. The global estimates of use, disposal, and emissions from consumer and industrial products and firefighting foam are presented in Table 35. Table 35 also identifies the estimated proportion attributable to Washington state, excluding manufacturing emissions. For the 42-year period from 1960 – 2002, this would represent average emissions of 0.10 metric tons per year for Washington state.

Table 35. Global and Washington state estimated PFCA and FTOH emissions for the period 1960 – 2002.

Use, disposal, and emissions*	Global emissions (metric tons)	Washington emissions (metric tons)
Consumer and industrial	520	3.38
AFFF	131	0.85
TOTAL	**651**	**4.23**

Note: * = Not including manufacturing emissions.

Wang et al. (2014a) expanded on the Prevedouros (2006) study, estimating that indirect degradation sources in the period 1951 – 2002 could have been five times higher than those presented by Prevedouros.

3.5.2 Estimate of POSF and PFOS emissions

Paul et al. (2009) estimated global historic manufacture, consumer use and disposal of POSF, and environmental releases of POSF and PFOS from 1970 – 2002. Manufacture estimates in the Paul et al. (2009) study do not apply to Washington for reasons stated above. Total global consumer use and disposal of perfluorooctanesulfonyl fluoride (POSF) from direct (use and consumer products) and indirect PFOS (precursors and/or impurities) sources are presented in Tables 36 and 37 respectively. These tables also present the estimated Washington proportion.

Estimates indicate that direct emissions from POSF-derived products are the major source to the environment resulting in releases into wastewater streams, primarily through losses from stain repellent treated carpets, waterproof apparel, and aqueous firefighting foams. For the 32-year period from 1970 – 2002, this would represent average direct emissions of 20.4 metric tons per year for Washington.

Table 36. Global and Washington state POSF direct use and disposal emissions for the period 1970 – 2002.

Direct use and disposal emission category	Global (metric tons)	Washington (metric tons)
Carpet	48,000	312
Paper and packaging	24,000	156
Apparel	12,500	81
AFFF	10,000	65
Performance chemicals (hydraulic fluids)	6,000	39
TOTAL	**100,500**	**653**

Table 37. Global and Washington state POSF and PFOS indirect emissions to water and air for the period 1970 – 2002.

Indirect consumer emission category	Global (metric tons)	Washington (metric tons)
Carpet	21,500	140
Apparel	12,600	82
Performance chemicals (hydraulic fluids)	9,610	62
Paper and packaging	367	2.4
AFFF	47	0.3
TOTAL	**44,124**	**286.7**

3.5.3 Estimate of PHxSF and PFDS emissions

Boucher et al. (2019) estimated global historic manufacture, consumer use, and disposal of perfluorohexane sulfonate (PFHxS), perfluorohexane sulfonyl fluoride (PHxSF), and perfluorodecane sulfonate (PFDS) from 1958 – 2015. Manufacture estimates in the Boucher et al. (2019) study do not apply to Washington for the reasons stated above. Total global use and disposal of PFHxS and PFDS and degradate emissions are summarized in Table 38 and reflect the Washington proportion.

Table 38. Global and Washington PFHxSF and PFDS Emissions in the period 1958 – 2015 (Boucher et al., 2019).

Emissions from use, disposal, and degradates*	Global (metric tons)	Washington (metric tons)
PFHxS	32 – 126	0.2 – 0.8
PDFS	34 – 372	0.2 – 2.4
TOTAL	**66 – 498**	**0.4 – 3.2**

Note: * = Not including manufacturing emissions.

3.5.4 Summary of historical emissions

We summed all of the Washington proportions of historical PFAS emissions calculated above. Uncertainty is introduced regarding total emissions over a certain period of time because different time accounting periods were considered in each of the studies above. Nevertheless, we can estimate Washington state's average annual contribution over this historical period at approximately 29.5 metric tons per year. Table 39 provides the summation of Washington's proportion of PFAS emissions.

Table 39. Average annual historical Washington state PFAS emissions based on global estimates.

PFAS emission type	Period of estimate	WA emissions during period (metric tons)	Average annual WA emissions (metric tons)	Reference
PFCA and FTOH	1960 – 2002	4.23	0.10	Prevedouros et al., 2006
Direct POSF	1970 – 2002	653.00	20.41	Paul et al., 2009
Indirect POSF and PFOS	1970 – 2002	286.70	8.96	Paul et al., 2009
PFHxS and PDFS	1958 – 2015	0.40 – 3.20	0.01 – 0.06	Boucher et al., 2019
TOTAL			**29.47 – 29.52**	

3.5.5 Current emissions

Both Wang et al. (2014a) and Boucher et al. (2019) recognized that estimates previously performed by others were limited to historical emissions during periods when PFAS manufacturing was not limited in the U.S. However, as identified in Appendix 1: Chemistry, Section 1.3.4 Technical quality and implications for environmental impacts, following voluntary phase-outs of PFOA in fluoropolymer manufacturing in the U.S., Japan, and Europe, production of these PFAS moved to other countries. Estimates by Wang et al. (2014a) and Boucher et al. (2019) indicate that although production and degradation emissions of some PFAS identified above may have decreased (PFNA products and FTOH-based products as impurities), overall emissions after 2015 may have remained similar to those during the period 2003 – 2015. The estimates in Boucher et al. (2019) also emphasize that even though PFHxS and PFDS production emissions have significantly decreased, degradation emissions of PFHxS continue.

3.6 Data gaps and recommendations

3.6.1 Data gaps

Secondary manufacturing use of products containing PFAS

As identified in Section 3.1.2 above, various information sources indicate that PFAS can be used in manufacturing industries that operate, or have operated in Washington. Although some uses have been readily identifiable (for example, AFFF use), we do not know the extent of PFAS used in Washington manufacturing, the types of PFAS which were historically used, or whether manufacturers have transitioned to new generation PFAS or ceased use altogether. We also do not know whether manufacturing uses resulted in human exposure or emissions to the environment, and if so, the risks associated.

Information regarding PFAS use may be readily available for certain sectors. For example, the electroplating industry identified its use of PFOS early, and sought to eliminate or replace such usage industry-wide in the U.S. (National Association of Surface Finishers (NASF), 2019a). The industry, however, has identified that legacy use of PFOS can continue to be a source of emissions, and has researched the effects of replacement PFAS used such as 6:2 FTS (NASF, 2019b). Electroplaters are regulated in Washington state via various regulations—therefore, more is likely known about past and current electroplating locations and can be learned about their PFAS usage practices. However, use in other sectors is simply derivative of component manufacturing—for example the medical industry uses PFAS coated components which may or not be manufactured in Washington (UNEP, 2015a). Similarly, we do not know if semiconductor manufacturing in the state employs PFAS substances. More research is needed to identify industrial sectors that contribute to PFAS use, and which of those have a connection to environmental or human exposure.

Consumer products

In 2020, information became available that fluorinated plastic containers can be a source of commercial product contamination (EPA, 2021b). Fluorination is intended to create a barrier to reinforce and provide additional storage ability to treated containers. Initial reports identified PFAS contamination of pesticides stored in such containers, however fluorination of containers is also used for storage of a range of products and industries (Environmental Defense Fund, 2021).

The FDA (under 21 CFR 177.1615[135]) is also examining the use of fluorinated containers in food-contact applications—in light of this new information and in the context of existing FDA regulations for polyethylene containers (FDA, 2021). Future data regarding this PFAS release source will provide insight on the significance of this pathway for both environmental contamination and human exposure.

Use of AFFF in industry

Use of PFAS at military installations and the extent of resulting environmental impacts are under investigation by the DOD at a number of sites in Washington state (see Section 3.2.3). AFFF use in firefighting, and especially use by public fire departments, is being addressed through the implementation of Chapter 70A.400[136] RCW (see Appendix 9: Regulations, Section 9.1.1 Washington state laws). Ecology is already working with public fire departments to assess quantities of AFFF stored and means for its collection and disposal. Over time, Chapter 70A.400 RCW will require civilian airports and other industry to find non-PFAS firefighting products. However, Ecology has insufficient information about AFFF holdings by civilian airports and petrochemical industries. Ecology also lacks a complete list of regionalized fire training centers.

WWTPs

At this time, Ecology has limited data confirming the presence of PFAS in WWTP effluents. Ecology does not know the range of PFAS concentrations in WWTP influent, effluent, and sludge, and therefore cannot assess the relative contribution of these discharge streams to the environment. This information is also needed to determine the efficacy of possible treatment technologies at WWTPs to remove PFAS. Ecology also needs more information regarding PFAS removal performances of different treatment technologies (e.g. secondary, secondary with nutrient removal, tertiary membrane filtration), and the role of multiple-benefits of different technologies, including nutrient removal and removal of a broad spectrum of contaminants of concern. Information collected about WWTP influents can inform identification of upstream PFAS discharges, which can then allow further consideration of pre-treatment strategies at industrial sources as well as consumer and commercial source control efforts.

[135] https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=177.1615
[136] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

Landfill PFAS emissions

Although information about PFAS emissions from landfills is being collected elsewhere, we do not have information regarding the incidence of PFAS in landfill leachate in Washington. We also do not know if PFAS-contaminated landfill leachate is a source of groundwater contamination. Finally, we do not know the extent to which PFAS entering landfills partitions into gaseous emissions, preventing us from understanding the true mass balance of PFAS emissions from this source.

Compost

The investigation of PFAS pathways into and out of composting operations is beginning to provide data regarding the feedstocks that can contribute PFAS to compost products and how certain PFAS behave in composting processes. Further data development in this area, as well as validated analysis methods, are needed to allow evaluation of human and environmental exposures to PFAS from commercial composting activity.

3.6.2 Recommendations

The following recommendations result from the analyses presented in this appendix:

Recommendation 2.3: Work to prevent PFAS releases from firefighting foam use and manufacturing processes.

Ecology will continue to work proactively with industry, manufacturers, and businesses to eliminate releases to the environment from the use of PFAS-containing AFFF or other manufacturing processes using PFAS.

To address PFAS in AFFF, Ecology would continue implementing the Firefighting Agents and Equipment Toxic Chemical Use law (Chapter 70A.400[137] RCW), as follows:

- Collaborate with users of firefighting foam to develop and share outreach materials and best management practices that address the proper use, storage, and disposal of PFAS-containing AFFF.
- Ensure that industrial use of PFAS-containing AFFF provides for containment procedures along with collection of this foam and contaminated soil or sediment for proper designation and disposal. Costs to industrial users to collect and dispose of released PFAS-containing AFFF include plan development, employee training, methods for containment, and disposal of waste.
- Continue identifying organizations and industries which store and use AFFF in training and emergency firefighting, including use of AFFF in highway tunnels.
- Assist state and local governments, airports, industry, and fire districts with prioritizing the quantification, disposal, and replacement of PFAS-containing AFFF, especially in communities with cumulative impacts, health disparities, and environmental justice considerations.

[137] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

- Share information about PFAS-free Class B firefighting foam with users of firefighting foam as information or research is available, including GreenScreen® certifications (New York State Pollution Prevention Institute, 2019).
- Provide funding to airports to purchase equipment to test their firefighting capabilities without the use of PFAS foam.
- Conduct compliance and enforcement actions to ensure the law is being followed.

Ecology will work proactively with industry, manufacturers, and businesses to eliminate releases to the environment from the use of PFAS in manufacturing or other processes.

- Ecology will review data from other states and countries to identify industrial or manufacturing uses of PFAS. Ecology will also consider (as data is collected under activities conducted under other CAP) recommendations to identify potential industrial and manufacturing PFAS dischargers. Ecology will use this information to identify industries in Washington that have used or continue to use commercial quantities of PFAS. Ecology will also track future TRI reports (starting in 2021) for industries.
- Ecology will evaluate PFAS release potential from those industries which may have used, or continue to use, PFAS.
- Ecology will reach out to these industries to discuss their use of PFAS, identify opportunities to switch to safer alternatives, implement best practices, and ensure proper waste management.

Recommendation 3.1: Reduce PFAS exposure from carpets, water and stain resistance treatments, and leather and textile furnishings.

Under Chapter 70A.350[138] RCW, Ecology identified carpets, water and stain resistance treatments, and leather and textile furnishings as significant sources and uses of PFAS. As required by the law, Ecology is evaluating whether safer alternatives are feasible and available. If such alternatives are available, Ecology could then make regulatory determinations to restrict PFAS in these products, and report these determinations to the Legislature by June 2022.

Beyond the work being conducted under Chapter 70A.350 RCW, we can also propose actions to reduce legacy PFAS-containing carpet and carpet care products remaining in homes, especially in low-income households, where items may be retained past the typical product lifespan.

Recommendation

We recommend that as part of the work conducted under 70A.350 RCW the following regulatory actions be considered:

- Requesting that manufacturers:
  - Identify products that contain PFAS.
  - Disclose their use of priority chemicals in product ingredients.
  - Release information on exposure and chemical hazard.
  - Describe the amount and function of PFAS in products.

[138] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350

In addition to the work conducted under Chapter 70A.350 RCW above, we recommend the following actions:

- Implement a purchasing preference policy for PFAS-free carpet. Work with vendors on the state flooring contract to offer PFAS-free carpet on all state master contracts and all agency contracts. Purchasing PFAS-free carpet could result in increased costs to the state.
- If safer alternatives are available, include them in Ecology's Product Replacement Program[139] to replace legacy PFAS-containing carpet in community centers, low-income housing, libraries, daycares, and other environments where children may be disproportionately exposed.

Recommendation 3.2: Identify additional sources and uses of PFAS to consider in the second Safer Products for Washington cycle.

The priority products identified in 2020 under the Safer Products for Washington program do not account for all sources and uses of PFAS. Ecology will continue research to better understand how other products contribute to PFAS concentrations in homes, workplaces, and the environment. These include PFAS in:

- Water-resistant clothing and gear.
- Nonstick cookware and kitchen supplies.
- Personal care products (e.g., cosmetics and dental floss).
- Cleaning agents.
- Automotive products.
- Floor waxes and sealants.
- Ski waxes.
- Car waxes.

Ecology should engage with overburdened communities regarding consumer products that may contain PFAS. Communities use consumer products differently. Ecology should identify consumer products which might be disproportionately exposing overburdened communities.

Ecology should conduct preliminary investigations into the availability and feasibility of safer alternatives, prior to Phase 2 of Cycle 2 of Safer Products for Washington, for the products listed above. If safer alternatives are identified, in the preliminary investigations, outreach should be conducted to increase voluntary adoption in the marketplace.

Ecology should determine if the products listed above are significant sources or uses of PFAS. If so, they should be evaluated during Phase 2 of Cycle 2 of Safer Products for Washington to determine if they should be recommended as priority products. If identified as a priority product in the report to the Legislature, the product will be evaluated to determine if safer alternatives are feasible and available. If they are, Ecology may determine that a restriction or ban is appropriate.

[139] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Product-Replacement-Program

Recommendation 3.3: Implement additional reduction actions for PFAS from consumer products.

Ecology should investigate uses and regulatory actions to further reduce exposures and releases to the environment from the priority consumer products containing PFAS.

Actions should include:

- Gather input from low-income and other historically overburdened communities, including communities of color. Develop a list of ways to reduce exposure that include low cost and subsidized approaches. These may be particularly important measures to employ in communities with higher exposure from drinking water. No cost estimate is provided to conduct this evaluation or to develop exposure reduction recommendations.
- Establish a purchasing preference policy for products free of intentionally added PFAS. Work with vendors to offer PFAS-free textiles, furniture, and paints. If possible, select products that do not have stain or water resistance or use safer alternatives. Apply this policy to all state master contracts and all agency contracts.
- Consider PFAS as a class when the list of chemicals of high concern to children, WAC 173-334-130,[140] is updated.
- Propose a ban on the import or sale of all products in Washington containing phased-out long-chain PFAAs. Long-chain PFAAs include perfluorinated carboxylates (PFCAs) with seven or more fully fluorinated carbons (for example, PFOA) and perfluorinated sulfonates (PFSAs) with six or more fully fluorinated carbons (for example, PFHxS and PFOS), their salts, and precursor compounds capable of forming long-chain PFAAs.

Recommendation 4.1: Evaluate PFAS in wastewater treatment.

Ecology should evaluate PFAS in wastewater treatment plant (WWTP) effluent and influent to develop a greater understanding of PFAS in discharges in Washington:

- Ecology should develop a study design to sample PFAS in three different types of plants: WWTPs with secondary treatment, nutrient removal, and advanced solids removal. Sampling should include products of selected WWTP unit processes (for example, primary and secondary clarifiers or dechlorination) to help differentiate removal efficiencies of the different treatment types.
- The study design should ensure that the WWTPs that are sampled receive industrial discharges that are likely to contain PFAS, or that have drinking water sources with known PFAS contamination.
- Ecology should identify industries that are likely to generate wastewater containing PFAS.
- Based on the information from the study, Ecology should consider additional monitoring requirements for WWTP dischargers. This should include consideration

[140] https://apps.leg.wa.gov/wac/default.aspx?cite=173-334-130

of whether EPA has developed approved analytical methods for PFAS suitable for WWTP effluent and a regulatory target (a nationally recommended water quality criterion for PFAS) for waters of the state.
- Based on this evaluation, Ecology should require possible PFAS monitoring for some or all domestic and industrial WWTPs.

Recommendation 4.2: Evaluate landfill PFAS emissions.

Ecology will develop and conduct a sampling program at selected landfills throughout the state to test for the presence of PFAS in leachate, groundwater, and air emissions.

Leachate

The Solid Waste Management program (SWM) developed Phase I of the program, leachate sampling, which has been funded and approved.

Ecology has developed a study to better characterize landfill leachate. The study design will:

- Sample leachate at selected landfills in the state.
- Determine the range of values for 33 PFAS substances in leachate, and compare to landfills throughout the country.
- Arrive at an estimate of the total PFAS materials in the landfill leachate through Total Oxidized Precursor (TOP) analyses.
- Determine if differences in amount of PFAS occurs in landfill cells of different ages.
- Determine if specific types of waste streams lead to higher PFAS values.
- Identify disposed wastes that are likely to generate PFAS releases to leachate.
- Perform a one-time testing of leachate from approximately 23 landfills.
- Consider additional sampling of leachate for landfills not yet sampled after the initial Phase I is completed. This second step of Phase I may include landfills that are undergoing MTCA cleanups, or landfills that contain specific refuse streams that have shown to have high PFAS values from the Phase I sampling.

If warranted, Ecology would manage PFAS in landfill leachate long term by:

- Considering additional monitoring requirements for landfills to test leachate for PFAS using information from the study mentioned above.
- Potentially updating the rules (Chapters 173-350[141] and 173-351[142] WAC) to require PFAS testing of leachate during landfill monitoring.

Groundwater and gaseous emissions

Phase II of the program will sample groundwater and gaseous emissions at landfills for PFAS. This phase of the program is in the conceptual stage. Landfills to be sampled will be based on the results of the Phase I leachate study. Groundwater will be sampled from existing monitoring wells.

[141] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350
[142] https://apps.leg.wa.gov/wac/default.aspx?cite=173-351

The Solid Waste Management program (SWM), in conjunction with the Air Quality Program (AQ), will develop the gas emissions sampling portion of the program. Ecology will also monitor landfill gas emissions monitoring being conducted by North Carolina State University and Oregon State University (EPA, 2019d).

Landfill waste makeup

In parallel to landfill gas emission sampling above, Ecology will continue to research the makeup of PFAS waste entering and potentially currently stored in landfills.

Supplement 1: Estimated PFAS in Consumer Products in a Typical Home

Table 40. Estimated PFCA in consumer products in a typical home.

Category name	Total PFCA	Typical quantity	PFAS in the home	Reference
Pre-treated carpeting	484 µg/ m^2	150 m^2	72,600 µg	Guo et al., 2009
Commercial carpet-care liquids	12,000 µg/kg	6 kg	72,000 µg	Guo et al., 2009
Treated home textile and upholstery	346 µg/ m^2	50 m^2	17,300 µg	Herzke et al., 2012
Waterproofing agents	29,889 µg/L	0.5 L	14,945 µg	Herzke et al., 2012
Pre-treated carpeting	57.2 µg/kg	50 kg	2,860 µg	Kotthoff, 2015
Food contact material (paper)	2,859.9 µg/kg	1 kg	2,860 µg	Kotthoff, 2015
Treated floor waxes and stone/wood sealants	2,430 µg/kg	1 kg	2,430 µg	Guo et al., 2009
Sunscreen	19,000 µg/kg	0.1 kg	1,900 µg	Fujii, 2013
Treated home textile and upholstery	336 µg/kg	5 kg	1,680 µg	Guo et al., 2009
Non-stick cookware	1,234.74 µg/kg	1 kg	1,235 µg	Herzke et al., 2012
Household carpet/fabric-care liquids and foams	953 µg/kg	1 kg	953 µg	Guo et al., 2009
Leather samples	627.3 µg/kg	1 kg	627 µg	Kotthoff, 2015
Foundation cosmetic	5,900 µg/kg	0.1 kg	590 µg	Fujii, 2013
Treated apparel	198 µg/kg	2 kg	396 µg	EPA, 2009
Compounding agent	35,000 µg/kg	0.01 kg	350 µg	Fujii, 2013
Talc	2,500 µg/kg	0.1 kg	250 µg	Fujii, 2013
Outdoor textiles	187.8 µg/kg	1 kg	188 µg	Kotthoff, 2015
Membranes for apparel	124 µg/kg	1 kg	124 µg	Guo et al., 2009
Ski waxes	11,365.5 µg/kg	0.01 kg	113 µg	Kotthoff, 2015
Gloves	169.4 µg/kg	0.2 kg	34 µg	Kotthoff, 2015
Awning cloth (outdoor)	31.6 µg/kg	1 kg	32 µg	Kotthoff, 2015
Treated food contact paper	3,100 µg/kg	0.01 kg	31 µg	Guo et al., 2009
Electronics and electronic parts	25.51 µg/kg	1 kg	26 µg	Herzke et al., 2012
Thread sealant tapes and pastes	603 µg/kg	0.02 kg	12 µg	Guo et al., 2009

Category name	Total PFCA	Typical quantity	PFAS in the home	Reference
Paints and inks	9.36 µg/kg	1 kg	9 µg	Herzke et al., 2012
Waterproofing agents	80.6 µg/kg	0.1 kg	8 µg	Kotthoff, 2015
Treated non-woven medical garments	795 µg/kg	0.01 kg	8 µg	Guo et al., 2009
Household carpet/fabric-care liquids and foams	3.5 µg/kg	1 kg	4 µg	Kotthoff, 2015
Non-stick cookware	0.28 µg/ m^2	1 m^2	0.3 µg	Guo et al., 2009
Dental floss and plaque removers	31.3 µg/kg	0.005 kg	0.2 µg	Guo et al., 2009

Table 41. Estimated FTOH or FTS in consumer products in a typical home.

Category	FTOH/FTS	Quantity	FTOH/FTS in the home	Reference
Cleaning agents	667,700 µg/kg	1 kg	667,700 µg	Kotthoff, 2015
Commercial carpet care liquids	105,000 µg/kg	6 kg	630,000 µg	Liu et al., 2015
Treated floor waxes and stone/wood sealants	423,000 µg/kg	1 kg	423,000 µg	Liu et al., 2015
Waterproofing agents	464,774 µg/L	0.5 L	232,387 µg	Herzke et al., 2012
Treated home textile and upholstery	42,900 µg/kg	5 kg	214,500 µg	Liu et al., 2015
Carpet	4,010 µg/kg	50 kg	200,500 µg	Liu et al., 2015
Impregnating sprays (waterproofing)	1,857,300 µg/kg	0.1 kg	185,730 µg	Kotthoff, 2015
Treated home textile and upholstery	757 µg/ m^2	50 m^2	37,850 µg	Herzke et al., 2012
Carpet samples	73.5 µg/kg	50 kg	3,675 µg	Kotthoff, 2015
Membranes for apparel	1,590 µg/kg	1 kg	1,590 µg	Liu et al., 2015
Treated apparel	464 µg/kg	2 kg	928 µg	Liu et al., 2015
Outdoor textiles	799.3 µg/kg	1 kg	799 µg	Kotthoff, 2015
Household carpet/fabric-care liquids and foams	372 µg/kg	1 kg	372 µg	Liu et al., 2015
Treated food contact paper	25,200 µg/kg	0.01 kg	252 µg	Liu et al., 2015
Treated home textile and upholstery	1.35 µg/m^2	50 m^2	68 µg	Herzke et al., 2012
Electronics and electronic parts	25.51 µg/kg	1 kg	26 µg	Herzke et al., 2012
Thread sealant tapes and pastes	1,220 µg/kg	0.02 kg	24 µg	Liu et al., 2015

Category	FTOH/FTS	Quantity	FTOH/FTS in the home	Reference
Food contact material (paper)	23.4 µg/kg	1 kg	23 µg	Kotthoff, 2015
Gloves	98.3 µg/kg	0.2 kg	20 µg	Kotthoff, 2015
Treated nonwoven medical garments	1,460 µg/kg	0.01 kg	15 µg	Liu et al., 2015
Non-stick cookware	10.55 µg/kg	1 kg	11 µg	Herzke et al., 2012
Electronics and electronic parts	0.57 µg/kg	1 kg	0.6 µg	Herzke et al., 2012

References

Agency for Toxic Substances and Disease Registry (ATSDR). (2018). Toxicological profile for Perfluoroalkyls. (Draft for Public Comment). Retrieved from https://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=1117&tid=237

Arvaniti, O., Andersen, H., Thomaidis, N., & Stasinakis, A. (2014). Sorption of perfluorinated compounds onto different types of sewage sludge and assessment of its importance during wastewater treatment. *Chemosphere, 111*, 405 – 411. https://doi.org/10.1016/j.chemosphere.2014.03.087

Banzhaf, S., Filipovic, M., Lewis, J., Sparrenbom, C. J., & Barthel, R. (2017). A review of contamination of surface-, ground-, and drinking water in Sweden by perfluoroalkyl and polyfluoroalkyl substances (PFASs). *Ambio*, *46*, 335–346. https://doi.org/10.1007/s13280-016-0848-8

Beecher, N., & Brown, S. (2018). PFAS and Organic Residuals Management. *BioCycle.* Retrieved from https://www.biocycle.net/pfas-organic-residuals-management/

Beesoon, S., Genuis, S. J., Benskin, J. P., & Martin, J. W. (2012). Exceptionally High Serum Concentrations of Perfluorohexanesulfonate in a Canadian Family are Linked to Home Carpet Treatment Applications. *Environmental Science & Technology*, *46*, 12960–12967. https://doi.org/10.1021/es3034654

Black, R. (2020). Comment on Draft PFAS Chemical Action Plan. November 20, 2020. Retrieved from https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did200002/pid_200743/assets/merged/ih0rinm_document.pdf?v=9BE2WNV76

Boucher, J. M., Cousins, I. T., Scheringer, M., Hungerbühler, K., & Wang, Z. (2019). Toward a Comprehensive Global Emission Inventory of C4 – C10 Perfluoroalkanesulfonic Acids (PFSAs) and Related Precursors: Focus on the Life Cycle of C6- and C10-Based Products. *Environmental Science & Technology Letters*, *6*, 1–7. https://doi.org/10.1021/acs.estlett.8b00531

Bowman, J. (2018). Comment on: CA DTSC Safer Consumer Product draft Product-Chemical Profile for Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs) in carpets and Rugs. Retrieved from https://calsafer.dtsc.ca.gov/workflows/Comment/11540/?from=search

Buck, R., Korzeniowski, S., Laganis, E., & Adamsky, F. (2021). Identification and Classification of Commercially Relevant Per-and Poly-fluoroalkyl Substances (PFAS). *Integrated Environmental Assessment and Management, 00,* 1 – 11. https://doi.org/10.1002/ieam.4450

Carter, C. (2020). Personal communication. Meeting with to Emily Celto, Washington Department of Ecology, and Cole Carter, Washington Department of Ecology, Solid Waste Management program. March 5, 2020.

Choi, Y. J., Kim Lazcano, R., Yousefi, P., Trim, H., & Lee, L. S. (2019). Perfluoroalkyl Acid Characterization in U.S. Municipal Organic Solid Waste Composts. *Environmental Science & Technology Letters*, *6*, 372–377. https://doi.org/10.1021/acs.estlett.9b00280

Clara, M., Scharf, S., Weiss, S., Gans, O., & Scheffknecht, C. (2008). Emissions of perfluorinated alkylated substances (PFAS) from point sources—identification of relevant branches. *Water Science and Technology*, *58*, 59–66. https://doi.org/10.2166/wst.2008.641

Commission for Environmental Cooperation (CEC). (2017). Furthering the Understanding of the Migration of Chemicals from Consumer Products: A Study of per- and Polyfluoroalkyl Substances (PFASs) in Clothing, Apparel, and Children's Items. Retrieved from http://www3.cec.org/islandora/en/item/11777-furthering-understanding-migration-chemicals-from-consumer-products

Cory, D. (2021). Personal communication. Email to Irina Makarow, Washington Department of Ecology, from Devon Cory, Washington State Department of Transportation. Subject: WA AFFF legislation, DOD coordination. May 17, 2021. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Cox, M. (2019). Personal communication. Email to Kara Steward, Washington Department of Ecology, from Matthew Cox, Washington State Department of Transportation, Hazardous Materials Specialist. Subject: Suggested AFFF Replacement Products. January 15, 2019. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Croker, C. (2020). Managing PFAS Chemicals in Composting and Anaerobic Digestion. *BioCycle*. Retrieved from https://www.biocycle.net/managing-pfas-chemicals-composting-anaerobic-digestion/

Danish Environmental Protection Agency (DEPA). (2013). Survey of PFOS, PFOA and other perfluoroalkyl and polyfluoroalkyl substances. Part of the LOUS-review. Environmental Project No. 1475, 2013. Retrieved from https://www2.mst.dk/Udgiv/publications/2013/04/978-87-93026-03-2.pdf

Danish Environmental Protection Agency (DEPA). (2018). Risk assessment of fluorinated substances in cosmetic products. Retrieved from https://www2.mst.dk/Udgiv/publications/2018/10/978-87-93710-94-8.pdf

Darwin, R. L. (2004). Estimated Quantities of Aqueous Film Forming Foam (AFFF) in the United States. *Fire Fighting Foam Coalition, Inc.*

Darwin, R. L. (2011). Estimated Inventory of PFOS-based Aqueous Film Forming Foam (AFFF). 2011 update to the 2004 report entitled "Estimated Quantities of Aqueous Film Forming Foam (AFFF) in the United States." *Fire Fighting Foam Coalition, Inc.*

Department of Toxic Substances Control, California (DTSC). (2017) Safer Consumer Products - PFAS Public Workshop: Jan 31, 2017 - YouTube. Retrieved July 8, 2017, from https://www.youtube.com/watch?v=MryvxUSlxbA&feature=youtu.be

Dupont Historical Museum (Dupont Museum). (2018). DuPont Plant History. Retrieved November 2, 2018 from https://www.dupontmuseum.com/dupont-plant

Environmental Defense Fund. (2021). Beyond paper: PFAS linked to common plastic packaging used for food, cosmetics, and much more. July 7, 2021. Retrieved from https://www.epa.gov/newsreleases/epa-takes-action-investigate-pfas-contamination

EnviroTrac Ltd. (2020). Site Investigation Report. Ridge Run PFAS HSCA Site East Rockhill Township, West Rockhill Township, and Perkasie Borough Bucks County, Pennsylvania. March 10, 2020. Retrieved from https://files.dep.state.pa.us/Water/DrinkingWater/Perfluorinated%20Chemicals/Ridge_Run_PFAS_Site/2020-03-10%20Ridge%20Run%20PFAS%20Site%20-%20Site%20Investigation%20Report%20(Final)%20-%20Reduced.pdf

Eschauzier, C., Beerendonk, E., Scholte-Veenendaal, P., & De Voogt, P. (2012). Impact of Treatment Processes on the Removal of Perfluoroalkyl Acids from the Drinking Water Production Chain. *Environmental Science & Technology*, *46*, 1708–1715. https://doi.org/10.1021/es201662b

Fay, V. (2020). Inactive Landfill Initiative. Presentation to NEWMOA. June 10, 2020. Retrieved from http://www.newmoa.org/events/docs/409_367/FayNewYorkLandfillsJune2020.pdf

Franko, J., Meade, B. J., Frasch, H. F., Barbero, A. M., & Anderson, S. E. (2012). Dermal Penetration Potential of Perfluorooctanoic Acid (PFOA) in Human and Mouse Skin. *Journal of Toxicology and Environmental Health, Part A*, *75*, 50–62. https://doi.org/10.1080/15287394.2011.615108

Fraser, A. J., Webster, T. F., Watkins, D. J., Nelson, J. W., Stapleton, H. M., Calafat, A. M., Kato, K., Shoeib, M., Vieira, V. M., & McClean, M. D. (2012). Polyfluorinated Compounds in Serum Linked to Indoor Air in Office Environments. *Environmental Science & Technology*, *46*, 1209–1215. https://doi.org/10.1021/es2038257

Freberg, B. I., Haug, L. S., Olsen, R., Daae, H. L., Hersson, M., Thomsen, C., Thorud, S., Becher, G., Molander, P., & Ellingsen, D. G. (2010). Occupational Exposure to Airborne Perfluorinated Compounds during Professional Ski Waxing. *Environmental Science & Technology*, *44*, 7723–7728. https://doi.org/10.1021/es102033k

Fujii, Y., Harada, K. H., & Koizumi, A. (2013). Occurrence of perfluorinated carboxylic acids (PFCAs) in personal care products and compounding agents. *Chemosphere*, *93*, 538–544. https://doi.org/10.1016/j.chemosphere.2013.06.049

Gaines, L. (2017). Per-and Polyfluoroalkyl Substances (PFASs) Usage; Draft: For Informational Purposes, May 25, 2017. *U.S. Environmental Protection Agency (EPA).* Retrieved April 8, 2020 from https://kkw.org/wp-content/uploads/2018/02/PFAS_Usage_DRAFT_May2017.pdf

Ginn, D. (2021). Department of the Navy Comment Letter on Draft PFAS Chemical Action Plan. Janaury 20, 2021. Retrieved from https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did200002/pid_200743/assets/merged/hi0qih3_document.pdf?v=9BE2WNV76

Glüge, J., Scheringer, M., Cousins, I.T., Dewitt, J. C., Goldenman, G., Herzke, D., Lohmann, R., Ng, C.A., Trier, X., & Wang, Z. (2020). An overview of the uses of per- and polyflioralkyl substances (PFAS). *Environmental Science: Processes and Impacts*, 22, 2345 – 2373. https://doi.org/10.1039/D0EM00291G

Guo, Z., Liu, X., Krebs, K. A., & Roache, N. F. (2009). Perfluorocarboxylic Acid Content in 116 Articles of Commerce. *U.S. Environmental Protection Agency*. Retrieved from https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=206124

GreenScreen for Safer Chemicals. (2020). GreenScreen® Certified™ Standard for Firefighting Foam Webinar. Retrieved from https://www.greenscreenchemicals.org/resources/entry/webinar-gsc-fff

Hamid, H., Li, L. Y., & Grace, J. R. (2018). Review of the fate and transformation of per- and polyfluoroalkyl substances (PFASs) in landfills. *Environmental Pollution*, *235*, 74–84. https://doi.org/10.1016/j.envpol.2017.12.030

Harris, M. H., Rifas-Shiman, S. L., Calafat, A. M., Ye, X., Mora, A. M., Webster, T. F., Oken, E., & Sagiv, S. K. (2017). Predictors of Per- and Polyfluoroalkyl Substance (PFAS) Plasma Concentrations in 6–10 Year Old American Children. *Environmental Science & Technology*, *51*, 5193–5204. https://doi.org/10.1021/acs.est.6b05811

Hart & Hickman PC. (2020) North Carolina Collective Study Report. Collection Study of PFAS and 1,4-Dioxane in Landfill Leachate and Estimated Influence on Wastewater Treatment Plant Facility Influent. March 10, 2020. Retrieved from https://files.nc.gov/ncdeq/Waste%20Management/DWM/NC-Collective-Study-Rpt-03-10-2020.pdf

Heads of EPAs Australia and New Zealand (HEPA). (2018). PFAS National Environmental Management Plan January 2018. Retrieved from http://www.environment.gov.au/protection/publications/pfas-nemp

Herzke, D., Olsson, E., & Posner, S. (2012). Perfluoroalkyl and polyfluoroalkyl substances (PFASs) in consumer products in Norway – A pilot study. *Chemosphere*, *88*, 980–987. https://doi.org/10.1016/j.chemosphere.2012.03.035

Hu, X. C., Andrews, D. Q., Lindstrom, A. B., Bruton, T. A., Schaider, L. A., Grandjean, P., Lohmann, R., Carignan, C. C., Blum, A., Balan, S. A., Higgins, C. P., & Sunderland, E. M. (2016). Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Military Fire Training Areas, and Wastewater Treatment Plants. *Environmental Science & Technology Letters*, *3*, 344–350. https://doi.org/10.1021/acs.estlett.6b00260

Infogroup, Inc. (2012). U.S. Business Listings. *ReferenceUSA Database*. Retrieved from http://resource.referenceusa.com/available-databases/

International Maritime Organization. (2007). Chapter II-2 of the International Convention for the Safety of Life at Sea (SOLAS); Part C Suppression of fire; Regulation 10 – Fire-fighting; 4: Fixed fire-extinguishing systems. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/460608/Regulation_10_-_Fire-Fighting.pdf

Interstate Technology & Regulatory Council (ITRC). (2020a). History and Use of Per- and Polyfluoroalkyl Substances (PFAS). Retrieved from https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_AFFF_April2020.pdf

Interstate Technology & Regulatory Council (ITRC). (2020b). Aqueous Film Forming Foam (AFFF). Retrieved from https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_History_and_Use_April2020.pdf

Kernen, B. (2018). The Impact of PFAS on Water Resources September 10, 2018 2018 Annual Forum - Groundwater Protection Council [PowerPoint Slides]. *New Hampshire Department of Environmental Services.* Retrieved from http://www.gwpc.org/sites/default/files/event-sessions/Kernen%2C Brandon.pdf

King County Department of Natural Resources and Parks. (2019). Contaminants of Emerging Concern in Reclaimed Water – Review of Status and Relevant Literature. August 2019. Retrieved from https://your.kingcounty.gov/dnrp/library/2019/kcr3058/kcr3058.pdf

Kotthoff, M., Müller, J., Jürling, H., Schlummer, M., & Fiedler, D. (2015). Perfluoroalkyl and polyfluoroalkyl substances in consumer products. *Environmental Science and Pollution Research*, *22*, 14546–14559. https://doi.org/10.1007/s11356-015-4202-7

Lang, J. R., Allred, B. M., Field, J. A., Levis, J. W., & Barlaz, M. A. (2017). National Estimate of Per- and Polyfluoroalkyl Substance (PFAS) Release to U.S. Municipal Landfill Leachate. *Environmental Science & Technology*, *51*, 2197–2205. https://doi.org/10.1021/acs.est.6b05005

Langer, V., Dreyer, A., & Ebinghaus, R. (2010). Polyfluorinated Compounds in Residential and Nonresidential Indoor Air. *Environmental Science & Technology*, *44*, 8075–8081. https://doi.org/10.1021/es102384z

Lee, J. H., Lee, C. K., Suh, C.-H., Kang, H.-S., Hong, C.-P., & Choi, S.-N. (2017). Serum concentrations of per- and poly-fluoroalkyl substances and factors associated with exposure in the general adult population in South Korea. *International Journal of Hygiene and Environmental Health*, *220*, 1046–1054. https://doi.org/10.1016/j.ijheh.2017.06.005

Liu, X., Guo, Z., Folk, E. E., & Roache, N. F. (2015). Determination of fluorotelomer alcohols in selected consumer products and preliminary investigation of their fate in the indoor environment. *Chemosphere*, *129*, 81–86. https://doi.org/10.1016/j.chemosphere.2014.06.012

Ma., J., Zhu, H, & Kannan, K. (2020) Fecal excretion of perfluorolkyo and polyfluroroalkyl substances in pets from New York State, United States. *Environmental Science & Technology Letters 2020*, 7, 135 – 142. https://doi.org/10.1021/acs.estlett.9b00786

Michigan Department of Environment, Great Lakes and Energy. (2019). Rule 57 Water Quality Values, Surface Water Assessment Section. Retrieved from https://www.michigan.gov/documents/deq/wrd-swas-rule57_372470_7.pdf

Michigan Department of Environment, Great Lakes and Energy. (2021a). Michigan PFAS Action Response Team. Grand Traverse County Grawn, Carl's Retreading. Retrieved from https://www.michigan.gov/pfasresponse/0,9038,7-365-86511_82704-473719--,00.html

Michigan Department of Environment, Great Lakes and Energy. (2021b). Michigan PFAS Action Response Team. Landfills Workgroup. Retrieved from https://www.michigan.gov/pfasresponse/0,9038,7-365-86513_99807_99808-527972--,00.html

Michigan PFAS Action Response Team. (2020). Central Sanitary Landfill, Pierson, Montcalm County. Department of Environment, Great Lakes, and Energy. Retrieved from https://www.michigan.gov/pfasresponse/0,9038,7-365-86511_95645-468563--,00.html

Michigan Waste & Recycling Association. (2019). Statewide Study on Landfill Leachate PFOA and PFOS Impact on Water Resource Recovery Facility Influent. Technical Report. March 1, 2019 (Second Revision March 6, 2019). Retrieved from https://www.bridgemi.com/sites/default/files/mwra-technical-report.pdf

National Association for Surface Finishing (NASF). (2019a). Per- and Polyfluoroalkyl Substances PFAS – NASF Concerns and Activities. Retrieved from https://nasf.org/wp-content/uploads/2019/04/PFAS-–NASF-Concerns-and-Activities.pdf

National Association for Surface Finishing (NASF). (2019b). 6:2 Fluorotelomer Sulfonate (6:2 FTS) Toxicology at a Glance. Retrieved on April 9, 2019 from https://nasf.org/wp-content/uploads/2019/04/Summary-of-Toxicology-Studies-on-6-2-FTS-and-Detailed-Technical-Support-Documents.pdf

National Fire Protection Association (NFPA). (2011). NFPA 502 Standard for Road Tunnels, Bridges, and Other Limited Access Highways, 2011 Edition. Retrieved from https://www.codot.gov/projects/Eisenhowerfiresystem/other-documents/draft-request-for-proposals-rfp/book-3/standard-nfpa-502-2011-edition.pdf

National Fire Protection Association (NFPA). (2014). NFPA 412: Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment. Retrieved from https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=412

Naturvårdsverket. (2016). Highly fluorinated substances (PFAS) and pesticides—An aggregative picture of the occurrence in the environment (in Swedish). Retrieved from https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6709-0.pdf?pid=17835

New York State Pollution Prevention Institute. (2019). Per- and Polyfluorinated Substances in Firefighting Foam. Retrieved from http://theic2.org/article/download-pdf/file_name/Per_and_Polyfluorinated_Substances_in_Firefighting_Foam_040919.pdf

Nilsson, H., Kärrman, A., Rotander, A., van Bavel, B., Lindström, G., & Westberg, H. (2013). Professional ski waxers' exposure to PFAS and aerosol concentrations in gas phase and different particle size fractions. *Environmental Science: Processes & Impacts*, *15*, 814. https://doi.org/10.1039/c3em30739e

North East Biosolids & Residuals Association (NEBRA). (2019). PFAS in Biosolids ("sludge") and Residuals: Recycling organic "wastes" benefits society and the environment. Retrieved from nebiosolids.org/pfas-biosolids

Organisation for Economic Co-operation and Development (OECD). (2015). Working Towards a Global Emission Inventory of PFASs: Focus on PFCAs - Status Quo and the Way Forward. In *OECD Environment, Health and Safety Publications Series on Risk Management No. 30*. Retrieved from https://www.oecd.org/chemicalsafety/risk-management/Working Towards a Global Emission Inventory of PFASs.pdf

Organisation for Economic Co-operation and Development (OECD). (2018). Toward a new comprehensive global database of per- and polyfluoroalkyl substances (PFASs): Summary report on updating the OECD 2007 list of per- and polyfluoroalkyl substances (PFASs). *OECD Environment, Health and Safety Publications, Series on Risk Management, No. 39*. Retrieved from http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en

Pan, C.-G., Liu, Y.-S., & Ying, G.-G. (2016). Perfluoroalkyl substances (PFASs) in wastewater treatment plants and drinking water treatment plants: Removal efficiency and exposure risk. *Water Research*, *106*, 562–570. https://doi.org/10.1016/j.watres.2016.10.045

Paul, A. G., Jones, K. C., & Sweetman, A. J. (2009). A First Global Production, Emission, and Environmental Inventory for Perfluorooctane Sulfonate. *Environmental Science & Technology*, *43*, 386–392. https://doi.org/10.1021/es802216n

Prevedouros, K., Cousins, I. T., Buck, R. C., & Korzeniowski, S. H. (2006). Sources, Fate and Transport of Perfluorocarboxylates. *Environmental Science & Technology*, *40*, 32–44. https://doi.org/10.1021/es0512475

Sanborn, Head & Associates, Inc. (2019). PFAS Waste Source Testing Report. New England Waste Services of Vermont, Inc. Coventry, Vermont. October 2019. Retrieved from https://anrweb.vt.gov/PubDocs/DEC/SolidWaste/OL510/OL510%202019.10.15%20NEWSVT%20PFAS%20Source%20Testing%20Rpt%20-%20Final.pdf

Schaider, L. A., Ackerman, J. M., & Rudel, R. A. (2016). Septic systems as sources of organic wastewater compounds in domestic drinking water wells in a shallow sand and gravel aquifer. *Science of the Total Environment*, *547*, 470–481. https://doi.org/10.1016/j.scitotenv.2015.12.081

Schlummer, M., Gruber, L., Fiedler, D., Kizlauskas, M., & Müller, J. (2013). Detection of fluorotelomer alcohols in indoor environments and their relevance for human exposure. *Environment International*, *57–58*, 42–49. https://doi.org/10.1016/j.envint.2013.03.010

Schultes, L., Vestergren, R., Volkova, K., Westberg, E., Jacobson, T., & Benskin, J. P. (2018). Per- and polyfluoroalkyl substances and fluorine mass balance in cosmetic products from the Swedish market: implications for environmental emissions and human exposure. *Environmental Science: Processes & Impacts*, *20*, 1680–1690. https://doi.org/10.1039/C8EM00368H

Senter, W. 2019. Personal communication. Email to Kara Steward, Washington Department of Ecology, from Wayne Senter, Washington State Fire Chiefs Association. Subject: PFAS CAP help. January 3, 2019. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Social Science Environmental Health Research Institute (SSEHRI). (2020). PFAS Contamination Site Tracker, Northeastern University. Retrieved on April 14, 2020 from https://pfasproject.com/pfas-contamination-site-tracker/

Swedish Chemicals Agency (KEMI). (2015). Occurrence and use of highly fluorinated substances and alternatives. Report 7/15. Retrieved from https://www.kemi.se/en/global/rapporter/2015/report-7-15-occurrence-and-use-of-highly-fluorinated-substances-and-alternatives.pdf

Thalheimer, A. H., McConney, L. B., Kalinovich, I. K., Pigott, A. V., Franz, J. D., Holbert, H. T., Mericas, D., & Puchacz, Z. J. (2017). Use and Potential Impacts of AFFF Containing PFASs at Airports. *Transportation Research Board*. https://doi.org/10.17226/24800

Tian, Z., Kim, S.-K., Shoeib, M., Oh, J.-E., & Park, J.-E. (2016). Human exposure to per- and polyfluoroalkyl substances (PFASs) via house dust in Korea: Implication to exposure pathway. *Science of the Total Environment*, *553*, 266–275. https://doi.org/10.1016/j.scitotenv.2016.02.087

Trier, X., Granby, K., & Christensen, J. H. (2011). Polyfluorinated surfactants (PFS) in paper and board coatings for food packaging. *Environmental Science and Pollution Research*, *18*, 1108–1120. https://doi.org/10.1007/s11356-010-0439-3

Trudel, D., Horowitz, L., Wormuth, M., Scheringer, M., Cousins, I. T., & Hungerbühler, K. (2008). Estimating Consumer Exposure to PFOS and PFOA. *Risk Analysis*, *28*, 251–269. https://doi.org/10.1111/j.1539-6924.2008.01017.x

United Nations Environmental Programme (UNEP). (2012). Technical paper on the identification and assessment of alternatives to the use of perfluorooctane sulfonic acid in open applications. *Stockholm Convention on Persistent Organic Pollutants*. Retrieved from https://www.informea.org/sites/default/files/imported-documents/UNEP-POPS-POPRC12FU-SUBM-PFOA-Canada-48-20161209.En.pdf

United Nations Environmental Programme (UNEP). (2015a). Guidance on alternatives to Perfluorooctane Sulfonic Acid, its Salts, Perfluorooctane Sulfonyl Fluoride and their Related Chemicals. *Stockholm Convention on Persistent Organic Pollutants*. Retrieved from http://chm.pops.int/Implementation/IndustrialPOPs/PFOS/Guidance/tabid/5225/Default.aspx

United Nations Environmental Programme (UNEP). (2015b). Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride. *Stockholm Convention on Persistent Organic Pollutants*. Retrieved from http://www.basel.int/Portals/4/download.aspx?d=UNEP-CHW-POPs-GUID-PFOS-20121214.English.pdf

United Nations Environmental Programme (UNEP). (2016). Consolidated Guidance on Alternatives to Perfluorooctane Sulfonic Acid and its Related Chemicals. *Stockholm Convention on Persistent Organic Pollutants*. Retrieved from http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-POPRC.12-INF-15-Rev.1.English.pdf

U.S. Bureau of Labor Statistics. (2021a). Private, NAICS 71392 Skiing facilities, All Counties in Washington; 2019 Annual Averages, All establishment sizes. Quarterly Census of Employment and Wages - Bureau of Labor Statistics. Retrieved from https://data.bls.gov/cew/apps/table_maker/v4/table_maker.htm#type=2&st=53&year=2019&qtr=A&own=5&ind=71392&supp=0

U.S. Bureau of Labor Statistics. (2021b). Private, NAICS 33992 Sporting and athletic goods manufacturing, All Counties in Washington; 2019 Annual Averages, All establishment sizes. Quarterly Census of Employment and Wages - Bureau of Labor Statistics. Retrieved from https://data.bls.gov/cew/apps/table_maker/v4/table_maker.htm#type=2&st=53&year=2019&qtr=A&own=5&ind=33992&supp=0

U.S. Bureau of Labor Statistics. (2021c). Private, NAICS 611620 Sports and recreation instruction, All Counties in Washington; 2019 Annual Averages, All establishment sizes. Quarterly Census of Employment and Wages - Bureau of Labor Statistics. Retrieved from https://data.bls.gov/cew/apps/table_maker/v4/table_maker.htm#type=2&st=53&year=2019&qtr=A&own=5&ind=611620&supp=0

U.S. Census Bureau. (2015). Number of Firms, Number of Establishments, Employment, and Annual Payroll by Enterprise Employment Size for the United States and States, Totals: 2015. Retrieved from https://www.census.gov/data/tables/2015/econ/susb/2015-susb-annual.html

U.S. Department of Defense (DOD). (2014). DOD inventory of Fire/Crash Training Area Sites as of the end of FY 2014. Retrieved from https://www.documentcloud.org/documents/2755131-List-of-military-fire-and-crash-training-sites.html

U.S. Department of Defense (DOD). (2019a). Fairchild AFB PFOS/PFOA Sampling Areas. Retrieved April 10, 2020 from https://www.fairchild.af.mil/Portals/23/documents/PFOS_PFOA/FAFB PFOS PFOA Sampling Area (Jan 2019 MBC Update).pdf?ver=2019-02-06-175110-770

U.S. Department of Defense (DOD). (2019b). Installations Where DOD is Performing an Assessment of PFAS Use or Potential Release. Retrieved from https://media.defense.gov/2020/Mar/17/2002265607/-1/-1/1/SPREADSHEET_OF_INSTALLATIONS_WHERE_DOD_PERFORMING_ASSESSMENT_OF_PFAS_USE_OR_POTENTIAL_RELEASE.PDF

U.S. Department of Defense (DOD). (2019c). Map of Installations Conducting Assessments for PFAS Use or Potential Release. Retrieved from https://media.defense.gov/2020/Mar/17/2002265608/-1/-1/1/MAP_OF_INSTALLATIONS_CONDUCTING_ASSESSMENTS_FOR_PFAS_USE_OR_POTENTIAL_RELEASE.PDF

U.S. Department of the Navy (DON). (2016a). Aqueous Film Forming Foam (AFFF) Control, Removals and Disposal. Retrieved from http://www.secnav.navy.mil/eie/Documents/Aqueous-Film-Forming-Foam-(AFFF)-Control-Removal-and-Disposal-(1).pdf

U.S. Department of the Navy (DON). (2016b). Perfluorinated Compounds/Perfluoroalkyl Substances (PFC/PFAS) Identification of Potential Areas of Concern. Retrieved from http://www.secnav.navy.mil/eie/Documents/Perfluorinated-Compounds-Perfluoroalkyl-Substances-(PFC-PFAS)–Identification-of-Potential-Areas-of-Concern-(AOCs).pdf

U.S. Department of the Navy (DON). (2017). Department of the Navy (DON) is implementing a comprehensive strategy to manage and address Perfluorinated Compounds (PFC)/Perfluoroalkyl Substances (PFAS) issues. Retrieved from https://www.secnav.navy.mil/eie/Pages/PFC-PFAS.aspx

U.S. Department of the Navy (DON). (2018). Naval Air Station Whidbey Island Area 6: Groundwater and Drinking Water Investigation. Retrieved from https://www.navfac.navy.mil/content/dam/navfac/NAVFAC Atlantic/NAVFAC Northwest/PDFs/About Us/PFAS Groundwater and Drinking Water Investigation/2020-pfas/area-6/2018.06.07_Area6_GW_and_DrinkingWater_factsheet_FINAL.pdf

U.S. Department of the Navy (DON). (2019). Ault Field Phase 4 DW Sampling Results. Retrieved from https://www.navfac.navy.mil/content/dam/navfac/NAVFAC Atlantic/NAVFAC Northwest/PDFs/About Us/environmental-restoration-2019/NASWI_DW Ault Field Phase4 Data Summary.pdf

U.S. Department of the Navy (DON). (2020a). Emergency Response Action Memo - March 3, 2020. Retrieved from https://www.navfac.navy.mil/navfac_worldwide/pacific/fecs/northwest/about_us/northwest_documents/environmental-restoration/pfas-groundwater-and-drinking-water-investigation/nbk_pfas.html

U.S. Department of the Navy (DON). (2020b). Naval Base Kitsap Bangor Silverdale, Washington: PFAS Drinking Water Investigation Fact Sheet. Retrieved from https://www.navfac.navy.mil/content/dam/navfac/NAVFAC Atlantic/NAVFAC Northwest/PDFs/About Us/PFAS Groundwater and Drinking Water Investigation/bangor/Bangor_PFAS_FactSheet_20200114_web.pdf

U.S. Environmental Protection Agency (EPA). (2019a). EPA's per- and Polyfluoroalkyl Substances (PFAS) Action Plan. Retrieved from https://www.epa.gov/sites/production/files/2019-02/documents/pfas_action_plan_021319_508compliant_1.pdf

U.S. Environmental Protection Agency (EPA). (2019b). Environmental Protection Agency. 40 CFR Part 372. EPA–HQ–TRI–2019–0375; FRL–10002–70. RIN 2070–AK51 Addition of Certain Per- and Polyfluoroalkyl Substances; Community Right-to-Know Toxic Chemical Release Reporting. Action: Advance notice of proposed rulemaking. Retrieved from https://www.govinfo.gov/content/pkg/FR-2019-12-04/pdf/2019-26034.pdf

U.S. Environmental Protection Agency (EPA). (2019c). Small Wastewater Systems Research. Retrieved from https://www.epa.gov/water-research/small-wastewater-systems-research

U.S. Environmental Protection Agency (EPA). (2019d). Characterization and Quantification of per- and polyfluoroalkyl substances in landfill gas and estimate of emissions from U.S. Landfills. Retrieved from https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract_id/10990/report/0

U.S. Environmental Protection Agency (EPA). (2020). Enforcement and Compliance History Online (ECHO). Retrieved from https://echo.epa.gov/

U.S. Environmental Protection Agency (EPA). (2021a). 2020 TRI Preliminary Dataset. Retrieved from https://www.epa.gov/toxics-release-inventory-tri-program/2020-tri-preliminary-dataset

U.S. Environmental Protection Agency (EPA). (2021b). EPA takes action to investigate PFAS Contamination, January 14, 2021. Retrieved from https://www.epa.gov/newsreleases/epa-takes-action-investigate-pfas-contamination

U.S. Federal Aviation Administration (FAA). (2004). Advisory Circular 150/5210-6D. Aircraft Fire Extinguishing Agents. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_150_5210-6D.pdf

U.S. Federal Aviation Administration (FAA). (2018). Aircraft Rescue and Fire Fighting (ARFF) Airports. Retrieved from https://www.faa.gov/airports/airport_safety/aircraft_rescue_fire_fighting/

U.S. Federal Aviation Administration (FAA). (2019). National Part 139 CertAlert: Aqueous Film Forming Foam (AFFF) Testing at Certificated Part 139 Airports No. 19-01. Retrieved from https://www.faa.gov/airports/airport_safety/certalerts/media/part-139-cert-alert-19-01-AFFF.pdf

U.S. Federal Aviation Administration (FAA). (2020). Airport Data & Contact Information. Retrieved November 9, 2018 from https://www.faa.gov/airports/airport_safety/airportdata_5010/

U.S. Food and Drug Administration (FDA). (2015). FDA Revokes Food Additive Approval for the Use of Long-Chain Perfluorinated Compounds as Oil and Water Repellents for Paper Used in Food Packaging. Retrieved from http://wayback.archive-it.org/7993/20171114120118/https://www.fda.gov/Food/NewsEvents/ConstituentUpdates/ucm479465.htm

U.S. Food and Drug Administration (FDA). (2020a). Inventory of Effective Food Contact Substance (FCS) Notifications. Retrieved from https://www.accessdata.fda.gov/scripts/fdcc/?set=FCN

U.S. Food and Drug Administration (FDA). (2020b). FDA Announces the Voluntary Phase-Out by Industry of Certain PFAS Used in Food Packaging. Constituent Update. July 31,2020. Retrieved from https://www.fda.gov/food/cfsan-constituent-updates/fda-announces-voluntary-phase-out-industry-certain-pfas-used-food-packaging

U.S. Food and Drug Administration (FDA). (2021). Letter to Manufacturers and Distributors of Fluorinated Polyethylene Food Contact Containers. August 5, 2021. Retrieved from https://www.fda.gov/media/151326/download

Walker, B. (2018). UPDATE: Mapping the expanding PFAS crisis. *Environmental Working Group*. Retrieved from https://www.ewg.org/research/update-mapping-expanding-pfas-crisis

Wang, Z., Cousins, I. T., Scheringer, M., Buck, R. C., & Hungerbühler, K. (2014a). Global emission inventories for C4–C14 perfluoroalkyl carboxylic acid (PFCA) homologues from 1951 to 2030, Part I: production and emissions from quantifiable sources. *Environment International*, *70*, 62–75. https://doi.org/10.1016/j.envint.2014.04.013

Wang, Z., Cousins, I. T., Scheringer, M., Buck, R. C., & Hungerbühler, K. (2014b). Global emission inventories for C4–C14 perfluoroalkyl carboxylic acid (PFCA) homologues from 1951 to 2030, part II: The remaining pieces of the puzzle. *Environment International*, *69*, 166–176. https://doi.org/10.1016/j.envint.2014.04.006

Washington, J. W., & Jenkins, T. M. (2015). Abiotic Hydrolysis of Fluorotelomer-Based Polymers as a Source of Perfluorocarboxylates at the Global Scale. *Environmental Science & Technology*, *49*, 14129–14135. https://doi.org/10.1021/acs.est.5b03686

Washington State Department of Ecology (Ecology). (2010). 2009 Washington Statewide Waste Characterization Study. Retrieved from https://apps.ecology.wa.gov/publications/documents/1007023.pdf

Washington State Department of Ecology (Ecology). (2016). 2015 – 2016 Washington Statewide Waste Characterization Study. Retrieved from https://apps.ecology.wa.gov/publications/documents/1607032.pdf

Washington State Department of Ecology (Ecology). (2017). Solid waste disposal data by facility. Retrieved from https://fortress.wa.gov/ecy/ezshare/swm/SWMData2017/DisposalbyFacility2017.xlsx

Washington State Department of Ecology (Ecology). (2018). Focus on: Alternatives to PFAS in Food Packaging. Retrieved from https://apps.ecology.wa.gov/publications/documents/1804034.pdf

Washington State Department of Ecology (Ecology). (2020a). Ecology survey regarding AFFF disposal program open to municipal fire departments, fire district, fire authorities, port authority fire departments, and fire training facilities. *SurveyMonkey.* Retrieved April 10, 2020 from https://www.surveymonkey.com/r/PRHKQHD

Washington State Department of Ecology (Ecology). (2020b). Worldwide Response Resource List. Retrieved from https://ecology.wa.gov/Regulations-Permits/Plans-policies/Contingency-planning-for-oil-industry/Worldwide-Response-Resource-List

Washington State Department of Ecology (Ecology). (2020c). Priority Consumer Products Report to the Legislature—Safer Products for Washington Implementation Phase 2. Retrieved from https://apps.ecology.wa.gov/publications/documents/2004019.pdf

Washington State Department of Ecology (Ecology). (2021a). Reclaimed water. Retrieved from https://ecology.wa.gov/Water-Shorelines/Water-quality/Reclaimed-water#safe

Washington State Department of Ecology (Ecology). (2021b). Ecology Water Quality Permitting and Reporting Information System (PARIS). Retrieved from https://apps.ecology.wa.gov/paris/PermitLookup.aspx

Washington State Department of Transportation (WSDOT). (2017). All Washington State Airports – Online Map. Retrieved from http://www.wsdot.wa.gov/aviation/AllStateAirports/

Washington State Employment Security Department (ESD). (2017a). Establishment size data for 2016 Quarter 1. Retrieved from https://esd.wa.gov/labormarketinfo/establishment-size

Washington State Employment Security Department (ESD). (2019). Labor Market Information: Occupational Employment & Wages - June 2018. Retrieved on April 14, 2020 from https://esd.wa.gov/labormarketinfo/occupations

Washington State Employment Security Department (ESD). (2020). Labor Market Information: Occupational Employment & Wages - June 2019 (2020 Release). Retrieved on April 14, 2021 from https://esd.wa.gov/labormarketinfo/occupations

Wood Environment & Infrastructure Solutions, Inc. (2019). Site Investigation Report. Investigation of Per-and Polyfluoroalkyl Substances at Select Source Separated Organic Material and Yard Waste Sites, Minnesota. September 2019. Retrieved from https://www.pca.state.mn.us/sites/default/files/w-sw4-37.pdf

World Furniture Online. (2017). The upholstered furniture market in the United States. October 2017. Retrieved from https://www.worldfurnitureonline.com/research-market/the-upholstered-furniture-market-united-states-0058519.html

Wright, Patrick. (2019). Personal communication. Email to Kara Steward, Washington Department of Ecology, from Patrick Wright, Washington State Department of Transportation, Aviation Division. Subject: Review of AFFF text – reminder. January 4, 2019. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Wu, X. (May), Bennett, D. H., Calafat, A. M., Kato, K., Strynar, M., Andersen, E., Moran, R. E., Tancredi, D. J., Tulve, N. S., & Hertz-Picciotto, I. (2015). Serum concentrations of perfluorinated compounds (PFC) among selected populations of children and Adults in California. *Environmental Research*, *136*, 264–273. https://doi.org/10.1016/j.envres.2014.09.026

List of acronyms

General acronyms

Table 42. Acronyms found in the sources and uses appendix.

Acronym	Definition
ACRP	Airport Cooperative Research Program
AFFF	Aqueous film forming foam
AKART	All Known Available and Reasonable Technology
BLS	United States Bureau of Labor Statistics
CAA	Clean Air Act
CFR	Code of Federal Regulations
CSPA	Children's Safe Products Act
CWA	Clean Water Act
DEPA	Danish Environmental Protection Agency
DOD	Unites States Department of Defense
DON	Department of Navy
DTSC	Department of Toxic Substances Control, California
ECHO	Enforcement and Compliance History
ESTCP	Environmental Security Technology Certification Program
EPA	United States Environmental Protection Agency
ERTS	Emergency Reporting Tracking System
ESD	Washington State Employment Security Department
EWG	Environmental Working Group
FAA	Federal Aviation Administration
HEPA	Heads of EPAs Australia and New Zealand
ITRC	Interstate Technology & Regulatory Council
kg	Kilogram
L	Liter
µg	Microgram
m^2	Square meter
MIL-SPEC	U.S. Military Specification
MSRC	Marine Spills Response Corporation
NAICS	North American Industry Classification System
NASF	National Association of Surface Finishers
NFPA	National Fire Protection Association
NHDES	New Hampshire Department of Environmental Service
NRCNW	National Response Corporation Northwest

Acronym	Definition
OECD	Organisation for Economic Co-Operation and Development
PPE	Personal protective equipment
RCRA	Resource Conservation and Recovery Act
RCW	Revised Code of Washington
SERDP	Strategic Environmental Research and Development Program
SSEHRI	Social Science Environmental Health Research Institute
UNEP	United Nations Environment Programme
WAC	Washington Administrative Code
WSDOT	Washington State Department of Transportation
WWRL	Worldwide Response Resource List
WWTP	Wastewater treatment plant

Chemical names

Table 43. Chemical name acronyms found in the sources and uses appendix, excluding the general acronyms listed in the table above.

Acronym	Chemical Name
6:2 FTOH	6:2 fluorotelomer alcohol
ADONA	Ammonium 4,8-dioxa-3H-perfluorononanoate
AFFF	Aqueous film forming foam
FTOH	Fluorotelomer alcohol
FTS	Fluorotelomer sulfonates
PFAA	Perfluoroalkyl acid
PFAS	Per- and polyfluoroalkyl substances
PFCA	Perfluorocarboxylic acid
PFDS	Perfluorodecane sulfonate
PHXsF	Perfluorohexane sulfonyl fluoride
PFOS	Perfluorooctane sulfonic acid
POFS	Perfluorooctanesulfonyl fluoride
PFHxS	Perfluorohexane sulfonate

Appendix 4: Fate and Transport

4.0 Overview

4.0.1 Findings

Transformation:

- All poly-fluorinated per- and polyfluoroalkyl substances (PFAS) are perfluoroalkyl acid (PFAA) precursors.
- PFAA precursors represent a large group of PFAS, which contribute terminal PFAS such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) to the environment.
- It is believed that all PFAA precursors will transform to PFAAs, with a timeframe that could range from hours to hundreds of years.
- Some PFAS polymers will likely serve as a continued source of PFAS emission due to polymer breakdown.

Fate:

- PFAS can be released to the ambient environment as a solid, liquid, or gas, depending on the source of the release (manufacturing or environmental degradation).
- Gas phase and aerosol particulate transport can cause PFAS contamination to occur at long distances from emission sources.
- With the exception of polymers, most PFAS are at least slightly water soluble and can be transported by water movement.
- Adsorption to carbon compounds in soil and sediments can slow PFAS transport by groundwater and surface water.
- Short-chain PFAS are more mobile, less bioaccumulative in animals, and equally as persistent as long-chain versions.
- Chemical transformation of precursor compounds may change preferential partitioning into transport media and rate of transport.
- Landfill waste and biosolids from composting and wastewater treatment plants (WWTPs) may serve as continued sources of PFAS emissions into the environment.
- Some PFAS can bioaccumulate in plants and animals, and biomagnify in higher organisms in the food chain.

4.0.2 Introduction

The purpose of this appendix is to review PFAS transformation in the environment, and address how PFAS transformation products are transported and portioned in various environmental media.

As identified in Appendix 1: Chemistry, because there are hundreds of different PFAS currently on the market, their environmental fate and transport—which describes the chemical transformation and geographic distribution of compounds after release to the environment—can vary greatly. Commercially manufactured PFAS and their subsequent transformation

compounds can exist in many different forms (gas, water, solid) and will partition (i.e., group with separate media) differently depending on the type of compound and the surrounding ambient conditions.

Rate of PFAS chemical transformation can also vary quite dramatically depending on the chemical in question, the phase, and the environment where it is located. Some compounds have a half-life as low as hours in the environment, while others do not transform naturally.

4.1 Non-polymer PFAS

As presented in in Appendix 1: Chemistry, Section 1.1.3, many non-polymer PFAS have been identified and characterized.

PFOS and PFOA, both PFAAs, have been a primary source of attention in research and investigations regarding PFAS impacts. The presence of PFOS and PFOA in the environment results directly from their use and emission from manufacturing processes, or as a result of the degradation of long-chain or polymer substances—usually called precursors. PFAAs are very stable in the environment, and are referred to as terminal substances. As discussed in additional detail below, precursors can undergo several degradation steps prior to forming terminal PFAAs. PFAAs have not been shown to degrade or transform under natural conditions (Ochoa-Herrera, Field, Luna-Velasco & Sierra-Alvarez, 2016; Liou, Szostek, DeRito & Madsen, 2010).

The stability of PFAAs is due to the strength of the high energy carbon-fluorine bond (531.5 kilojoule per mole [kJ/mol]) (Hudlicky & Pavlath, 1995) and the shielding effect of the carbon backbone conformation (Torres, Ochoa-Herrera, Blowers & Sierra-Alvarez, 2009). Precursor compounds, which will eventually turn into PFAAs, have additional moieties added on to the carbon-fluorine chain where other substances and organisms can attack and degrade them. After this process, all that is remaining is the carbon-fluorine backbone and a headgroup: a PFAA. Thus, most scientists consider PFAAs terminal chemicals because they will not undergo further transformation in the natural environment, and will most likely exist on a timeframe longer than can be reliably calculated.

There has been one controversial study showing slight degradation of PFAAs under extreme natural conditions (Taniyasu, et al., 2013b; Wang, Cousins, & Scheringer, 2015). There has also been successful decomposition of PFAAs in the lab using experimental techniques (Luo, Lu & Zhang, 2015; Luo, Yan, Lu & Huang, 2018; Trojanowicz, Bojanowska-Czajka, Bartosiewicz & Kulisa, 2018) such as fungal treatment (Tseng, 2018) and high temperature reaction with persulfate (Park, Lee, Medina, Zull & Waisner, 2016). However, current research suggests that all PFAS ever produced will either transform into a PFAA and never degrade, or will itself not degrade under common conditions in the environment.

The timeframe for the transformation from precursor to PFAA depends on the compound and the conditions. Half-lives are not known or studied for most precursors, with some calculated values ranging from hours to more than a thousand years (Figure 27) (Dassuncao, Hu & Zhang, 2017; Rankin, Lee, Tseng & Mabury, 2014; Wang, Huang & Yang, 2013). With the vast number of potential starting materials and environments, the exact mechanism and changes that occur

for each precursor is unknown. However, scientists have studied many changes in the laboratory, and are starting to characterize transformations in the field. The result of these ongoing transformation processes is that the presence and amount of certain PFAS will evolve over time at any one specific sampling location.

Figure 26. Illustration of precursor transformation leading to PFAAs.

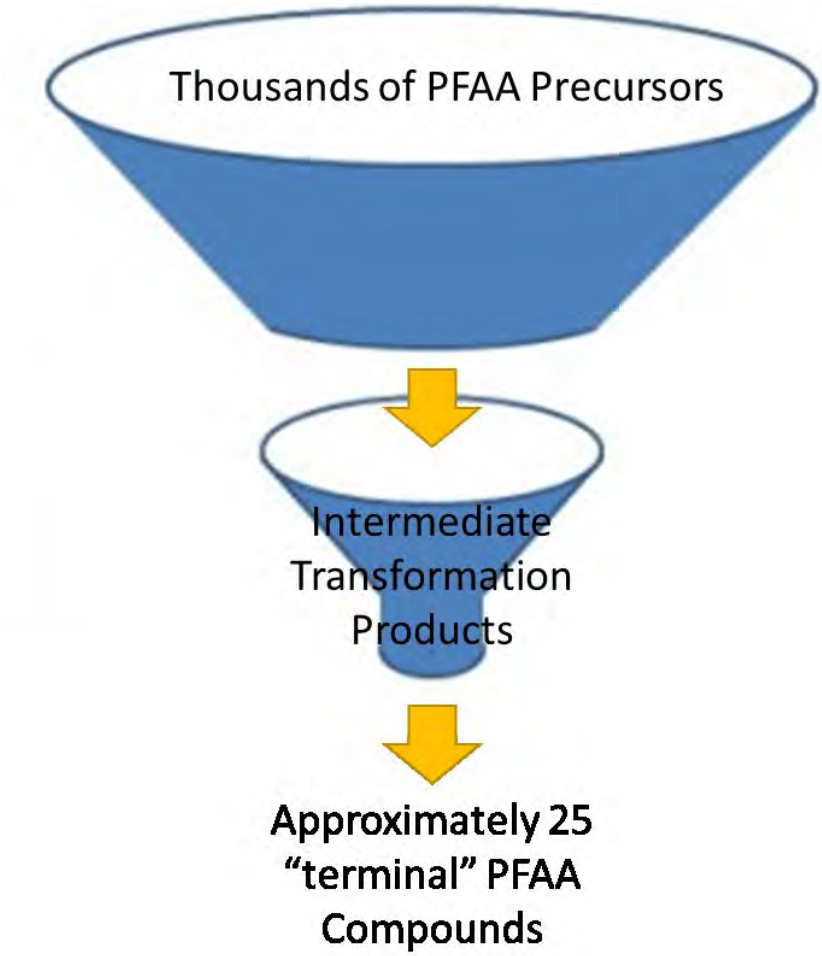
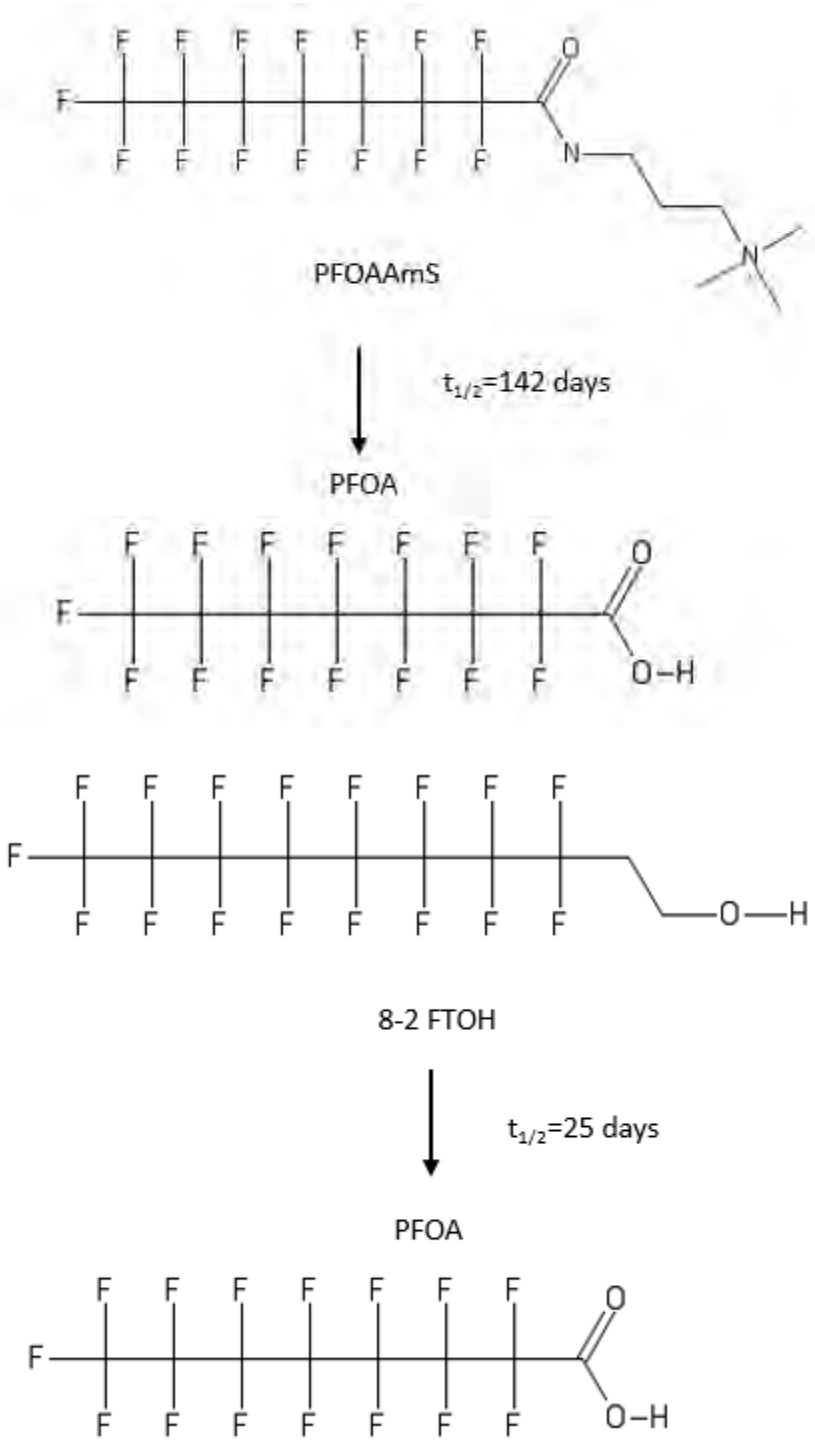
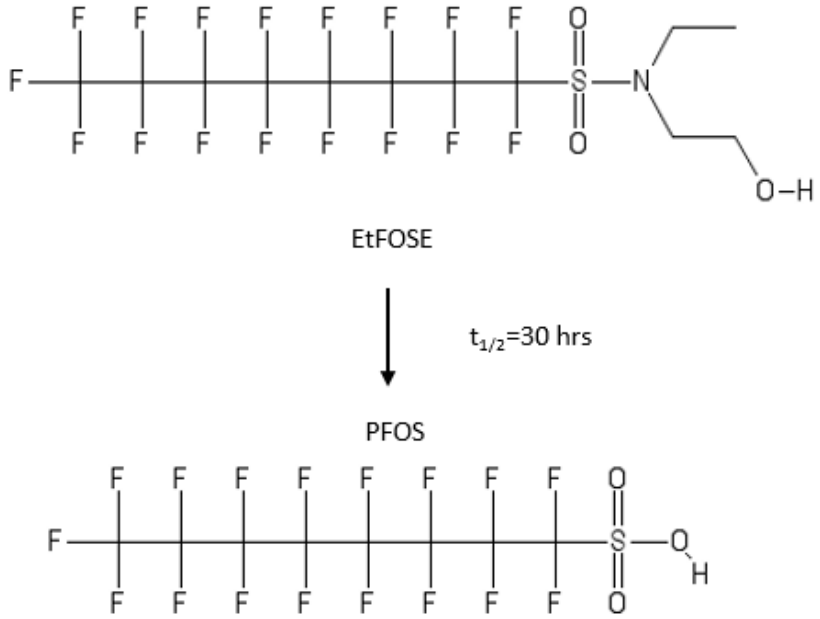


Figure 27. Examples of precursor aerobic biotransformation to PFAAs with half-lives (as described in Section 4.1).





4.1.1 Abiotic transformation

Abiotic transformation (transformation without living organisms) can form both perfluoro-sulfonic acids (PFSAs) and perfluoro-carboxylic acids (PFCAs)—the two main types of PFAAs—from a wide range of precursors. For example, reaction with hydroxyl radicals gives N-methyl perfluorobutane sulfonamidoethanol (NMeFBSE) a half-life of two days, and creates both sulfonic and carboxylic acid byproducts (D'Eon, Hurley, Wallington & Mabury, 2006). Additionally, fluorotelomer alcohol (FTOH) compounds have been found to transform in the atmosphere through reactions with chlorine and hydroxyl radicals to form PFCAs (Ellis, Martin & De Silva, 2004; Ellis et al., 2003). N-ethyl perfluorobutanesulfonamide (NEtFBSA) can transform into PFCAs through a similar mechanism in the atmosphere, with a lifetime in air of 20 – 50 days (Martin, Ellis, Mabury, Hurley & Wallington, 2006).

4.1.2 Biotic aerobic transformation

Researchers have demonstrated aerobic biotransformation (transformation by organisms with access to oxygen) of PFAA precursors several times, and this type of modification is probably the most prevalent form of PFAS chemical transformation. Several studies have been performed with focus on transformation that may occur at WWTPs or aqueous film forming foam (AFFF)-impacted sites (Arvaniti & Stasinakis, 2015). Laboratory studies have shown degradation of FTOHs into PFCAs. In addition, N-ethyl perfluorooctane sulfonamido ethanol (N-EtFOSE) is biodegraded into perfluorooctane sulfonate (PFOS) with a half-life of 0.7 – 44 days (Benskin et al., 2013; Mejia-Avendaño & Liu, 2015; Rhoads, Janssen, Luthy & Criddle, 2008; Zhao, Ma, Fang & Zhu, 2016) and perfluorooctaneamido quaternary ammonium salt (PFOAAmS) transforms into perfluorooctanoic acid (PFOA) with a half-life of 142 days (Mejia-Avendaño, Duy, Sauvé & Liu, 2016). Perfluoroacylphosphates (POPs) have also been shown to biodegrade into FTOHs and eventually to PFCAs (Lee, D'Eon & Mabury, 2009). All precursors tested have shown the ability to be aerobically biotransformed to PFAAs, with most

perfluoroalkane sulfonyl fluoride (PASF)-based substances eventually being biotransformed into PFSAs while all FTOH based substances are eventually transformed into PFCAs (Martin, Ellis, Mabury, Hurley & Wallington, 2006).

4.1.3 Biotic anaerobic transformation

Anaerobic biotransformation (transformation by organisms without oxygen) has been studied much less than aerobic biotransformation. Most evidence suggests that it is slower and transformation into final PFAA forms is less complete. For instance, some PFAA precursors have been shown to remain stable for long periods of time under anaerobic conditions (Boulanger, Vargo, Schnoor & Hornbuckle, 2005; Lange, 2018; Yi, Harding-Marjanovic & Houtz, 2018), with most fluorotelomer sulfonates (FTSAs) remaining more stable than FTOHs (Zhang, Lu, Wang & Buck, 2016). However, in general, anaerobic studies have had similar results to aerobic studies, with PFAAs not biodegrading and other compounds eventually leading to PFAAs.

4.1.4 Consequences of chemical transformation

Because of the transformation processes outlined above, even though U.S. production of PFOS was phased out in 2002 and most production of PFOA was phased out in 2015 through the Environmental Protection Agency's (EPA) PFOA stewardship program, levels of PFAAs have continued to increase in wildlife (Dassuncao, Hu & Zhang, 2017; Roos, Berger, Järnberg, Van Dijk & Bignert, 2013). Manufacturers continue to produce precursor compounds, which will change into PFAAs (including PFOS and PFOA if of sufficient chain length) once released to the environment.

Tracking changes in environmental levels of all PFAS is difficult because there are a large number of precursors, and it is only practical to test for a small fraction in each experiment. Most precursors require advanced analytical methods to detect. These are expensive, available in only a few labs around the world, and often cannot accurately measure quantities of compounds. Additionally, there are very few validated methods endorsed by governmental bodies, so much of the testing done uses experimental techniques. With different methods used by different researchers, comparing results from different studies can be poorly reliable.

Terminal PFAAs are the most prevalent and the most persistent type of PFAS, so they have been studied the most. However, the fact that several precursors have measurable levels in both surface waters (Gebbink, Van Asseldonk & Van Leeuwen, 2017; Pan, Zhang & Cui, 2018) and wildlife (Shi at al., 2015) shows that it is not only PFAAs that have to be considered when evaluating impact and risk, since exposure to precursors can be significant. A study in the Baltic Sea found PFAAs and precursors in most aquatic organisms, but concluded that PFAA levels were not necessarily correlated with precursor intake (Gebbink, Bignert & Berger, 2016). This suggests that it is important to evaluate exposure to precursors and PFAAs separately when considering risk.

In another example of precursor exposure, North Atlantic pilot whales do not contain the enzyme to convert perfluorooctanesulfonamide (PFOSA) to PFOS like most animals do, so when they adsorb PFOSA, they are exposed to its effects for much longer than other species (Dassuncao, Hu & Zhang, 2017). Scientists will need to consider the rate of a chemical's

transformation to PFAA in addition to the chemical hazards of both the chemical itself and the terminal PFAA to get the full picture of risks involved with use and emission.

The PFAS released to the environment from products and manufacturing operations transform over time into a variety of chemical transformation products. The lifetimes and toxicity of these individual transformation products and the final terminal degradates all contribute to a still uncertain environmental impact.

4.2 Polymeric PFAS

There are three different classes of polymeric PFAS to consider when looking at transformation and hazard: fluoropolymers, side-chain fluorinated polymers, and polymeric perfluoropolyethers.

An important consideration is how (or whether) the polymer backbone may degrade, and what unreacted monomers and catalysts may be present. There is evidence that bacteria or light can degrade some fluorotelomer-based PFAS polymers (side-chain fluorinated polymers). This would release soluble monomer or other PFAS fragments to the environment with a half-life of decades to two centuries (Rankin, Lee, Tseng & Mabury, 2014; Washington, Ellington, Jenkins & Yoo, 2010; Washington & Jenkins, 2015; Washington, Jenkins, Rankin, Naile, 2015; Washington, Rankin, Libelo, Lynch & Cyterski, 2019). However, this finding is still unsettled, due to alternate reports using different methods, which show a half-life of approximately 1,200 – 1,700 years for fluorotelomer-based polymers (Russell, Berti, Szostek & Buck, 2008; Russell, Wang, Berti, Szostek & Buck, 2010).

The finding of a half-life of thousands of years for side-chain fluorinated polymers is of note because it contrasts with degradation times for similarly structured monomers, which have half-lives of days to years. If side-chain fluorinated polymers—which are often used as oil- and water-resistance treatments for consumer products—degrade, they could be a potential source of PFAS emissions for decades or centuries if not properly disposed and contained (Li, Liu, Hu & Wania, 2017). One study suggests that degradation of polymers could increase PFAS loading to the environment by four to eight times in coming years (Washington & Jenkins, 2015).

Intact fluoropolymers and perfluoropolyether polymers (PFPEs) are generally agreed to be inert and not bioavailable or bioaccumulative, suggesting minimal health impact (Henry, Carlin & Hammerschmidt, 2018). PFPEs have thermal, chemical, photochemical, hydrolytic, oxidative, and biological stability (Buck & Korzeniowski, 2018). Polytetrafluoroethylene (PTFE) and PFPEs are practically insoluble in water and hydrocarbons, and not subject to long-range transport. However, as identified in Appendix 1: Chemistry, Section 1.4.5, the use of non-polymer processing aids during the application of PTFE coatings has also been a source of PFAA emissions into the environment.

In addition to polymer degradation as a source of PFAS, the polymerization of PFAS polymer requires the use of monomers and, in some cases, non-polymer processing aids. These may be a source of PFAS emissions into the environment. In the past, PFOA was used as a processing aid in fluoropolymer manufacture (Prevedouros, Cousins, Buck & Korzeniowski, 2006; Hopkins, Sun, DeWitt & Knappe, 2018). Manufacturers have since switched to chemicals thought of as

safer, such as or ammonium 4,8-dioxa-3H-perfluorononanoate (ADONA) and hexafluoropropylene oxide (HFPO) dimer acid (GenX) (Gordon, 2011). Although these substitutes are not used in the final polymer, they have been detected numerous times worldwide, including in drinking water in North Carolina and the Netherlands (Gebbink, Van Asseldonk & Van Leeuwen, 2017; Pan, Zhang & Cui, 2018; Song, Vestergren, Shi, Huang & Cai, 2018).

4.3 Emission sources

PFAS can be released into the environment in their manufactured form, as ambient air emissions, in aqueous solution to water sinks, or in solid form which can later be subject to degradation. Emissions can result from:

- Location of PFAS manufacturing.
- Locations where PFAS are used in manufacturing other products.
- Use of products containing PFAS.
- Locations where wastes containing PFAS are stored.
- Degradation of PFAS released to the environment.
- Inadvertent releases to the environment via uncontrolled spills, improper burial, or dumping.

Properties of an individual PFAS will affect its solubility in water, adsorption to soil, or ability to exist as a gas. These attributes will affect the rate of transport when released to environmental media. Chemical changes caused by environmental exposure further complicate the rate of transport. An emitted compound may initially have more affinity for one type of media, but as time passes, it may change and be more likely to migrate and exist in another.

The subsections below address general mechanisms of environmental PFAS fate and transport. Appendix 5: Environmental Occurrence provides information on levels of PFAS measured in environmental media in Washington.

4.3.1 Air

During direct or secondary manufacturing, PFAS can be released to the ambient air through uncontrolled stack emissions (National Ground Water Association (NWGA), 2017). Such emissions can occur in the gaseous phase, or as an aerosol in small particles.

Anionic forms of PFAS, such as PFCAs at low pH, are more likely to be adsorbed to particulates in the air (Ahrens et al., 2012; NWGA, 2017). Once in the air, PFAS can travel large distances before deposition. Deposition occurs via settling of particulates or by transformation of gaseous phases into non-volatile compounds. Deposition can occur either by dry deposition (particles landing by themselves) or by wet deposition (precipitation contributing to deposition) (Taniyasu, et al., 2013a).

Short-range air transport causes PFAS distribution to be much more extensive than just water-based transport, which is the focus of most concerns from manufacturing plants and regulators. Air-based transport can cause contamination of soil, groundwater, and surface water that otherwise would not be anticipated from merely looking at water flow. Long-range air transport

is responsible for the wide distribution of PFAS across the globe, as shown by their occurrence vast distances from all manufacturing sites, including both the Arctic and Antarctic. In addition, sea spray may help re-aerosolize PFAS that have been deposited in oceans (Armitage, Macleod & Cousins, 2009; Gouin & Wania, 2007), contributing to further air-based transport.

Most PFAS are not very volatile, but those that are (like fluorotelomers, FTIs and FTOHs, and perfluoroalkane sulfonamides (FASA)) may partition from liquid to gaseous phases (Buck et al., 2011). This has been identified as an important transformation mechanism in landfills, resulting in landfill gas emissions (see Appendix 3: Sources and Uses, Section 3.4.3 Landfilled Products). PFAS off-gassing from consumer products has also been confirmed, as well as migration of PFAS-containing particulate from products into indoor air in both domestic and occupational settings (Buck et al., 2011). See Appendix 7: Health, Section 7.2.2 Populations with elevated PFAS exposure).

4.3.2 Water

Release to aqueous media

In many cases, PFAS manufacturing processes involve aqueous solutions, which are often a mixture of compounds. Environmental release to aqueous media resulting from manufacturing or secondary manufacturing activities can occur when industrial wastewater is discharged to surface water, or when liquid phase PFAS are directly released to ground or surface water without pre-treatment. Neither the state nor federal Clean Water Act (CWA) regulate PFAS in industrial wastewater discharges via numeric standards.

Certain industrial wastewater discharges are sometimes routed to WWTPs. Such discharges require pre-treatment permits, however these permits also do not regulate PFAS. WWTPs, in turn, discharge treated wastewater to surface water.

PFAS can be present in sewage as a result of products containing PFAS being used in residential, commercial, and institutional facilities, and disposed of in domestic wastewater (see Appendix 3: Sources and Uses, Sections 3.3). For example, a study conducted for the European Union (EU) determined that within the textiles, upholstery, leather apparel, and carpet sector, the greatest life cycle emission of certain PFAS (PFSAs, PFCAs, and FTOHs) was release to sewer resulting from washing of articles over their service life (Whiting et al, 2020). As discussed in Appendix 3: Sources and Uses, Section 3.4.1, PFAS has been found in both WWTP influent and effluent. This has been recognized as one of the larger emission sources for PFAS (NWGA, 2017).

Similarly, PFAS can also be present in domestic wastewater effluents—which are then released to domestic onsite wastewater systems (i.e. septic systems), which typically discharge to groundwater. For example, a study conducted in Cape Cod, Massachusetts, correlated the presence of PFAS in domestic drinking wells with septic system leachate sources that contributed PFAS to local groundwater concentrations (Schaider et al., 2016).

Improper storage of base or secondary manufactured PFAS-containing products can result in leaching of PFAS when exposed to water. Legacy disposal of PFAS wastes in areas not classified as landfills has resulted in groundwater contamination in numerous locations in the U.S. (EPA

Enforcement and Compliance History [ECHO], 2020a). Stormwater disposal into injection wells may act as another potential source of groundwater contamination.

Due to the high solubility of some PFAS (see Appendix 1: Chemistry, Section 1.2.4), compounds may be susceptible to leaching from landfills and contaminated biosolids, compost, and soils when exposed to water (Hamid & Grace, 2018; Kim, Li, Grace, Benskin & Ikonomou, 2015; Lang, Allred, Field, Levis & Barlaz, 2017; Lang, Allred, Peaslee, Field & Barlaz, 2016). Leachate from PFAS-contaminated landfills is estimated to contain around 600 kg per year of PFAS in the U.S. (Lang, Allred, Field, Levis & Barlaz, 2017). In Washington, leachate from some landfills is collected and either sent to a WWTP or deposited in evaporation ponds. Landfill leachate has been identified as a pathway by which PFAS can be redistributed into the environment, especially when leachate is sent for treatment in WWTPs (NWGA, 2017). PFAS impacts from landfill leachate are discussed in Appendix 3: Sources and uses, Section 3.4.3.

Other transport mechanisms include deposition of PFAS aerosols into water bodies as described above, as well as release of PFAS to deposited snow and soils as a result of wax shed from skis during ski competitions (Plassmann & Berger, 2013).

Firefighting using AFFF has historically represented a large source of release of water-based PFAS mixtures into the environment through runoff into surface water as well as migration to groundwater, as discussed in Appendix 3: Sources and uses, Section 3.2.

Many PFAS transport easily through groundwater and surface water due to their high solubility. Dispersion, diffusion, and advection will all affect the movement of PFAS in water, but generally, the compounds will follow the water flow. It is estimated that the oceans are the main final sink for PFAS (Armitage, et al., 2006).

Soil interactions

One important process that affects PFAS transportation and can complicate water transport is adsorption to organic compounds. Most PFAS have a fluorinated carbon tail, which is both hydrophobic and lipophobic, and a polar headgroup, which is hydrophilic. Depending on the types of tail and headgroup, properties of the compound will change. This means that different PFAS can have significantly different attraction to both water and soil. Hydrophobic, lipophobic, and electrostatic interactions will all influence the affinity for different phases. Due to the differences in the chemical and physical properties between the head and the tail, PFAS will often localize at phase interfaces, such as soil and water and water and air boundaries (Brusseau, 2018; Guelfo & Higgins, 2013).

Individual PFAS will adsorb to organic carbon in soil to varying degrees using hydrophobic interactions or electrostatic interactions with minerals. Scientists have mostly studied this interaction in PFAAs, which are relatively soluble in water over a wide range of pH. Because of this solubility, they move easily through water flow, either in groundwater, surface water, or through leaching. However, water transport can be slowed by association with organic carbon in soil (Guelfo & Higgins, 2013; Higgins & Luthy, 2006).

PFSAs tend to adsorb more strongly to soil than PFCAs do (Guelfo & Higgins, 2013; Higgins & Luthy, 2006) and thus are less mobile. Longer carbon chain lengths are also generally associated

with increased adsorption relative to shorter chains (Guelfo & Higgins, 2013). This indicates that a partitioning may occur during wastewater treatment. Shorter chains tend to leave the effluent and longer-chained compounds are more likely to stay in the solid fraction.

Adsorption of PFAS to soil increases as the soil's total organic carbon percentage increases. Soil type, its organic carbon content, and water pH can directly affect the leaching rate (or retention time) of PFAS when spilled on the ground such as during firefighting or training with AFFF. In addition, the chemical constituents of the flammable materials onto which AFFF is applied may influence transport of PFAS through soil and groundwater. Spills into coarse, poorly aggregated soils (such as drainage ditches) will likely leach PFAS faster compared to soil with good structure and high organic carbon.

The retention time of PFAS in soil is dependent upon numerous site-specific variables, though there is evidence that desorption is often incomplete (Chen, Reinhard, Nguyen & Gin, 2016). Soil contaminated with PFAS may remain as a low volume source of contamination for ground and surface water for a long time, complicating hazard assessment.

4.3.3 Solids

Solid phase PFAS resulting from secondary manufacturing, domestic, commercial, and institutional product use (see Appendix 3: Sources and Uses) can be disposed of in solid waste landfills or, in the case of food packaging materials, recycled in composting facilities (Kim, Li, Grace, Benskin & Ikonomou, 2015; Choi et al., 2019). Waste containing PFAS at concentrations above 100 parts per million (ppm) designates as a state-only dangerous waste and must be disposed of as such. Such solid phase PFAS contaminants can serve as potential future sources for emission if exposed to environmental degradation conditions.

Solids contained in sanitary effluents can contain PFAS resulting from human ingestion of PFAS or PFAS that has entered domestic water as a result of abrasion or from disposal of water contaminated via the use of cleaning or treatment products containing these compounds. Sanitary solids are disposed of in WWTP biosolid sludges, or as solid or liquid mixtures removed from on-site sanitary systems, which are then typically transferred and discharged to local WWTP or other appropriate treatment location. Biosolids resulting from treatment of sewage effluent in WWTPs are also known to contain PFAS.

Farmers often use compost as well as biosolids from WWTPs as amendments for agricultural soils. In the U.S., solid sewage sludge from WWTPs not used as biosolids is landfill disposed or incinerated. PFAS present in biosolids and compost applied to agricultural lands can leach and travel (Gottschall, 2017). PFAS that have leached can also be available for plant uptake as described in Section 4.3 below. Biosolids have been identified as a source of PFAS emissions (NWGA, 2017).

Appendix 8: Biosolids provides a more detailed discussion of biosolids application and risk assessment. See Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products for additional discussion of landfilled solids and leachate.

4.4 Uptake by living organisms

Living organisms exposed to PFAS compounds in the ambient or built environment may ingest or otherwise absorb these chemicals via exposure to PFAS in various types of media. Due to the persistence and ability to transport large distances, animals do not need to be near sources of PFAS to show bioaccumulation (Roos et al., 2013). Plants have been shown to take up some types of PFAS from the soil (Blaine et al., 2013; Blaine, Rich & Sedlacko, 2014; Scher, 2018), an issue of concern since agricultural fields have the potential to be treated with PFAS-contaminated biosolids from WWTPs or PFAS-contaminated compost materials. Organisms in the natural food chain can also ingest PFAS directly in water they drink, or indirectly via PFAS present in their prey, with higher levels of PFAS appearing in animals higher on the food chain (Ahrens & Bundschuh, 2014; Houde, Silva & Muir, 2011). Appendix 6: PFAS Ecotoxicology, Section 6.2 Bioaccumulation, addresses bioaccumulation of PFAS in additional detail. Appendix 8: Biosolids addresses the potential for plant uptake of PFAS from contaminated soils.

Human beings can likewise ingest PFAS after handling or coming into contact with products that contain PFAS, drinking PFAS-contaminated water, or eating foods where PFAS is present. As identified above, some PFAS, especially shorter-chain PFAAs, may be taken up by food plants growing in contaminated soils, biosolids, or water. Those PFAS that do bioaccumulate will build up in livestock and fish when present in their food or water (Kowalczyk, 2013; Michigan Department of Community Health, 2012; New Jersey Department of Environmental Protection, 2018; van Asselt et al., 2013; Vestergren et al., 2013). PFAS may also migrate into food from coated food wrappers, fast food containers, microwave popcorn, and nonstick baking papers (Begley et al., 2005; European Commission, 2012; Geueke, 2016). Impacts of human exposure to PFAS are further addressed in Appendix 7: Health, Section 7.2 PFAS exposure in people.

4.5 Long term PFAS management

It is beyond the scope of this document to discuss in detail all of the methods available or being developed for management or mitigation of PFAS in environmental media in the long term. The purpose of this section is to provide a brief overview of methods or technologies that have been proven, or are still being developed, to mitigate or remediate PFAS contamination. Inclusion or omission of any technology in the discussion below does not imply any recommendation by Ecology or Health as to a requirement, regulated or otherwise.

Mitigation goals and approaches are site-specific and tailored to address each site's PFAS mixture loading as well as financial and technological resources available to reduce PFAS risks to sensitive populations. Financial considerations include both short-term capital costs and long-term operation and maintenance costs for the life of the treatment system.

Prior to implementing any one technology, the context of all mitigation strategies has to be considered, including the possibility to stop or remove the PFAS source altogether, or, for example, in the case of drinking water, to find alternative, non-contaminated sources. The following summarizes the most prevalent remediation techniques available (EPA, 2019; Interstate Technology & Regulatory Council (ITRC), 2020a, b; NWGA, 2017). Often more than one technique is necessary to achieve intended remediation goals.

4.5.1 Removal of PFAS from drinking water

Much effort has been focused on remediation of those PFAS that have been identified in drinking water systems through the third unregulated contaminant monitoring rule (UCMR3) data collection. This exercise has underlined that consideration of PFAS precursors is very important to implementation of long-term remediation solutions, as remediation efforts could cause precursor compounds to degrade to more stable PFAS, such as PFOA and PFOS (NGWA, 2017). Conventional water treatments, such as low pressure membranes, biological treatments, disinfection, oxidation, and advanced oxidation, have to date proven to be ineffective at removing PFAS from water (EPA, 2020b; Ozekin & Fulmer, 2019). Technologies identified to date to remove PFAS from water include sorption onto granular activated carbon (GAC), ion exchange (IX), and membranes.

Sorption on to GAC has proven removal efficacies to reduce PFAS concentrations down to and below EPA's Health Advisory Levels and state drinking water guidelines or established levels. GAC systems can be designed to meet the needs of various sizes of drinking water purveyors. PFAS sorb to the GAC substrates. However, as flow through GAC materials proceeds, sorption sites are used up and "breakthrough" can occur. GAC must then be changed out, which introduces an important maintenance cost for these systems. Some GAC can be regenerated for reuse, however disposal may need to be implemented at the end of the GAC's useful life (ITRC, 2020b). GAC are more effective for capturing long-chain PFAS—short-chain PFAS break through GAC systems much more rapidly. These systems therefore need to be designed based on the entire mixture of PFAS present in the influent. Complex contamination of influent to GAC treatment systems may also require pre-treatment for effective removal of PFAS in the PFAS treatment system (ITRC, 2020a). Biochar, a carbon-rich, porous solid synthesized from biomass through high-temperature, low-oxygen pyrolysis is also being investigated as a substitute for GAC.

Ion exchange (IX) technologies use synthetic, polymeric sorbent media to remove PFAS from water. Similar to GAC, as the IX media sorption sites become used up, breakthrough will occur. IX media is available in both non-regenerable (single use) and regenerable (multi-use) versions. Single-use media is disposed of through landfilling for example. Multi-use media can be treated to remove the PFAS it has collected, so that the media can be placed back into service. Regeneration, however, creates a concentrated PFAS liquid waste stream. IX technologies have been used for many other types of contaminants and are scalable for various types of applications. They can be designed to capture long- and short-chain PFAS.

Reverse osmosis and nanofiltration are two high pressure membrane technologies. Both involve mechanisms to filter out large PFAS molecules from water. Although they can be very effective even on the smallest PFAAs, they have not been tested beyond bench scale. Both are expensive and result in treatment concentrate waste streams that have to be disposed of (ITRC, 2020a; Ozekin & Fulmer, 2019).

Researchers continue to investigate many other technologies which are currently either in limited application or developing phases—such as precipitation or flocculation, redox manipulation, and surface activation foam fractionation (ITRC, 2020a, b). Although these have shown promise at the bench scale, they are not fully developed technologies.

Appendix 10: Economic Analysis, Section 10.1 Costs of recommended actions, provides illustrative examples of costs borne by water suppliers in the state to mitigate PFAS in drinking water supplies. Disposal of concentrated waste streams or residuals (such as spent GAC or other media), also entails additional costs over the life of the treatment system.

4.5.2 Stabilization of PFAS in soils

As discussed above in Section 4.3.2, leaching from soil to groundwater generally decreases with increasing chain length, but depending on the specific soil conditions, longer chain compounds (such as PFOA and PFOS) can readily migrate through the unsaturated zone soils and into groundwater. Sorption and stabilization technologies reduce or remove the potential for PFAS to mobilize from soil to groundwater. These technologies involve amendments such as activated carbon and carbon nanotubes (CNTs), resins, minerals, biomaterials, and molecularly imprinted polymers that are added to soils (ITRC 202a, b). The amendments bind to PFAS and thus reduce their release from soil. However, the efficacy of these methods is highly dependent on site-specific geochemical conditions, which can change in-situ with changing environmental conditions. Use of activated carbon has the potential to limit leaching of PFAS from soil to groundwater, but can be influenced by the presence of co-contaminants, chain length, and the PFAS functional group. Other methods being developed are promising but should be evaluated using laboratory testing with site-specific contaminants and soil types before proceeding to full scale implementation.

4.5.3 Ultimate disposal

Ultimate disposal of residual PFAS or concentrated PFAS wastes can occur via long-term storage or destruction. As addressed in Appendix 9: Regulations, Section 9.1.2 Washington state rules, only certain wastes containing PFAS will designate as dangerous. In the case of long term storage, holding locations have to be designed for long-term protection of PFAS-containing materials or wastes from conditions which can result in future PFAS migration from the storage means of containment and the storage site. For example, if materials are landfilled, they need to include caps to protect the waste from long-term water incursion to avoid leaching of the PFAS (ITRC, 2020). Likewise, liners are imperative to collect leachate which might form. Storage design solutions must consider long-term preservation, as the PFAS will outlast many human generations.

In December 2020, the EPA issued for public comment draft interim guidance on the destruction and disposal of six waste streams that commonly contain PFAS as identified in the National Defense Authorization Act for Fiscal Year 2020 (NDAA), Public Law No: 116-92 (EPA, 2020c). The guidance presented background information on the manufacture and uses of PFAS, as well as solid, liquid, and gas waste streams containing PFAS, including AFFF, soils and biosolids, textiles, spent water treatment materials, and landfill leachate.

EPA recognized that the uncertainties associated with technologies' capabilities to control migration of PFAS to the environment need to be considered in parallel with:

- Whether it is imperative to destroy or dispose of the waste immediately (versus storing it and waiting for those uncertainties to be reduced).
- The cost and availability of destruction and disposal options.

- The type of waste materials.
- Concentrations of PFAS in the waste.

EPA identified options with lower uncertainty such as interim storage, permitted deep-well injection, permitted hazardous waste landfills (Resource Conservation and Recovery Act [RCRA] subtitle C) and solid waste landfills (RCRA subtitle D) that have composite liners and leachate collection treatment systems. It should be noted that Washington state does not have any permitted deep-well injection facilities.

Destruction of PFAS by thermal decomposition (incineration) is currently the only other available long-term management solution. Thermal decomposition of PFAS by incineration has been proven effective if sufficiently high temperatures are employed (EPA, 2019). The decomposition involves several carbon-fluorine atomic bond breaking processes, which can gradually reduce PFAS to their elemental constituents. However, improperly controlled incineration conditions can result in the formation of smaller PFAS products or products of incomplete combustion, which may not have been studied and result in unknown long-term adverse impacts.

EPA's interim guidance identified that thermal destruction of PFAS offers a pathway to dispose of materials containing PFAS, but may have higher levels of uncertainty regarding the capacity to manage the migration of PFAS into the environment if destruction conditions are not properly selected, implemented, and monitored (EPA, 2020c). Additional research is continuing to better understand thermal PFAS decomposition processes, byproducts formed, how they can be captured in emissions streams, and the overall efficacy of incineration (EPA, 2019; ITRC, 2020).

Numerous efforts are under way to identify methods for disposal and destruction of PFAS-contaminated media and waste. For example, the PFAS Innovative Treatment Team (PITT) was established in the Spring of 2020 (EPA, 2021). Over the six months of its tenure, the PITT assessed current and emerging destruction methods, explored methods' efficacy (including the consideration of potentially hazardous byproducts) and evaluated their feasibility, performance, and costs. Researchers also continue to investigate innovative destructive techniques, for example plasma technologies, electrochemical methods, or catalysts paired with ultraviolet light (Jansen, 2019; RTI International, 2020). However, these have yet to be demonstrated to reach desired destruction levels, scaling for actual applications, or technological and financial feasibility.

4.6 Data gaps and recommendations

4.6.1 Data gaps

As a whole, the study of the fate and transport of PFAS within the environment is an ongoing effort, and many data gaps remain to be filled by the scientific community. Persistence of precursors to terminal PFAS is only beginning to be mapped out and studied.

4.6.2 Recommendations

As identified above, several areas of concern regarding the presence and transport of PFAS throughout the environment have emerged, and are the subject of recommendations elsewhere in this Chemical Action Plan (CAP):

- For presence of PFAS in biosolids produced from WWTPs, and impacts resulting from their application in agriculture, see Appendix 8: Biosolids.
- For presence of PFAS in WWTP influents and effluents, and discharges of WWTP effluent to surface water, see Appendix 3: Sources and Uses, Section 3.4.2 Wastewater.
- For presence of PFAS in landfill leachate, see Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products.
- For contamination of drinking water resulting from use of AFFF, see Appendix 3: Sources and Uses, Section 3.2 Aqueous film forming foam.

The following recommendations also result from the analyses presented in this appendix:

Recommendation 2.1 Establish PFAS cleanup levels for soil and groundwater

- Using existing authority under the Model Toxics Control Act (MTCA),[143] Ecology plans to develop cleanup levels for PFOA, PFOS, perfluorononanoic acid (PFNA), PFHxS and perfluorobutane sulfonate (PFBS), the five PFAS for which the State Board of Health (SBOH) is planning to promulgate state action levels in 2021. Ecology will use SBOH drinking water standards or action levels adopted in rule to develop these cleanup levels.
- Ecology will explore methods for investigation and cleanup of PFAS contamination.
- Ecology will conduct monitoring for PFAS compounds in environmental media (soils, surface water, and sediment) and wildlife tissue to identify sources of contamination and assess exposure.
- Once sufficient supporting data are available, Ecology plans to develop cleanup levels for individual or mixtures of PFAS in soil, sediment, freshwater, and saltwater to protect ecological receptors.
- In this context, the following activities will be implemented to support activity under the recommendations above:
    - Trophic transfer and bioaccumulation of PFAS compounds should be further evaluated in aquatic and terrestrial food webs to further understand exposure.

[143] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.305&full=true

    - Selected individual PFAS compounds, as well as common PFAS mixtures, should be evaluated for ecotoxicity in aquatic and terrestrial biota, using both laboratory and field methods.
    - Ecological risk assessment should be performed for PFAS compounds by detailing exposure and effects in order to estimate risks to nonhuman biota.
    - An uncertainty analysis should accompany PFAS ecorisk assessment to promote transparency in the risk assessment and communication processes and to more clearly identify data gaps.
    - Results of these risk assessments should support potential interventions (for example, species protections) and characterization of potential impacts on ecological services.
- Ecology will provide information to interested parties about cleanup efforts.

Recommendation 2.2 Partner with local organizations in communities with contaminated water or contaminated sites

Department of Health will identify local health departments or community-based organizations to address health equity related to contaminated sites in public communications. Health will coordinate with Ecology to distribute funding to those organizations selected for assistance. Health's new Community Engagement Guide[144] may support this effort.

Funded organizations would:

- Address potential health equity issues through culturally and linguistically informed engagement.
- Find trusted messengers or platforms to deliver audience-tested risk communication messages to engage historically overburdened and higher risk populations.
- Support impacted populations in finding their own solutions through collective action and decision-making.
- Engage the community throughout the course of the public health response, source investigation, and site cleanup.
- Invite area residents to actively participate on advisory committees, in site information meetings, and in public decision-making about remediation.
- Aim to remove participation barriers by providing child care, reducing transportation costs, and planning for convenient meetings times at familiar locations.
- When possible, appropriately compensate community advisors for participation—particularly in areas with low-income populations.

[144] https://www.doh.wa.gov/Portals/1/Documents/1000/CommEngageGuide.pdf

References

Ahrens, L., & Bundschuh, M. (2014). Fate and effects of poly- and perfluoroalkyl substances in the aquatic environment: A review. *Environmental Toxicology and Chemistry, 33*, 1921–1929. https://doi.org/10.1002/etc.2663

Ahrens, L., Harner, T., Shoeib, M., Lane, D. A., & Murphy, J. G. (2012). Improved Characterization of Gas–Particle Partitioning for Per- and Polyfluoroalkyl Substances in the Atmosphere Using Annular Diffusion Denuder Samplers. *Environmental Science & Technology, 46*, 7199–7206. https://doi.org/10.1021/es300898s

Armitage, J. M., MacLeod, M., & Cousins, I. T. (2009a). Modeling the Global Fate and Transport of Perfluorooctanoic Acid (PFOA) and Perfluorooctanoate (PFO) Emitted from Direct Sources Using a Multispecies Mass Balance Model. *Environmental Science & Technology, 43*, 1134–1140. https://doi.org/10.1021/es802900n

Armitage, J. M., Schenker, U., Scheringer, M., Martin, J. W., MacLeod, M., & Cousins, I. T. (2009b). Modeling the Global Fate and Transport of Perfluorooctane Sulfonate (PFOS) and Precursor Compounds in Relation to Temporal Trends in Wildlife Exposure. *Environmental Science & Technology*, *43*, 9274–9280. https://doi.org/10.1021/es901448p

Arvaniti, O. S., & Stasinakis, A. S. (2015). Review on the occurrence, fate and removal of perfluorinated compounds during wastewater treatment. *Science of the Total Environment, 524–525,* 81–92. https://doi.org/10.1016/j.scitotenv.2015.04.023

Begley, T. H., White, K., Honigfort, P., Twaroski, M. L., Neches, R., & Walker, R. A. (2005). Perfluorochemicals: Potential sources of and migration from food packaging. *Food Additives and Contaminants*, *22*, 1023–1031. https://doi.org/10.1080/02652030500183474

Benskin, J. P., Ikonomou, M. G., Gobas, F. A. P. C., Begley, T. H., Woudneh, M. B., & Cosgrove, J. R. (2013). Biodegradation of N -Ethyl Perfluorooctane Sulfonamido Ethanol (EtFOSE) and EtFOSE-Based Phosphate Diester (SAmPAP Diester) in Marine Sediments. *Environmental Science & Technology, 47*, 1381–1389. https://doi.org/10.1021/es304336r

Blaine, A. C., Rich, C. D., Hundal, L. S., Lau, C., Mills, M. A., Harris, K. M., & Higgins, C. P. (2013). Uptake of Perfluoroalkyl Acids into Edible Crops via Land Applied Biosolids: Field and Greenhouse Studies. *Environmental Science & Technology, 47,* 14062–14069. https://doi.org/10.1021/es403094q

Blaine, A. C., Rich, C. D., Sedlacko, E. M., Hundal, L. S., Kumar, K., Lau, C., Mills, M. A., Harris, K. M., & Higgins, C. P. (2014). Perfluoroalkyl Acid Distribution in Various Plant Compartments of Edible Crops Grown in Biosolids-Amended soils. *Environmental Science & Technology, 48*, 7858–7865. https://doi.org/10.1021/es500016s

Boulanger, B., Vargo, J. D., Schnoor, J. L., & Hornbuckle, K. C. (2005). Evaluation of Perfluorooctane Surfactants in a Wastewater Treatment System and in a Commercial Surface Protection Product. *Environmental Science & Technology, 39*, 5524–5530. https://doi.org/10.1021/es050213u

Brusseau, M. L. (2018). Assessing the potential contributions of additional retention processes to PFAS retardation in the subsurface. *Science of the Total Environment, 613–614*, 176–185. https://doi.org/10.1016/j.scitotenv.2017.09.065

Buck, R. C., & Korzeniowski, S. H. (2019). The PFAS Universe: Uses, Classes & Degradation; Webinar for IC2 & MA TURI. IC2 Webinar, Slides and Questions and Answers January 30, 2019. *Interstate Chemicals Clearinghouse*. Retrieved from http://theic2.org/ic2_webinar_the_pfas_universe

Chen, H., Reinhard, M., Nguyen, V. T., & Gin, K. Y.-H. (2016). Reversible and irreversible sorption of perfluorinated compounds (PFCs) by sediments of an urban reservoir. *Chemosphere, 144*, 1747–1753. https://doi.org/10.1016/j.chemosphere.2015.10.055

Choi, Y. J., Kim Lazcano, R., Yousefi, P., Trim, H., & Lee, L. S. (2019). Perfluoroalkyl Acid Characterization in U.S. Municipal Organic Solid Waste Composts. *Environmental Science & Technology Letters*, *6*, 372–377. https://doi.org/10.1021/acs.estlett.9b00280

Conder, J. M., Hoke, R. A., Wolf, W. de, Russell, M. H., & Buck, R. C. (2008). Are PFCAs Bioaccumulative? A Critical Review and Comparison with Regulatory Criteria and Persistent Lipophilic Compounds. *Environmental Science & Technology, 42*, 995–1003. https://doi.org/10.1021/es070895g

Cousins, I. T., Vestergren, R., Wang, Z., Scheringer, M., & McLachlan, M. S. (2016). The precautionary principle and chemicals management: The example of perfluoroalkyl acids in groundwater. *Environment International, 94*, 331–340. https://doi.org/10.1016/j.envint.2016.04.044

D'eon, J. C., Hurley, M. D., Wallington, T. J., & Mabury, S. A. (2006). Atmospheric Chemistry of N -methyl Perfluorobutane Sulfonamidoethanol, C 4 F 9 SO 2 N(CH 3)CH 2 CH 2 OH: Kinetics and Mechanism of Reaction with OH. *Environmental Science & Technology, 40*, 1862–1868. https://doi.org/10.1021/es0520767

Dassuncao, C., Hu, X. C., Zhang, X., Bossi, R., Dam, M., Mikkelsen, B., & Sunderland, E. M. (2017). Temporal Shifts in Poly- and Perfluoroalkyl Substances (PFASs) in North Atlantic Pilot Whales Indicate Large Contribution of Atmospheric Precursors. *Environmental Science & Technology, 51*, 4512–4521. https://doi.org/10.1021/acs.est.7b00293

Ellis, D. A., Martin, J. W., De Silva, A. O., Mabury, S. A., Hurley, M. D., Sulbaek Andersen, M. P., & Wallington, T. J. (2004). Degradation of Fluorotelomer Alcohols: A Likely Atmospheric Source of Perfluorinated Carboxylic Acids. *Environmental Science & Technology, 38*, 3316–3321. https://doi.org/10.1021/es049860w

Ellis, D. A., Martin, J. W., Mabury, S. A., Hurley, M. D., Sulbaek Andersen, M. P., & Wallington, T. J. (2003). Atmospheric Lifetime of Fluorotelomer Alcohols. *Environmental Science & Technology, 37*, 3816–3820. https://doi.org/10.1021/es034136j

Eschauzier, C., Beerendonk, E., Scholte-Veenendaal, P., & De Voogt, P. (2012). Impact of Treatment Processes on the Removal of Perfluoroalkyl Acids from the Drinking Water Production Chain. *Environmental Science & Technology, 46*, 1708–1715. https://doi.org/10.1021/es201662b

European Commission. (2012). Final Report Summary - PERFOOD (PERFluorinated Organics in Our Diet). Retrieved from https://cordis.europa.eu/project/rcn/91268/reporting/en

Gebbink, W. A., Bignert, A., & Berger, U. (2016). Perfluoroalkyl Acids (PFAAs) and Selected Precursors in the Baltic Sea Environment: Do Precursors Play a Role in Food Web Accumulation of PFAAs? *Environmental Science & Technology, 50*, 6354–6362. https://doi.org/10.1021/acs.est.6b01197

Gebbink, W. A., van Asseldonk, L., & van Leeuwen, S. P. J. (2017). Presence of Emerging Per- and Polyfluoroalkyl Substances (PFASs) in River and Drinking Water near a Fluorochemical Production Plant in the Netherlands. *Environmental Science & Technology, 51*, 11057–11065. https://doi.org/10.1021/acs.est.7b02488

Geueke, B. (2016). Dossier – Per- and polyfluoroalkyl substances (PFASs). *Food Packaging Forum*, 1–13. Retrieved from https://www.foodpackagingforum.org/fpf-2016/wp-content/uploads/2016/07/FPF_Dossier10_PFASs.pdf

Gordon, S. C. (2011). Toxicological evaluation of ammonium 4,8-dioxa-3H-perfluorononanoate, a new emulsifier to replace ammonium perfluorooctanoate in fluoropolymer manufacturing. *Regulatory Toxicology and Pharmacology, 59,* 64–80. https://doi.org/10.1016/j.yrtph.2010.09.008

Gottschall, N., Topp, E., Edwards, M., Payne, M., Kleywegt, S., & Lapen, D. R. (2017). Brominated flame retardants and perfluoroalkyl acids in groundwater, tile drainage, soil, and crop grain following a high application of municipal biosolids to a field. *Science of the Total Environment*, *574*, 1345–1359. https://doi.org/10.1016/j.scitotenv.2016.08.044

Gouin, T., & Wania, F. (2007). Time Trends of Arctic Contamination in Relation to Emission History and Chemical Persistence and Partitioning Properties. *Environmental Science & Technology, 41*, 5986–5992. https://doi.org/10.1021/es0709730

Guelfo, J. L., & Higgins, C. P. (2013). Subsurface Transport Potential of Perfluoroalkyl Acids at Aqueous Film-Forming Foam (AFFF)-Impacted Sites. *Environmental Science & Technology, 47*, 4164–4171. https://doi.org/10.1021/es3048043

Hamid, H., Li, L. Y., & Grace, J. R. (2018). Review of the fate and transformation of per- and polyfluoroalkyl substances (PFASs) in landfills. *Environmental Pollution, 235*, 74–84. https://doi.org/10.1016/j.envpol.2017.12.030

Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., Seed, J., & Hernandez, O. (2018). A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integrated Environmental Assessment and Management, 14*, 316–334. https://doi.org/10.1002/ieam.4035

Higgins, C. P., & Luthy, R. G. (2006). Sorption of Perfluorinated Surfactants on Sediments †. *Environmental Science & Technology, 40*, 7251–7256. https://doi.org/10.1021/es061000n

Hopkins, Z. R., Sun, M., DeWitt, J. C., & Knappe, D. R. U. (2018). Recently Detected Drinking Water Contaminants: GenX and Other Per- and Polyfluoroalkyl Ether Acids. *Journal - American Water Works Association, 110*, 13–28. https://doi.org/10.1002/awwa.1073

Houde, M., De Silva, A. O., Muir, D. C. G., & Letcher, R. J. (2011). Monitoring of Perfluorinated Compounds in Aquatic Biota: An Updated Review. *Environmental Science & Technology, 45*, 7962–7973. https://doi.org/10.1021/es104326w

Hudlicky, M., & Pavlath, A. E. (1995). Chemistry of organic fluorine compounds II: a critical review. Washington, DC: *American Chemical Society*.

Interstate Technology & Regulatory Council (ITRC). (2020a). PFAS- Per-and Polyfluoroalkyl Substances. 12 Treatment Technologies. Retrieved from https://pfas-1.itrcweb.org/12-treatment-technologies/

Interstate Technology & Regulatory Council (ITRC). (2020b). Treatment Technologies and methods for Per-and Polyfluoroalkyl Substances (PFAS). August 2020. Retrieved from https://pfas-1.itrcweb.org/wp-content/uploads/2020/10/treatment_tech_508_Aug-2020-Final.pdf

Jansen, K. (2019, March 25). 'Forever chemicals' no more? These technologies aim to destroy PFAS in water: Researchers are developing a battery of new treatments to better target and ultimately obliterate fluorinated contaminants in water supplies. *Chemical and Engineering News*, *97*. Retrieved from https://cen.acs.org/environment/persistent-pollutants/Forever-chemicals-technologies-aim-destroy/97/i12

Jones, P. D., Hu, W., De Coen, W., Newsted, J. L., & Giesy, J. P. (2003). Binding of perfluorinated fatty acids to serum proteins. *Environmental Toxicology and Chemistry, 22*, 2639. https://doi.org/10.1897/02-553

Kim, M., Li, L. Y., Grace, J. R., Benskin, J. P., & Ikonomou, M. G. (2015). Compositional Effects on Leaching of Stain-Guarded (Perfluoroalkyl and Polyfluoroalkyl Substance-Treated) Carpet in Landfill Leachate. *Environmental Science & Technology, 49*, 6564–6573. https://doi.org/10.1021/es505333y

Kowalczyk, J., Ehlers, S., Oberhausen, A., Tischer, M., Fürst, P., Schafft, H., & Lahrssen-Wiederholt, M. (2013). Absorption, Distribution, and Milk Secretion of the Perfluoroalkyl Acids PFBS, PFHxS, PFOS, and PFOA by Dairy Cows Fed Naturally Contaminated Feed. *Journal of Agricultural and Food Chemistry*, *61*, 2903–2912. https://doi.org/10.1021/jf304680j

Lang, J. R., Allred, B. M., Field, J. A., Levis, J. W., & Barlaz, M. A. (2017). National Estimate of Per- and Polyfluoroalkyl Substance (PFAS) Release to U.S. Municipal Landfill Leachate. *Environmental Science & Technology, 51*, 2197–2205. https://doi.org/10.1021/acs.est.6b05005

Lang, J. R., Allred, B. M., Peaslee, G. F., Field, J. A., & Barlaz, M. A. (2016). Release of Per- and Polyfluoroalkyl Substances (PFASs) from Carpet and Clothing in Model Anaerobic Landfill Reactors. *Environmental Science & Technology, 50*, 5024–5032. https://doi.org/10.1021/acs.est.5b06237

Lange, C. C. (2018). Anaerobic biotransformation of N -methyl perfluorobutanesulfonamido ethanol and N -ethyl perfluorooctanesulfonamido ethanol. *Environmental Toxicology and Chemistry, 37*, 768–779. https://doi.org/10.1002/etc.4014

Lau, C., Anitole, K., Hodes, C., Lai, D., Pfahles-Hutchens, A., & Seed, J. (2007). Perfluoroalkyl Acids: A Review of Monitoring and Toxicological Findings. *Toxicological Sciences, 99*, 366–394. https://doi.org/10.1093/toxsci/kfm128

Lee, H., D'eon, J., & Mabury, S. A. (2009). Biodegradation of polyfluoroalkyl phosphate surfactants as a source of perfluorinated carboxylic acids and fluorotelomer acids. *Reproductive Toxicology, 27*, 421–422. https://doi.org/10.1016/j.reprotox.2008.11.071

Li, L., Liu, J., Hu, J., & Wania, F. (2017). Degradation of Fluorotelomer-Based Polymers Contributes to the Global Occurrence of Fluorotelomer Alcohol and Perfluoroalkyl Carboxylates: A Combined Dynamic Substance Flow and Environmental Fate Modeling Analysis. *Environmental Science & Technology, 51*, 4461–4470. https://doi.org/10.1021/acs.est.6b04021

Li, Y., Fletcher, T., Mucs, D., Scott, K., Lindh, C. H., Tallving, P., & Jakobsson, K. (2018). Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water. *Occupational and Environmental Medicine, 75*, 46–51. https://doi.org/10.1136/oemed-2017-104651

Liou, J.-C., Szostek, B., DeRito, C. M., & Madsen, E. L. (2010). Investigating the biodegradability of perfluorooctanoic acid. *Chemosphere, 80*, 176–183. https://doi.org/10.1016/j.chemosphere.2010.03.009

Luo, Q., Yan, X., Lu, J., & Huang, Q. (2018). Perfluorooctanesulfonate Degrades in a Laccase-Mediator System. *Environmental Science & Technology, 52*, 10617–10626. https://doi.org/10.1021/acs.est.8b00839

Martin, J. W., Ellis, D. A., Mabury, S. A., Hurley, M. D., & Wallington, T. J. (2006). Atmospheric Chemistry of Perfluoroalkanesulfonamides: Kinetic and Product Studies of the OH Radical and Cl Atom Initiated Oxidation of N -Ethyl Perfluorobutanesulfonamide. *Environmental Science & Technology, 40*, 864–872. https://doi.org/10.1021/es051362f

Martin, J. W., Mabury, S. A., Solomon, K. R., & Muir, D. C. G. (2013). Progress toward understanding the bioaccumulation of perfluorinated alkyl acids. *Environmental Toxicology and Chemistry, 32*, 2421–2423. https://doi.org/10.1002/etc.2376

Mejia-Avendaño, S., & Liu, J. (2015). Production of PFOS from aerobic soil biotransformation of two perfluoroalkyl sulfonamide derivatives. *Chemosphere, 119*, 1084–1090. https://doi.org/10.1016/j.chemosphere.2014.09.059

Mejia-Avendaño, S., Vo Duy, S., Sauvé, S., & Liu, J. (2016). Generation of Perfluoroalkyl Acids from Aerobic Biotransformation of Quaternary Ammonium Polyfluoroalkyl Surfactants. *Environmental Science & Technology, 50*, 9923–9932. https://doi.org/10.1021/acs.est.6b00140

Michigan Department of Community Health. (2012). Evaluation of Fish Tissue Data - Wurtsmith Air Force Base Oscoda, Iosco County, Michigan. *Agency for Toxic Substances and Disease Registry*. Retrieved from https://www.atsdr.cdc.gov/HAC/pha/WurtsmithAFB/WurtsmithAFBLHC08312012.pdf

National Groundwater Association (NGWA). (2017). Groundwater and PFAS: State of Knowledge and Practice. Retrieved from https://my.ngwa.org/NC__Product?id=a183800000kbKF9AAM

New Jersey Department of Environmental Protection. (2018). Investigation of Levels of Perfluorinated Compounds in New Jersey Fish, Surface Water, and Sediment. Retrieved from https://www.nj.gov/dep/dsr/publications/Investigation%20of%20Levels%20of%20Perfluorinated%20Compounds%20in%20New%20Jersey%20Fish,%20Surface%20Water,%20and%20Sediment.pdf

Nordén, M., Berger, U., & Engwall, M. (2013). High levels of perfluoroalkyl acids in eggs and embryo livers of great cormorant (Phalacrocorax carbo sinensis) and herring gull (Larus argentatus) from Lake Vänern, Sweden. *Environmental Science and Pollution Research, 20*, 8021–8030. https://doi.org/10.1007/s11356-013-1567-3

Ochoa-Herrera, V., Field, J. A., Luna-Velasco, A., & Sierra-Alvarez, R. (2016). Microbial toxicity and biodegradability of perfluorooctane sulfonate (PFOS) and shorter chain perfluoroalkyl and polyfluoroalkyl substances (PFASs). *Environmental Science: Processes & Impacts, 18*, 1236–1246. https://doi.org/10.1039/C6EM00366D

Organisation for Economic Co-operation and Development (OECD). (2018). Toward a New Comprehensive Global Database of Per-and Polyfluoroalkyl Substances (PFASs): Summary Report On Updating the OECD 2007 List of Per- and Polyfluoroalkyl Substances (PFASs). Retrieved from https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en

Ozekin, K., & Fulmer, A. (2019). Per- and Polyfluoroalkyl Substances: Background Technical Information. *The Water Research Foundation*. Retrieved from https://www.waterrf.org/sites/default/files/file/2019-09/PFCs_StateOfTheScience.pdf

Pan, C.-G., Liu, Y.-S., & Ying, G.-G. (2016). Perfluoroalkyl substances (PFASs) in wastewater treatment plants and drinking water treatment plants: Removal efficiency and exposure risk. *Water Research, 106*, 562–570. https://doi.org/10.1016/j.watres.2016.10.045

Pan, Y., Zhang, H., Cui, Q., Sheng, N., Yeung, L. W. Y., Sun, Y., Guo, Y., & Dai, J. (2018). Worldwide Distribution of Novel Perfluoroether Carboxylic and Sulfonic Acids in Surface Water. *Environmental Science & Technology, 52*, 7621–7629. https://doi.org/10.1021/acs.est.8b00829

Park, S., Lee, L. S., Medina, V. F., Zull, A., & Waisner, S. (2016). Heat-activated persulfate oxidation of PFOA, 6:2 fluorotelomer sulfonate, and PFOS under conditions suitable for in-situ groundwater remediation. *Chemosphere, 145*, 376–383. https://doi.org/10.1016/j.chemosphere.2015.11.097

Parsons, J. R., Sáez, M., Dolfing, J., & de Voogt, P. (2008). Biodegradation of Perfluorinated Compounds. *Reviews of Environmental Contamination and Toxicology, 196,* 53–71. https://doi.org/10.1007/978-0-387-78444-1_2

Plassmann, M. M., & Berger, U. (2013). Perfluoroalkyl carboxylic acids with up to 22 carbon atoms in snow and soil samples from a ski area. *Chemosphere*, *91*, 832–837. https://doi.org/10.1016/j.chemosphere.2013.01.066

Prevedouros, K., Cousins, I. T., Buck, R. C., & Korzeniowski, S. H. (2006). Sources, Fate and Transport of Perfluorocarboxylates. *Environmental Science & Technology, 40*, 32–44. https://doi.org/10.1021/es0512475

Rankin, K., Lee, H., Tseng, P. J., & Mabury, S. A. (2014). Investigating the Biodegradability of a Fluorotelomer-Based Acrylate Polymer in a Soil–Plant Microcosm by Indirect and Direct Analysis. *Environmental Science & Technology, 48*, 12783–12790. https://doi.org/10.1021/es502986w

Rhoads, K. R., Janssen, E. M.-L., Luthy, R. G., & Criddle, C. S. (2008). Aerobic Biotransformation and Fate of N -Ethyl Perfluorooctane Sulfonamidoethanol (N -EtFOSE) in Activated Sludge. *Environmental Science & Technology, 42*, 2873–2878. https://doi.org/10.1021/es702866c

Roos, A., Berger, U., Järnberg, U., van Dijk, J., & Bignert, A. (2013). Increasing Concentrations of Perfluoroalkyl Acids in Scandinavian Otters (Lutra lutra) between 1972 and 2011: A New Threat to the Otter Population? *Environmental Science & Technology, 47*, 11757–11765. https://doi.org/10.1021/es401485t

RTI International. (2020). A New Method for the Destruction of Perfluorinated Contaminants Found in Water Supplies. Retrieved from https://www.rti.org/impact/new-method-destruction-perfluorinated-contaminants-found-water-supplies

Russell, M. H., Berti, W. R., Szostek, B., & Buck, R. C. (2008). Investigation of the Biodegradation Potential of a Fluoroacrylate Polymer Product in Aerobic Soils. *Environmental Science & Technology, 42*, 800–807. https://doi.org/10.1021/es0710499

Schaider, L. A., Ackerman, J. M., & Rudel, R. A. (2016). Septic systems as sources of organic wastewater compounds in domestic drinking water wells in a shallow sand and gravel aquifer. *Science of the Total Environment*, *547*, 470–481. https://doi.org/10.1016/j.scitotenv.2015.12.081

Scher, D. P., Kelly, J. E., Huset, C. A., Barry, K. M., Hoffbeck, R. W., Yingling, V. L., & Messing, R. B. (2018). Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. *Chemosphere*, *196*, 548–555. https://doi.org/10.1016/j.chemosphere.2017.12.179

Shi, Y., Vestergren, R., Zhou, Z., Song, X., Xu, L., Liang, Y., & Cai, Y. (2015). Tissue Distribution and Whole Body Burden of the Chlorinated Polyfluoroalkyl Ether Sulfonic Acid F-53B in Crucian Carp (Carassius carassius): Evidence for a Highly Bioaccumulative Contaminant of Emerging Concern. *Environmental Science & Technology, 49*, 14156–14165. https://doi.org/10.1021/acs.est.5b04299

Taniyasu, S., Yamashita, N., Yamazaki, E., Petrick, G., & Kannan, K. (2013a). The environmental photolysis of perfluorooctanesulfonate, perfluorooctanoate, and related fluorochemicals. *Chemosphere, 90*, 1686–1692. https://doi.org/10.1016/j.chemosphere.2012.09.065

Taniyasu, S., Yamashita, N., Moon, H.-B., Kwok, K. Y., Lam, P. K. S., Horii, Y., Petrick, G., & Kannan, K. (2013b). Does wet precipitation represent local and regional atmospheric transportation by perfluorinated alkyl substances? *Environment International, 55*, 25–32. https://doi.org/10.1016/j.envint.2013.02.005

Torres, F. J., Ochoa-Herrera, V., Blowers, P., & Sierra-Alvarez, R. (2009). Ab initio study of the structural, electronic, and thermodynamic properties of linear perfluorooctane sulfonate (PFOS) and its branched isomers. *Chemosphere, 76*, 1143–1149. https://doi.org/10.1016/j.chemosphere.2009.04.009

Trojanowicz, M., Bojanowska-Czajka, A., Bartosiewicz, I., & Kulisa, K. (2018). Advanced Oxidation/Reduction Processes treatment for aqueous perfluorooctanoate (PFOA) and perfluorooctanesulfonate (PFOS) – A review of recent advances. *Chemical Engineering Journal, 336*, 170–199. https://doi.org/10.1016/j.cej.2017.10.153

Tseng, N. S.-I. (2012). Feasibility of Biodegradation of Polyfluoroalkyl and Perfluoroalkyl Substances [UCLA]. Retrieved from https://escholarship.org/uc/item/2x47296b

Turley, A. (2018, November 22). Norwegian review finds that PFBS persists and is mobile: But the bioaccumulation potential is low compared with PFOS. *Chemical Watch*. https://chemicalwatch.com/72228/norwegian-review-finds-that-pfbs-persists-and-is-mobile?pa=true

U.S. Environmental Protection Agency (EPA). (2019). Per- and Polyfluoroalkyl Substances (PFAS): Incineration to Manage PFAS Waste Streams. Retrieved from https://www.epa.gov/sites/production/files/2019-09/documents/technical_brief_pfas_incineration_ioaa_approved_final_july_2019.pdf

U.S. Environmental Protection Agency (EPA). (2020a). EPA Enforcement and Compliance History Online. Retrieved from https://echo.epa.gov/

U.S. Environmental Protection Agency (EPA). (2020b). Drinking Water Treatability Database. Retrieved from https://www.epa.gov/water-research/drinking-water-treatability-database-tdb

U.S. Environmental Protection Agency (EPA). (2020c). Draft Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances, December 18, 2020. Retrieved from https://beta.regulations.gov/docket/EPA-HQ-OLEM-2020-0527/document

U.S. Environmental Protection Agency (EPA). (2021). PFAS Innovative Treatment Team (PITT). Retrieved from https://www.epa.gov/chemical-research/pfas-innovative-treatment-team-pitt

van Asselt, E. D., Kowalczyk, J., van Eijkeren, J. C. H., Zeilmaker, M. J., Ehlers, S., Fürst, P., Lahrssen-Wiederholt, M., & van der Fels-Klerx, H. J. (2013). Transfer of perfluorooctane sulfonic acid (PFOS) from contaminated feed to dairy milk. *Food Chemistry*, *141*, 1489–1495. https://doi.org/10.1016/j.foodchem.2013.04.035

Vestergren, R., Orata, F., Berger, U., & Cousins, I. T. (2013). Bioaccumulation of perfluoroalkyl acids in dairy cows in a naturally contaminated environment. *Environmental Science and Pollution Research*, *20*, 7959–7969. https://doi.org/10.1007/s11356-013-1722-x

Wang, S., Huang, J., Yang, Y., Hui, Y., Ge, Y., Larssen, T., Yu, G., Deng, S., Wang, B., & Harman, C. (2013). First Report of a Chinese PFOS Alternative Overlooked for 30 Years: Its Toxicity, Persistence, and Presence in the Environment. *Environmental Science & Technology, 47*, 10163–10170. https://doi.org/10.1021/es401525n

Wang, Z., Cousins, I. T., & Scheringer, M. (2015). Comment on "The environmental photolysis of perfluorooctanesulfonate, perfluorooctanoate, and related fluorochemicals." *Chemosphere, 122*, 301–303. https://doi.org/10.1016/j.chemosphere.2014.03.066

Wang, Z., DeWitt, J. C., Higgins, C. P., & Cousins, I. T. (2017). A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? *Environmental Science & Technology, 51*, 2508–2518. https://doi.org/10.1021/acs.est.6b04806

Washington, J. W., Ellington, J. J., Jenkins, T. M., & Yoo, H. (2010). Response to Comments on "Degradability of an Acrylate-Linked, Fluorotelomer Polymer in Soil." *Environmental Science & Technology, 44*, 849–850. https://doi.org/10.1021/es902672q

Washington, J. W., & Jenkins, T. M. (2015). Abiotic Hydrolysis of Fluorotelomer-Based Polymers as a Source of Perfluorocarboxylates at the Global Scale. *Environmental Science & Technology, 49*, 14129–14135. https://doi.org/10.1021/acs.est.5b03686

Washington, J. W., Jenkins, T. M., Rankin, K., & Naile, J. E. (2015). Decades-Scale Degradation of Commercial, Side-Chain, Fluorotelomer-Based Polymers in Soils and Water. *Environmental Science & Technology, 49*, 915–923. https://doi.org/10.1021/es504347u

Washington, J. W., Rankin, K., Libelo, E. L., Lynch, D. G., & Cyterski, M. (2019). Determining global background soil PFAS loads and the fluorotelomer-based polymer degradation rates that can account for these loads. *Science of the Total Environment, 651*, 2444–2449. https://doi.org/10.1016/j.scitotenv.2018.10.071

Whiting, I., Nicol, L., Keyte, I., KriBig, J., Crookes, M., Gebbink, W., Potrykus, A., & Schopel, M. (2020). The use of PFAS and fluorine-free alternatives in textiles, upholstery, carpets, leather and apparel: Final report under framework contract ENV.A3/FRA/2015/0010. In V3 ed. October 10, 2020. Retrieved from https://echa.europa.eu/documents/10162/13641/pfas_in_textiles_final_report_en.pdf/0a3b1c60-3427-5327-4a19-4d98ee06f041

Yi, S., Harding-Marjanovic, K. C., Houtz, E. F., Gao, Y., Lawrence, J. E., Nichiporuk, R. V., Iavarone, A. T., Zhuang, W.-Q., Hansen, M., Field, J. A., Sedlak, D. L., & Alvarez-Cohen, L. (2018). Biotransformation of AFFF Component 6:2 Fluorotelomer Thioether Amido Sulfonate Generates 6:2 Fluorotelomer Thioether Carboxylate under Sulfate-Reducing Conditions. *Environmental Science & Technology Letters, 5*, 283–288. https://doi.org/10.1021/acs.estlett.8b00148

Zhang, S., Lu, X., Wang, N., & Buck, R. C. (2016). Biotransformation potential of 6:2 fluorotelomer sulfonate (6:2 FTSA) in aerobic and anaerobic sediment. *Chemosphere, 154*, 224–230. https://doi.org/10.1016/j.chemosphere.2016.03.062

Zhao, S., Ma, X., Fang, S., & Zhu, L. (2016). Behaviors of N-ethyl perfluorooctane sulfonamide ethanol (N-EtFOSE) in a soil-earthworm system: Transformation and bioaccumulation. *Science of the Total Environment, 554–555*, 186–191. https://doi.org/10.1016/j.scitotenv.2016.02.180

List of acronyms

General acronyms

Table 44. Acronyms found in the fate and transport appendix.

Acronym	Definition
AFFF	Aqueous film forming foam
CAP	Chemical Action Plan
CWA	Clean Water Act
ECHO	EPA Enforcement and Compliance History
EPA	United States Environmental Protection Agency
EU	European Union
GAC	Granular activated carbon
ITRC	Interstate Technology & Regulatory Council
IX	Ion exchange
MTCA	Model Toxics Control Act
NDAA	National Defense Authorization Act
NGWA	National Ground Water Association
PITT	PFAS Innovative Treatment Team
RCRA	Resource Conservation and Recovery Act
SBOH	State Board of Health
WWTP	Wastewater treatment plant
UCMR3	Third unregulated contaminant monitoring rule

Chemical names

Table 45. Chemical name acronyms found in the fate and transport appendix, excluding the acronyms listed in the table above.

Acronym	Chemical name
ADONA	Ammonium 4,8-dioxa-3H-perfluorononanoate
FASA	Perfluoroalkane sulfonamide
FTI	Fluorotelomer iodide
FTOH	Fluorotelomer alcohol
FTSA	Fluorotelomer sulfonate
HFPO	Hexafluoropropylene oxide
HFPO-DA (GenX)	Hexafluoropropylene oxide dimer acid
NEtFBSA	N-ethyl perfluorobutanesulfonamide
N-EtFOSE	N-ethyl perfluorooctane sulfanamido ethanol
NMeFBSE	N-methyl perfluorobutane sulfonamido ethanol
PASF	Perfluoroalkane sulfonyl fluoride
PFAA	Perfluoroalkyl acid
PFAS	Per- and polyfluoroalkyl substances
PFBS	Perfluorobutane sulfonate
PFCA	Perfluoro-carboxylic acid
PFHxS	Perfluorohexane sulfonate
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOAAmS	Perflurorooctaneamido quaternary ammonium salt
PFOS	Perfluorooctane sulfonate
PFOSA	Perfluorooctanesulfonamide
PFPE	Perfluoropolyether polymer
PFSA	Perfluoro-sulfonic acid
POP	Perfluoroacylphosphate
PTFE	Polytetrafluoroethylene

Appendix 5: Environmental Occurrence

5.0 Overview

5.0.1 Findings

In Washington, perfluoroalkyl acids (PFAAs) have been detected in surface waters, groundwater, WWTP effluent, freshwater and marine sediments, freshwater and marine fish, and osprey eggs. Other media types have not been sampled in Washington.

Environmental monitoring in the state has shown that PFAA concentrations are highest in urban surface water and surface waters receiving minimally diluted wastewater treatment plant (WWTP) effluent. Monitoring also suggests that stormwater, WWTP effluent, and aqueous film forming foam (AFFF) for firefighting use are primary ways that PFAAs are delivered to water bodies.

Perfluorooctane sulfonate (PFOS), and to a lesser extent perfluorodecanoic acid (PFDA), perfluorododecanoic acid (PFDoA), perfluoroundecanoate (PFUnA), and perfluorooctanesulfonamide (PFOSA), were widespread in freshwater fish tissue of water bodies in the state. PFOS was measured in urban lake fish tissue at levels that may trigger consumption advisories to protect human health. PFOS and other long-chain PFAAs are also detected in osprey eggs, at concentrations lower than would affect offspring survival, but potentially high enough to reduce hatchability in samples from sites affected by urban sources and WWTP inputs. PFOS and PFOA were the most dominant compounds detected in marine fish, but currently below the concentrations that may trigger consumption advisories.

Environmental concentrations of PFAAs in Washington surface waters, WWTP effluent, and freshwater fish tissue sampled in 2016 were consistent with PFAS levels in other parts of the U.S. not impacted by PFAS manufacturing facilities. Additional sampling in 2018 confirmed that PFAS concentrations in freshwater fish collected from Washington urban lakes are consistent with other urban water bodies in North America. Osprey egg PFAS concentrations measured in 2016 were similar to recent findings in rural osprey eggs collected in Sweden, with the exception of higher concentrations found in the Washington samples near urban or WWTP effluent discharge locations. Compared to freshwater species, concentrations in marine biota from Puget Sound are generally lower than concentrations measured in marine species in other countries.

Environmental monitoring in 2016 suggested that PFAA levels in surface waters and WWTP effluent had decreased since the last round of sampling in 2008. A general shift in PFAA constituents was evident in WWTP effluent samples, with short-chain PFAAs replacing perfluorooctanoic acid (PFOA) as the most dominant compounds in effluent. PFAS concentrations (primarily made up of PFOS) in freshwater fish tissue and osprey eggs have remained unchanged between 2008 and 2016. Insufficient data are available to assess temporal changes in PFAS in marine and anadromous species. PFOS continues to be a ubiquitous contaminant in Washington aquatic biota.

Data gaps in our understanding of PFAS contamination in Washington's environment include a lack of monitoring ambient groundwater and landfill leachate, assessing sources of PFAS in urban water bodies, and testing PFAS compounds beyond PFAAs.

5.0.2 Introduction

This appendix summarizes the available PFAS data on environmental media collected in Washington state. Relatively few studies have been conducted on PFAS in Washington. PFAS analyses in Washington have generally been limited to the PFAA included in EPA Method 537 (refer to Appendix 2: Analytical Methods for more discussion on PFAS analytical methods). Additional PFAS compounds, including precursors that have known potential to break down into PFAAs, were analyzed in surface water and WWTP effluent samples collected in 2016. Ecology studies discussed below have been conducted following the data quality and acceptance limits included in EPA Method 537. Discussions of data quality can be found in individual references.

As discussed in Appendices 3: Sources and Uses and 4: Fate and Transport, PFAS can be released to the environment during manufacturing, use, and disposal of consumer and industrial products containing PFAS. Currently, the relative importance of different environmental pathways for PFAS transport is not well characterized for Washington state. However, environmental monitoring in Washington shows that PFAA concentrations are highest in water bodies located in urban settings and where WWTP effluent makes up a significant portion of the flow, or hydrologic dilution is minimal. This suggests WWTP effluent, stormwater, and AFFF use are important pathways. Monitoring in the state has focused on releases of PFAS to surface water and the aquatic food chain—the ambient concentrations of PFAS in soils, groundwater, or air have not been investigated.

5.1 PFAS in Washington's environment

5.1.1 Air

Ecology did not identify any studies or analyses of PFAS compounds in Washington's air.

5.1.2 Soil

In 2014, one soil sample from the Moses Lake Port Aircraft Rescue and Firefighting School facility was analyzed for PFAAs and PFOSA, following a release of fire suppressant (Ecology, 2016a). Ecology's Environmental Information Management Database[145] includes the results of measured PFAS concentrations in this study. This soil sample had an elevated concentration of PFO (12,000 micrograms (µg)/gram (g)), perfluoroundecanoic acid (PFUnDA) (1,100 µg/g), perfluorononanoic acid (PFNA) (120 µg/g), and perfluorodecane sulfonate (PFDS) (110 µg/g). Other perfluoroalkyl acids were detected at levels less than 100 µg/g. Following this sampling event, the impacted soils were excavated and removed from the site for proper disposal.

[145] https://ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database

5.1.3 Groundwater

Ecology did not identify any ambient groundwater monitoring for PFAS in Washington. However, PFAS have been detected in groundwater wells used for drinking water in several areas. Appendix 7: Health, Section 7.4 Known areas of PFAS contamination, describes this sampling in more detail.

5.1.4 Surface water

Ecology's 2008 statewide study

In 2008, Ecology carried out a study measuring PFAAs in a variety of environmental media throughout the state to determine their occurrence in fresh water systems (Ecology, 2010). This study collected fresh water from 14 water bodies in the spring and fall for analysis of 11 PFAAs.

All spring samples contained measurable concentrations of at least one of the target PFAAs, ranging in total perfluoroalkyl acids (summed concentration of PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFBS, PFHxS, PFOS, and PFDS) (T-PFAAs) from 1.11 – 185 ng/L (nanograms per liter) (median = 7.5 ng/L). Fall samples contained detected PFAAs in all but two samples, ranging in T-PFAAs from less than 0.9 – 170 ng/L (median = 3.6 ng/L).

The highest concentrations were found in sites receiving wastewater treatment plant effluent with limited dilution (West Medical Lake and South Fork Palouse River), followed by an urban lake (Lake Washington). The rest of the sites—mid-sized rivers draining a variety of land-use types—had T-PFAA concentrations of 1.0 – 10 ng/L.

Ecology's 2016 statewide study

Ecology conducted a second statewide study in 2016 to assess changes in concentrations and compound make-up following the 2008 survey (Ecology, 2017). Surface waters from 15 water bodies were collected in the spring and fall for analysis of 12 PFAAs and 13 known or potential precursors to PFAAs. Precursors analyzed included polyfluorinated sulfonamides, fluorotelomer carboxylates (saturated and unsaturated), and fluorotelomer sulfonates. Fewer than half of the surface water samples contained PFAS compounds, with 7 out of 15 sites containing at least one sample with PFAS detections. T-PFAA concentrations (sum of PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, perfluorododecanoic acid [PFDoDA], PFBS, PFHxS, and PFOS) ranged from less than 2 – 153 ng/L (median = <2 ng/L) in the spring and less than 2 – 170 ng/L (median = <2 ng/L) in the fall. Only heavily impacted water bodies had detections—those with significant WWTP inputs or in urban areas. Detection frequencies and total concentrations were generally lower than those of surface water samples collected in 2008 at the same sites.

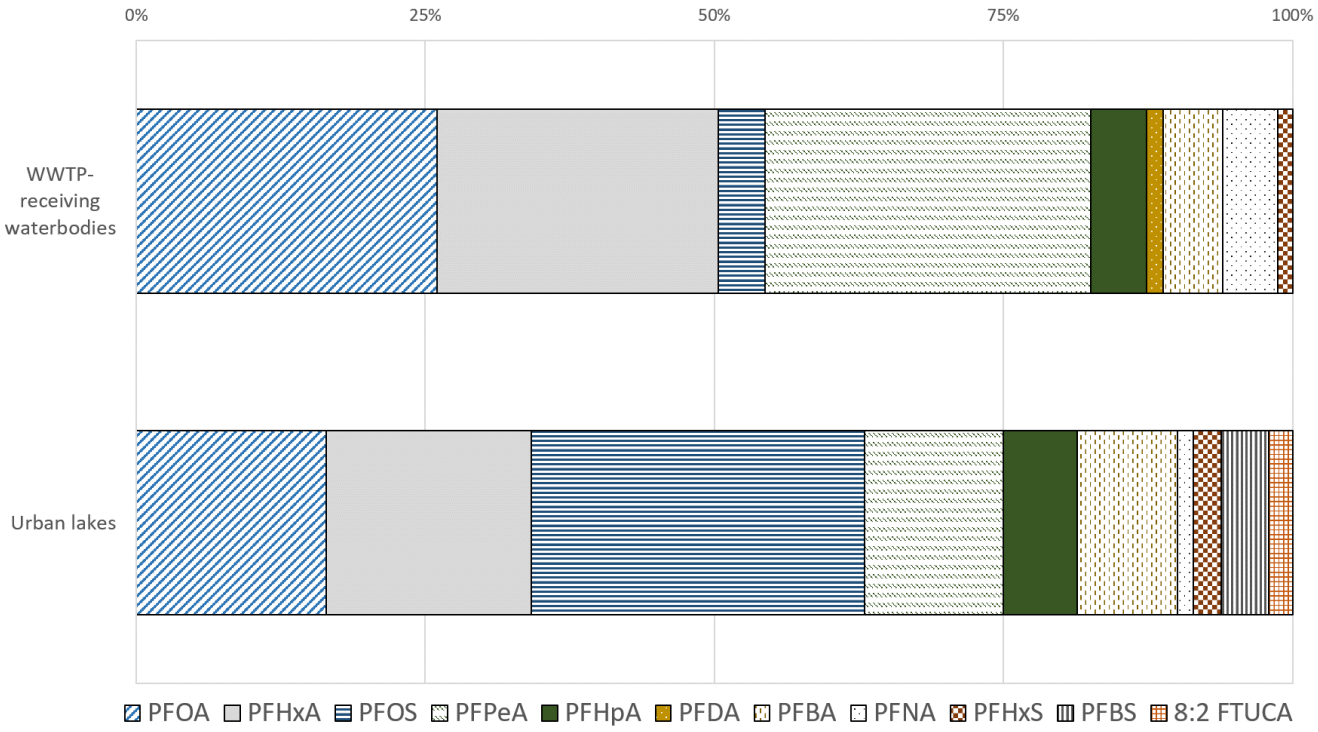
With the exception of West Medical Lake and South Fork Palouse River samples, surface water PFAA concentrations in 2016 were very similar to PFAA concentrations recently measured in other water bodies lacking point sources collected throughout Michigan, Rhode Island, and New York (MIDEQ, 2015; Zang et al., 2016). All surface water samples were one to two orders of magnitude lower than levels found in surface water impacted by AFFF use or manufacturing facilities in the U.S. (Anderson et al., 2016; MIDEQ, 2015; Newton et al., 2017).

Perfluoroalkyl acids were the primary compound type found in the surface waters. In addition to the PFAAs analyzed, 13 precursors that potentially break down into PFAAs were analyzed in

the 30 surface water samples. The only precursor PFAS compounds detected were 8:2 fluorotelomer unsaturated carboxylic acid (8:2 FTUCA), 4:2 fluorotelomer sulfonate (4:2 FTS), and 6:2 fluorotelomer sulfonate (6:2 FTS), which were all detected only once at 1.02, 11.3, and 6.87 ng/L, making up 12%, 100%, and 100% of the total PFAS concentration, respectively.

Figure 28 shows the relative percent contribution of individual PFAS observed in surface water samples. In the water bodies impacted by WWTP effluent (West Medical Lake and South Fork Palouse River), perfluoropentanoic acid (PFPeA), PFOA, and PFHxA were the most dominant compounds, each contributing an average of 24% – 28% of the total PFAS concentration. The urban lakes (Angle, Meridian, and Washington Lakes) were dominated by PFOS first, and then by the compounds seen in the WWTP-impacted sites.

Figure 28. Average PFAS compound profiles in two types of surface waters collected from Washington state water bodies in 2016.



Local source control monitoring

Ecology (2018) analyzed 12 PFAAs in stormwater of urban and industrial catchments in 2017 as part of a larger study to support Ecology's Local Source Control actions. Stormwater was collected twice from seven commercial drainages in Clark County following spring storm events of greater than 0.2 inches (in.) of rain. All 12 PFAAs were detected at nearly every site in the study. Stormwater T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS) concentrations ranged from 31.9 – 114 ng/L. PFOS was measured in the highest concentrations (range: 3.8 – 71 ng/L), followed by perfluorohexane sulfonate (PFHxS) (range: 0.4 – 16.1 ng/L) and PFOA (range: 2.89 – 11.9 ng/L).

Puget Sound study

Dinglasan-Panlilio et al. (2014) measured 14 PFAA compounds in surface water from seven sites in the Puget Sound area, as well as six sites in the nearby Clayoquot and Barkley Sounds in British Columbia, Canada. Samples were collected in spring, summer, and fall of 2009 and 2010, as well as winter 2011. At least one PFAA compound was detected in all samples analyzed. T-PFAA (sum of detected compounds: PFBA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA, PFBS, PFHxS, PFOS, and PFDS) concentrations ranged from 1.5 – 41 ng/L. The highest concentrations were found in two urbanized sites draining to Puget Sound (First Creek in Tacoma and Portage Bay in Seattle). T-PFAA concentrations in marine waters of the Puget Sound were lower than the urban freshwater sites and comparable to levels measured in the more remote sampling locations in Clayoquot and Barkley Sounds. Perfluoroheptanoic acid (PFHpA), PFOA, and PFOS were the most frequently detected compounds in the samples. Individual compound concentrations were not reported.

5.1.5 WWTP effluent

Statewide study, 2008

Ecology's 2008 PFAS survey analyzed 11 PFAAs in effluent of four WWTPs during the spring and fall (Ecology, 2010). All samples contained multiple compounds, with T-PFAAs (sum of detected perfluoroalkyl acid concentrations: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFBS, PFHxS, PFOS, and PFDS) ranging from 61 – 418 ng/L (median = 218 ng/L) in the spring and 73 – 188 ng/L (median = 140 ng/L) in the fall. PFOA, the dominant compound detected, contributed an average of 36% in the spring and 32% in the fall to the T-PFAA concentration. In spring samples, perfluorohexanoic acid (PFHxA) was the next most dominant compound (average of 28% contribution to T-PFAA concentration), followed by PFPeA (average of 10%). PFHxA and PFPeA had similar percent contributions in the fall samples (16 – 17% of the total).

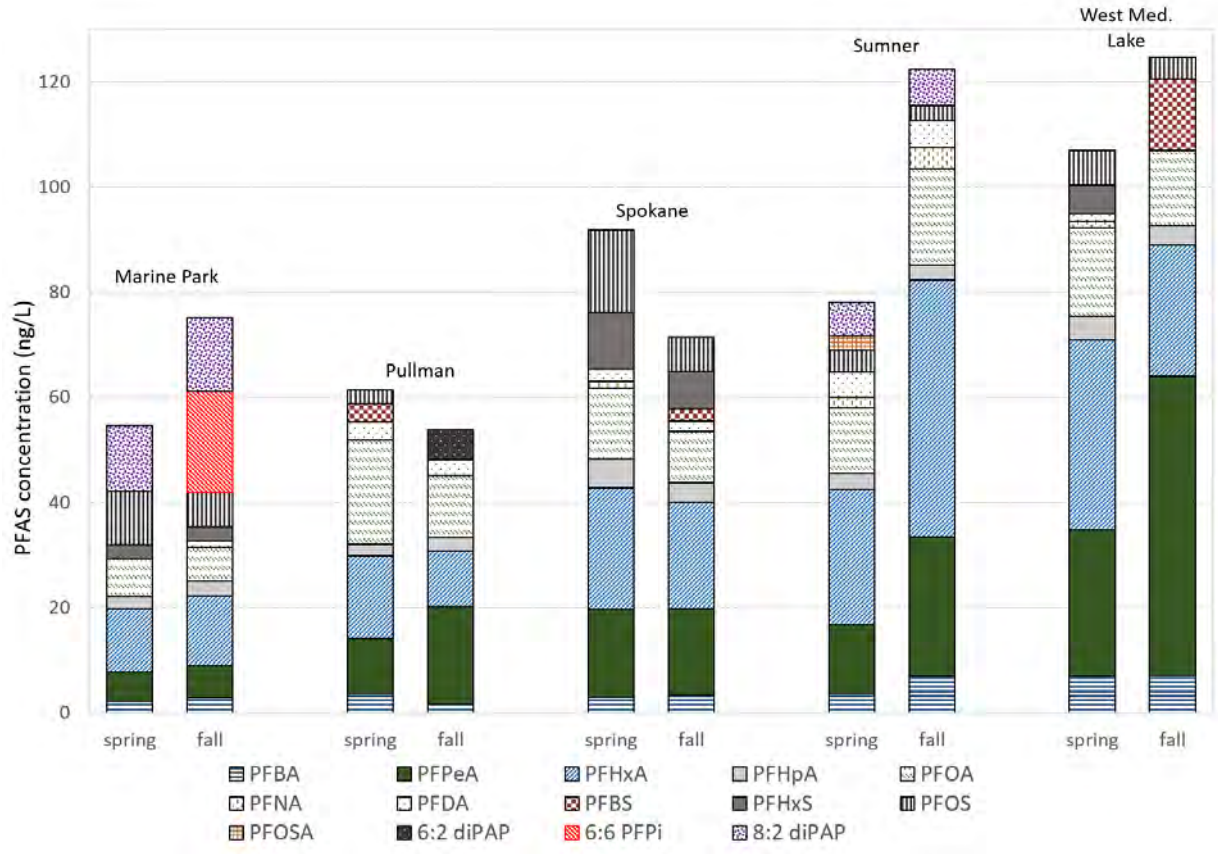
Statewide study, 2016

Ecology collected effluent from five WWTPs during the spring and fall of 2016 for analysis of 35 PFAS compounds (12 PFAAs and 23 known or potential precursor compounds) (Ecology, 2016b, 2017). Precursors analyzed included polyfluorinated sulfonamides, fluorotelomer carboxylates (saturated and unsaturated), fluorotelomer sulfonates, perfluoroalkyl phosphonates, and polyfluoroalkyl phosphates. Figure 29 shows PFAS concentrations of the individual effluent samples analyzed. PFAS were detected in all WWTP effluent samples analyzed. Spring T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS) concentrations ranged from 42.1 – 107 ng/L, with a median of 68.9 ng/L. Fall concentrations were similar, ranging in T-PFAAs from 41.8 – 125 ng/L, with a median of 71.4 ng/L. The PFAA concentrations from all WWTPs sampled were within the range found in other recent reports of municipal WWTP effluent in the U.S., but much lower than concentrations found in effluent samples that treat wastewater containing AFFF (Appleman et al., 2014; Houtz et al., 2016).

PFAAs were the primary PFAS compound type found in the effluent samples. Only four of the precursor compounds were detected: PFOSA, bis(perfluorohexyl) phosphinate (6:6 PFPi), bis(1H,1H,2H,2H-perfluorooctyl) phosphate (6:2 diPAP), and bis(1H,1H,2H,2H-perfluorodecyl)

phosphate (8:2 diPAP), which ranged in concentration from 2.8 – 19.3 ng/L, contributing 6 – 26% of the total PFAS concentration in individual samples. Overall, PFHxA was the most dominant compound in effluent samples (average contribution of 27%), followed by PFPeA (average of 22%), and PFOA (average of 16%). The low detection frequencies of precursor compounds seen in the Washington WWTP effluent was similar to the low number of precursors detected in effluent collected in California (Appleman et al., 2014).

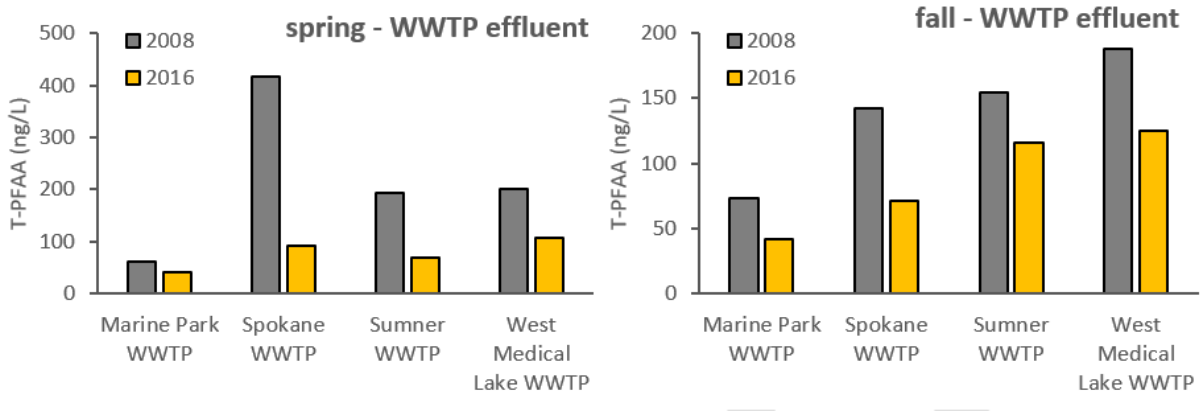
Figure 29. PFAS concentrations (ng/L) in wastewater treatment plant effluent samples collected in 2016.



Note: Results below quantitation limits are excluded from figure.

Figure 30 displays T-PFAA concentrations of WWTP effluent samples collected from the same facility in 2016 compared to 2008. T-PFAA concentrations in effluent samples collected in 2016 were consistently lower than T-PFAA concentrations measured in 2008 by Ecology (2010) at the same WWTPs. A general shift in the composition of PFAS compounds was evident in the WWTP effluent samples as well, with the percent contribution of PFOA decreased in all samples, while the percent contribution of short-chain compounds increased: PFHxA, PFPeA, and perfluorobutanoic acid (PFBA).

Figure 30. Total perfluoroalkyl acid (T-PFAA) concentrations in wastewater treatment plant effluent collected in 2008 (grey bars on the left) and 2016 (orange bars on the right).



Control of toxic chemicals in Puget Sound study, phase 3

Ecology and Herrera (2010) conducted a study to provide estimates of contaminant loadings to the Puget Sound. The study analyzed 12 PFAAs and PFOSA in effluent from ten WWTPs during the winter and summer of 2009. All ten WWTPs discharged treated effluent to Puget Sound tributaries. Six to ten of the PFAA compounds were detected in every sample. T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS) concentrations ranged from 35.3 – 194 ng/L (median = 73.5 ng/L) in the winter and from 46.3 – 146 ng/L (median = 93 ng/L) in the summer.

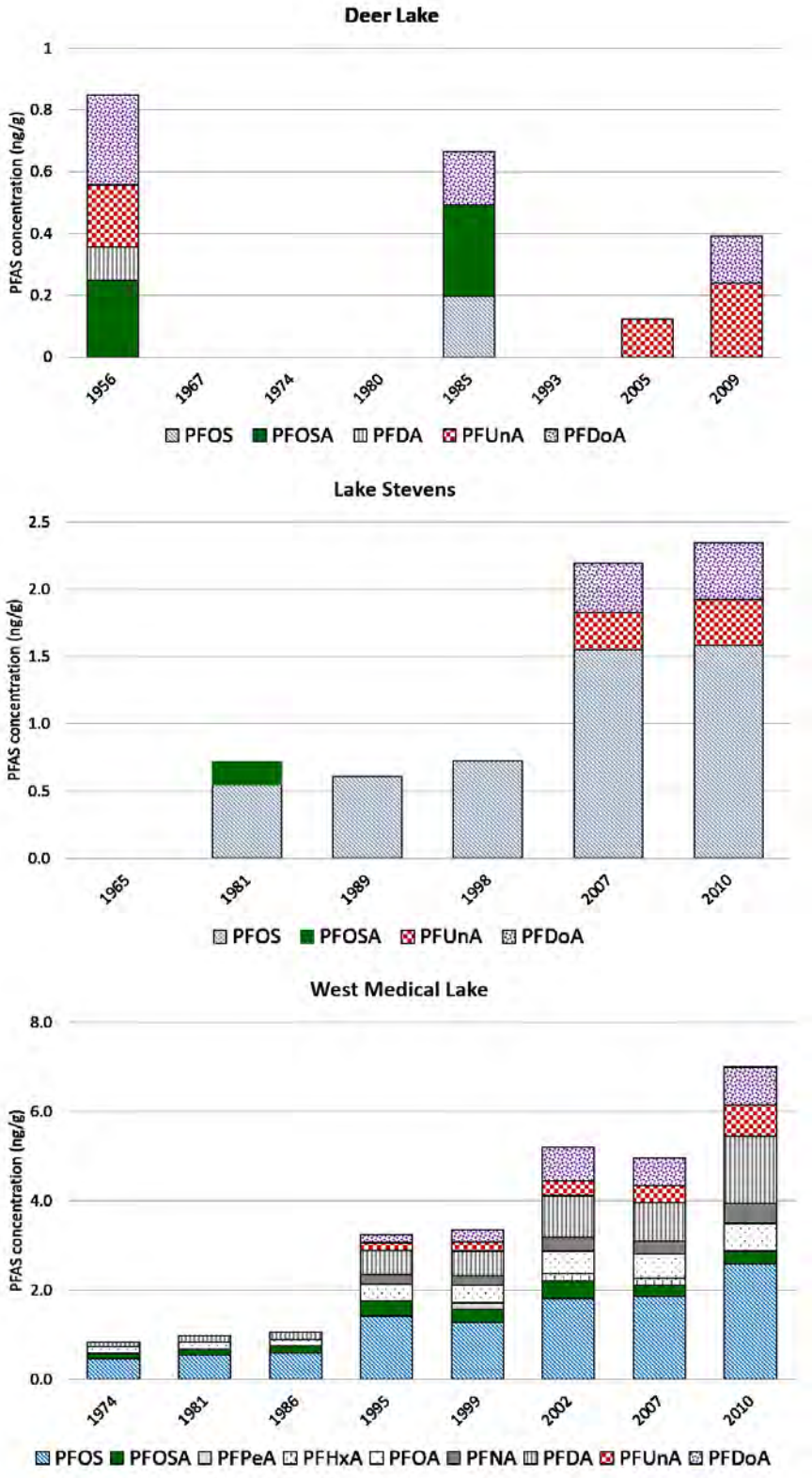
PFHxA, PFNA, PFOS, and PFOA were present in the greatest concentrations and were detected in all samples. Loading estimates for T-PFAAs in the effluents were higher than estimated loadings of T-polychlorinated biphenyls, T-polybrominated diphenyls, and T-polycyclic aromatic hydrocarbons.

5.1.6 Sediments

2012 Sediment cores

In 2012, Ecology collected sediment cores from three freshwater lakes for analysis of 12 PFAAs and PFOSA (Ecology, 2013). Figure 31 displays PFAS concentrations for each dated sediment layer. PFOS and long-chain PFAAs were the dominant compounds measured. T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS) concentrations in the surface sediments ranged from 0.392 ng/g dry weight (dw) at the remote Deer Lake to 7.0 ng/g dw in West Medical Lake, which is impacted by WWTP effluent. The urban lake—Lake Stevens—had a surface T-PFAA concentration of 2.35 ng/g dw. T-PFAA concentrations increased from the 1980s to present in the West Medical Lake and Lake Stevens cores. Concentrations and detections were erratic in the rural Deer Lake core.

Figure 31. PFAS concentrations (ng/g dw) in sediment core samples collected in Washington state in 2012.



Local source control monitoring

As part of Local Source Control monitoring, Ecology (2018) collected catch basin sediments over three sampling events in spring and early summer of 2017 for analysis of a suite of parameters that included 12 PFAAs. Sediments were collected from seven urban and industrial catchments during dry-weather events. PFAAs were detected in all sediment samples analyzed. Sediment T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS) concentrations ranged from 0.6 – 17.4 ng/g dw. The maximum concentration measured was of PFDoDA (10.5 ng/g dw) and the maximum PFOS concentration was 9.68 ng/g dw. All other individual compound results were less than 5 ng/g dw.

Marine sediment

Ecology's Marine Sediment Monitoring Program collected sediments from Puget Sound urban bays in 2013 (Elliott Bay), 2014 (Commencement Bay), and 2015 (Bainbridge Basin) for analysis of 12 PFAAs and PFOSA. Ecology's Environmental Information Management Database[146] includes the results measured through this monitoring program. T-PFAA values were not reported. In Elliott Bay, PFOS was detected in seven out of 30 stations, with detected concentrations ranging from 0.24 – 0.48 ng/g dw (Ecology, 2014). PFDA and PFUnDA were detected in one Elliott Bay station, at slightly lower levels. In Commencement Bay sediments, PFOA, PFOS, PFOSA, and PFDoDA were detected at concentrations ranging from 0.11 – 0.57 ng/g dw. Six out of 30 Commencement Bay stations (20%) contained one or more PFAS. In Bainbridge Basin, PFOS was detected in about half of the stations monitored (17 out of 33) and one station also contained detections of PFOSA and PFUnDA. Detected concentrations ranged from 0.11 – 1.6 ng/g dw. The highest concentration of PFOS (1.6 ng/g dw) was found in a sediment sample collected from Sinclair Inlet.

5.1.7 Freshwater fish

Statewide study, 2008

Ecology collected freshwater fish from seven water bodies throughout the state in 2008 for analysis of ten PFAAs (Ecology, 2010). A total of 11 different species were collected and analyzed as a total of 15 composite fillet samples and 15 composite liver samples. Of the PFAAs analyzed, only PFOS, PFDA, PFUnDA, and PFDoDA were detected and quantified. Quantitation limits were fairly high, ranging from 5 – 25 ng/g. PFOS was detected in 67% of the liver samples (10 out of 15) and 40% of fillet samples (6 out of 15). Concentrations of PFOS in liver samples ranged from less than 10 – 527 ng/g wet weight (ww) (median = 47.5 ng/g ww). Fillet samples had PFOS concentrations of less than 10 – 75.5 ng/g ww (median = under 10 ng/g ww). PFDoDA, PFUnDA, and PFDA were each detected once at concentrations of 21.0 – 46.1 ng/g ww in liver tissue and 5.5 – 7.5 ng/g ww in fillet tissue.

[146] https://ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database

PBT screening study, 2011

In 2011, Ecology collected common carp and large-scale suckers from Lake Washington, lower Columbia River, Lake Spokane, and the lower Yakima River as part of a screening survey for PBTs (Ecology, 2012). All samples contained PFOS, at concentrations ranging from 2.1 – 19.8 ng/g wet weight (ww) in common carp fillet tissue and from 2.9 – 45.7 ng/g ww in whole body large-scale suckers. PFDA, PFUnDA, and PFDoDA were detected in approximately 80% of the samples, at lower concentrations than PFOS. Other PFAAs were detected infrequently or not at all. T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS) concentrations across both species and sample types ranged from 2.1 – 91.9 ng/g ww, with the highest concentration in the Lake Washington large-scale sucker whole body sample.

Statewide study, 2016

Ecology collected freshwater fish of various species from 11 water bodies in Washington in 2016 (Ecology, 2017) as part of the follow-up study to the 2008 sampling (Ecology, 2010). A total of 22 composite samples of freshwater fish fillet tissue and 22 composite liver tissue samples were analyzed for 12 PFAAs and PFOSA. Eighty-six percent of fillet samples contained at least one PFAS, while the detection frequency for liver samples was 100%. Fillet T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS) concentrations ranged from less than 1 – 87.3 ng/g ww (median = 3.92 ng/g ww) and liver T-PFAS concentrations ranged from 5.12 – 399 ng/g ww (median = 19.3 ng/g ww).

PFOS was the dominant compound in all fillet samples, making up 62 – 100% of the total concentration. PFAA concentrations in the Washington fish were generally much lower than concentrations found near point sources by recent U.S. and Canadian studies, and within the range seen in other water bodies lacking point sources (Gewurtz et al., 2014; Lanza et al., 2017; MIDEQ, 2015).

PFOS concentrations in six of the fillet samples were above the Washington Department of Health's (Health) provisional general population screening level for PFOS in edible fish tissue at the time of publication (23 ng/g). All six fillet samples above the provisional screening level were collected from urban lakes in Western Washington. Seven fillet samples were above Health's provisional high consumer population screening level for PFOS in edible fish tissue (8 ng/g). Only one sample was above the provisional high consumer population screening level, but below the provisional general population screening level. This data was evaluated by Health, but determined to have insufficient sample sizes for a fish advisory assessment.

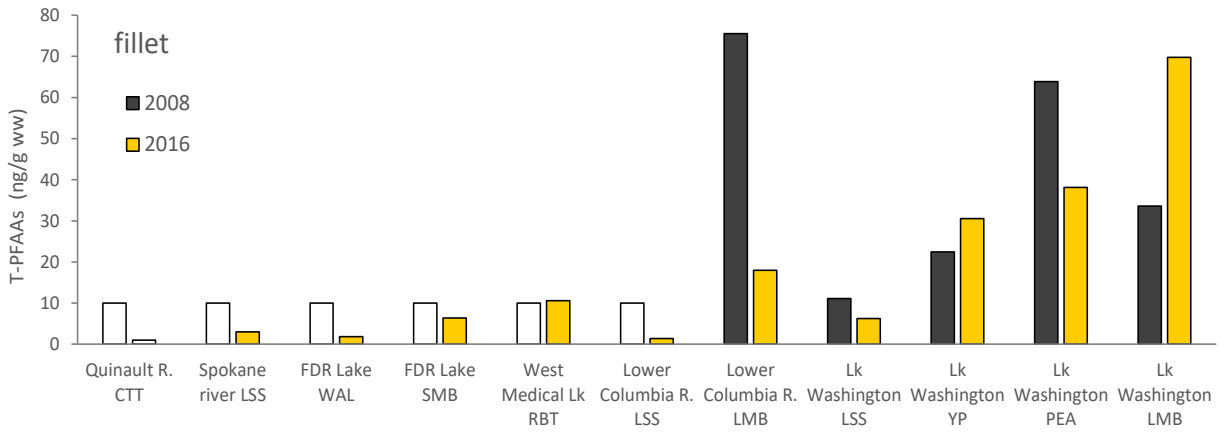
2018 follow-up study

Ecology collected a large dataset of freshwater fish tissue samples from three urban lakes in 2018 to characterize species-specific PFAS concentrations and provide data for Health fish consumption advisory assessments (Ecology, in prep.). A total of 76 composite samples (328 individual fish) were collected from Lake Meridian, Lake Sammamish, and Lake Washington. PFOS was the dominant compound in all samples analyzed. PFCAs with chain lengths of 9 – 14 were detected frequently at low concentrations.

Species-specific concentrations were similar for all three lakes. Across all sites, PFOS concentrations of 19.1 – 50 ng/g ww (largemouth bass), 4.1 – 19.8 ng/g ww (yellow perch), and 0.5 – 4.8 ng/g ww (brown bullhead). Smallmouth bass samples were collected from two of the sites and contained the highest PFOS concentrations of the study: 60 – 99.9 ng/g ww. Cutthroat trout and kokanee were also collected at a subset of the sites and contained PFOS concentrations of 23.9 – 44.1 ng/g ww (cutthroat trout) and 6.4 – 7.9 ng/g ww (kokanee). Health is currently updating its screening levels for PFOS and will evaluate this data when screening levels are finalized.

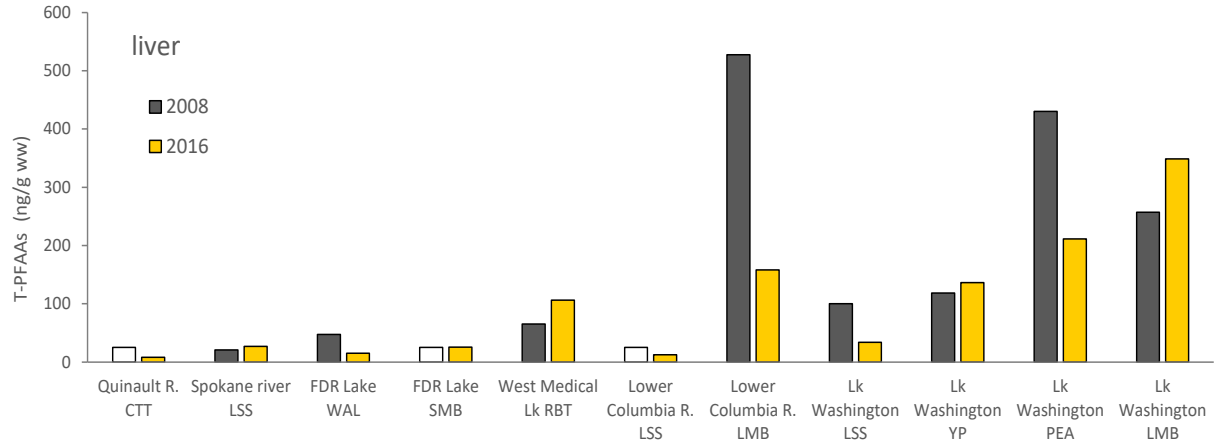
Eleven freshwater fish tissue samples analyzed for PFAS in 2016 had paired species and water body data from 2008. Figure 32 shows PFAS concentrations of fillet composites analyzed in 2016 compared to 2008 and a comparison of liver PFAS concentrations is shown in Figure 32. Of the eleven samples, a difference in quantitation limits hampered comparison in five paired fillet samples and three paired liver samples. The direction of change was mixed for fillet samples greater than the limit of quantitation (LOQ), showing no overall apparent pattern. No consistent increase or decrease over the time period was evident with liver samples either, despite higher detection frequencies.

Figure 32. Total perfluoroalkyl acid (T-PFAA) concentrations in freshwater fish fillet tissue collected in 2008 (grey bars on the left) and 2016 (yellow bars on the right).



Note: White bars indicate PFAS were not detected and the height of the bar represents the limit of quantitation (Quinault River, Spokane River LSS, FDR Lake WAL, FDR Lake SMB, West Medical Lake, and Lower Columbia River LSS).

Figure 33. Total perfluoroalkyl acid (T-PFAA) concentrations in freshwater fish liver tissue collected in 2008 (grey bars on the left) and 2016 (yellow bars on the right).



Note: White bars indicate PFAS were not detected at that concentration (Quinault River and FDR Lake SMB).

5.1.8 Osprey

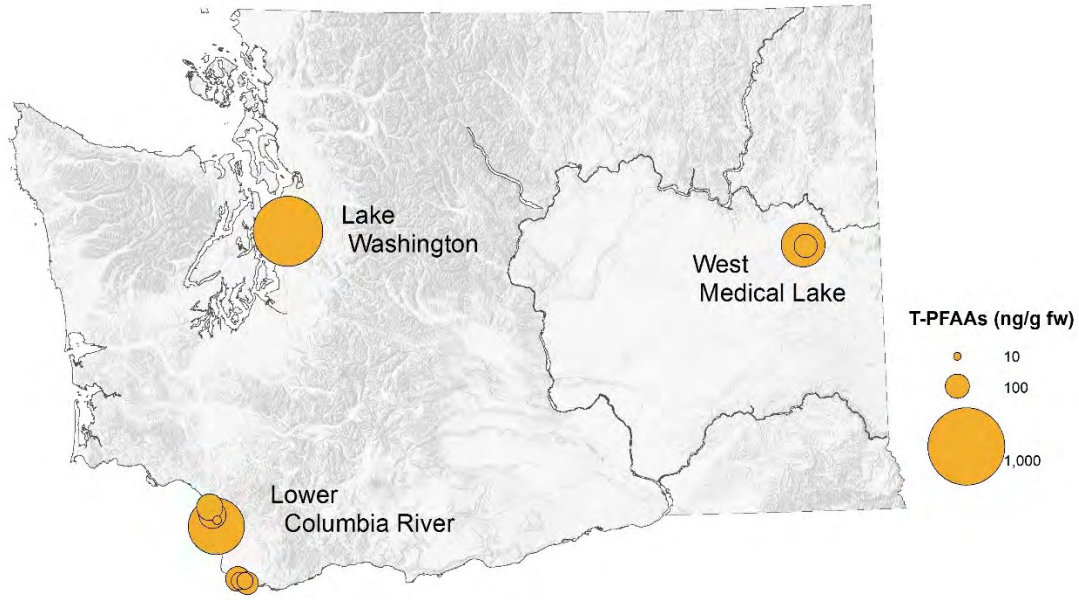
Statewide study, 2008

Ecology collected eleven osprey eggs in 2008 from the Lower Columbia River and tested the inner contents (whole egg without shell) for 13 PFAAs (Ecology, 2010). Egg homogenates contained T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, PFOS, and PFDS) concentrations ranging from 38 – 910 ng/g fresh weight (fw) (Ecology, 2010). Similar to fish tissue, PFOS was the dominant compound (range = 23.5 – 884 ng/g fw; median = 69.0 ng/g fw), followed by PFUnDA (range = 3.5 – 12.6 ng/g fw; median = 7.8) and PFDA (range = 2.0 – 10.2 ng/g fw; median = 5.8 ng/g fw). Other acids were detected less frequently and at low concentrations.

Statewide study, 2016

In 2016, Ecology collected osprey eggs from the Lower Columbia River, Lake Washington, and West Medical Lake (Ecology, 2017). A total of 11 osprey eggs were analyzed for 12 PFAAs and PFOSA. All eggs contained at least four PFAA compounds. T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, PFOS, and PFOSA) concentrations ranged from 11.7 – 820 ng/g fw (median = 99.8 ng/g fw). Figure 34 displays the T-PFAA concentration in osprey eggs collected throughout the state. The highest concentration was found in an osprey egg collected from Lake Washington. Two other elevated concentrations were measured in samples collected near WWTP inputs—along the Lower Columbia River and at West Medical Lake. Osprey egg concentrations were similar to recent findings in rural osprey eggs collected in Sweden (Eriksson et al., 2016), with the exception of higher concentrations found in the three Washington samples near urban or WWTP inputs.

Figure 34. Total perfluoroalkyl acid concentrations (ng/g fw) measured in osprey eggs collected in 2016.

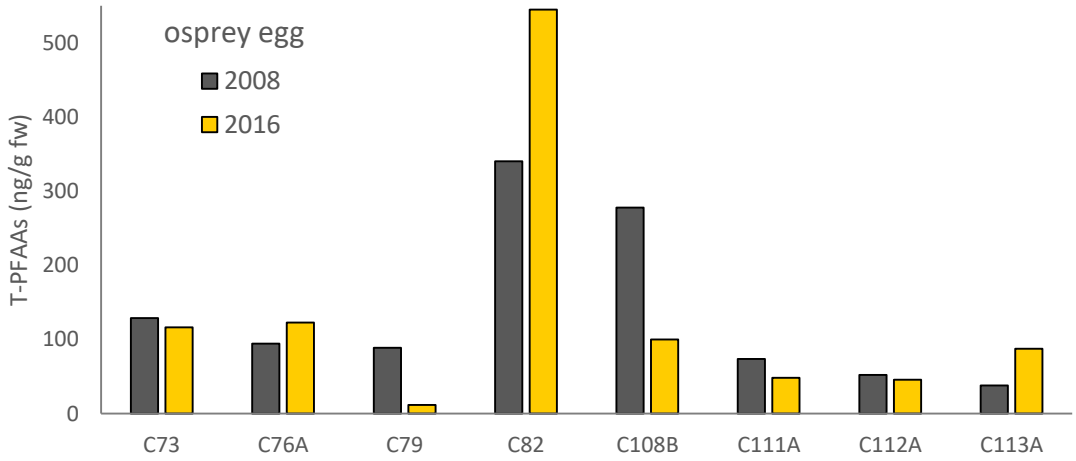


PFOS made up 69 – 94% of the PFAA burden in the osprey eggs (median concentration = 92.5 ng/g fw; range = 9.08 – 675 ng/g fw). PFDA, PFDoDA, and PFUnDA were also detected in every sample, each making up less than 10% of the total PFAS concentration. Almost all of the PFAS contamination in osprey eggs was from long-chain compounds, but the short-chain PFPeA was detected in three samples—all from Lower Columbia River nests. However, PFPeA concentrations were quite low, at 0.45 – 1.83 ng/g fw, and made up less than 2% of the total.

None of the osprey eggs analyzed for this study had PFOS concentrations exceeding a Practical No Effects Concentration of 1,000 ng/g for offspring survival in a top avian predator (Newsted et al., 2005). PFOS concentrations in five of the samples were above a lowest observable adverse effect level (LOAEL) level of 100 ng/g ww for reduced hatchability based on injections in chicken embryos (Molina et al., 2006). These five samples were collected from Lake Washington, West Medical Lake, and Lower Columbia River downstream of the Willamette River confluence. This LOAEL value of 100 ng/g is more conservative, as chicken embryos are more sensitive than wildlife species and another study found higher values for reduced hatchability (Peden-Adams et al., 2009).

Figure 35 displays PFAS concentrations of osprey eggs collected from the Lower Columbia River in 2016 compared to 2008. No consistent change in concentration levels or compound make up was evident between osprey eggs collected along the Lower Columbia River in 2008 and 2016.

Figure 35. Total perfluoroalkyl acid (T-PFAA) concentrations in osprey eggs collected from the Lower Columbia River in 2008 (grey bars on the right) and 2016 (yellow bars on the left).



Note: Sample location codes along the x-axis indicate the river mile along the Columbia River where nests were located (i.e., C73 indicates Columbia River at River Mile 73).

5.1.9 Marine biota

Transplanted bay mussels exposed to 18 near-shore locations in Puget Sound from November 2012 through January 2013 were analyzed for a large suite of toxic contaminants, including 13 PFAS, by James et al. (2020). PFAS were largely undetected in the mussel samples. PFOSA was the only compound detected, which was present near reporting limits in only one sample. The authors suggest that PFAS are poorly accumulated by mussels and that mussel tissue PFAS concentrations do not provide a good indication of environmental exposure to PFAS. Muschy et al. (2019) reported PFAS concentrations in mussels worldwide with concentrations typically in the sub ng/g range, which is below the levels of detection in the Puget Sound study.

Meador et al. (2017) analyzed PFAS in two species of fish collected from three sites in Puget Sound. Whole body composites of Chinook salmon and Pacific Staghorn sculpin contained low concentrations of PFOS, with the exception of a Chinook composite collected from Sinclair Inlet, which had a PFOS concentration of 34 ng/g ww. All other PFOS results were less than 2 ng/g ww or not detected. PFOSA was detected in Sculpin collected from the Puyallup Estuary and Sinclair Inlet at concentrations of 2.2 ng/g ww and 0.82 ng/g ww, respectively. PFDA was detected in only one sample, the Sinclair Inlet Chinook composite, at 0.78 ng/g ww.

In addition to the transplanted mussel samples reported by James et al. (2020), Washington Department of Fish and Wildlife (WDFW) analyzed 108 samples of marine fish, a subset of samples collected for their Toxics Biological Observation System (TBiOS), for chemicals of emerging concern, including 12 PFAAs and PFOSA. These samples represent a reconnaissance survey of PFAS in WDFW's monitoring indicator species, from a range of locations (urban to rural) throughout Puget Sound for each species. A total of 74 fillet samples, suitable for assessing potential impacts to human health, were collected, including 44 composite English sole samples from 2017 and 30 individual resident sub-adult Chinook salmon from 2016 and

2017. Samples suitable to assess fish health included 30 whole-body samples (15 composite samples each of juvenile Chinook salmon from 2013 and 2016 and Pacific herring from 2018), and four liver samples of Pacific herring from 2018.

At least one PFAS was detected in 77% of whole body and 100% of the liver samples, whereas the detection frequency for fillet was only 4%. Concentrations of T-PFAA (sum of detected compounds: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, PFOS, and PFOSA) in fillet samples ranged from less than 0.9 – 1.9 ng/g ww (median = 1.0 ng/g ww) for English sole and less than 1 – 3.3 ng/g ww (median = 0.99 ng/g ww) for resident Chinook salmon. T-PFAA concentrations in whole body samples ranged from 1 – 16.1 ng/g ww (median = 2.0 ng/g ww) for juvenile Chinook salmon and less than 0.5 – 2.7 ng/g ww (median = 0.73 ng/g ww) for adult Pacific herring. Liver T-PFAS concentrations in Pacific herring ranged from 1.3 – 5.4 ng/g ww (median = 3.6 ng/g ww).

PFOS was the dominant compound detected in most marine fish samples, ranging from 38% – 100% of the T-PFAA concentrations. Concentrations of PFOS in all fillet samples (0.988 – 14.20 ng/g ww) were below Health's provisional general population screening level for PFOS in edible fish tissue at the time of publication (23 ng/g). Health is currently updating its screening levels for PFOS and will evaluate this data when screening levels are finalized. PFOSA was commonly the dominant PFAA in herring, and was the second most dominant compound detected in other species, ranging from 8% – 100% of the T-PFAA concentration. Concentrations of PFOSA ranged from 0.554 – 2.380 ng/g ww. PFUnA, PFHxA, PFNA, and PFBA were detected less frequently (1 – 5% of all samples) and at lower concentrations, ranging from 0.517 – 1.330 ng/g ww for individual compounds. All other PFAA compounds were not detected.

Overall, average T-PFAA concentrations in fillets of marine species were less than 3 ng/g ww, considerably lower than those measured in fillet of freshwater fish collected in Puget Sound (Figures 36 and 37). Among fillet samples, PFAA were only detected in three of 14 locations for English sole (i.e., Tacoma City Waterway, Eagle Harbor, and Bremerton Waterfront; Figure 36) and two of eight sample locations for resident Chinook salmon (i.e., South Whidbey Basin/Marine Area 8.2 and South Puget Sound Basin/Marine Area 13; Figure 37).

Figure 36. Mean total perfluoroalkyl acid (T-PFAA) concentrations in English sole fillet collected in 2017.

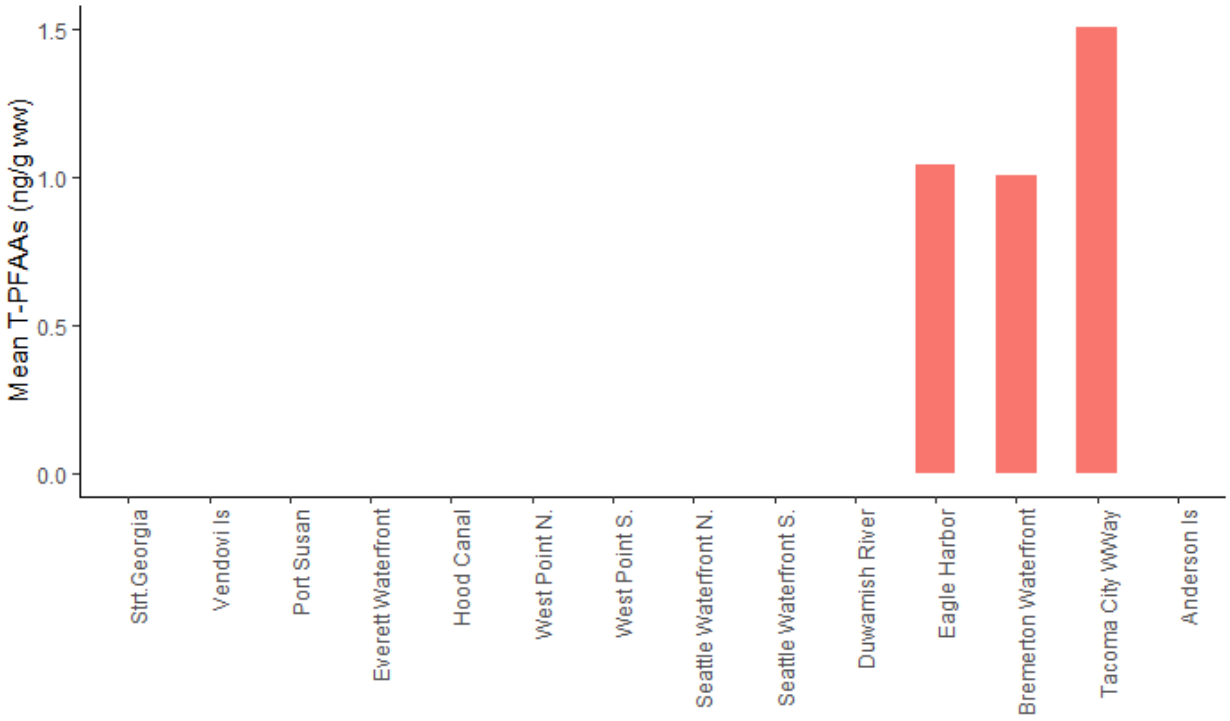
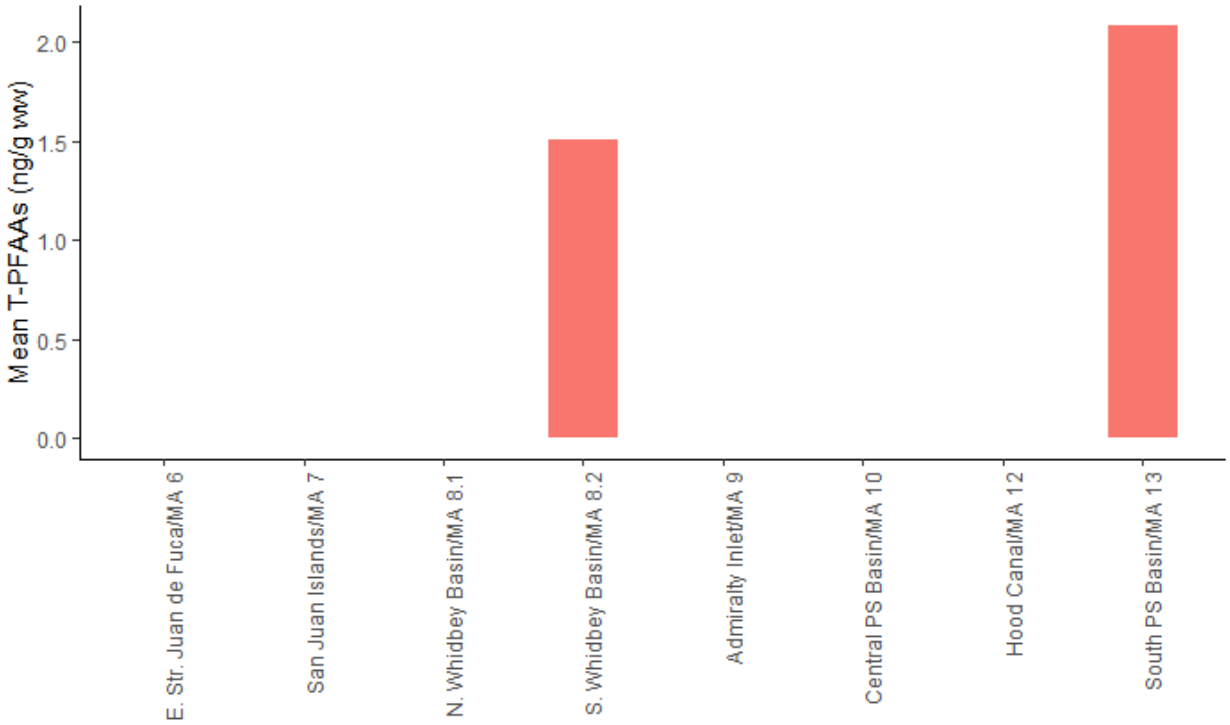


Figure 37. Mean total perfluoroalkyl acid (T-PFAA) concentrations in fillet of sub-adult resident Chinook salmon collected in 2016 and 2017.



T-PFAA concentrations in whole body samples of marine species from specific locations ranged from less than 1.0 – 16.1 ng/g ww for juvenile Chinook salmon (Figure 38) and averaged 0.6 – 1.5 ng/g ww for Pacific herring locations. PFAS were detected in 11 of 15 juvenile Chinook sampling locations, possibly associated with their proximity to freshwater sources, with generally higher T-PFAA concentrations observed in the more urbanized locations near Seattle (i.e., Duwamish River and Elliott Bay nearshore) and Everett (i.e., Port Gardner nearshore). Uniformly low average T-PFAA concentrations were detected in all five Pacific herring sampling locations. Paired whole body and liver samples were collected at four of the five Pacific herring locations, with T-PFAA concentrations in liver two to four times higher than the concentration in whole body herring from the same locations (Figure 39).

Herring liver samples measured in Puget Sound are lower than herring liver samples from the Swedish west coast, which contained PFOS and PFOSA concentrations ranging from 4.06 – 8.97 ng/g and 6.52 – 18.2 ng/g, respectively, between 1991 and 2011 (Ullah et al., 2014). Similarly, a study of PFAA concentrations in Pacific Cod fillet from the North Pacific Ocean indicated that PFAA concentrations in the Northeast Pacific Ocean were two to four times less than those in Japanese and Korean waters (Fujii et al., 2019).

Figure 38. Mean total perfluoroalkyl acid (T-PFAA) concentrations in juvenile Chinook whole body tissue collected in 2013 and 2016.

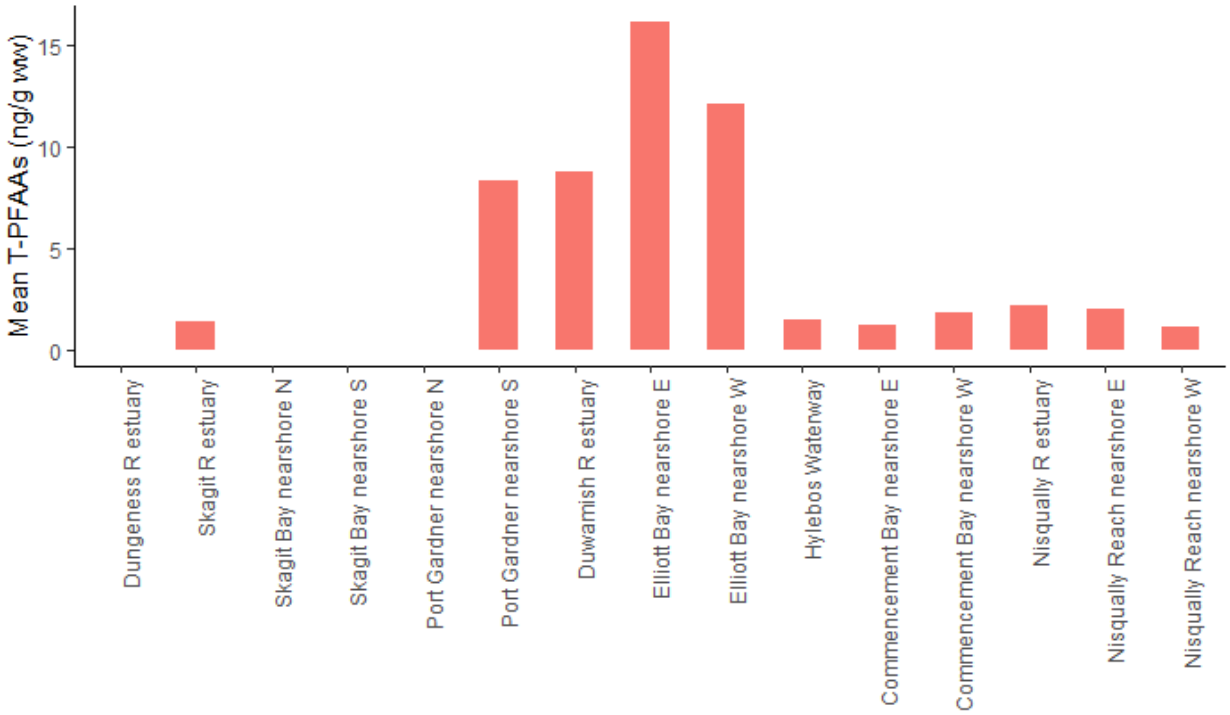
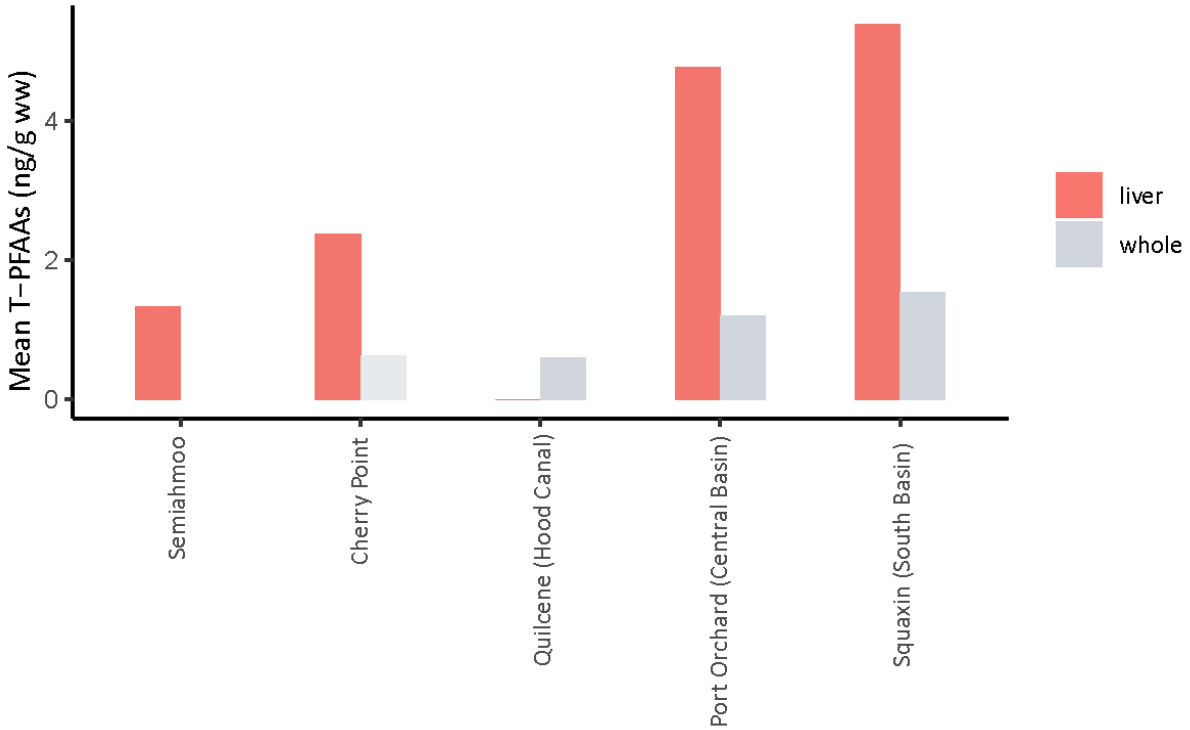


Figure 39. Mean total perfluoroalkyl acid (T-PFAA) concentrations in herring liver (left bars) and whole body tissue (right bars) collected in 2013 and 2016.



5.2 Wildlife studies outside of Washington

PFAS have been detected throughout the world in wildlife types that haven't been sampled in Washington, with PFOS generally detected at the highest frequency and in the greatest amounts. Giesy and Kannan (2001) were the first to report detectable levels of PFOS in a wide range of biota, including species such as bald eagles, polar bears, and seals. Their study included PFOS detections in wildlife from urbanized centers in North America to remote regions of the Arctic and North Pacific Oceans.

Literature reviews done in the mid-2000s confirmed PFOS contamination at all levels of the food chain, and particularly elevated levels in fish-eating animals living near industrialized areas (Houde et al., 2006; Lau et al., 2007). Other perfluoroalkyl sulfonates, long-chain perfluoroalkyl carboxylates, and PFOSA were detected in wildlife such as fish, amphibians, seabirds, and marine mammals (reviewed by Houde et al., 2006). A more recent review by Houde et al. (2011) concluded that PFOS and long-chain PFCAs continue to be widespread in invertebrates, fish, reptiles, aquatic birds, and marine mammals throughout the globe (Houde et al., 2011).

5.3 Data gaps and recommendations

5.3.1 Data gaps

Washington state is lacking data in some key areas for characterizing PFAS contamination in the environment, such as monitoring of ambient groundwater and landfill leachate, source assessments of PFAS in urban water bodies, and testing PFAS compounds beyond PFAAs. With the exception of drinking water wells and military base investigations, no ambient groundwater studies have been conducted in Washington. Around the U.S., PFAA compounds have been found at high concentrations in groundwater near areas of repeated AFFF use, such as airports, oil and gas sites, firefighter training areas, and military bases (Cousins, 2016), but levels of concern may be present in groundwater of other land uses as well.

Environmental monitoring identified Washington urban lakes as sites of elevated PFAA contamination relative to other water body types. The source of this contamination is not fully understood. Research on PFAA contamination in urban water bodies has suggested sources related to automobile and railway transportation may be important (Kim and Kannan, 2007; Zushi and Masunaga, 2009), as well as the transfer of indoor air PFAS loads to the outdoor environment (Gewurtz et al., 2009). An assessment of industrial users of PFAS-containing products in Washington may also contribute to our understanding of sources in the environment.

Recent research using new analytical methods has identified novel PFAS compounds—such as perfluoro-1-butane-sulfonamide (FBSA) and polyfluoroalkyl ether sulfonic acid (F-53B)—in wildlife, though levels have generally been lower than PFOS (Baygi et al., 2016; Chu et al., 2016; Shi et al., 2015). Other novel PFAS, such as cyclic perfluoroalkyl acids and fluorosurfactants, have been found to accumulate in fish from water bodies directly impacted by AFFF use (Munoz et al., 2017; Wang et al., 2016). Recent research has identified hundreds of new PFAS, many of which have been found in the aquatic environment (Xiao, 2017). Aside from a limited list of

precursor compounds measured in surface waters and WWTP effluent in 2016, none of these emerging PFAS compounds have been analyzed in Washington samples.

5.3.2 Recommendations

Filling the data gaps discussed above is recommended to further our understanding of PFAS contamination in Washington's environment. Ecology should conduct sampling in matrices not yet tested, such as ambient groundwater and landfill leachate, as well as conduct source characterization studies in areas of known PFAS contamination, like urban water bodies.

Emerging or novel PFAS which have not been tested in environmental samples should also be sampled. Filling these data gaps will help guide efforts to manage PFAS contamination in the state. Ecology should conduct investigations of areas where contamination is likely to have occurred, but where we currently lack data. These efforts would support local health departments, cities, counties, and other public entities in Washington when PFAS contamination is discovered. Initial investigation efforts could identify areas at high risk of contamination. This could include areas where training or firefighting activities used large quantities of PFAS-containing foam, or where spills released the foam.

Based on the analysis in this appendix, we make the following sub-recommendations as part of Recommendation 2.1:

Recommendation 2.1: Establish PFAS cleanup levels for soil and groundwater:

Ecology will conduct monitoring for PFAS compounds in environmental media (soils, surface waters, sediment) and in tissues of aquatic and terrestrial wildlife to identify sources and to assess exposure. Activity conducted under the following recommendations will serve to further inform our knowledge and understanding of the environmental occurrence of PFAS in the state.

- 1.2 Technical support for site characterization, source investigation, and mitigation at contaminated sites: Investigation of PFAS contamination in groundwater and surface water. See Appendix 7: Health, Section 7.6.2 Recommendations.
- 2.1 Establish PFAS cleanup levels for soil and groundwater: Investigation of PFAS contamination. See Appendix 7: Health, Section 7.6.2 Recommendations, and Appendix 6: PFAS Ecotoxicology.
- 4.1 Evaluate PFAS in wastewater treatment: Investigation of PFAS in WWTP influent and effluent. See Appendix 3: Sources and Uses.
- 4.2 Evaluate PFAS in landfill leachate and gaseous emissions: Investigation of landfill-related PFAS emissions. See Appendix 3: Sources and Uses.
- 4.3 Evaluate Washington biosolids management: Investigation of PFAS in biosolids and land application sites. See Appendix 8: Biosolids.

5.4 Washington environmental concentrations data

Notes for Tables 46 through 56:

- Accessed from Ecology's Environmental Information Management Database.[147]
- Median concentrations included in parentheses, when available.
- NR = not reported.
- LOQ = limit of quantitation.
- ND = not detected.
- Mult. sp. = multiple species.
- CC = common carp.
- LSS = largescale sucker.
- n = sample size.

Table 46. PFAS concentration ranges in Washington state surface water (ng/L).

Collection year	n	# PFAA compounds analyzed	T-PFAAs range (median)	PFBA range	PFPeA range	PFHxA range	PFHpA range	PFOA range	PFNA range	Reference
Spring (2008)	14	11	1.1 – 185 (7.5)	<0.1 – 3.6	<0.1 – 26.5	<1.0 – 10.5	<1.0 – 28	<1.0 – 96	<0.1 – 17	Ecology, 2010
Fall (2008)	14	11	<0.9 –170 (3.6)	<0.1 – 5.5	<0.5 – 32	<0.1 – 37	<0.9 – 22	<0.5 – 48	<0.5 – 7.0	Ecology, 2010
Four season mean (2009 – 2010)	13	14	1.5 – 40	NR	—	NR	NR	NR	NR	Dinglasan-Panlilio et al., 2014
Spring (2016)	15	12	<2 – 153 (<2)	<1.0 – 13	<1.0 – 29	<1.0 – 33	<1.0 – 13	<1.0 – 42.5	<1.0 – 5.2	Ecology, 2017
Fall (2016)	15	12	<2 – 170 (<2)	<1.0 – 12	<1.0 – 39	<1.0 – 32.5	<1.0 – 13	<1.0 – 55	<1.0 – 5.8	Ecology, 2017

[147] https://ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database

Table 47. PFAS concentration ranges in Washington state surface water (ng/L).

Sample type (collection year)	n	PFDA range	PFUnA range	PFDoA range	PFBS range	PFHxS range	PFOS range	PFDS range	PFOSA range	Reference
Spring (2008)	14	<0.1 – 4.9	—	—	<0.1 – 0.6	<1.0 – 3.3	<0.1 – 6.5	<1.0	—	Ecology, 2010
Fall (2008)	14	<0.1 – 3.8	—	—	<0.1 – 2.0	<0.5 – 4.5	<0.5 – 7.6	<0.1 – 1.3	—	Ecology, 2010
Four season mean (2009 – 2010)	13	NR	NR	NR	NR	NR	NR	NR	—	Dinglasan-Panlilio et al., 2014
Spring (2016)	15	<1.0 – 1.9	<1.0 – <1.2	<1.0 – <1.2	<2.0 – 2.1	<2.0 – 5.3	<2.0 – 9.2	—	<1.0 – <2.6	Ecology, 2017
Fall (2016)	15	<1.0 – 3.2	<1.0 – <1.1	<1.0 – <1.1	<2.0 – 13	<2.0 – 3.0	<2.0 – 12.5	—	<1.0 – <1.2	Ecology, 2017

Note for Table 47:

- In each sample, 13 PFAA compounds were analyzed.

Table 48. PFAS concentration ranges in Washington state WWTP effluent (ng/L).

Collection year	n	# PFAA compounds analyzed	T-PFAAs range (median)	PFBA range	PFPeA range	PFHxA range	PFHpA range	PFOA range	PFNA range	Reference
Spring (2008)	4	11	61 – 418 (218)	0.7 – 3.3	3.8 – 31	14.5 – 141	4.1 – 35	16.5 – 128	3.6 – 18	Ecology, 2010
Fall (2008)	4	11	73 – 188 (140)	1.9 – 5.4	13 – 47	11 – 30	<3.5 – 13	22 – 63	5.7 – 14	Ecology, 2010
Summer (2009)	10	12	46 – 146 (93)	<1.0 – 4.9	<1.0 – 18	9.6 – 44	3.4 – 9.7	11 – 52.5	3.3 – 29	Ecology & Herrera, 2010
Winter (2009)	10	12	35 – 194 (73.5)	<1.0 – 3.6	<1.5 – 16	11 – 52	2.1 – 10	11 – 70	1.4 – 134	Ecology & Herrera, 2010
Spring (2016)	5	12	42 – 107 (69)	2.2 – 7.1	5.5 – 28	12 – 36	2.2 – 5.5	7.2 – 20	<1.0 – 1.9	Ecology, 2017
Fall (2016)	5	12	42 – 125 (71)	1.6 – 7.1	6.1 – 57	10.5 – 49	2.6 – 3.7	6.6 – 18	<1.0 – 4.0	Ecology, 2017

Table 49. PFAS concentration ranges in Washington state WWTP effluent (ng/L).

Collection year	n	PFDA range	PFUnA range	PFDoA range	PFBS range	PFHxS range	PFOS range	PFDS range	PFOSA range	Reference
Spring (2008)	4	3.6 – 13	—	—	<0.1 – 1.5	1.3 – 16	3.9 – 31	<0.1	—	Ecology, 2010
Fall (2008)	4	3.7 – 13	—	—	<0.5 – 6.6	2.2 – 12	9.4 – 18	<0.1 – <0.5	—	Ecology, 2010
Summer (2009)	10	1.5 – 10	<1.0	<1.0	<2.0 – 18	<2.0 – 8.3	<2.0 – 55	—	<2.5	Ecology and Herrera, 2010
Winter (2009)	10	1.4 – 7.9	<1.0	<1.0	<2.0	<1.9 – 6.9	<2.0 – 19.5	—	<1.0 – 2.0	Ecology and Herrera, 2010
Spring (2016)	5	<1.0 – 4.9	<1.0	<1.0	<2 – 3.4	<2.0 – 11	2.6 – 16	—	<2.5 – 2.8	Ecology, 2017
Fall (2016)	5	<1.0 – 5.0	<1.0	<1.0	<2.0 – 14	<2.0 – 7.1	<2.0 – 6.5	—	<1.0	Ecology, 2017

Note for Table 49:

- In each sample, 13 PFAA compounds were analyzed.

Table 50. PFAS concentration ranges in Washington state sediment (ng/g dw) (Ecology, 2010; EIM database).

Sample type (collection year)	n	# PFAA compounds analyzed	T-PFAAs range (median)	PFBA range	PFPeA range	PFHxA range	PFHpA range	PFOA range	PFNA range
Fresh water (0 – 2 cm) (2013)	3	12	0.4 – 7.0 (2.35)	<0.2	<0.2	<0.2	<0.2	<0.1 – 0.6	<0.1 – 0.4
Marine (0 – 3 cm) (2013 – 2015)	101	12	—	<0.1	<0.1	<0.1	<0.1	<0.1 – 0.21	<0.1

Table 51. PFAS concentration ranges in Washington state freshwater fish (ng/g ww) (Ecology 2010, 2012, 2017, in prep.).

Sample type (collection year)	n	# PFAA compounds analyzed	T-PFAAs range (median)	PFBA range	PFPeA range	PFHxA range	PFHpA range	PFOA range	PFNA range
Fillet – mult. sp. (2008)	15	10	<10 – 76 (<10)	—	—	<5.0	<5.0	<5.0	<5.0
Liver – mult. sp. (2008)	15	10	<25 – 527 (48)	—	—	<10.0	<10.0	<10.0	<10.0
Fillet – CC (2011)	4	12	2.1 – 21.5 (12)	<LOQ	<LOQ	<LOQ	<0.3	<0.25	<0.3
Whole body – LSS (2011)	4	12	3.3 – 92 (23)	<LOQ	<LOQ	<LOQ	<0.2 – 0.6	<0.2 – 0.8	<0.2 – 1.6
Fillet – mult. sp. (2016)	22	12	<1 – 87 (3.9)	<0.5	<0.5-1.8	<0.5	<0.5	<0.5	<0.5 – 0.9
Liver – mult. sp. (2016)	22	12	5.1 – 394 (20)	<1.0	<0.5 – <2.9	<0.5 – 2.5	<0.5 – 1.1	<0.7	<0.5 – 7.3
Fillet – mult. sp. (2018)	76	13	0.9 – 132 (20)	—	—	<0.5	<0.5	<0.5	ND – 0.5

Table 52. PFAS concentration ranges in Washington state freshwater fish (ng/g ww) (Ecology 2010, 2012, 2017, in prep.).

Sample type (collection year)	n	PFDA range	PFUnA range	PFDoA range	PFBS range	PFHxS range	PFOS range	PFDS range	PFOSA range
Fillet – mult. sp. (2008)	15	<5.0 – 7.5	<5.0 – 7.2	<5	<5.0	<5.0	<10.0 – 76	—	—
Liver – mult. sp. (2008)	15	<21.0 – 25	<10.0 – 46	<10.0 – 21	<10.0	<10.0	<10.0 – 527	—	—
Fillet – CC (2011)	4	<0.25 – 1.2	<0.25 – 1.3	<0.3 – 1.8	<LOQ	<LOQ	2.1 – 20	—	<0.4
Whole body – LSS (2011)	4	0.3 – 10	<0.24 – 20	<0.2 – 9.5	<LOQ	<LOQ	2.9 – 46	—	<0.3 – 3.4

Sample type (collection year)	n	PFDA range	PFUnA range	PFDoA range	PFBS range	PFHxS range	PFOS range	PFDS range	PFOSA range
Fillet – mult. sp. (2016)	22	<0.5 – 5.5	<0.5 – 5.5	<0.5 – 6.0	<1.0	<1.0	<1.0 – 74	—	<0.5
Liver – mult. sp. (2016)	22	<0.5 – 20	<0.5 – 26	<0.5 – 17	<0.9 – 6.2	<1	1.4 – 336	—	<0.5 – 4.9
Fillet – mult. sp. (2018)	76	ND – 10	0.06 – 11.3	0.11 – 10.6	<0.5	<0.5	0.5 – 99.9	—	—

Note for Table 52:

- In each sample, 13 PFAA compounds were analyzed.

Table 53. PFAS concentration ranges in Washington state Osprey eggs (ng/g fw) (Ecology, 2010, 2017).

Collection year	n	# PFAA compounds analyzed	T-PFAAs range (median)	PFBA range	PFPeA range	PFHxA range	PFHpA range	PFOA range	PFNA range
2008	11	13	37.5 – 910 (91)	<0.5	<0.5	<0.5 – 0.8	<0.5 – 0.8	<0.2 – <1.0	<0.5 – 6.4
2016	11	12	12 – 820 (100)	<0.5	<0.4 – 1.8	<0.5	<0.5	<0.5	<0.5 – 5.7

Table 54. PFAS concentration ranges in Washington state Osprey eggs (ng/g fw) (Ecology 2010, 2017).

Collection year	n	PFDA range	PFUnA range	PFDoA range	PFBS range	PFHxS range	PFOS range	PFDS range	PFOSA range
2008	11	2.0 – 10	3.5 – 13	<5.0 – 11	<0.5	<0.5 – 1.8	24 – 884	<1.0 – 5.8	—
2016	11	1.0 – 47	1.1 – 45	0.6 – 47	<1.0	<1.0	9.1 – 675	—	<0.5

Note for Table 54:

- In each sample, 13 PFAA compounds were analyzed.

Table 55. PFAS concentration ranges in Washington state sediment (ng/g dw) (Ecology, 2010; EIM database).

Sample type (collection year)	n	PFDA range	PFUnA range	PFDoA range	PFBS range	PFHxS range	PFOS range	PFDS range	PFOSA range
Fresh water (0 – 2 cm) (2013)	3	<0.1 – 1.5	0.2 – 0.7	0.2 – 0.9	<0.4	<0.4	<0.2 – 2.6	—	<0.1 – 0.3
Marine (0 – 3 cm) (2013 – 2015)	101	<0.1 – 0.14	<0.1 – 0.2	<0.1 – 0.2	<0.2	<0.2	<0.2 – 1.6	—	<0.1 – 0.3

Note for Table 55:

- In each sample, 13 PFAA compounds were analyzed.

Table 56. PFAS concentrations in Puget Sound free-ranging marine and anadromous fish (ng/g ww). (WDFW, in prep.)

Sample type (collection year)	n	T-PFAAs range (median)	PFOS range (median)	PFOSA range (median)	PFUnA range (median)	PFHxA range (median)	PFNA range (median)	PFBA range (median)	PFDoA range (median)
English sole fillet (2017)	44	<0.9 – 1.9 (1.0)	<1.0 – 1.1 (1.0)	<0.5	<0.5	<0.5	<0.5	<0.5 – 0.89	<0.5
Sub-adult resident Chinook salmon fillet (2016 – 17)	30	<1 – 3.3 (1.6)	<1.0 – 2.4 (0.99)	<0.5 – 0.83 (0.67)	<0.5 – 0.52	<0.5 – 0.78	<0.5	<0.5	<0.5
Juvenile Chinook salmon whole body (2013 and 2016)	15	<1 – 16.1 (2.0)	<1.0 – 14.2 (2.0)	<0.6 – 1.1 (0.94)	<0.5 – 0.58 (0.57)	<0.5 – 0.53	<0.5 – 1.3	<1.5	<0.5 – 0.65
Pacific herring whole body (2018)	15	<0.5 – 2.7 (0.73)	<1.0 – 1.0	<0.5 – 2.1 (0.78)	<0.5	<0.5	<0.5 – 0.6	<0.5	<0.5

Sample type (collection year)	n	T-PFAAs range (median)	PFOS range (median)	PFOSA range (median)	PFUnA range (median)	PFHxA range (median)	PFNA range (median)	PFBA range (median)	PFDoA range (median)
Pacific herring liver (2018)	4	1.3 – 5.4 (3.6)	<1.0 – 2.6	<0.6 – 2.4 (1.7)	<0.5 – 1.1	<0.6 – 1.3	<0.6	<0.6	<0.6

Notes for Table 56:

- In each sample, 13 PFAA compounds were analyzed.
- PFPeA, PFOA, PFHxS, PFHpA, PFDA and PFBS were not detected in any samples measured.

References

Anderson, R. H., Long, G. C., Porter, R. C., & Anderson, J. K. (2016). Occurrence of select perfluoroalkyl substances at U.S. Air Force aqueous film-forming foam release sites other than fire-training areas: Field-validation of critical fate and transport properties. *Chemosphere*, *150*, 678–685. https://doi.org/10.1016/j.chemosphere.2016.01.014

Appleman, T. D., Higgins, C. P., Quiñones, O., Vanderford, B. J., Kolstad, C., Zeigler-Holady, J. C., & Dickenson, E. R. V. (2014). Treatment of poly- and perfluoroalkyl substances in U.S. full-scale water treatment systems. *Water Research*, *51*, 246–255. https://doi.org/10.1016/j.watres.2013.10.067

Baygi, F. S., Crimmins, B. S., Hopke, P. K., & Holsen, T. M. (2016). Comprehensive Emerging Chemical Discovery: Novel Polyfluorinated Compounds in Lake Michigan Trout. *Environmental Science & Technology*, *50*, 9460–9468. https://doi.org/10.1021/acs.est.6b01349

Chu, S., Letcher, R. J., McGoldrick, D. J., & Backus, S. M. (2016). A New Fluorinated Surfactant Contaminant in Biota: Perfluorobutane Sulfonamide in Several Fish Species. *Environmental Science & Technology*, *50*, 669–675. https://doi.org/10.1021/acs.est.5b05058

Cousins, I. T., Vestergren, R., Wang, Z., Scheringer, M., & McLachlan, M. S. (2016). The precautionary principle and chemicals management: The example of perfluoroalkyl acids in groundwater. *Environment International*, *94*, 331–340. https://doi.org/10.1016/j.envint.2016.04.044

Dinglasan-Panlilio, J. M., Prakash, S. S., & Baker, J. E. (2014). Perfluorinated compounds in the surface waters of Puget Sound, Washington and Clayoquot and Barkley Sounds, British Columbia. *Marine Pollution Bulletin*, *78*, 173–180. https://doi.org/10.1016/j.marpolbul.2013.10.046

Eriksson, U., Roos, A., Lind, Y., Hope, K., Ekblad, A., & Kärrman, A. (2016). Comparison of PFASs contamination in the freshwater and terrestrial environments by analysis of eggs from osprey (Pandion haliaetus), tawny owl (Strix aluco), and common kestrel (Falco tinnunculus). *Environmental Research*, *149*, 40–47. https://doi.org/10.1016/j.envres.2016.04.038

Fujii, Y., Tuda, H., Kato, Y., Kimura, O., Endo, T., Harada, K. H., Koizumi, A. & Haraguchi, K. (2019). Levels and profiles of long-chain perfluoroalkyl carboxylic acids in Pacific cod from 14 sites in the North Pacific Ocean. *Environmental Pollution, 247,* 312–318. https://doi.org/10.1016/j.envpol.2019.01.006

Gewurtz, S. B., Bhavsar, S. P., Crozier, P. W., Diamond, M. L., Helm, P. A., Marvin, C. H., & Reiner, E. J. (2009). Perfluoroalkyl Contaminants in Window Film: Indoor/Outdoor, Urban/Rural, and Winter/Summer Contamination and Assessment of Carpet as a Possible Source. *Environmental Science & Technology*, *43*, 7317–7323. https://doi.org/10.1021/es9002718

Gewurtz, S. B., Bhavsar, S. P., Petro, S., Mahon, C. G., Zhao, X., Morse, D., Reiner, E. J., Tittlemier, S. A., Braekevelt, E., & Drouillard, K. (2014). High levels of perfluoroalkyl acids in sport fish species downstream of a firefighting training facility at Hamilton International Airport, Ontario, Canada. *Environment International*, *67*, 1–11. https://doi.org/10.1016/j.envint.2014.02.005

Giesy, J. P., & Kannan, K. (2001). Global Distribution of Perfluorooctane Sulfonate in Wildlife. *Environmental Science & Technology*, *35*, 1339–1342. https://doi.org/10.1021/es001834k

Houde, M., Martin, J. W., Letcher, R. J., Solomon, K. R., & Muir, D. C. G. (2006). Biological Monitoring of Polyfluoroalkyl Substances: A Review. *Environmental Science & Technology*, *40*, 3463–3473. https://doi.org/10.1021/es052580b

Houde, M., De Silva, A. O., Muir, D. C. G., & Letcher, R. J. (2011). Monitoring of Perfluorinated Compounds in Aquatic Biota: An Updated Review. *Environmental Science & Technology*, *45*, 7962–7973. https://doi.org/10.1021/es104326w

Houtz, E. F., Sutton, R., Park, J.-S., & Sedlak, M. (2016). Poly- and perfluoroalkyl substances in wastewater: Significance of unknown precursors, manufacturing shifts, and likely AFFF impacts. *Water Research*, *95*, 142–149. https://doi.org/10.1016/j.watres.2016.02.055

Interstate Technology & Regulatory Council (ITRC). (2020). ITRC PFAS Fact Sheets: Environmental Fate and Transport for Per- and Polyfluoroalkyl Substances. Retrieved from https://pfas-1.itrcweb.org/fact-sheets/.

James, C. A., Lanksbury, J., Khangaonkar, T., & West, J. (2020). Evaluating exposures of bay mussels (Mytilus trossulus) to contaminants of emerging concern through environmental sampling and hydrodynamic modeling. *Science of the Total Environment*, *709*, 136098. https://doi.org/10.1016/j.scitotenv.2019.136098

Kim, S.-K., & Kannan, K. (2007). Perfluorinated Acids in Air, Rain, Snow, Surface Runoff, and Lakes: Relative Importance of Pathways to Contamination of Urban Lakes. *Environmental Science & Technology*, *41*, 8328–8334. https://doi.org/10.1021/es072107t

Lanza, H. A., Cochran, R. S., Mudge, J. F., Olson, A. D., Blackwell, B. R., Maul, J. D., Salice, C. J., & Anderson, T. A. (2017). Temporal monitoring of perfluorooctane sulfonate accumulation in aquatic biota downstream of historical aqueous film forming foam use areas. *Environmental Toxicology and Chemistry*, *36*, 2022–2029. https://doi.org/10.1002/etc.3726

Lau, C., Anitole, K., Hodes, C., Lai, D., Pfahles-Hutchens, A., & Seed, J. (2007). Perfluoroalkyl Acids: A Review of Monitoring and Toxicological Findings. *Toxicological Sciences*, *99*, 366–394. https://doi.org/10.1093/toxsci/kfm128

Meador, J. P., Yeh, A., & Gallagher, E. P. (2017). Determining potential adverse effects in marine fish exposed to pharmaceuticals and personal care products with the fish plasma model and whole-body tissue concentrations. *Environmental Pollution*, *230*, 1018–1029. https://doi.org/10.1016/j.envpol.2017.07.047

Michigan Department of Environmental Quality (MIDEQ). (2015). Reconnaissance Sampling of Perfluorinated Compounds in Michigan Surface Waters and Fish 2010 – 2014.

Molina, E. D., Balander, R., Fitzgerald, S. D., Giesy, J. P., Kannan, K., Mitchell, R., & Bursian, S. J. (2006). Effects of air cell injection of perfluorooctane sulfonate before incubation on development of the white leghorn chicken (Gallus domesticus) embryo. *Environmental Toxicology and Chemistry*, *25*, 227. https://doi.org/10.1897/04-414R.1

Munoz, G., Desrosiers, M., Duy, S. V., Labadie, P., Budzinski, H., Liu, J., & Sauvé, S. (2017). Environmental Occurrence of Perfluoroalkyl Acids and Novel Fluorotelomer Surfactants in the Freshwater Fish Catostomus commersonii and Sediments Following Firefighting Foam Deployment at the Lac-Mégantic Railway Accident. *Environmental Science & Technology*, *51*, 1231–1240. https://doi.org/10.1021/acs.est.6b05432

Munschy, C., Bely, N., Pollono, C., & Aminot, Y. (2019). Perfluoroalkyl substances (PFASs) in the marine environment: Spatial distribution and temporal profile shifts in shellfish from French coasts. *Chemosphere, 228,* 640–648. https://doi.org/10.1016/j.chemosphere.2019.04.205

Newsted, J. L., Jones, P. D., Coady, K., & Giesy, J. P. (2005). Avian Toxicity Reference Values for Perfluorooctane Sulfonate. *Environmental Science & Technology*, *39*, 9357–9362. https://doi.org/10.1021/es050989v

Newton, S., McMahen, R., Stoeckel, J. A., Chislock, M., Lindstrom, A., & Strynar, M. (2017). Novel Polyfluorinated Compounds Identified Using High Resolution Mass Spectrometry Downstream of Manufacturing Facilities near Decatur, Alabama. *Environmental Science & Technology*, *51*, 1544–1552. https://doi.org/10.1021/acs.est.6b05330

Organisation for Economic Co-operation and Development (OECD). (2013). OECD/UNEP Global PFC Group: synthesis paper on per- and polyfluorinated chemicals (PFCs). Retrieved from https://www.oecd.org/env/ehs/risk-management/PFC_FINAL-Web.pdf

Peden-Adams, M. M., Stuckey, J. E., Gaworecki, K. M., Berger-Ritchie, J., Bryant, K., Jodice, P. G., Scott, T. R., Ferrario, J. B., Guan, B., Vigo, C., Boone, J. S., McGuinn, W. D., DeWitt, J. C., & Keil, D. E. (2009). Developmental toxicity in white leghorn chickens following in ovo exposure to perfluorooctane sulfonate (PFOS). *Reproductive Toxicology*, *27*, 307–318. https://doi.org/10.1016/j.reprotox.2008.10.009

Shi, Y., Vestergren, R., Zhou, Z., Song, X., Xu, L., Liang, Y., & Cai, Y. (2015). Tissue Distribution and Whole Body Burden of the Chlorinated Polyfluoroalkyl Ether Sulfonic Acid F-53B in Crucian Carp (Carassius carassius): Evidence for a Highly Bioaccumulative Contaminant of Emerging Concern. *Environmental Science & Technology*, *49*, 14156–14165. https://doi.org/10.1021/acs.est.5b04299

Ullah, S., Huber, S., Bignert, A., & Berger, U. (2014). Temporal trends of perfluoroalkane sulfonic acids and their sulfonamide-based precursors in herring from the Swedish west coast 1991–2011 including isomer-specific considerations. *Environment International, 65,* 63–72. https://doi.org/10.1016/j.envint.2014.01.005

Wang, Y., Vestergren, R., Shi, Y., Cao, D., Xu, L., Cai, Y., Zhao, X., & Wu, F. (2016). Identification, Tissue Distribution, and Bioaccumulation Potential of Cyclic Perfluorinated Sulfonic Acids Isomers in an Airport Impacted Ecosystem. *Environmental Science & Technology*, *50*, 10923–10932. https://doi.org/10.1021/acs.est.6b01980

Washington State Department of Ecology (Ecology). (2010). Perfluorinated Compounds in Washington Rivers and Lakes. Retrieved from https://apps.ecology.wa.gov/publications/documents/1003034.pdf

Washington State Department of Ecology (Ecology). (2012). PBTs Analyzed in Bottom Fish from Four Washington Rivers and Lakes: Hexabromocyclododecane, Tetrabromobisphenol A, Chlorinated Paraffins, Polybrominated Diphenylethers, Polychlorinated Napthalaenes, Perfluorinated Organic Compounds, Lead, and Cadmium. Retrieved from https://apps.ecology.wa.gov/publications/documents/1203042.pdf

Washington State Department of Ecology (Ecology). (2013). PBT Chemical Trends in Washington State Determined from Age-Dated Lake Sediment Cores, 2012 Sampling Results. https://apps.ecology.wa.gov/publications/documents/1303036.pdf

Washington State Department of Ecology (Ecology). (2014). Pharmaceuticals, Personal Care Products, and Perfluoroalkyl Substances in Elliott Bay Sediments: 2013 Data Summary. Retrieved from https://apps.ecology.wa.gov/publications/documents/1403049.pdf

Washington State Department of Ecology (Ecology). (2016a). Moses Lake Port Aircraft Rescue and Firefighting School – VCP Opinion on Site Cleanup – No Further Action. Retrieved from https://apps.ecology.wa.gov/eim/search/Detail/Detail.aspx?DetailType=Study&SystemProjectId=99970718

Washington State Department of Ecology (Ecology). (2016b). Quality Assurance Project Plan: Statewide Survey of Per- and Poly-fluoroalkyl Substances in Washington State Rivers and Lakes. Retrieved from https://apps.ecology.wa.gov/epublications/documents/1603110.pdf

Washington State Department of Ecology (Ecology). (2017). Survey of Per- and Poly-fluoroalkyl Substances in Rivers and Lakes, 2016. Retrieved from https://apps.ecology.wa.gov/publications/documents/1703021.pdf

Washington State Department of Ecology (Ecology). (2018). Clark County Local Source Control Partnership Monitoring, Findings, and Recommendations, 2017. Retrieved from https://apps.ecology.wa.gov/publications/documents/1803018.pdf

Washington State Department of Ecology (Ecology). (in prep). Per- and Poly-fluoroalkyl Substances in Freshwater Fish: Lakes Meridian, Sammamish, and Washington. Washington State Department of Ecology, Olympia, WA. Publication in preparation.

Washington State Department of Fish and Wildlife (WFDW). (in prep). Toxics Biological Observation System (TBiOS) 108 sample anlysis for 12 PFAAs and PFOSA. Washington State Department of Fish and Wildlife, Olympia, WA. Publication in preparation.

Washington State Department of Ecology (Ecology), & Herrerra Environmental Consultants. (2010). Control of Toxic Chemicals in Puget Sound – Summary Technical Report for Phase 3: Loadings from POTW Discharge of Treated Wastewater. Retrieved from https://apps.ecology.wa.gov/publications/documents/1010057.pdf

Xiao, F., Gulliver, J. S., & Simcik, M. F. (2013). Perfluorooctane sulfonate (PFOS) contamination of fish in urban lakes: A prioritization methodology for lake management. *Water Research*, *47*, 7264–7272. https://doi.org/10.1016/j.watres.2013.09.063

Zushi, Y., & Masunaga, S. (2009). Identifying the nonpoint source of perfluorinated compounds using a geographic information system based approach. *Environmental Toxicology and Chemistry*, *28*, 691. https://doi.org/10.1897/08-194.1

List of acronyms

General acronyms

Table 57. Acronyms found in the environmental occurrence appendix.

Acronym	Definition
AFFF	Aqueous film forming foam
dw	Dry weight
DOH	Washington Department of Health
EPA	United States Environmental Protection Agency
fw	Fresh weight
g	Gram
in.	Inch
L	Liter
LOAEL	Lowest observable adverse effect level
LOQ	Limit of quantitation
µg	Microgram
MIDEQ	Michigan Department of Environmental Quality
ng	Nanogram
ww	Wet weight
WWTP	Wastewater treatment plant

Chemical names

Table 58. Chemical name acronyms found in the environmental occurrence appendix, excluding the acronyms listed in the table above.

Acronym	Chemical Name
4:2 FTS	4:2 fluorotelomer sulfonate
6:2 FTS	6:2 fluorotelomer sulfonate
8:2 FTUCA	8:2 fluorotelomer unsaturated carboxylic acid
FBSA	Perfluoro-1-butane-sulfonamide
PFAA	Perfluoroalkyl acid
PFAS	Per- and poly-fluorinated alkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonate
PFDA	Perfluorodecanoic acid
PFDoA	Perfluorododecanoic acid
PFDoDA	Perfluorododecanoic acid
PFDS	Perfluorodecane sulfonate
PFHpA	Perfluoroheptanoic acid

Acronym	Chemical Name
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonate
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
PFOSA	Perfluorooctanesulfonamide
PFPeA	Perfluoropentanoic acid
PFTeDA	Perfluorotetradecanoic acid
PFTrDA	Perfluorotridecanoate
PFUnA	Perfluoroundecanoate
PFUnDA	Perfluoroundecanoic acid
T-PFAA	Total perfluoroalkyl acid (summed concentration)

Appendix 6: Ecological Toxicology

6.0 Overview

6.0.1 Findings

Salient findings in our review on ecotoxicology of per- and polyfluoroalkyl substances (PFAS) include the following:

- PFAS are globally distributed in the environment and biota (e.g., plants, algae, invertebrates, mammals, birds, fish), including locally in Washington state.
- Both short- and long-chain PFAS are environmentally persistent.
- Short-chain PFAS (e.g., perfluorobutane sulfonate [PFBS], perfluorohexanoic acid [PFHxA]) are more water soluble, more volatile, and show greater mobility in the environment (transport in water and air), relative to long-chain PFAS.
- Relative to short-chain PFAS (but with some notable exceptions, e.g., 6:2 fluorotelomer alcohol [6:2 FTOH]), long-chain PFAS (such as perfluorooctane sulfonate [PFOS], perfluorooctanoic acid [PFOA]) bioaccumulate to a greater extent within wildlife species, increasing their likelihood of eliciting adverse toxicological effects (e.g., endocrine disruption, immunotoxicity).
- Bioaccumulation factor (BAF) values in aquatic biota vary by specific PFAS compound, species, and tissue.
- PFOA and PFOS are the most widely studied of the long-chain PFAS in wildlife.
- Biomagnification is observed primarily in aquatic food webs with long-chain PFAS (e.g., marine mammals).
- Perfluoroalkyl carboxylic acid (PFCA) and perfluoroalkyl sulfonic acid (PFSA) bind to protein more readily than lipid and accumulate in protein-rich tissues (e.g., liver, blood) in wildlife.
- The proteinophilic nature and apparent deficiency in metabolic biotransformation of PFAS compounds influence their toxicokinetics (e.g., tissue distribution, bioaccumulation), species sensitivity, and biological effects.
- Surrogate species are often used to evaluate PFAS compounds in wildlife (especially for birds and mammals).
- PFAS effects range from subtle alterations in genetic expression to deficits in apical endpoints (e.g., growth, survival, reproduction), which may increase ecological risk (consistent with an adverse outcome pathway (AOP) framework).

6.0.2 Introduction

This appendix summarizes the ecotoxicology of per- and polyfluoroalkyl substances (PFAS). To address this objective, a range of PFAS compounds are included in order to evaluate several bioaccumulation and toxicity endpoints with representative aquatic and terrestrial wildlife species. The ecotoxicology of PFAS includes the following considerations:

- Distribution, concentration, and persistence.
- Bioaccumulation.
- Toxicokinetics (i.e., absorption, distribution, metabolism, and excretion (ADME)).
- Toxicological effects.

Distribution, concentration, and persistence of PFAS in the environment is described in Appendix 5: Environmental Occurrence. As a result, the focus of this appendix is on bioaccumulation, toxicokinetics, and the resulting toxicological responses of biota to PFAS compounds.

PFAS terminology proposed by Buck et al. (2011) is used as overall guidance in this appendix. However, terminology specific to cited articles is not altered to avoid translation errors. In some cases, this conflicts with acronyms recommended by Buck et al. (2011). For example, in the wildlife study authored by Reiner and Place (2015), the PFAS acronym appears to denote perfluoroalkyl acids (PFAA), which include perfluoroalkyl carboxylic acids (PFCA) and perfluoroalkyl sulfonic acids (PFSA). Additionally, terminology presented by Kelly et al. (2009) and Houde et al. (2006a) include perfluoroalkyl contaminant (PFC) and polyfluoroalkyl substance (PFS), respectively, which both appear to denote PFAS.

6.1 PFAS chain length and representative PFAS

6.1.1 Short versus long-chain PFAS

An early step in the assessment of evaluating the potential risk of PFAS is to group the short- and long-chain substances based on the number of associated perfluorinated carbons.

As described in Appendix 1: Chemistry, Section 1.1.1 PFAS terminology, short-chain PFAS contain up to five perfluorinated carbons terminating with a sulfonate group, or up to six perfluorinated carbons terminating with a carboxyl group (Buck et al., 2011). While resistant to degradation, these substances do not generally appear to be highly bioaccumulative or to have significant toxicological effects on ecological receptors (Environmental Protection Agency [EPA], 2017; Inventory Multi-Tiered Assessment Prioritisation [IMAP], 2017a, 2017b, 2017c).

Additional literature suggests that 6:2 FTOH, 6:2 fluorotelomer acrylate (6:2 FTAC), and 6:2 fluorotelomer methacrylate (6:2 FTMAC) (considered short-chain PFAS) would not meet the criteria for persistence, bioaccumulation, or toxicity based on the Stockholm Convention on Persistent Organic Pollutants (Ramboll Environ, 2016).

However, more recent research by Food and Drug Administration (FDA) investigators used pharmacokinetic data from published rat and human studies on 6:2 FTOH to estimate clearance, demonstrating that shorter-chain PFAS compounds may persist in mammalian tissues (i.e., exhibit “biopersistence”). Specifically, 6:2 FTOH is biopersistent, along with its

metabolite, 5:3 fluorotelomer carboxylic acid (5:3 A) (Kabadi et al., 2018, 2020). In particular, 5:3 A clearance decreased with increasing 6:2 FTOH exposure, and 5:3 A is an important biomarker of internal 6:2 FTOH exposure. In addition, 6:2 FTOH has been reported to be significantly more toxic than perfluorohexanoic acid (PFHxA), consistent with rapid elimination of PFHxA (Rice et al., 2020).

As summarized in Tables 59 and 60 (for perfluoroalkyl sulfonates and perfluorocarboxylates, respectively), research findings suggest that biomagnification and bioaccumulation increase as the number of fluorinated carbons also increase (Conder et al., 2008). Although short-chain PFAS are not bioaccumulative, according to regulatory criteria (BAF/BCF>1000 – 5000 L/kg, according to Conder et al., 2008), high mobility and bioavailability lead to relatively high levels in fish tissues (Shi et al., 2018). Tables 59 and 60 refer to bioaccumulation factor (BAF) and bioconcentration factor (BCF). BAF is calculated as chemical concentration in the organism divided by chemical concentration in the surrounding medium (e.g., food, water), whereas BCF is calculated as chemical concentration in the organism divided by chemical concentration in water. That is, a BAF accounts for uptake from all exposure routes, whereas a BCF is limited to uptake from water only. A higher BAF indicates more contaminant accumulates within the organism, relative to environmental media.

Table 59. Perfluoroalkyl sulfonates. Example of the bioaccumulation potential of some PFAS, as related to the number of fluorinated carbons comprising each compound's molecular structure (Conder et al., 2008).

# fluorinated carbons	Compound	Frequency of detection	BAF/BCF values (L/Kg)	Biomagnification	Bioaccumulative
4	PFBS	Not detected	< 1	No	No
6	PFHxS	Detected in some wildlife	10	No	No
8	PFOS	Detected in most wildlife	18 – 11,000	Possibly	Yes

Table 60. Perfluorocarboxylates. Example of the bioaccumulation potential of some PFAS, as related to the number of fluorinated carbons comprising each compound's molecular structure (Conder et al., 2008).

# fluorinated carbons	Compound	Frequency of detection	BAF/BCF values (L/Kg)	Biomagnification	Bioaccumulative
4 – 6	PFPn, PFHx, PFHp	Not detected or infrequently detected	< 1	No	No

# fluorinated carbons	Compound	Frequency of detection	BAF/BCF values (L/Kg)	Biomagnification	Bioaccumulative
7	PFO	Detected in some wildlife	2 – 570	No	No
8 – 13	PFN, PFD, PFU, PFDo, PFTri, PFT	Detected in most wildlife	100 – 23,000	Possibly	Possibly

As discussed in Appendix 1: Chemistry, Section 1.1.1 PFAS terminology, long-chain PFAS contain seven or more perfluorinated carbons terminating with a carboxylate group, or six or more perfluorinated carbons terminating with a sulfonate group (Buck et al., 2011; Organisation for Economic Co-operaiton and Development [OECD], 2013; Wang et al., 2017). These chemicals also resist degradation. Data in Tables 60 and 61 (Conder et al., 2008) limit bioaccumulation to PFAS with eight or more fluorinated carbons. In contrast to short-chain PFAS, recent data confirm that long-chain PFAS tend to be more bioaccumulative and produce adverse toxicological effects to both upland and aquatic ecological receptors, even at relatively low contaminant levels (IMAP, 2017d, 2017e, 2017f, 2017g).

Relative to long-chain PFAS, it is important to note that there appears to be less research available on short-chain PFAS. Although bioaccumulation may be lower, short-chain PFAS are more water soluble and show greater mobility in the environment, relative to long-chain PFAS (Guelfo & Higgins, 2013; Interstate Technology & Regulatory Council [ITRC], 2020a; Wang et al., 2015). However, the information presented above indicates that the potential risk of these short-chain PFAS substances (e.g., PFBS, PFPn, PFHx, PFHp) is generally less than that of the long-chain substances (e.g., PFOA, PFOS) to both aquatic and upland ecological receptors. As a result, this review will focus on evaluating the potential risks of long-chain PFAS on ecological receptors.

6.1.2 Representative PFAS substances

As mentioned earlier, the potential risk for ecological receptors is much greater for the general class of chemicals known as long-chain PFAS. It is important to note that most of the information presented in this review is derived from the most commonly detected long-chain PFAS (i.e., PFOA and PFOS). The rationale for using these two specific chemicals as representative of the general class of long-chain PFAS chemicals is:

- PFOA and PFOS are the most widely studied of the long-chain PFAS (e.g., OECD, 2002).
- These chemicals are structurally related, in that one of the defining characteristics that differentiates the chemicals within this class from other classes is chain length (or number of carbon atoms in the molecule).
- The carbon-fluorine bonds are among the strongest in organic chemistry, which renders them practically non-biodegradable and persistent in the environment (Key et al., 1997; Lau et al., 2007; Prescher et al., 1985), including their presence and persistence in:
    - Water.

    - Soil and sediment.
    - Ambient air.
    - Aquatic and terrestrial wildlife.
- The toxicokinetics and toxicological response for these chemicals appears closely related, depending on species observed (Kelly et al., 2009; Lau et al., 2007; Lindstrom et al., 2011; White et al., 2011).

6.2 Bioaccumulation

Fluorine atoms are substituted for the hydrogen atoms that compose part of the hydrocarbon backbone in PFAS compounds. The fluorine-carbon bonds present in PFAS compounds confer high chemical and thermal stability, which contributes to their persistence in the environment and resistance to natural degradation. Despite commercial and industrial use for more than 50 years, only in the past 20 years have low level detections revealed that PFAS are globally distributed in the environment and biota (Li, 2009; Stahl et al., 2009). Some long-chain PFAS bioaccumulate in the environment and can also undergo biomagnification (Stahl et al., 2011).

As discussed in Appendices 3: Sources and Uses, 4: Fate and Transport, and 8: Biosolids PFAS are released to the environment and transported over various pathways (e.g., soil, water, air), potentially exposing biota. For example, PFOA and PFOS are the major PFAS contaminants found in oceanic waters (Yamashita et al., 2015), and PFCAs (e.g., perfluorooctanoate [PFO], perfluorononanoate [PFN], or perfluorodecanoate [PFD])) have been detected in a variety of wildlife across the globe (Conder et al., 2008; Houde et al., 2006b; Tao et al., 2006). PFCA tissue residues confirm the widespread presence of these compounds from multiple sources (Prevedouros et al., 2006).

PFAS stability and water solubility have allowed for considerable transport through marine environments (Yamashita et al., 2005). Many studies report concentrations of PFAS in marine organisms (e.g., Giesy & Kannan, 2002; Houde et al., 2011). These studies found significant levels of several PFAS (including PFOS, PFOA, PFHxS, PFOSA) worldwide in a wide array of mammal, bird, and fish species, including grey seals, polar bears, brown pelicans, black footed albatross, bald eagles, and yellow-fin tuna. PFAS are easily accumulated throughout all trophic levels, including at the lowest levels of grazing, filtering, and shredding invertebrates (Ahrens & Bundschuh, 2014).

Available evidence shows the likely potential for bioaccumulation or biomagnification in marine or terrestrial species (EPA, 2009). Biomagnification results in greater levels of PFAS in animals higher on the food chain (e.g., seals, polar bears), relative to animals at lower trophic levels (Ahrens & Bundschuh, 2014; Houde et al., 2011). PFOS and longer chain PFCAs (> C_8) bioaccumulate and persist in protein-rich compartments of fish and birds, and in marine mammal tissues, such as carcass, blood, and liver (Conder et al., 2008). Carcass typically consists of bones, but sometimes includes head, fins, skin, or feathers, as well. PFOS has been the most frequently detected PFAA in zooplankton and other invertebrate studies (Reiner & Place, 2015). However, these authors note that while some studies have shown concentrations of PFOS and other PFAAs very close to detection limits, more recent studies have improved

analytical techniques (e.g., lower detection limits, better recovery, and use of reference materials), which produce less uncertainty in analytical results.

Levels of PFSAs and PFCAs in organisms are consistently measured at higher levels compared to other PFAS, and chain lengths of eight and above predominate (Martin et al., 2013; Dassuncao et al., 2017). In fact, many studies have suggested that PFCAs and PFSAs with shorter than seven and six fluorinated carbons, respectively, would not be considered bioaccumulative according to common regulatory criteria (Conder et al., 2008; Martin et al., 2013). However, there may be exceptions to this.

As described in Appendix 5: Environmental Occurrence, such chemicals have also been identified in wildlife present in Washington state. For example, PFOS and other long-chain PFAAs have been detected in freshwater and marine fish fillet and liver samples, as well as in osprey eggs (Ecology, 2017, in prep.). However, detection of chemicals in wildlife does not necessarily imply high bioaccumulation potential for any specific chemical, but does comprise a standard element of many environmental monitoring programs.

The large number of biota samples collected that contain quantifiable amounts of PFCAs, the ongoing scientific discourse regarding the high persistence and long-range fate and transport of PFCAs, and perceived similarities with perfluorinated sulfonates (including PFOS) have prompted concerns regarding the bioaccumulation potential of PFCAs (Conder et al., 2008). For example, due to their persistence and ability to transport long distances, animals do not need to be near emission sources of PFAS to show bioaccumulation. In particular, one study has shown elevated levels of PFAS in Scandinavian marine animals, although there is no production of PFAS in Scandinavia (Roos et al., 2013). In addition to long-range transport, PFOS is reported to have a very low Henry's law constant (i.e., ratio of a chemical concentration in the air to its concentration in water), indicating aquatic environments may be a significant sink for PFOS with a potential for bioaccumulation in fish (Boudreau et al., 2003).

Plants have been shown to take up some types of PFAS from the soil (Ahrens et al., 2016; Blaine et al., 2014), an issue of concern, since, for example, agricultural fields have the potential to be treated with PFAS-contaminated biosolids from WWTPs. Certain types of PFAS (e.g., shorter chain PFAS) can accumulate in leaves, fruits, and roots, with levels correlating with water content of the plant (Blaine et al., 2013; Scher et al., 2018). Concentrations of PFOA and PFOS in plants vary greatly, depending on the concentrations applied to the soil and soil-to-plant uptake factors. The uptake and transfer of these substances to vegetative parts of the plants appear to be greater than the transfer to storage organs within the plants (Stahl et al., 2009).

PFAA studies of birds have benefited from having species derived from many regions of the planet, including both aquatic and terrestrial ecosystems, representing a broad range of PFAA sources. The majority of these studies focus on birds from the Arctic, North America, and Europe. However, there does appear to be limited studies from the Southern Hemisphere (Antarctica and the Southern Ocean). Although initial wildlife studies focused on PFOS and PFOA, subsequent studies have expanded to include PFSAs, PFCAs, and PFAA precursors (e.g., FT alcohols, sulfonamide ethanols, perfluorosulfonamides, FT saturated and unsaturated carboxylic acids) (Reiner & Place, 2015).

In an earthworm study focused on bioaccumulation of PFAAs, the highest BAF (139 g soil dry wt/g worm dry wt) was observed for PFHxS in a soil contaminated with firefighting foam (Rich et al., 2015). BAFs increased with chain length for PFCAs but decreased with chain length for PFSAs (Rich et al., 2015). The unexpected finding for PFSAs may relate to decreased bioavailability. Overall, results from this study indicated that PFAA bioaccumulation into earthworms depends on soil concentrations, soil characteristics, analyte, and duration of exposure, and that accumulation into earthworms may be a potential route of entry of PFAAs into terrestrial foodwebs (Rich et al., 2015).

Other studies have assessed PFAS uptake in terrestrial biota. For example, Das et al. (2015) reported BAFs, ranging from 1.2 – 13.9 in earthworms exposed to soils contaminated with aqueous film forming foams (AFFF) containing PFOS. In their study, BAFs were higher from soils with lower PFOS concentrations. In another study, biota-soil accumulation factors (BSAFs) in earthworms increased as PFAS chain length increased (Mohammadi, 2015). However, chain length had an inverse effect in zucchini plants, showing a decreased BCF with longer chain length (Mohammadi, 2015), similar to results of Rich et al. (2015) noted above for PFSAs. In addition, Mohammadi (2015) reported no significant differences in BSAF or BCF among PFAS compounds with the same chain length but different functional groups. However, Shi et al. (2018) found that functional group was a relatively more important predictor of internal distribution than chain length for PFAS in an aquatic study.

In summary, bioaccumulation is generally apparent for a variety of long-chain PFAS compounds in both terrestrial and aquatic wildlife. However, as shown in Table 61, BAF values in aquatic biota vary by specific compound, species, and tissue.

Table 61. BAF values for aquatic biota.

PFAS	Species	Tissue	BAF (L/Kg)	Reference
PFOS	Bluegill	Fillet	2,700	MPCA, 2013
PFOS	Carp	Fillet	1,237	MPCA, 2013
PFOS	Freshwater Drum	Fillet	3,077	MPCA, 2013
PFOS	Smallmouth Bass	Fillet	2,845	MPCA, 2013
PFOS	White Bass	Fillet	4,618	MPCA, 2013
PFOS	Common Shiner	Liver	6,300 – 125,000	Moody et al., 2002
PFOS	Rainbow Trout	Carcass	690	ECCC, 2017
PFOS	Rainbow Trout	Blood	3,100	ECCC, 2017
PFOS	Rainbow Trout	Liver	2,900	ECCC, 2017
PFOS	Phytoplankton	Whole body	169	Loi et al., 2011
PFOS	Lake Trout	Whole body	31,623	De Silva et al., 2011
PFOA	Phytoplankton	Whole body	292	Loi et al., 2011
PFOA	Lake Trout	Whole body	126	De Silva et al., 2011
PFOA	Rainbow Trout	Blood	27	OECD, 2008
PFOA	Rainbow Trout	Liver	8	OECD, 2008
PFOA	Rainbow Trout	Whole body	4	OECD, 2008
PFHxS	Phytoplankton	Whole body	58	Loi et al., 2011

PFAS	Species	Tissue	BAF (L/Kg)	Reference
PFNA	Phytoplankton	Whole body	1,650	Loi et al., 2011
PFDA	Phytoplankton	Whole body	765	Loi et al., 2011
PFECHS	Lake Trout	Whole body	631	De Silva et al., 2011
PFUnDA	Phytoplankton	Whole body	4,510	Loi et al., 2011

PFOS is typically a dominant PFAS compound in fish (Taniyasu et al., 2003; Yoo et al., 2009), although internal distribution and relative PFAS compound concentrations in fish depend on tissue (e.g., blood versus liver) and their proteinophilic properties (Jeon et al., 2010). Shi et al. (2018) observed that BAF patterns in carp are most consistent with protein-binding mechanisms, although partitioning to phospholipids may contribute to the accumulation of long-chain PFAS in specific tissues. Among several PFOS isomers, linear PFOS represented a much higher proportion of total PFOS (sum of linear and branched isomers) in zooplankton and fish (Houde et al., 2008). BAFs for linear PFOS were also greater than for branched PFOS isomers in this food web (Houde et al., 2008). Longer chain PFCAs (e.g., C_{12}, C_{14}) were associated with higher BCFs in carp (10,000 – 17,000), relative to shorter chain PFCAs (e.g., C_8, C_{11}) (Inoue et al., 2012). In this study, viscera contained higher PFAS concentrations than head and integument in carp. With most PFAS compounds (except PFOA), a positive correlation has been observed between BCF in blackrock fish and salinity (Jeon et al., 2010).

Due to the persistence of all PFAAs, including short-chain PFAAs, exposure will continue regardless of accumulation because bioaccumulation is not required for sustained internal exposure (Cousins et al., 2016). For this reason, the Norwegian and German environmental agencies have proposed adding a new designation to the REACH Substances of High Concern list—mobile (M) and very mobile (vM). This would allow short-chain compounds, which do not categorize as persistent, bioaccumulative, and toxic (PBT) since they are not bioaccumulative, to still be added to the list as persistent, mobile, and toxic (PMT) (Kotthoff & Bucking, 2018; Turley, 2018). The theory is that PMT compounds would be an equivalent concern to PBT compounds, since they would also have sustained exposure.

In summary, bioaccumulation within the organism appears to be dependent on chain length. PFAS that contain six or more perfluorinated carbons have the potential to bioaccumulate within ecological receptors. It is apparent that wildlife from around the world are exposed to PFAS compounds. The main compound found in most wildlife species is PFOS. However, especially in more recent studies, long-chain PFCAs are frequently detected and measured (Reiner & Place, 2015).

6.3 Toxicokinetics

The toxicokinetic properties and toxicological responses of PFOS and PFOA have been studied in some detail. These chemicals may act as endocrine disruptors, although their molecular mechanisms are still debated (Kang et al., 2019). Immunotoxicity seems to be another effect. For example, the literature demonstrates a high confidence in the association between PFOA exposure and suppressed antibody response in animals (NTP, 2016). While there appears to be more literature available for aquatic than upland biota, enough information is available for both to summarize the fate, as well as possible adverse effects, of these contaminants. In particular, animal studies with both PFOS and PFOA have shown that they are well-absorbed orally, but poorly eliminated, not metabolized, and undergo extensive re-uptake from enterohepatic circulation (Lau, et al. 2007). Enterohepatic circulation refers to the circulation of the chemical from the liver to the bile, followed by entry into the small intestine, absorption by the intestinal absorptive cells, and then transport back to the liver.

Unlike most other bioaccumulating compounds, PFAAs do not bind to lipids (fats), but instead bind to proteins (Jones et al., 2003). Because of this, they are found mostly in the liver and blood (Norden et al., 2013), which lessens the utility of using measures such as K_{ow} (octanol-water partition coefficient) to predict bioaccumulation. K_{ow} is not particularly relevant for assessing PFAS distribution in tissues. Thus, it is difficult to predict bioaccumulation of PFAS compounds, such that evaluating bioaccumulation may require experimental testing.

Conder et al (2008) also noted that the principal repository of bioaccumulated PFCA and PFSA in organisms is not lipid but protein. Although a portion of these chemicals is hydrophobic and may interact with lipids, the presence of the carboxylate or sulfonate functional group imparts high hydrophilicity, thereby making the molecule partly lipophilic and partly hydrophilic (Houde et al., 2008; Shi et al,. 2018).

Several studies have suggested that PFAAs are proteinophilic. For example, PFO in both rats and humans was strongly associated with serum albumin and other cytosolic proteins, and the proteinophilic nature of this class of chemicals has been hypothesized for the longer-chain PFAS (seven to eight fluorinated carbons). In support of this hypothesis, PFD (nine fluorinated carbons) has been shown to be more potent than PFO (seven fluorinated carbons) in binding to avian and carp serum proteins (Conder et al., 2008).

Therefore, in general, studies indicate that PFAAs are proteinophilic. For example, the tissue distribution of PFOA is dictated, to some extent, by its ability to bind plasma and other proteins (Kennedy et al., 2004). In contrast to the protein-binding ability of those chemicals with longer fluorinated carbon chains, the shorter perfluorinated compounds (PFSA and PFCA with four and three fluorinated carbons, respectively) were found to be one to two orders of magnitude less proteinophilic (Conder et al., 2008).

6.4 Toxicological Effects

Comparing adverse effects among studies can be confounded by differences in species and gender, as well as experimental differences in dose regimen (e.g., spacing, magnitude, duration, and route of administration). However, if the toxic mechanism is conserved, and some measure of the tissue concentration (i.e., dosimetry) at the biological target can be determined, then it is expected that this dosimetric anchor would be conserved across studies. Careful consideration of toxicokinetics is therefore required in order to link chemical exposure to toxicity (Wambaugh, 2015). Tables 63, 64, and 65 presented later in this section illustrate effects associated with chemical concentrations in water (aquatic species) or chemical dose (upland species).

6.4.1 Aquatic biota

Several toxicological effects have been tabulated for PFOA and PFOS in aquatic biota (Tables 63 and 64). A variety of endpoints and effect concentrations are listed. As expected, gene expression effects occur at low concentrations, relative to concentrations linked with deficits in apical endpoints (e.g., growth, survival, reproduction) (Table 62). This observation is consistent with an adverse outcome pathway (AOP) framework, ranging from a molecular initiating event to lethality (Ankley et al., 2010; Kramer et al., 2011).

Table 62. Toxicological effects of PFOA and PFOS in freshwater species.

Chemical	Species	Concentration (µg/L)	Effect	Reference
PFOA	Blue-green algae	5,000 (LOEC)	Physiology/Membrane potential	Rodea-Palomares et al., 2015
PFOA	Atlantic salmon	100 (LOEC)	Genetics/Bone development	Spachmo & Arukwe, 2012
PFOS	African clawed frog	0.1 (LOEC)	Genetics/Up-regulation of thyroid hormone regulated genes	Cheng et al., 2011
PFOS	Water flea	312.5 (LOEC)	Reproduction	Ji et al., 2008
PFOS	Fathead minnow	3,300 (NOEC)	Survival	Drottar & Krueger, 2000

Notes:

- LOEC is lowest observed effect concentration.
- NOEC is no observed effect concentration.

Freshwater biota

It has been reported that PFAS inhibited growth and had detrimental effects on photosynthesis on green algae (P. subcapitata, S. capricornutum, and C. vulgaris) (Boudreau et al., 2003; Ding et al., 2012), as well as the floating macrophyte, L. gibba (Boudreau et al., 2003). PFOS has been shown to be moderately toxic to aquatic invertebrates with acute toxicity values (48 and 96 hr LC50) in the range of 10 – 300 mg/L, while PFOA has been shown to be only slightly toxic to aquatic invertebrates, with toxicity values in the range of 100 – 1,000 mg/L (Li, 2009).

OECD (2002) lists a 42 d NOEC (survival) of 0.3 mg/l in an early life stage test with fathead minnows, using the potassium salt of PFOS. Although no significant effects were observed in another study (Ankley et al., 2005) on survival and growth for developing fathead minnows over 24 days at this same concentration (0.3 mg/L PFOS), these authors reported a 21-day EC50 (fecundity) of 0.23 mg/L PFOS in adult fish. This highlights the influence of life stage, test duration, and endpoint on effect concentration. PFOA concentrations were observed in the following order in the tissues of rainbow trout (Oncorhynchus mykiss): blood > kidney > liver > gall bladder > gonads > adipose > muscle tissue, at average water exposure concentrations between 0.014 and 1.7 µg/L (Martin et al., 2003). PFAAs also were detectable in the gills, suggesting that this was the site of uptake, depuration, or both, as has been determined for other xenobiotics (Martin et al., 2003).

Table 63. Toxicological effects of PFOA and PFOS in saltwater species.

Chemical	Species	Concentration (µg/L)	Effect	Reference
PFOA	Sea urchin	20,000 (LOEC)	Growth/length	Mhadhbi et al., 2012
PFOA	Mysid	7,800 (EC10)	Mortality	Mhadhbi et al., 2012
PFOS	Mysid	530 (LOEC)	Survival	Drottar & Krueger, 2000
PFOS	Algae	12,200 (EC10)	Population/growth rate	Mhadhbi et al., 2012
PFOS	Mysid	3,200 (EC10)	Mortality	Mhadhbi et al., 2012
PFOS	Sea urchin	2,000 (EC10)	Growth/length	Mhadhbi et al., 2012

Notes:

- LOEC is lowest observed effect concentration.
- EC10 is 10% effect concentration.

Marine environment

Marine diatoms are far more sensitive to PFCAs than green algae, probably because of differences in cell wall structure (Latala et al., 2009). These authors recommended that further research focus on effects of PFAS mixtures and their derivatives in aquatic systems.

Biomagnification of PFOS, along a marine food chain (Greenland and Faroe Islands), was in the order shorthorn sculpin > ringed seal > polar bear (Bossi et al., 2005). The greatest concentration of PFOS was found in the liver of polar bears (mean = 1,285 ng/g wet wt, n = 2). In a lower latitude region (southeastern U.S.), PFOS and C_8 and C_{10} PFCAs concentrations have been detected in dolphin plasma and tissue samples, and long-chain PFCAs were found to biomagnify in this dolphin food web (Houde et al., 2006a). Although dolphins in southern Australia contained relatively high PFOS concentrations in liver, adverse effects were not apparent (Gaylard, 2017).

In contrast, data presented on PFOS exposure to marine wildlife (e.g., nursing beluga whale calves) suggests risk for developmental impacts in a Canadian Arctic marine food web (Kelly et al., 2009). PFOS and $C_8 – C_{14}$ PFCAs were highly bioaccumulative in this Arctic marine food web.

However, biomagnification of perfluorinated acids (e.g., PFCAs, PFSAs) was seen in air-breathers (e.g., seals, whales, polar bears) but not in water-breathers (e.g., fish). The lack of PFAS biomagnification observed in water-respiring biota may be due to high aqueous solubility of these PFAS compounds, along with their efficient respiratory elimination via gills. In contrast, resistance to metabolism and low volatility (such as slow protein or air elimination) of PFAS results in biomagnification in air-breathing wildlife (Kelly et al., 2009).

6.4.2 Terrestrial biota

Upland plants (and surrogates)

Surrogate plant species are often used to evaluate the effect of contaminants on native wild plant species (EPA, 2012). For example, effects of PFAS on growth and reproduction have been studied in lettuce, pak choi, and cucumber (Ding et al., 2012; Li et al., 2009). In these studies, there were no obvious effects on seed germination for these species. However, based on EC_{10}, EC_{50}, and NOECs, the five-day root elongation sensitivity of test plants to both PFOS and PFOA were in the order lettuce > pak choi > cucumber (Li et al., 2009). In addition, another study evaluated effects of seven PFCs (PFBA; 2,2,3,3,4,4,5,5 Octafluoro-1-pentanol; PFOA; PFNA; PFDA; PFUnA; PFDoA) in a five-day test on root elongation of lettuce (*L. sativa*) (Ding et al., 2012). This study indicated that toxic effects of the seven PFCs increased with increasing fluorinated carbon chain length. It should be noted that extrapolating effects of PFAS on these surrogate test species to upland plants introduces additional uncertainty into an assessment of wild native plants.

Upland animal wildlife (and surrogates)

Limited information is available on the toxicokinetics and toxicological properties of PFOS and PFOA on upland wildlife receptors. Because few studies have determined safe exposure levels (NOAELs) for situations in which wildlife have been exposed over an entire lifespan or several generations, chronic exposures to a particular chemical are often estimated from toxicity studies conducted on a surrogate species with standard protocols. In many cases, the only available information is from studies on a laboratory species (primarily rats and mice) (Sample et al., 1996). While not ideal, these surrogate species do provide valuable information.

For example, a study was performed exploring the induction of liver tumors in Wistar rats for several chemicals, including PFOA (Abdellatif et al., 1990). In comparison to controls, this study indicated that PFOA caused a 24-fold increase in the peroxisomal β-oxidation of fatty acids, but only about a 2-fold increase in catalase activity. These results suggest that PFOA has a promoting action on liver carcinogenesis.

In other laboratory studies, exposure to PFOA significantly increased relative liver weights in offspring in all treatment groups in a full gestation study. Offspring of PFOA-treated dams exhibited significantly stunted mammary epithelial growth, as assessed by developmental scoring (Macon et al., 2011). Evaluation of internal dosimetry in offspring revealed that PFOA concentrations remained elevated in liver and serum for up to six weeks and that brain concentrations were low and undetectable after four weeks. Additionally, in wild-type mice, concentrations of PFOA measured in the serum and liver were directly correlated with

increasing dose to the animal, while the livers had ultrastructural changes induced by PFOA (Wolf et al., 2008).

In an air cell injection study of PFOS with white leghorn chicken embryos, Molina et al. (2006) report an LD50 of 4.9 µg/g egg (embryos) and a LOAEL of 0.1 µg/g egg (reduced hatchability). Pathological changes in the liver were observed at doses as low as 1.0 µg/g egg, including bile duct hyperplasia, periportal inflammation, and hepatic cell necrosis. Based on reproductive studies with mallard and northern bobwhite, Molina et al. (2006) suggest that the chicken embryo is considerably more sensitive to PFOS, as compared with wild avian species. NOAELs, LOAELs, toxicity reference values (TRVs), and predicted no effects concentrations (PNECs) have been derived for dietary PFOS exposure for the mallard and northern bobwhite quail (Newsted et al., 2005). Toxicological endpoints included mortality, growth, feed consumption, and histopathology. Reproductive endpoints included egg production, fertility, hatchability and survival, and growth of offspring. Newsted et al. (2005) report a TRV of 0.021 mg/kg bw/d and a PNEC of 0.013 mg/kg bw/d for dietary PFOS intake, proposing that these benchmarks are protective of avian populations.

It was not Ecology's objective to present a comprehensive review of all PFAS chemicals with effects data in birds and mammals. Rather, a representative sample of reproductive and developmental effects on surrogate terrestrial animal species for several PFAS chemicals is presented in Table 64. Again, a variety of endpoints and dose levels are listed. In some cases, NOAELs and LOAELs were identified for selected endpoints from the study. Most of these data are for surrogate test animals, which imperfectly represent wildlife species.

Table 64. Reproductive and developmental effects of selected PFAS compounds in terrestrial upland and surrogate animal species (Stahl et al., 2011).

Chemical and dose	Species	Exposure period (gestation days)	Effect	NOAEL	LOAEL	Reference
PFOS 1 – 10 mg/kg BW/d	Rats	6 – 15	Decreased body mass and lens abnormalities	5 (fetal, maternal)	10 (fetal, maternal)	Gortner, 1980
PFOS 10 – 150 mg/kg feed	Quail	NR	Decreased viability of the 14 day old progeny; slight increase in incidences of small testes, however spermatogenesis and fertility were not affected	<10 mg/kg feed (progeny)	10 mg/kg feed (progeny)	Newsted et al., 2007

Chemical and dose	Species	Exposure period (gestation days)	Effect	NOAEL	LOAEL	Reference
PFOS 0.1 – 3.75 mg/kg BW/d	Rabbits	6 – 20	Decrease in weight gain of the maternal animal; decreased birth weight and delayed ossification	0.1 (maternal), 1 (fetal)	1 (maternal), 2.5 (fetal)	Case et al., 2001
PFOS 1 – 5 mg/kg egg	Leghorn chickens	Before incubation	No effect on hatching rate; increased spleen mass; right wings shorter; frequent occurrence of brain asymmetry; decreased immunoglobulin; increased plasma lysozyme activity; increased liver mass; increased body length	<1 mg/kg egg	1 mg/kg egg	Peden-Adams et al., 2009
APFO 1 – 30 mg/kg	Rats	NR	Decreased body weight; increased liver and kidney mass; decreased birth weight; delayed puberty; increased mortality rate after weaning	>30 mg/kg (parent and F1 reproduction), 10 mg/kg (F1 mortality and birth weight)	1 mg/kg (parent and F1 male decreased body weght (BW) and organ weight increases), 30 mg/kg (F1 increased mortality, decreased birth weight)	Butenhoff et al., 2004

Chemical and dose	Species	Exposure period (gestation days)	Effect	NOAEL	LOAEL	Reference
PFOA 1 – 40 mg/kg BW/d	Mice	During gestation	Liver enlargement; decrease in full term gestation, viable fetuses, fetus weight, and postnatal viability; growth deficit; delayed opening of eyes; accelerated sexual maturity of male progeny	10 (dam weight gain), <1 (dam liver mass), 3 (offspring survival), 1 (offspring growth)	20 (dam decreased weight gain), 1 (dam liver enlargement), 5 (lower offspring survival), 3 (offspring growth deficit)	Lau et al., 2006
PFOA 5 – 40 mg/kg egg	Chickens	Before incubation	Impaired hatching rate; high prevalence of splayed legs; chicks with partial or complete loss of yellow pigment in the down	<5 mg/kg egg (hatching success), 20 mg/kg egg (splayed legs), 5 mg/kg egg (abnormal pigmentation)	5 mg/kg egg (decreased hatching), 40 mg/kg egg (splayed legs), 20 mg/kg egg (abnormal pigmentation)	Yanai et al., 2008
PFBA 35 – 350 mg/kg BW/d	Mice	1 – 17	No adverse effects on survival rate of progeny or their postnatal growth; delayed opening of eyes; delayed onset of puberty; at the highest dosage, loss of complete litter	<35 (maternal weight gain, fetus weight, neonatal survival, postnatal growth)	35 (offspring delayed eye opening), 175 (offspring delayed onset of puberty), 350 (full litter loss)	Das et al., 2008
PFDA 0.25 – 32 mg/kg BW/d	Mice	10 – 13	Decrease in weight gain of maternal animal at high doses, fetal body weight reduced a low doses, no malformations observed	>32 no malformations	16 (maternal decreased wt gain), 0.5 (fetal wt reduced)	Harris & Birnbaum, 1989

Notes:

- NR is not reported.
- NOAEL is no observed adverse effect level.
- LOAEL is lowest observed adverse effect level.

- Dose, NOAEL, and LOAEL are presented in units of [mg/kg BW/d] or in units indicated.
- Exposure period presented as gestation days or as indicated.

6.5 Data gaps and recommendations

6.5.1 Data gaps

Broad data gaps exist in exposure and effects assessment for wildlife species. For example, surrogate species are often used to represent wildlife species, exposure pathways are incompletely elucidated (such as food chain exposures), and cleanup levels for ecological receptors are generally lacking. Because the literature is rapidly expanding in the areas of PFAS ecotoxicity and ecorisk, this review is not comprehensive but instead serves as a snapshot of the subject.

Recent efforts to investigate PFAS ecotoxicity and ecorisk in the U.S. include:

- EPA's PFAS Action Plan (EPA, 2019).
- A focused topic meeting organized by the Society of Environmental Toxicology and Chemistry (SETAC), held in August 2019 (SETAC, 2019).
- A document produced by the ITRC (ITRC, 2020b).
- Research conducted by the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP), which are DOD programs (DOD, 2019; Conder et al., 2020; Divine et al.,2020).

6.5.2 Recommendations

Organizations in the U.S. (e.g., EPA) and internationally (e.g., European Union [EU]) are pursuing research and developing guidance that will fill regulatory gaps related to PFAS and ecotoxicology. As such, Ecology could leverage some of this work to implement many of the broader, more generic recommendations listed below. Perhaps in some cases, the needed information could be generated or adapted by Ecology to unique features in Washington state (such as PFAS environmental monitoring or protection of orcas in Puget Sound), depending on agency resources like funding and staff time.

Based on the analysis in this appendix, we make the following sub-recommendations as part of Recommendation 2.1:

Recommendation 2.1: Establish PFAS cleanup levels for soil, surface water, and sediment for ecological receptors:

- Ecology will conduct monitoring for PFAS compounds in environmental media (soils, surface waters, sediment) and wildife tissue to identify sources of contamination and to assess exposure.
- Once sufficient supporting data are available, Ecology plans to develop cleanup levels for individual or mixtures of PFAS for soil, sediment, fresh water, and salt water to protect ecological receptors.

- In this context, the following activities will be implemented to support activity under the recommendations above:
  - Trophic transfer and bioaccumulation of PFAS compounds should be further evaluated in aquatic and terrestrial food webs to further understand exposure.
  - Selected individual PFAS compounds, as well as common PFAS mixtures, should be evaluated for ecotoxicity in aquatic and terrestrial biota, using both laboratory and field methods.
  - Ecological risk assessment should be performed for PFAS compounds by detailing exposure and effects in order to estimate risks to nonhuman biota.
  - An uncertainty analysis should accompany PFAS ecorisk assessment to promote transparency in the risk assessment and communication processes and to more clearly identify data gaps.
  - Results of these risk assessments should support potential interventions (for example, species protections) and characterization of potential impacts on ecological services.

References

Abdellatif, A. G., Préat, V., Vamecq, J., Nilsson, R., & Roberfroid, M. (1990). Peroxisome proliferation and modulation of rat liver carcinogenesis by 2,4-dichlorophenoxyacetic acid, 2,4,5-trichlorophenoxyacetic acid, perfluorooctanoic acid and nafenopin. *Carcinogenesis*, *11*, 1899–1902. https://doi.org/10.1093/carcin/11.11.1899

Ahrens, L., & Bundschuh, M. (2014). Fate and effects of poly- and perfluoroalkyl substances in the aquatic environment: A review. *Environmental Toxicology and Chemistry*, *33*, 1921–1929. https://doi.org/10.1002/etc.2663

Ahrens, L., Hedlund, J., Dürig, W., Tröger, R., & Wiberg, K. (2016). Screening of PFAS in groundwater and surface water. *Swedish Environmental Protection Agency*. https://pub.epsilon.slu.se/13236/1/ahrens_l_etal_160330.pdf

Ankley, G. T., Bennett, R. S., Erickson, R. J., Hoff, D. J., Hornung, M. W., Johnson, R. D., Mount, D. R., Nichols, J. W., Russom, C. L., Schmieder, P. K., Serrrano, J. A., Tietge, J. E., & Villeneuve, D. L. (2010). Adverse outcome pathways: A conceptual framework to support ecotoxicology research and risk assessment. *Environmental Toxicology and Chemistry*, *29*, 730–741. https://doi.org/10.1002/etc.34

Ankley, G. T., Kuehl, D. W., Kahl, M. D., Jensen, K. M., Linnum, A., Leino, R. L., & Villeneuve, D. A. (2005). Reproductive and developmental toxicity and bioconcentration of perfluorooctanesulfanate in a partial life-cycle test with the fathead minnow (Pimephales promelas). *Environmental Toxicology and Chemistry*, *24*, 2316. https://doi.org/10.1897/04-634R.1

Blaine, A. C., Rich, C. D., Hundal, L. S., Lau, C., Mills, M. A., Harris, K. M., & Higgins, C. P. (2013). Uptake of Perfluoroalkyl Acids into Edible Crops via Land Applied Biosolids: Field and Greenhouse Studies. *Environmental Science & Technology*, *47*, 14062–14069. https://doi.org/10.1021/es403094q

Blaine, A. C., Rich, C. D., Sedlacko, E. M., Hundal, L. S., Kumar, K., Lau, C., Mills, M. A., Harris, K. M., & Higgins, C. P. (2014). Perfluoroalkyl Acid Distribution in Various Plant Compartments of Edible Crops Grown in Biosolids-Amended soils. *Environmental Science & Technology*, *48*, 7858–7865. https://doi.org/10.1021/es500016s

Bossi, R., Riget, F. F., Dietz, R., Sonne, C., Fauser, P., Dam, M., & Vorkamp, K. (2005). Preliminary screening of perfluorooctane sulfonate (PFOS) and other fluorochemicals in fish, birds and marine mammals from Greenland and the Faroe Islands. *Environmental Pollution*, *136*, 323–329. https://doi.org/10.1016/j.envpol.2004.12.020

Boudreau, T. M., Sibley, P. K., Mabury, S. A., Muir, D. G. C., & Solomon, K. R. (2003). Laboratory Evaluation of the Toxicity of Perfluorooctane Sulfonate (PFOS) on Selenastrum capricornutum, Chlorella vulgaris, Lemna gibba, Daphnia magna, and Daphnia pulicaria. *Archives of Environmental Contamination and Toxicology*, *44*, 307–313. https://doi.org/10.1007/s00244-002-2102-6

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., de Voogt, P., Jensen, A. A., Kannan, K., Mabury, S. A., & van Leeuwen, S. P. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environmental Assessment and Management*, *7*, 513–541. https://doi.org/10.1002/ieam.258

Butenhoff, J. L., Kennedy, G. L., Frame, S. R., O'Connor, J. C., & York, R. G. (2004). The reproductive toxicology of ammonium perfluorooctanoate (APFO) in the rat. *Toxicology*, *196*, 95–116. https://doi.org/10.1016/j.tox.2003.11.005

Case M. T., Raymond G. York, Mildred S, M. (2001). Rat and Rabbit Oral Developmental Toxicology Studies with Two Perfluorinated Compounds. *International Journal of Toxicology*, *20*, 101–109. https://doi.org/10.1080/10915810151115236

Cheng, Y., Cui, Y., Chen, H., & Xie, W. (2011). Thyroid disruption effects of environmental level perfluorooctane sulfonates (PFOS) in Xenopus laevis. *Ecotoxicology*, *20*, 2069–2078. https://doi.org/10.1007/s10646-011-0749-3

Conder, J. M., Arblaster, J., Larson, E., Brown, J., & Higgins, C. (2020). Guidance for Assessing the Ecological Risks of PFASs to Threatened and Endangered Species at Aqueous Film Forming Foam-Impacted Sites. SERDP Project ER18-1614. *Strategic Environmental Research and Development Program (SERDP)*. Retrieved from https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/ER18-1614

Conder, J. M., Hoke, R. A., Wolf, W. de, Russell, M. H., & Buck, R. C. (2008). Are PFCAs Bioaccumulative? A Critical Review and Comparison with Regulatory Criteria and Persistent Lipophilic Compounds. *Environmental Science & Technology*, *42*, 995–1003. https://doi.org/10.1021/es070895g

Cousins, I. T., Vestergren, R., Wang, Z., Scheringer, M., & McLachlan, M. S. (2016). The precautionary principle and chemicals management: The example of perfluoroalkyl acids in groundwater. *Environment International*, *94*, 331–340. https://doi.org/10.1016/j.envint.2016.04.044

Das, K. P., Grey, B. E., Zehr, R. D., Wood, C. R., Butenhoff, J. L., Chang, S.-C., Ehresman, D. J., Tan, Y.-M., & Lau, C. (2008). Effects of Perfluorobutyrate Exposure during Pregnancy in the Mouse. *Toxicological Sciences*, *105*, 173–181. https://doi.org/10.1093/toxsci/kfn099

Das, P., Megharaj, M., & Naidu, R. (2015). Perfluorooctane sulfonate release pattern from soils of fire training areas in Australia and its bioaccumulation potential in the earthworm Eisenia fetida. *Environmental Science and Pollution Research*, *22*, 8902–8910. https://doi.org/10.1007/s11356-013-1782-y

Dassuncao, C., Hu, X. C., Zhang, X., Bossi, R., Dam, M., Mikkelsen, B., & Sunderland, E. M. (2017). Temporal Shifts in Poly- and Perfluoroalkyl Substances (PFASs) in North Atlantic Pilot Whales Indicate Large Contribution of Atmospheric Precursors. *Environmental Science & Technology*, *51*, 4512–4521. https://doi.org/10.1021/acs.est.7b00293

De Silva, A. O., Spencer, C., Scott, B. F., Backus, S., & Muir, D. C. G. (2011). Detection of a Cyclic Perfluorinated Acid, Perfluoroethylcyclohexane Sulfonate, in the Great Lakes of North America. *Environmental Science & Technology*, *45*, 8060–8066. https://doi.org/10.1021/es200135c

Ding, G., Wouterse, M., Baerselman, R., & Peijnenburg, W. J. G. M. (2012). Toxicity of Polyfluorinated and Perfluorinated Compounds to Lettuce (Lactuca sativa) and Green Algae (Pseudokirchneriella subcapitata). *Archives of Environmental Contamination and Toxicology*, *62*, 49–55. https://doi.org/10.1007/s00244-011-9684-9

Divine, C., Zodrow, J., Frenchmeyer, M., Dally, K., Osborn, E., & Anderson, P. (2020). Approach for Assessing PFAS Risk to Threatened and Endangered Species. SERDP Project ER18-1653. *Strategic Environmental Research and Development Program (SERDP)*. Retrieved from https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/ER18-1653

Drottar, K. R., & Krueger, H. O. (2000). PFOS: A 96-hr static acute toxicity test with the fathead minnow (Pimephales promelas). *Wildlife International, Ltd*., Project No. 454-102, U.S. EPA Docket AR226-0083

Environment and Climate Change Canada (ECCC). (2017). Ecological screening assessment report on perfluorooctane sulfonate, its salts and its precursors that contain the C8F17SO2 or C8F17SO3, or C8F17SO2N moiety. Retrieved from https://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=98B1954A-1&offset=1&toc=hide

Gaylard, S. (2017). Per and polyfluorinated alkyl substances (PFAS) in the marine environment – Preliminary ecological findings. *South Australia Environmental Protection Agency (SAEPA)*. Retrieved from https://www.epa.sa.gov.au/files/12580_report_pfas_marine.pdf

Giesy, J. P., & Kannan, K. (2002). Peer Reviewed: Perfluorochemical Surfactants in the Environment. *Environmental Science & Technology*, *36*, 146A-152A. https://doi.org/10.1021/es022253t

Gortner, E. G. (1980). Oral teratology study of FC-95 in rats: Experiment Number: 0680TR0008, AR-226 226-0016. *Riker Laboratories, Inc*. https://www.ag.state.mn.us/Office/Cases/3M/docs/PTX/PTX1247.pdf

Guelfo, J. L., & Higgins, C. P. (2013). Subsurface Transport Potential of Perfluoroalkyl Acids at Aqueous Film-Forming Foam (AFFF)-Impacted Sites. *Environmental Science & Technology*, *47*, 4164–4171. https://doi.org/10.1021/es3048043

Harris, M. W., & Birnbaum, L. S. (1989). Developmental Toxicity of Perfluorodecanoic Acid in C57BL/6N Mice. *Toxicological Sciences*, *12*, 442–448. https://doi.org/10.1093/toxsci/12.3.442

Houde, M., Bujas, T. A. D., Small, J., Wells, R. S., Fair, P. A., Bossart, G. D., Solomon, K. R., & Muir, D. C. G. (2006a). Biomagnification of Perfluoroalkyl Compounds in the Bottlenose Dolphin (Tursiops truncatus) Food Web. *Environmental Science & Technology*, *40*, 4138–4144. https://doi.org/10.1021/es060233b

Houde, M., Martin, J. W., Letcher, R. J., Solomon, K. R., & Muir, D. C. G. (2006b). Biological Monitoring of Polyfluoroalkyl Substances: A Review. *Environmental Science & Technology*, *40*, 3463–3473. https://doi.org/10.1021/es052580b

Houde, M., Czub, G., Small, J. M., Backus, S., Wang, X., Alaee, M., & Muir, D. C. G. (2008). Fractionation and Bioaccumulation of Perfluorooctane Sulfonate (PFOS) Isomers in a Lake Ontario Food Web. *Environmental Science & Technology*, *42*, 9397–9403. https://doi.org/10.1021/es800906r

Houde, M., De Silva, A. O., Muir, D. C. G., & Letcher, R. J. (2011). Monitoring of Perfluorinated Compounds in Aquatic Biota: An Updated Review. *Environmental Science & Technology*, *45*, 7962–7973. https://doi.org/10.1021/es104326w

Inoue, Y., Hashizume, N., Yakata, N., Murakami, H., Suzuki, Y., Kikushima, E., & Otsuka, M. (2012). Unique Physicochemical Properties of Perfluorinated Compounds and Their Bioconcentration in Common Carp Cyprinus carpio L. *Archives of Environmental Contamination and Toxicology*, *62*, 672–680. https://doi.org/10.1007/s00244-011-9730-7

Interstate Technology & Regulatory Council (ITRC). (2020a). Environmental fate and transport for per- and polyfluoroalkyl substances. Retrieved from https://pfas-1.itrcweb.org/fact_sheets_page/PFASFact_Sheet_Fate_and_Transport_April2020.pdf

Interstate Technology & Regulatory Council (ITRC). (2020b). Ecological Toxicology, Section 7.2 in: PFAS-Per- and Polyfluoroalkyl Substances. Retrieved from https://pfas-1.itrcweb.org/7-human-and-ecological-health-effects-of-select-pfas/#7_2

Inventory Multi-Tiered Assessment Prioritisation (IMAP). (2017a). Perfluorobutanesulfonic acid and its direct precursors: Environment tier II assessment. *Australian Inventory of Chemical Substances.* Retrieved from https://www.industrialchemicals.gov.au/sites/default/files/Perfluorobutanesulfonic acid and its direct precursors_ Environment tier II assessment.pdf

Inventory Multi-Tiered Assessment Prioritisation (IMAP). (2017b). Indirect precursors of perfluorobutanesulfonate (PFBS): Environment Tier II Assessment. *Australian Inventory of Chemical Substances.* Retrieved from https://www.industrialchemicals.gov.au/sites/default/files/Indirect precursors of perfluorobutanesulfonate %28PFBS%29_ Environment tier II assessment.pdf

Inventory Multi-Tiered Assessment Prioritisation (IMAP). (2017c). Short-chain perfluorocarboxylic acids and their direct precursors: Environment Tier II Assessment. *Australian Inventory of Chemical Substances.* Retrieved from https://www.industrialchemicals.gov.au/sites/default/files/Short-chain perfluorocarboxylic acids and their direct precursors_ Environment tier II assessment.pdf

Inventory Multi-Tiered Assessment Prioritisation (IMAP). (2017d). Direct precursors to perfluoroheptanesulfonate (PFHpS), perfluorohexanesulfonate (PFHxS) and perfluoropentanesulfonate (PFPeS): Environment Tier II Assessment. *Australian Inventory of Chemical Substances*. Retrieved from https://www.industrialchemicals.gov.au/sites/default/files/Direct precursors to perfluoroheptanesulfonate %28PFHpS%29%2C perfluorohexanesulfonate %28PFHxS%29 and perfluoropentanesulfonate %28PFPeS%29_ Environment tier II assessment.pdf

Inventory Multi-Tiered Assessment Prioritisation (IMAP). (2017e). Direct precursors to perfluorooctanesulfonate (PFOS): Environment Tier II Assessment. *Australian Inventory of Chemical Substances.* Retrieved from https://www.industrialchemicals.gov.au/sites/default/files/Direct precursors to perfluorooctanesulfonate %28PFOS%29_ Environment tier II assessment.pdf

Inventory Multi-Tiered Assessment Prioritisation (IMAP). (2017f). Perfluorooctanoic acid (PFOA) and its direct precursors. Environment Tier II Assessment. *Australian Inventory of Chemical Substances.* Retrieved from https://www.industrialchemicals.gov.au/sites/default/files/Perfluorooctanoic acid %28PFOA%29 and its direct precursors_ Environment tier II assessment.pdf

Inventory Multi-Tiered Assessment Prioritisation (IMAP). (2017g). Direct precursors to perfluorocyclohexane sulfonate and related perfluoroalkylcyclohexane sulfonates: Environment Tier II Assessment. *Australian Inventory of Chemical Substances*. Retrieved from https://www.industrialchemicals.gov.au/sites/default/files/Direct precursors to perfluorocyclohexane sulfonate and related perfluoroalkylcyclohexane sulfonates_ Environment tier II assessment.pdf

Jeon, J., Kannan, K., Lim, H. K., Moon, H. B., & Kim, S. D. (2010). Bioconcentration of perfluorinated compounds in blackrock fish, Sebastes schlegeli, at different salinity levels. *Environmental Toxicology and Chemistry*, *29*, 2529–2535. https://doi.org/10.1002/etc.310

Ji, K., Kim, Y., Oh, S., Ahn, B., Jo, H., & Choi, K. (2008). Toxicity of perfluorooctane sulfonic acid and perfluorooctanoic acid on freshwater macroinvertebrates (Daphnia magna and Moina macrocopa) and fish (Oryzias latipes). *Environmental Toxicology and Chemistry*, *27*, 2159. https://doi.org/10.1897/07-523.1

Jones, P. D., Hu, W., De Coen, W., Newsted, J. L., & Giesy, J. P. (2003). Binding of perfluorinated fatty acids to serum proteins. *Environmental Toxicology and Chemistry*, *22*, 26 – 39. https://doi.org/10.1897/02-553

Kabadi, S. V., Fisher, J., Aungst, J., & Rice, P. (2018). Internal exposure-based pharmacokinetic evaluation of potential for biopersistence of 6:2 fluorotelomer alcohol (FTOH) and its metabolites. *Food & Chemical Toxicology, 112*, 375 – 382. https://doi.org/10.1016/j.fct.2018.01.012

Kabadi, S. V., Fisher, J. W., Doerge, D. R., Mehta, D., Aungst, J., & Rice, P. (2020). Characterizing biopersistence potential of the metabolite 5:3 fluorotelomer carboxylic acid after repeated oral exposure to the 6:2 fluorotelomer alcohol. *Toxicology & Applied Pharmacology, 388*, 114 – 878. https://doi.org/10.1016/j.taap.2020.114878

Kang, J. S., Ahn, T.-G., & Park, J.-W. (2019). Perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) induce different modes of action in reproduction to Japanese medaka (Oryzias latipes). *Journal of Hazardous Materials*, *368*, 97–103. https://doi.org/10.1016/j.jhazmat.2019.01.034

Kelly, B. C., Ikonomou, M. G., Blair, J. D., Surridge, B., Hoover, D., Grace, R., & Gobas, F. A. P. C. (2009). Perfluoroalkyl Contaminants in an Arctic Marine Food Web: Trophic Magnification and Wildlife Exposure. *Environmental Science & Technology*, *43*, 4037–4043. https://doi.org/10.1021/es9003894

Kennedy, G. L., Butenhoff, J. L., Olsen, G. W., O'Connor, J. C., Seacat, A. M., Perkins, R. G., Biegel, L. B., Murphy, S. R., & Farrar, D. G. (2004). The Toxicology of Perfluorooctanoate. *Critical Reviews in Toxicology*, *34*, 351–384. https://doi.org/10.1080/10408440490464705

Key, B. D., Howell, R. D., & Criddle, C. S. (1997). Fluorinated Organics in the Biosphere. *Environmental Science & Technology*, *31*, 2445–2454. https://doi.org/10.1021/es961007c

Kotthoff, M., & Bücking, M. (2018). Four Chemical Trends Will Shape the Next Decade's Directions in Perfluoroalkyl and Polyfluoroalkyl Substances Research. *Frontiers in Chemistry*, *6*. https://doi.org/10.3389/fchem.2018.00103

Kotthoff, M., Müller, J., Jürling, H., Schlummer, M., & Fiedler, D. (2015). Perfluoroalkyl and polyfluoroalkyl substances in consumer products. *Environmental Science and Pollution Research*, *22*, 14546–14559. https://doi.org/10.1007/s11356-015-4202-7

Kramer, V. J., Etterson, M. A., Hecker, M., Murphy, C. A., Roesijadi, G., Spade, D. J., Spromberg, J. A., Wang, M., & Ankley, G. T. (2011). Adverse outcome pathways and ecological risk assessment: Bridging to population-level effects. *Environmental Toxicology and Chemistry*, *30*, 64–76. https://doi.org/10.1002/etc.375

Latała, A., Nędzi, M., & Stepnowski, P. (2009). Acute toxicity assessment of perfluorinated carboxylic acids towards the Baltic microalgae. *Environmental Toxicology and Pharmacology*, *28*, 167–171. https://doi.org/10.1016/j.etap.2009.03.010

Lau, C., Thibodeaux, J. R., Hanson, R. G., Narotsky, M. G., Rogers, J. M., Lindstrom, A. B., & Strynar, M. J. (2006). Effects of Perfluorooctanoic Acid Exposure during Pregnancy in the Mouse. *Toxicological Sciences*, *90*, 510–518. https://doi.org/10.1093/toxsci/kfj105

Lau, C., Anitole, K., Hodes, C., Lai, D., Pfahles-Hutchens, A., & Seed, J. (2007). Perfluoroalkyl Acids: A Review of Monitoring and Toxicological Findings. *Toxicological Sciences*, *99*, 366–394. https://doi.org/10.1093/toxsci/kfm128

Li, M.-H. (2009). Toxicity of perfluorooctane sulfonate and perfluorooctanoic acid to plants and aquatic invertebrates. *Environmental Toxicology*, *24*, 95–101. https://doi.org/10.1002/tox.20396

Lindstrom, A. B., Strynar, M. J., & Libelo, E. L. (2011). Polyfluorinated Compounds: Past, Present, and Future. *Environmental Science & Technology*, *45*, 7954–7961. https://doi.org/10.1021/es2011622

Loi, E. I. H., Yeung, L. W. Y., Taniyasu, S., Lam, P. K. S., Kannan, K., & Yamashita, N. (2011). Trophic Magnification of Poly- and Perfluorinated Compounds in a Subtropical Food Web. *Environmental Science & Technology*, *45*, 5506–5513. https://doi.org/10.1021/es200432n

Macon, M. B., Villanueva, L. R., Tatum-Gibbs, K., Zehr, R. D., Strynar, M. J., Stanko, J. P., White, S. S., Helfant, L., & Fenton, S. E. (2011). Prenatal Perfluorooctanoic Acid Exposure in CD-1 Mice: Low-Dose Developmental Effects and Internal Dosimetry. *Toxicological Sciences*, *122*, 134–145. https://doi.org/10.1093/toxsci/kfr076

Martin, J.W., Mabury, S.A., Solomon, K.R., & Muir, D.C. (2003). Bioconcentration and tissue distribution of perfluorinated acids in rainbow trout (Oncorhynchus mykiss). *Environmental toxicology and chemistry, 22*, 196–204.

Martin, J. W., Mabury, S. A., Solomon, K. R., & Muir, D. C. G. (2013). Progress toward understanding the bioaccumulation of perfluorinated alkyl acids. *Environmental Toxicology and Chemistry*, *32*, 2421–2423. https://doi.org/10.1002/etc.2376

Mhadhbi, L., Rial, D., Pérez, S., & Beiras, R. (2012). Ecological risk assessment of perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) in marine environment using *Isochrysis galbana*, *Paracentrotus lividus*, *Siriella armata* and *Psetta maxima*. *Journal of Environmental Monitoring*, *14*, 13–75. https://doi.org/10.1039/c2em30037k

Minnesota Pollution Control Agency (MPCA). (2013). Aquatic Life Criteria and Water Quality Standards. https://www.pca.state.mn.us/sites/default/files/pfos-mississippiriver.pdf

Mohammadi, M. (2015). The bioavailability of perfluoroalkyl substances (PFASs) and polycyclic aromatic hydrocarbons (PAHs) in soil to *Eisenia fetida* and *Cucurbita pepo*. *Swedish University of Agricultural Sciences*.

Molina, E. D., Balander, R., Fitzgerald, S. D., Giesy, J. P., Kannan, K., Mitchell, R., & Bursian, S. J. (2006). Effects of air cell injection of perfluorooctane sulfonate before incubation on development of the white leghorn chicken (*Gallus domesticus*) embryo. *Environmental Toxicology and Chemistry*, *25*, 227. https://doi.org/10.1897/04-414R.1

Moody, C. A., Martin, J. W., Kwan, W. C., Muir, D. C., & Mabury, S. A. (2002). Monitoring perfluorinated surfactants in biota and surface water samples following an accidental release of fire-fighting foam into Etobicoke Creek. *Environmental science & technology*, *36*, 545–551. https://doi.org/10.1021/es011001+

National Toxicology Program (NTP). (2016). NTP Monograph on Immunotoxicity Associated with Exposure to Perfluorooctanoic Acid or Perfluorooctane Sulfonate. Retrieved from https://ntp.niehs.nih.gov/ntp/ohat/pfoa_pfos/pfoa_pfosmonograph_508.pdf

Newsted, J. L., Coady, K. K., Beach, S. A., Butenhoff, J. L., Gallagher, S., & Giesy, J. P. (2007). Effects of perfluorooctane sulfonate on mallard and northern bobwhite quail exposed chronically via the diet. *Environmental Toxicology and Pharmacology*, *23*, 1–9. https://doi.org/10.1016/j.etap.2006.04.008

Newsted, J. L., Jones, P. D., Coady, K., & Giesy, J. P. (2005). Avian Toxicity Reference Values for Perfluorooctane Sulfonate. *Environmental Science & Technology*, *39*, 9357–9362. https://doi.org/10.1021/es050989v

Nordén, M., Berger, U., & Engwall, M. (2013). High levels of perfluoroalkyl acids in eggs and embryo livers of great cormorant (*Phalacrocorax carbo sinensis*) and herring gull (*Larus argentatus*) from Lake Vänern, Sweden. *Environmental Science and Pollution Research*, *20*, 8021–8030. https://doi.org/10.1007/s11356-013-1567-3

Organisation for Economic Co-operation and Development (OECD). (2002). Hazard assessment of perfluorooctane sulfonate (PFOS) and its salts. Retrieved from http://www.oecd.org/env/ehs/risk-assessment/2382880.pdf

Organisation for Economic Co-operation and Development (OECD). (2008). SIDS initial assessment report for ammonium perfluorooctanoate and perfluorooctanoic acid. Retrieved from http://webnet.oecd.org/HPV/UI/handler.axd?id=1f391916-96ba-46f6-a7ce-c96712da3b7e

Organisation for Economic Co-operation and Development (OECD). (2013). OECD/UNEP Global PFC Group: synthesis paper on per- and polyfluorinated chemicals (PFCs). Retrieved from https://www.oecd.org/env/ehs/risk-management/PFC_FINAL-Web.pdf

Peden-Adams, M. M., Stuckey, J. E., Gaworecki, K. M., Berger-Ritchie, J., Bryant, K., Jodice, P. G., Scott, T. R., Ferrario, J. B., Guan, B., Vigo, C., Boone, J. S., McGuinn, W. D., DeWitt, J. C., & Keil, D. E. (2009). Developmental toxicity in white leghorn chickens following in ovo exposure to perfluorooctane sulfonate (PFOS). *Reproductive Toxicology*, *27*, 307–318. https://doi.org/10.1016/j.reprotox.2008.10.009

Prescher D, Gross U, Wotzka J, Txcheu-Schlueter M, Starke W (1985). Environmental behavior of fluoro surfactants: Part 2: Study on biochemical degradability. *Acta Hydrochim Hydrobiol*. *13*: 17–24

Prevedouros, K., Cousins, I. T., Buck, R. C., & Korzeniowski, S. H. (2006). Sources, Fate and Transport of Perfluorocarboxylates. *Environmental Science & Technology*, *40*, 32–44. https://doi.org/10.1021/es0512475

Ramboll Environmental (Ramboll Environ). (2016). Companion report to Ramboll Environ Jan 2014 assessment for POP criteria for specific short-chain perfluorinated alkyl substances. *FluoroCouncil*. Retrieved from https://fluorocouncil.com/wp-content/uploads/2017/08/2016-Ramboll-ENVIRON-Report.pdf

Reiner, J. L., & Place, B. J. (2015). *Chapter 5: Perfluorinated Alkyl Acids in Wildlife. Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances* (J. C. DeWitt (ed.)). Springer International Publishing. https://doi.org/10.1007/978-3-319-15518-0

Rice, P. A., Aungst, J., Cooper, J., Bandele, O., & Kabadi, S. V. (2020). Comparative analysis of the toxicological databases for 6:2 fluorotelomer alcohol (6:2 FTOH) and perfluorohexanoic acid (PFHxA). *Food & Chemical Toxicology, 138*, 111–210. https://doi.org/10.1016/j.fct.2020.111210

Rich, C. D., Blaine, A. C., Hundal, L., & Higgins, C. P. (2015). Bioaccumulation of Perfluoroalkyl Acids by Earthworms (Eisenia fetida) Exposed to Contaminated Soils. *Environmental Science & Technology*, *49*, 881–888. https://doi.org/10.1021/es504152d

Rodea-Palomares, I., Makowski, M., Gonzalo, S., González-Pleiter, M., Leganés, F., & Fernández-Piñas, F. (2015). Effect of PFOA/PFOS pre-exposure on the toxicity of the herbicides 2,4-D, Atrazine, Diuron and Paraquat to a model aquatic photosynthetic microorganism. *Chemosphere*, *139*, 65–72. https://doi.org/10.1016/j.chemosphere.2015.05.078

Roos, A., Berger, U., Järnberg, U., van Dijk, J., & Bignert, A. (2013). Increasing Concentrations of Perfluoroalkyl Acids in Scandinavian Otters (Lutra lutra) between 1972 and 2011: A New Threat to the Otter Population? *Environmental Science & Technology*, *47*, 11757–11765. https://doi.org/10.1021/es401485t

Sample, B. E., Opresko, D. M., & Suter, G.W., I. (1996). Toxicological benchmarks for wildlife: 1996 Revision. https://doi.org/10.2172/258027

Scher, D. P., Kelly, J. E., Huset, C. A., Barry, K. M., Hoffbeck, R. W., Yingling, V. L., & Messing, R. B. (2018). Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. *Chemosphere*, *196*, 548–555. https://doi.org/10.1016/j.chemosphere.2017.12.179

Shi, Y., Vestergren, R., Nost, T. H., Zhou, Z., & Cai, Y. (2018). Probing the Differential Tissue Distribution and Bioaccumulation Behavior of Per- and Polyfluoroalkyl Substances of Varying Chain-Lengths, Isomeric Structures and Functional Groups in Crucian Carp. *Environmental Science & Technology*, *52*, 4592–4600. https://doi.org/10.1021/acs.est.7b06128

Society of Environmental Toxicology and Chemistry (SETAC). (2019). Environmental risk assessment of PFAS, SETAC North America Focused Topic Meeting, 12-15 Aug 2019, Durham, NC. Retrieved from https://pfas.setac.org/

Spachmo, B., & Arukwe, A. (2012). Endocrine and developmental effects in Atlantic salmon (Salmo salar) exposed to perfluorooctane sulfonic or perfluorooctane carboxylic acids. *Aquatic Toxicology*, *108*, 112–124. https://doi.org/10.1016/j.aquatox.2011.07.018

Stahl, T., Heyn, J., Thiele, H., Hüther, J., Failing, K., Georgii, S., & Brunn, H. (2009). Carryover of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) from Soil to Plants. *Archives of Environmental Contamination and Toxicology*, *57*, 289–298. https://doi.org/10.1007/s00244-008-9272-9

Stahl, T., Mattern, D., & Brunn, H. (2011). Toxicology of perfluorinated compounds. *Environmental Sciences Europe*, *23*, 38. https://doi.org/10.1186/2190-4715-23-38

Taniyasu, S., Kannan, K., Horii, Y., Hanari, N., & Yamashita, N. (2003). A Survey of Perfluorooctane Sulfonate and Related Perfluorinated Organic Compounds in Water, Fish, Birds, and Humans from Japan. *Environmental Science & Technology*, *37*, 2634–2639. https://doi.org/10.1021/es0303440

Tao, L., Kannan, K., Kajiwara, N., Costa, M. M., Fillmann, G., Takahashi, S., & Tanabe, S. (2006). Perfluorooctanesulfonate and Related Fluorochemicals in Albatrosses, Elephant Seals, Penguins, and Polar Skuas from the Southern Ocean. *Environmental Science & Technology*, *40*, 7642–7648. https://doi.org/10.1021/es061513u

Turley, A. (2018, November 22). Norwegian review finds that PFBS persists and is mobile: But the bioaccumulation potential is low compared with PFOS. *Chemical Watch*. https://chemicalwatch.com/72228/norwegian-review-finds-that-pfbs-persists-and-is-mobile?pa=true

U.S. Department of Defense (DOD). (2019, May 29). Statement of Need on PFAS ecotoxicity, knowledge gaps, and ecological risk characterization. *Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP)*. Retrieved from https://www.serdp-estcp.org/News-and-Events/Blog/PFAS-Ecotoxicity-Risks-How-SERDP-is-Closing-the-Knowledge-Gaps

U.S. Environmental Protection Agency (EPA). (2009). Long-Chain Perfluorinated Chemicals (PFCs) Action Plan. Retrieved from https://www.epa.gov/sites/production/files/2016-01/documents/pfcs_action_plan1230_09.pdf

U.S. Environmental Protection Agency (EPA). (2012). Ecological Effects Test Guidelines, OCSPP 850.4100: Seedling Emergence and Seedling Growth. *Office of Chemical Safety and Pollution Prevention*.

U.S. Environmental Protection Agency (EPA). (2017). Risk management for per- and polyfluoroalkyl substances (PFAS) under TSCA. Retrieved from https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-PFAS

U.S. Environmental Protection Agency (EPA). (2019). EPA's per- and Polyfluoroalkyl Substances (PFAS) Action Plan. Retrieved from https://www.epa.gov/sites/production/files/2019-02/documents/pfas_action_plan_021319_508compliant_1.pdf

Wambaugh, J. F. (2015). Chapter 14: Dosimetric anchoring of toxicological studies. Pp 337 – 361 in: Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances (J. C. DeWitt (ed.)). Springer International Publishing. https://doi.org/10.1007/978-3-319-15518-0

Wang, Z., Cousins, I. T., Scheringer, M., & Hungerbuehler, K. (2015). Hazard assessment of fluorinated alternatives to long-chain perfluoroalkyl acids (PFAAs) and their precursors: Status quo, ongoing challenges and possible solutions. *Environment International*, *75*, 172–179. https://doi.org/10.1016/j.envint.2014.11.013

Wang, Z., DeWitt, J. C., Higgins, C. P., & Cousins, I. T. (2017). A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? *Environmental Science & Technology*, *51*, 2508–2518. https://doi.org/10.1021/acs.est.6b04806

Washington State Department of Ecology (Ecology). (2017). Survey of Per- and Poly-fluoroalkyl Substances (PFAS) in Rivers and Lakes, 2016. Retrieved from https://apps.ecology.wa.gov/publications/documents/1703021.pdf

Washington State Department of Ecology (Ecology). (in prep). Per- and Poly-fluoroalkyl Substances in Freshwater Fish: Lakes Meridian, Sammamish, and Washington. Washington State Department of Ecology, Olympia, WA. Publication in preparation.

White, S. S., Fenton, S. E., & Hines, E. P. (2011). Endocrine disrupting properties of perfluorooctanoic acid. *The Journal of Steroid Biochemistry and Molecular Biology*, *127*, 16–26. https://doi.org/10.1016/j.jsbmb.2011.03.011

Wolf, D. C., Moore, T., Abbott, B. D., Rosen, M. B., Das, K. P., Zehr, R. D., Lindstrom, A. B., Strynar, M. J., & Lau, C. (2008). Comparative Hepatic Effects of Perfluorooctanoic Acid and WY 14,643 in PPAR-α Knockout and Wild-type Mice. *Toxicologic Pathology*, *36*, 632–639. https://doi.org/10.1177/0192623308318216

Yamashita, N., Kannan, K., Taniyasu, S., Horii, Y., Petrick, G., & Gamo, T. (2005). A global survey of perfluorinated acids in oceans. *Marine Pollution Bulletin*, *51*, 658–668. https://doi.org/10.1016/j.marpolbul.2005.04.026

Yanai, J., Dotan, S., Goz, R., Pinkas, A., Seidler, F. J., Slotkin, T. A., & Zimmerman, F. (2008). Exposure of Developing Chicks to Perfluorooctanoic Acid Induces Defects in Prehatch and Early Posthatch Development. *Journal of Toxicology and Environmental Health, Part A*, *71*, 131–133. https://doi.org/10.1080/15287390701613280

Yoo, H., Yamashita, N., Taniyasu, S., Lee, K. T., Jones, P. D., Newsted, J. L., Khim, J. S., & Giesy, J. P. (2009). Perfluoroalkyl Acids in Marine Organisms from Lake Shihwa, Korea. *Archives of Environmental Contamination and Toxicology*, *57*, 552–560. https://doi.org/10.1007/s00244-008-9282-7

List of acronyms

General acronyms

Table 65. Acronyms found in the ecological toxicology appendix.

Acronym	Definition
BAF	Bioaccumulation factor
BCF	Bioconcentration factor
BW	Body weight
CAP	Chemical Action Plan
EC(…)	Percent effect concentration
ECCC	Environment and Climate Change Canada
EPA	United States Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FDA	United States Food and Drug Administration
EU	European Union
Kg	Kilogram
IMAP	Inventory Multi-Tiered Assessment Prioritisation
ITRC	Interstate Technology & Regulatory Council
L	Liter
LOAEL	Lowest observed adverse effects level
LOEC	Lowest observed effects concentration
NOAEL	No observed adverse effects level
NOEC	No observed effects concentration
OECD	Organisation for Economic Co-operation and Development
SERDP	Strategic Environmental Research and Development Program
SETAC	Society of Environmental Toxicology and Chemistry

Chemical names

Table 66. Chemical name acronyms found in the ecological toxicology appendix, excluding the general acronyms listed in the table above.

Acronym	Chemical name
6:2 FTAC	6:2 Fluorotelomer acrylate
6:2 FTMAC	6:2 Fluorotelomer methacrylate
6:2 FTOH	6:2 Fluorotelomer alcohol
5:3 A	5:3 Fluorotelomer carboxylic acid
APFO	Ammonium perfluorooctanoate
FT	Fluorotelomer
PASF	Perfluoroalkane sulfonyl fluoride
PFAA	Perfluoroalkyl acid
PFAS	Per- and polyfluoroalkyl substances
PFBA	Perfluorobutanoic acid

Acronym	Chemical name
PFBS	Perfluorobutane sulfonate
PFC	Perfluoroalkyl contaminants
PFCA	Perfluoroalkyl carboxylic acid
PFD	Perfluorodecanoate
PFDA	Perfluorodecanoic acid
PFDo	Perfluorododecanoate
PFDoA	Perfluorododecanoic acid
PFECHS	Perfluoroethylcyclohexanesulfonate
PFHp	Perfluoroheptanoate
PFHpS	Perfluoroheptanesulfonate
PFHx	Perfluorohexanoate
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonate
PFN	Perfluorononanoate
PFNA	Perfluorononanoic acid
PFO	Perfluorooctanoate
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
PFOSA	Perfluorooctane sulfonamide
PFPeS	Perfluoropentanesulfonate
PFPn	Perfluoropentanoate
PFS	Perfluoroalkyl substance
PFSA	Perfluoroalkyl sulfonic acid
PFT	Perfluorotetradecanoate
PFTri	Perfluorotridecanoate
PFU	Perfluoroundecanoate
PFUnA/PFUnDA	Perfluoroundecanoic acid

Appendix 7: Health

7.0 Overview

7.0.1 Findings

- We are still learning about potential health risks of per- and polyfluoroalkyl substances (PFAS) in humans. Much of what we know comes from toxicity testing in laboratory animals on several perfluoroalkyl acids (PFAAs). The evidence base is strongest for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), and is rapidly expanding for other PFAAs.
- Animal studies provide strong evidence that some PFAAs produce liver and kidney toxicity, immune toxicity, reproductive and developmental toxicity, endocrine disruption (altered thyroid and testosterone hormones), and certain tumors. The strongest evidence from epidemiological studies is for links between higher exposures to PFAAs and reduced antibody response to childhood vaccines, increased serum cholesterol and liver enzymes, and slightly reduced birth weights. More limited evidence exists for links to thyroid disease, hormone disruption, and reduced resistance to infections, cardiovascular disease, and cancer.
- Some long-chain PFAAs are strongly bioaccumulative in people. It takes years for human bodies to excrete PFOS, PFOA, perfluorononanoic acid (PFNA), perfluorohexane sulfonate (PFHxS), and other long-chain PFAS. Other PFAAs, such as perfluorobutanoic acid (PFBA), perfluorobutane sulfonic acid (PFBS), and perfluorohexanoic acid (PFHxA), are more rapidly cleared. The absorption, distribution, and clearance in humans for most other PFAS have not been studied.
- PFOS, PFOA, PFHxS, and PFNA have been detected in the serum of nearly every person tested in Centers for Disease Control and Prevention (CDC) surveys of the U.S. general population since 1999. Levels have declined since phase-outs of these PFAS and their precursors from domestic production and use.
- People can be exposed to PFAS from contaminated drinking water, dietary sources, indoor dust and air that contain PFAS from consumer products, contact with consumer products that contain PFAS, and local environmental contamination or industrial sources of PFAS release. Although it has been difficult to assess which sources contribute the most to human exposure, studies identify food and drinking water as the likely main routes of non-occupational exposure.
- In Washington, PFAAs have been identified in drinking water in the lower Issaquah Valley Aquifer and at or near four military bases: Naval Air Station (NAS) Whidbey Island, Fairchild Air Force Base, Joint Base Lewis-McChord, and Navy Base Kitsap-Bangor. In each area, the sum of PFOA and PFOS in at least one drinking water well exceeded the lifetime health advisory level (70 parts per trillion (ppt)) set by the U.S. Environmental Protection Agency (EPA). PFAS-based firefighting foam is the suspected source of contamination at all of these areas. Ongoing investigations may identify other contributing sources.

- Washington Department of Health (Health) is supporting the State Board of Health (SBOH) in developing state drinking water standards for PFAAs. In 2019, Health published draft recommendations for state action levels for five PFAAs in drinking water: PFOS (15 ppt), PFOA (10 ppt), PFNA (9 ppt), PFHxS (65 ppt), and PFBS (345 ppt). The SBOH expects to complete the rulemaking process in 2021. Health is also developing fish consumption advisories for PFOS in freshwater fish based on Washington State Department of Ecology (Ecology) fish sampling data.

7.0.2 Introduction

The purpose of this appendix is to review potential human health impacts of the PFAS measured in food, water, the environment, and bodies. It describes how humans are exposed and what levels are commonly measured in the general population and in populations with higher exposure. It describes the known sites of drinking water contamination across the state and the actions taken to protect public health at each site. It reviews the public health advice being developed by Washington state for PFAS in drinking water and fish.

The appendix focuses on PFAAs as these are the best studied and are the ultimate environmental and metabolic breakdown products for a large number of PFAS (see Appendix 4: Fate and Transport).

7.1 Human Health Hazard Assessment

There is a growing base of toxicological and epidemiological evidence available to support health assessments for a small number of PFAS. Authoritative bodies that have reviewed available evidence include EPA (EPA, 2016b, 2016c, 2021), the Agency for Toxic Substances and Disease Registry (ATSDR) (ATSDR, 2015a, 2021), the National Toxicology Program (NTP) (2016) (NTP, 2016), the C8 Science Panel (C8 Science Panel, 2012), the International Agency for Research on Cancer (IARC) (IARC, 2016), and the European Food Safety Authority (EFSA) (EFSA, 2018, 2020). Additional PFAS toxicity testing and health assessment is underway at EPA and NTP (Patlewicz et al., 2019). Health scientists also evaluated the available science to guide action on PFAS in public drinking water (Health, 2021).

In animal studies, some PFAAs produce reproductive and developmental toxicity, liver and kidney toxicity, altered levels of thyroid hormones, immune toxicity, endocrine disruption, and tumors (See Supplement 1 for a summary of findings for eight PFAAs). Studies of humans with occupational, community, or background exposures to PFAAs have reported that higher exposures are associated with a number of adverse health outcomes such as reduced antibody response to vaccines, higher serum cholesterol and liver enzymes, reduced birth weights, and increased rates of thyroid disease and cancer. These are summarized briefly in Supplement 1.

Replacement PFAS may not be safer than the legacy PFAS they replaced. Short-chain PFAAs reviewed in Table 72 appear to be less of a human health concern compared to legacy PFAAs. However, toxicological and epidemiological studies of a number of replacement PFAS show concerning findings (Conley et al., 2021; Hong et al., 2020; Kang et al., 2020; Nian et al., 2020; Shi et al., 2018). It is also important to study more than just the final products of PFAS environmental degradation. A Food and Drug Administration (FDA) study found that 6:2

fluorotelomer alcohol (6:2 FTOH) was more toxic and biopersistent in rats than its primary environmental metabolite: PFHxA (Rice et al., 2020). This led to a phase out of certain food packaging that contained 6:2 FTOH (FDA, 2020).

7.1.1 Epidemiology

Epidemiological studies have been valuable in understanding the potential relevance of laboratory animal data to human populations. They have also been instrumental in understanding the much longer retention of some PFAAs in humans. A landmark epidemiological study in the mid-Ohio River Valley called the C8 Health Project is also described below.

Human observational studies are limited in their capacity to establish a causal relationship between PFAA exposure and human health effects. Variable findings on outcomes measured in different populations have been noted and make interpretation of the epidemiological evidence stream challenging.

Apparent inconsistencies may be due to differences in study populations (e.g., age, gender, occupational versus community exposure), study design (e.g., cross-sectional, longitudinal), level of exposure, and variations in the mixture of PFAS present. Other sources of variability may be unmeasured historical exposures influencing the rates of health effects observed and other risk factors for outcomes measured that may not be adequately controlled.

Taken together, evidence streams from epidemiology, animal toxicity testing, mechanistic studies, and *in vitro* and gene expression assays, have led many scientific and government agencies to reasonably conclude that some PFAS likely pose a health risk to humans. A number have established exposure guidelines or limits to protect human health (Interstate Technology & Regulatory Council (ITRC), 2020b). Supplement 1 shows some of their recommended limits for human exposure.

The C8 Health Project, Ohio River Valley, 2005 – 2012

The largest epidemiological study of health outcomes associated with mostly PFOA exposure in drinking water is the C8 Health Project. This study, funded by a lawsuit settlement, set out to identify which conditions or diseases were more probably than not related to area-wide contamination around Dupont's Washington Works plant in Parkersburg, West Virginia. This fluoropolymer production plant released primarily PFOA into the air, water (Ohio River), and soil around their manufacturing site between 1950 and 2004. PFOA was detected in six public water systems in the mid-Ohio Valley in 2002. PFOA exposures to the communities are believed to have peaked in the early 1990s. Investigators concluded that drinking water contaminated with PFOA was the principal route of exposure for this population (Emmett et al., 2006; Hoffman et al., 2011; Shin et al., 2011; Steenland et al., 2009; Winquist et al., 2013).

In all, the C8 Health Project recruited more than 69,000 residents who had consumed drinking water for at least one year from six water districts in West Virginia and Ohio (Frisbee et al., 2009). The very high participation rate (81%) strengthened the relevance of study results for this population. At the time of water sampling, the highest average PFOA concentrations in drinking water were found at Lubeck, West Virginia (520 µg/L), and Tuppers Plain, Ohio (310 µg/L) (Olsen, 2015b).

Blood samples were collected for the C8 Health Project in 2005 and 2006. Compared to the general U.S. population, average serum concentrations for the cohort were about eight times higher for PFOA, 1.4 times higher for PFNA, 1.7 times higher for PFHxS, and not elevated for PFOS (Frisbee et al., 2009). The mean serum PFOA level varied significantly across the populations served by six water districts and ranged from 16 micrograms per liter (µg/L) for participants from the Village of Pomeroy to 228 µg/L for the Little Hocking Water Association. Females had slightly lower average serum levels than males for all four PFAS (Frisbee et al., 2009). Women have additional pathways to clear PFAAs through their menstrual cycle, childbirth, and breastfeeding. PFOA levels in groups of workers at DuPont's facilities were much higher: their mean serum ranged from 494 µg/L to 3,210 µg/L (ATSDR, 2015b).

Between 2005 and 2012, the C8 Health Project carried out exposure and health studies in the mid-Ohio Valley communities affected by drinking water contamination. The project science panel assessed the links between PFOA and a number of diseases, and concluded that a "probable link" existed between PFOA and high cholesterol, ulcerative colitis, thyroid disease, testicular cancer, kidney cancer, and pregnancy-induced hypertension among the population evaluated (C8 Science Panel, 2012). They also found no probable link to other conditions including heart disease, chronic liver or kidney disease, stroke, several autoimmune diseases, occurrence of common infectious diseases or respiratory disease, asthma, or birth defects.

Following the C8 Health Project, carbon filters were installed to remove PFOA from public drinking water systems. As a result, PFOA serum concentrations declined 26% between the end of 2007 and mid-2008 in the groups from Little Hocking and Lubeck water districts—indicating a serum elimination half-life of 2.3 years for highly exposed populations (Bartell et al., 2010).

The C8 Science Panel authors and collaborators published updated scientific evidence on PFOA in 2020 (Steenland et al., 2020). Compared to their 2012 findings, they acknowledged strengthening evidence for kidney cancer, impaired immune function (reduced response to vaccines), and altered liver enymes. The authors cited a modest weakening of evidence for thyroid disease and ulcerative colitis.

7.1.2 Primary health endpoints of concern

Liver toxicity

In experimental animals, the liver is a sensitive biological target for most PFAAs tested (PFOA, PFNA, PFDA, PFHxA, PFOS, PFHxS, and PFBS). Specific effects observed include increased liver weight, lipid accumulation (steatosis), increased liver cell size (hypertrophy), cell proliferation (hyperplasia), and tumors. Degenerative changes in the rodent liver have been observed for PFOS, PFOA, PFNA, perfluorodecanoic acid (PFDA), and PFBS (EPA, 2016b, 2016c; NTP, 2019a, 2019b). Human liver is expected to be less sensitive than rodent liver to effects mediated by peroxisome proliferator-activated receptor alpha (PPARα), but effects like steatosis appear to occur by another mechanism (Das et al., 2017; Hall et al., 2012).

In human observational studies, modest increases in serum liver enzyme levels and other markers suggestive of liver damage have been associated with higher serum levels of PFOA, PFOS, PFNA, and PFHxS in adults in some studies (Bassler et al., 2019; Darrow et al., 2016; Gallo et al., 2012; Gleason et al., 2015; Salihovic et al., 2018). In children, serum levels of ALT were not positively associated with prenatal exposure (PFAS in maternal serum) or current exposure (PFAS in serum at age eight years old) in a Boston-area cohort recruited from the general population before the PFOS and PFOA phase-out (Mora et al., 2018).

Elevated PFOA exposure was not associated with an increase of clinically diagnosed liver disease in the large C8 study despite subclinical indications of liver damage in this and other studies (Bassler et al., 2019; Darrow et al., 2016). A recent study reported positive associations between serum levels of PFHxS and PFOS and severity of disease in adolescents with nonalcoholic fatty liver disease (Jin et al., 2020).

Serum cholesterol levels and cardiovascular effects

PFAAs appear to alter lipid metabolism in the rodent and monkey. In animal studies, PFAA exposure produces decreased serum cholesterol and triglyceride levels (ATSDR, 2018b).

In human populations with environmental exposures, serum PFOA, PFOS, PFNA, and PFHxS are often positively associated with increased serum levels of total cholesterol and low-density lipoprotein (LDL) cholesterol (Frisbee et al., 2010; Graber et al., 2019; Li et al., 2020; Nelson et al., 2010; Steenland et al., 2009), including in children (Mora et al., 2018; Rappazzo et al., 2017). The difference in effect direction may represent a different effect at low doses—in fact, the direction of effect was reversed at very high doses in one study in humans (Convertino et al., 2018). The difference may also be a function of diet (rodents fed a high fat western diet showed an increase in cholesterol) (Rebholz et al., 2016) or a species difference in liver response (Corton et al., 2018). There is also an emerging uncertainty about potential confounding by enterohepatic circulation of lipids (EFSA, 2020), although this would not explain associations between higher cholesterol and PFAA exposure based on residence in a water district with contaminated drinking water as in Li et al. (2020). The C8 Science Panel concluded that there was a “probable link” between PFOA and clinically defined “high cholesterol” (C8 Science Panel, 2012). In studies of populations with lower exposure, PFHxS was inversely associated or not associated with serum cholesterol (Nelson et al., 2010; Seo et al., 2018; Starling, Engel, Whitworth, et al., 2014). There is limited data on this outcome for shorter chain PFAAs, but

PFHxA, perfluoroheptanoic acid (PFHpA), and PFBA were not associated with serum cholesterol levels in a small Chinese study (Fu et al., 2014).

There is a well-recognized relationship between elevated cholesterol and cardiovascular disease. Two studies in the CDC National Health and Nutrition Examination Survey (NHANES), a representative survey of the U.S. population, reported positive associations between serum PFAAs and self-reported cardiovascular disease after controlling for other risk factors (Huang et al., 2018; Shankar et al., 2012). No association between relatively high PFOA exposure and coronary heart disease was reported in the C8 study. The C8 study confined analysis to self-report verified by medical records (C8 Science Panel, 2012).

The C8 Science Panel found a "probable link" between a hypertensive disorder of pregnancy (through self-report of pre-eclampsia) and maternal PFOA and PFOS serum level (C8 Science Panel, 2012; Savitz, Stein, Bartell, et al., 2012). No association with pre-eclampsia was found in two other studies of populations with lower PFOA and PFOS exposures, which validated cases with medical records (Huang et al., 2019; Starling, Engel, Richardson, et al., 2014).

Immune toxicity

PFOS and PFOA can suppress both adaptive and innate immunity in rodents and non-human primates (Corsini et al., 2014). Outcomes observed include lower spleen and thymus weights, reduced antibody response to antigen, reduced survival after influenza infection, and altered cytokine production. Toxicity testing data indicates that PFNA and PFDA can also adversely impact the immune system in rodents (Frawley et al., 2018; Fang et al., 2009; Fang et al., 2008).

In 2016, NTP concluded that PFOA and PFOS are "presumed immune hazards" to humans based on a systematic review of available toxicology and epidemiology. Lower antibody response to antigen observed in rodent studies and reduced antibody titers to childhood vaccines were key points of evidence (NTP, 2016). Associations between PFOA, PFOS, PFHxS, and PFDA levels in serum and reduced antibody response to childhood vaccines have been reported in different populations (Grandjean et al., 2012; Granum et al., 2013; Mogensen et al., 2015; Stein et al., 2016). Since the NTP review, additional studies have reported inverse associations between the sum of PFOS, PFOA, PFNA, and PFHxS in serum and reduced antibodies titers to childhood vaccines (Abraham et al., 2020; Grandjean, Heilmann, Weihe, Nielsen, Mogensen, & Budtz-Jorgensen, 2017; Grandjean, Heilmann, Weihe, Nielsen, Mogensen, Timmermann, et al., 2017).

The NTP review did not find consistent associations between PFOS or PFOA exposure and lowered resistance to infectious disease in people. Since this review, several studies (including one large prospective cohort study) reported positive associations between maternal concentrations of PFAS and measures of offspring infection (Dalsager et al., 2016; Goudarzi et al., 2017; Impinen et al., 2019; Impinen et al., 2018).

PFOA has been associated with a single autoimmune outcome (ulcerative colitis) in two highly exposed U.S. populations (C8 community cohort and occupational cohort) (Steenland et al., 2015; Steenland et al., 2013). A case-control study in the general U.S. population also reported that higher serum PFOA was associated with ulcerative colitis but not other inflammatory bowel diseases (Steenland, Kugathasan, & Barr, 2018). A recent study of a Swedish population with high levels of PFOS and PFHxS in drinking water contaminated by firefighting foam did not

observe an association between exposure and ulcerative colitis, Crohn's Disease, or other inflammatory bowel disease (Xu, 2019).

NTP concluded it had a high level of confidence that PFOA increased hypersensitivity outcomes in animals but only low confidence in evidence from human studies (National Toxiciology Program, 2016). Hypersensitivity outcomes such as asthma and elevated Immunoglobulin E (IgE) have been reported to be associated with PFAS in several studies (Dong et al., 2013; Humblet et al., 2014; Kvalem et al., 2020; Zhu et al., 2016), but many other studies have looked for and not found associations. Overall the evidence for allergies and asthma is weak and unclear.

Developmental toxicity

There is evidence of profound developmental effects of PFOA and PFOS in experimental animals including fetal loss, altered fetal bone development, lower birth weight, reduced pup survival, altered behavior in offspring, and altered timing of sexual maturation in offspring at adolescence (Butenhoff et al., 2004; Lau et al., 2006; Luebker, Case, et al., 2005; Ngo et al., 2014; Thibodeaux et al., 2003). PFNA produced many similar effects in mouse studies (Das et al., 2015; Wolf et al., 2010). PFBA, PFHxA, and PFHxS were either less potent or did not produce developmental effects (see Supplement 1).

The most consistent developmental effect observed in humans is slightly lower birth weights associated with higher maternal serum levels of PFOA and PFOS. Limited but similar associations are reported for PFNA, PFHxS, PFDA, and perfluoroundecanoic acid (PFUnDA). Preterm birth was associated with higher exposure to PFNA and PFDA (EPA, 2016b; Johnson et al., 2014; Maisonet et al., 2012; Marks et al., 2019; Meng et al., 2018; Wang et al., 2016; Wikstrom et al., 2019). Several meta-analyses have reported small but consistently inverse relationships between maternal PFOA level and birth weight. Confounding by maternal glomerular filtration rate appears to explain some of the association observed by studies that measured prenatal PFOA or PFOS exposure in maternal serum later in pregnancy or in cord blood (Johnson et al., 2014; Negri et al., 2017; Steenland, Barry, & Savitz, 2018; Verner et al., 2015). However, two recent high quality studies measured maternal PFAA level early in pregnancy and reported significant inverse associations with birth weight (Meng, 2018; Wikstrom, 2020).

Slight delays in the age of puberty have been associated with serum PFOA (girls) and with serum PFOS (girls and boys) (Christensen et al., 2011; Kristensen et al., 2013; Lopez-Espinosa et al., 2011).

Reproductive toxicity and sex hormone disruption

Altered levels of reproductive hormones (serum testosterone, estradiol), altered sperm parameters, and changes in the testes have been observed in rodent studies following exposure to PFOS (Biegel et al., 2001; Lopez-Doval et al., 2014; Wan et al., 2011), PFOA (Biegel et al., 1995; Lau et al., 2007; NTP, 2019b), PFNA (Feng et al., 2009; NTP, 2019b), PFDA (NTP, 2019b), and PFDoDA (Shi et al., 2007). Inhibited development of mammary glands were observed in maternal mice exposed to PFOA during pregnancy and in their female offspring at puberty (White et al., 2009). The delays did not impair successful nursing of their young in either generation (White et al., 2011).

Eight PFAS were tested in vitro for binding affinity to the rat estrogen receptor alpha (ERα). PFOS and PFOA had the strongest affinity and showed higher affinity for human ERα than rat ERα receptor. Testing in rats confirmed that binding was functional (i.e., PFOS and PFOA increased expression of ERα in rat uterus and the levels of serum estradiol in rats) (Qiu et al., 2020).

Reproductive impairment such as reductions in rodent litter size were observed for PFOS, PFOA, and PFNA (Abbott et al., 2007; Lau et al., 2006; Singh & Singh, 2019a). No declines in fertility were evident in rodent testing for PFHxS, PFHxA, PFBA, or PFBS (Butenhoff et al., 2009; Das et al., 2008; Lieder et al., 2009; Loveless et al., 2009).

In a general population study, Vested et al. (2013) found that higher maternal serum PFOA was associated with lower sperm count in boys when they reached young adulthood (Vested et al., 2013). In a highly exposed population near a fluoropolymer plant in Italy, young adult men had higher serum PFAAs levels, reduced serum testosterone and semen quality, and shorter penis length and anogenital distance than a comparison population in an uncontaminated area (Di Nisio A, 2018). A number of other studies have not found associations between PFAS exposure, testosterone, or sperm parameters (Agency for Toxic Substances and Disease Registry (ATSDR), 2018b). Some epidemiological studies report reduced fertility associated with higher serum PFOA, PFOS, and PFHxS (Fei et al., 2009; Velez et al., 2015; Whitworth et al., 2012). Other studies have looked for and not found associations with fertility. Studies of communities with elevated exposure have looked for and generally not found associations between PFOA and birth defects or miscarriage. Other PFAAs are not as well studied.

Thyroid disease and thyroid hormone disruption

Alterations in thyroid hormone levels, particularly reductions in free thyroxine (T4) and free triidothyonine (T3) have been observed in laboratory animals exposed to long- and short-chain PFAAs (Butenhoff et al., 2002; National Toxicology Program (NTP), 2019a, 2019b; Seacat et al., 2002). Thyroid toxicity (i.e., increased organ weight, follicular cell hypertrophy, and hyperplasia) has been observed in some laboratory animal studies of PFOA, PFOS, PFHxS, and PFDA (Butenhoff, Chang, et al., 2009; J. L. Butenhoff, Ehresman, et al., 2009; NTP, 2019b, 2019c).

A systematic review of studies in pregnant women and their children (Ballesteros et al., 2017) and a meta-analysis of studies in adults (Kim et al., 2018) provide some suggestive evidence that PFOS, PFOA, and PFHxS are associated with altered hormones in people. Associations differed by gender and by PFAS, but no clear and consistent pattern of effect of PFAS on thyroid

hormone levels has emerged. Sex-linked effects and non-linear dose-response curves are not uncommon in endocrine disrupting chemicals.

Two studies in the general U.S population reported that thyroid disease was associated with serum PFOA, PFOS, and PFHxS (Melzer et al., 2010; Wen et al., 2013). The C8 Science Panel concluded there was a probable link between PFOA exposure and increased risk for thyroid disease in the C8 Health Project (C8 Science Panel, 2012) based on increased hypo- and hyperthyroidism, especially in women (Winquist & Steenland, 2014), and an association between PFOA and hypothyroidism in children (Lopez-Espinosa et al., 2012). A Swedish study of a community with very high exposure through drinking water to different PFAS (PFOS and PFHxS) did not show higher risk for thyroid disease in men or women (Andersson et al., 2019).

Cancer

Chronic PFAA exposure studies in adult rats have shown increased tumors in liver (PFOA, PFOS); pancreas, testes, uterus (PFOA); and thyroid (PFOS) (Biegel et al., 2001; Butenhoff, Chang, Olsen, & Thomford, 2012; Butenhoff, Kennedy, Chang, & Olsen, 2012; Hardisty et al., 2010; NTP, 2020; Thomford, 2002). Chronic oral exposure to hexafluoropropylene oxide dimer acid (HFPO-DA, also known as GenX) produced hepatic, Leydig cell, and pancreatic acinar cell tumors similar to PFOA (Caverly-Rae et al., 2015), whereas PFHxA did not produce evidence of tumors (Klaunig et al., 2015). The pattern of tumors observed for PFOA and GenX is consistent with other chemicals and drugs that activate PPARα in the rat, and is not considered relevant to human liver cancer risk (Klaunig et al., 2003).

No other PFAS have been studied for cancer in chronic animal assays, but some PFAS share attributes of chemical carcinogens (i.e., produce oxidative stress, are immunosuppressive, influence cell proliferation via nuclear receptors) (Temkin et al., 2020). For example, PFNA and PFDA were more potent than PFOA at promoting liver tumors in a trout model of PPARα-independent liver cancer. The gene-expression profile evident in liver of treated trout was similar to estrogen, which was used as a positive control in the study (Benninghoff et al., 2012).

Both occupational and non-occupational studies have investigated whether cancer is associated with PFOA and PFOS exposure in humans. IARC classified PFOA as possibly carcinogenic to humans (Group 2B) based on credible evidence of testicular and kidney cancer associated with PFOA exposure in animal testing and the C8 Health Project (Barry et al., 2013; IARC, 2016). The C8 Science Panel concluded that a "probable link" existed between PFOA exposure and testicular and kidney cancer, but no other types of cancer. A recent prospective study showed a positive association between PFOA exposure and kidney cancer in a general population cohort (Shearer et al., 2020). This study controlled for the possibility that an improperly working kidney might be slower to clear serum PFOA. Other studies of the general population have looked for but not found associations between serum PFOA levels and a range of cancers (Bonefeld-Jorgensen et al., 2014; Eriksen et al., 2009; Hardell et al., 2014; Innes et al., 2014).

In occupationally exposed workers, associations between exposure to PFOS or PFOA and male reproductive, kidney, and bladder cancers have been reported. These associations were generally weak and not consistent across studies (ATSDR, 2015b; Kennedy, 2015; Raleigh et al., 2014; Steenland & Woskie, 2012). In addition, the sample sizes for many of these studies are

small, and caution is needed in interpreting the results, as most studies did not control for other potential factors such as smoking (ATSDR, 2015a). A recent mortality study of Italian fluoropolymer workers highly exposed to PFOA reported higher mortality for liver cancer, liver cirrhosis, and diabetes than in a comparison group of workers at a nearby metalworking factory (Girardi & Merler, 2019).

PFOS serum levels were not associated with more breast, bladder, pancreatic, liver, or prostate cancers in the general Danish population (Bonefeld-Jorgensen et al., 2014; Eriksen et al., 2009; Roswall et al., 2018). A small case control study of Swedish men with prostate cancer found no overall association with PFOS except among a subgroup with a hereditary risk (i.e., first-degree relative with prostate cancer) (Hardell et al., 2014). Prostate specific antigen (PSA), a clinical marker used in screening for prostate cancer, was not associated with serum PFOS or other PFAA among greater than 25,000 men in the C8 cohort (Ducatman et al., 2015).

In 2016, EPA concluded that there was suggestive evidence of carcinogenic potential of both PFOA and PFOS in humans. For PFOA, EPA based its determination primarily on Leydig cell tumors observed in two rat studies and renal and testicular cancer in the C8 Health Project. For PFOS, EPA relied primarily on observations of liver and thyroid adenomas in chronic rat studies (EPA, 2016b, 2016c).

Sources of uncertainty in assessing hazard

We still know very little about the potential toxicity of thousands of individual PFAS. PFOA and PFOS have large evidence bases to support human health assessments. Another dozen or so PFAS have limited but growing data to support assessment. EPA and NTP are testing 150 PFAS using rapid high-throughput testing to more broadly inform hazard assessment of PFAS. This list includes PFAS from 75 different subclasses and may help regulators construct a grouped approach to managing PFAS (EPA, 2019; Patlewicz et al., 2019). Understanding how to assess PFAS mixtures is critical because most environmental samples and human biological samples contain mixtures of PFAS, and yet we have very little data to understand how PFAAs may interact or the hazard of these cumulative exposure to PFAS mixtures.

Laboratory animals differ from humans in how rapidly they excrete a number of PFAS (serum half-lives in hours to days in rodents versus years in humans), how their specific tissue responds (PPARα activation in rodent versus human liver tissue), and the adverse effects observed (reduced serum cholesterol in rodents versus increased cholesterol in humans). Toxicokinetic models of internal dose help us extrapolate from animal results to humans, but some of the inputs—like human clearance rates for different lifestages, gender, and level of exposure—are uncertain. The mechanisms of action underlying adverse effects observed are only partly understood. This adds to uncertainty about which outcomes in test animals are most relevant to human risk assessment and which animal models are best suited to investigating outcomes observed in human studies.

The cross-sectional study design of most PFAS epidemiological studies limits their use in determining causality. In fact, researchers believe some health outcomes associated with serum levels of PFAS could be due to reverse causation. For example, earlier menopause and shorter breast-feeding duration may result in increased serum PFAS since menstruation and lactation

are excretion pathways in women. Conditions like kidney disease that can reduce glomular filtration rate may lead to higher serum PFAS because the disease impairs a major excretion pathway.

Another concern is using a single serum sample to quantify human PFAS exposure. Serum levels reflect exposure across recent months to years, but will not provide information on a historical peak exposure or fluctuations in serum over time. A single serum will not necessarily reflect the level in serum that preceded the onset of a disease or condition. Some studies, like the C8 Health Project, did exhaustive exposure reconstruction to overcome this limitation. A final concern is that a number of the outcomes with the most robust evidence in people—increased cholesterol, reduced birth weight, and immunosuppression—have many possible causes, which are difficult to control for in community-wide observational studies.

Epidemiological studies are limited in their ability to tease out associations between a specific PFAS and health outcomes in populations with simultaneous exposure to multiple PFAS. This is especially true when studying populations exposed through a community drinking water system, as individual PFAS will be highly correlated with each other in serum samples from that community. In addition, analytical methods have typically only measured about a dozen PFAS in drinking water and serum. Unidentified PFAS in drinking water may be contributing to community exposure and may confound associations between health outcomes and measured PFAS. For example, four new (previously unmeasured) PFAS were recently identified in the drinking water and human serum of residents in Wilmington, North Carolina (Center for Human Health and the Environment, 2018).

PFAS toxicology continues to be a very active area of research. NTP and EPA both have high priority research efforts underway to fill important data gaps. In addition, the National Institute of Environmental Health Sciences (NIEHS) is granting more than $10 million dollars annually to universities to study PFAS. Hundreds of new peer-reviewed papers are published each year.

7.2 PFAS exposure in people

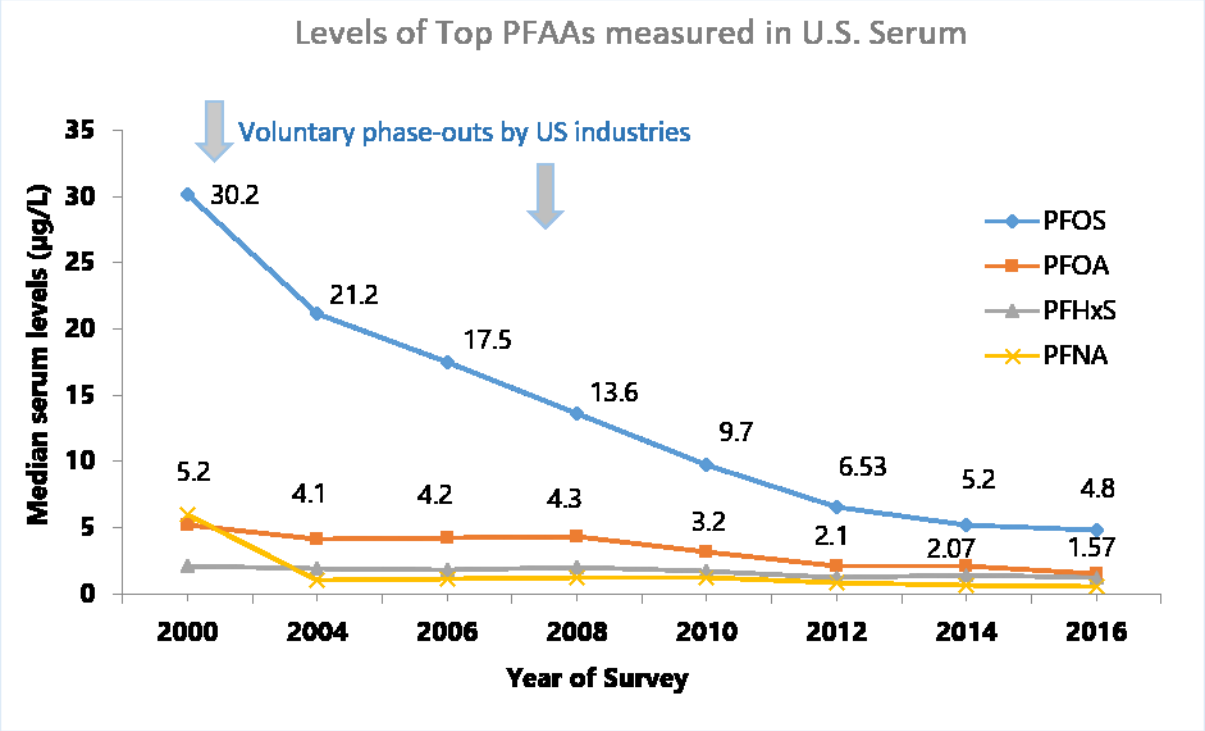
7.2.1 Trends and demographics of PFAA exposure

Widespread exposure to PFAAs in the U.S.

In national surveys, the CDC found that nearly all people tested had detectable levels of PFOS, PFOA, PFNA, and PFHxS in their blood serum. These four are the top four PFAAs measured in human serum in terms of frequency and concentration.

Figure 40 shows the average levels detected in U.S. serum over time. It's important to note that a voluntary phase-out of production of PFOS, PFOA, PFHxS, and related precursors by 3M occurred between 2000 and 2002, and a voluntary phase-out of PFOA and longer-chain perfluoro-carboxylic acids (PFCAs) occurred by eight major U.S. manufacturers between 2006 and 2015 under a stewardship agreement with EPA (ITRC, 2020a).

Figure 40. Time trend of median serum levels (µg/L) of four PFAS in a representative sample of U.S. residents over 11 years old from the NHANES (CDC, 2019).



Biomonitoring data for the general population of Washington is limited to one study in 2004 by Olsen et al., in which seven PFAAs compounds were measured in stored blood serum of 238 elderly men and women in Seattle (Olsen et al., 2004). These levels were comparable to national levels in adults at the time (CDC – NHANES, 2017).

Serum levels of these PFAAs have declined following phase-outs in domestic production and use that began in the year 2000. These PFAS have not been federally banned. Some uses were allowed to continue under EPA Significant New Use Rules. These PFAS may also be in imported materials and products (see Appendices 3: Sources and Uses, and 9: Regulations).

It is important to acknowledge that we have limited ability to measure and identify human exposures to PFAS. There are thousands of PFAS compounds, but only about a dozen have been regularly measured in blood serum of people (CDC – NHANES, 2019; Olsen et al., 2017). Individual research studies have employed expanded panels with up to 62 PFAS. PFOS, PFOA, and PFHxS still predominate among the identified PFAS in results (Miaz, 2020; Nakayama, 2020; Yeung, 2015).

Investigations of human serum with nontargeted methods, however, show that even expanded panels of PFAS can miss a considerable portion of organofluorine compounds in serum (Miaz, 2020; Yeung, 2015). In a recent Swedish study, 50% of the total extractable organofluorine content observed in archived pooled maternal serum samples collected in 1996 was unexplained by targeted analysis of 62 PFAS. The proportion of novel PFAS appeared to be growing over time, as only 20% of the total extractable organofluorine was explained by targeted analysis in their 2017 samples (Miaz, 2020).

Some PFAAs are highly bioaccumulative in people.

Bioaccumulation occurs because the human body readily absorbs PFAAs from the digestive tract, but only slowly eliminates them. Long-chain PFAAs accumulate in human blood serum, liver, lung, bone, and other locations in the body (Koskela et al., 2017; Perez et al., 2013). Some PFAAs can cross the placenta into fetal tissue (Mamsen et al., 2019). The body excretes other PFAS—such as PFBA and PFHxA—more rapidly. These are infrequently detected in the general population serum samples above 0.1 µg/L, but were detected more frequently in paired urine samples (Calafat et al., 2019).

A **half-life** is one way to measure the bioaccumulative nature of a substance. It represents the time required for the serum concentration of PFAS to drop by half after removing the source of exposure (such as contaminated drinking water). Estimates of half-life vary depending on the age and gender of the population studied, the level of PFAS exposure, the level of continuing background exposure, and the length of follow-up. Mean and median estimates of serum half that are most relevant to environmental exposures are provided below.

- PFOA: 2.3 to 3.9 years (Li et al., 2018).
- PFOS: 3.3 to 4.6 years (Li et al., 2018; Olsen et al., 2007).
- PFNA: 2.5 to 4.3 years (Zhang et al., 2013).
- PFHxS: 5.3 to 7.1 years (Li et al., 2018).
- PFHxA: 32 days (Russell et al., 2013).
- PFBS: 27 days to 44 days (Olsen et al., 2009; Xu et al., 2020).
- PFBA: 72 hours (Chang et al., 2008).

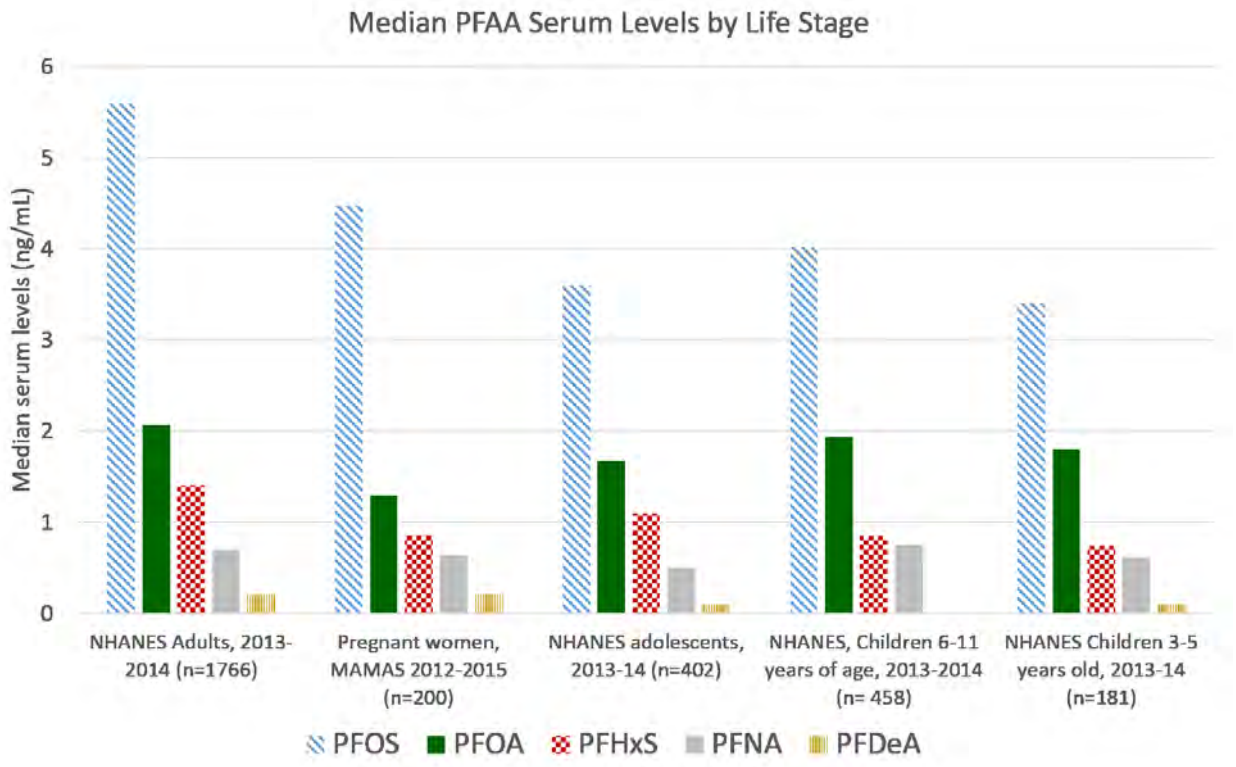
Serum levels of individual PFAAs vary across lifestage and sex

In the general population, children's serum levels of the primary PFAAs measured are often similar to or lower than adult levels. A study of 598 children ages 2 – 12 years in 1994 and 1995 by Olsen et al. reported that children were comparable to adults in their PFOS and PFOA levels. However, children had substantially higher 95th percentile values of PFHxS and FOSAA (Olsen et al., 2004). The higher levels in this subset of children may have been related to child-specific patterns of exposure to household items, such as treated carpet and textiles. In a 2009 study, 1-to-2-year old children had median serum levels of PFOA, PFOS, and PFHxS lower than adults levels measured in NHANES from the same years (Schecter et al., 2012). This study reported no difference between genders among young children. A nationally representative subsample of 639 children, ages 3 – 11 years, in NHANES 2013 – 2014 detected PFOA, PFOS, PFHxS, and PFNA in all children at levels that were similar to those of NHANES 2013 – 2014 in adolescents and adults (Ye et al., 2017). See Figure 41.

This is in contrast to children living in areas with contaminated drinking water who frequently have higher PFAA serum levels than adults due to their higher rate of intake of drinking water per pound of body weight and lactational transfer from mothers (if breastfed). For example, nearly 5,000 matched pairs of mothers and children aged 1 – 19 years were compared in the C8 Health Project. Children aged 1 – 5 years had mean serum levels of PFOA that were 44% higher than their mothers, and serum levels of PFOS were 30% higher than their mothers. Children's

serum remained higher until age 12 for PFOA but persisted through age 19 for PFOS (Mondal et al., 2012).

Figure 41. Median PFAAs serum levels in the general U.S. population by life stage.



Notes:

- The data on U.S. adults aged 20 and older and on adolescents aged 12 – 19 are from CDC NHANES (CDC – NHANES, 2017).
- Data on pregnant women are from a state of Califonia biomonitoring project called Measuring Analytes in Maternal Archived Samples (MAMAS), which is a representative sample of pregnant women statewide (California, 2017a).
- Data on children aged 3 – 11 years comes from a representative subset of NHANES (Ye et al., 2018).
- None of these studies were conducted in populations with known industrial sources of elevated PFAAs exposure.

Breastmilk can be a major contributor to infant exposure. A recent German study of PFAA serum levels in breastfed infants analyzed archived samples from a 1990 study. Compared to formula-fed infants, the breastfed infants had 4.4 times more PFOA, 2.2 times more PFOS, 3 times more PFNA, and 1.2 times more PFHxS (Abraham et al., 2020). A study of 100 mother-infant pairs in Sweden estimated that serum levels in exclusively breastfed infants increased 30% per month for PFOA, 45% per month for PFNA, and 40% per month for PFHxS of breast feeding (Gyllenhammar et al., 2018).

Only slight differences in PFAS serum levels are seen across adult age brackets, although older women have higher serum levels of PFOS, PFOA, and PFNA than younger adult women (Calafat et al., 2007). This may be due to the loss of several PFAS excretion pathways: menstration, pregnancy, and lactation (Jain, 2013; Taylor et al., 2014). The levels measured in these studies likely reflect non-occupational exposures to PFAS in diet, consumer products, and homes.

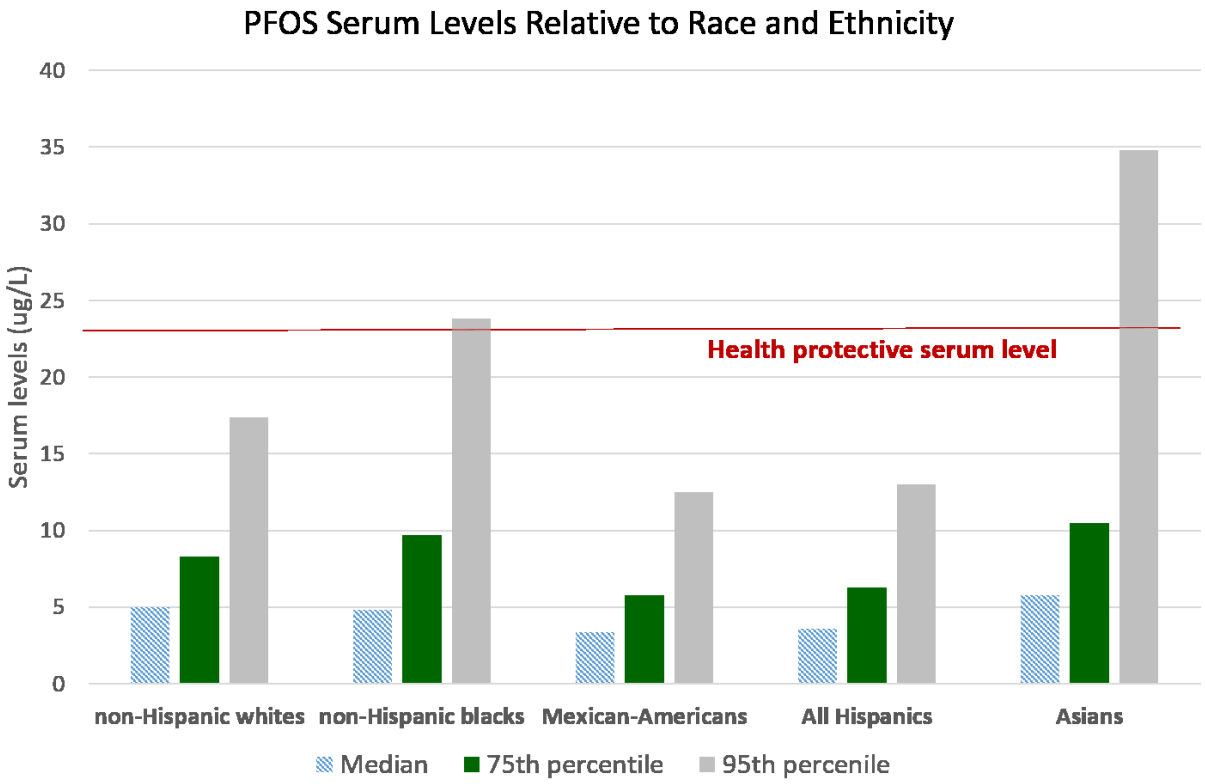
There are also observed sex differences in exposure to some PFAAs. Mean serum levels are generally lower in females post-puberty than in males. Compared to males over 11 years old, the geometric mean serum level for females over 11 years old was 24.4% lower for PFOA, 16% lower for PFNA, 40.9% lower for PFOS, and 45.6% lower for PFHxS in the latest CDC survey data (2015 – 16). The other eight PFAAs measured did not have sufficent frequency of detection to calculate a mean value for males versus females (CDC, 2019).

PFAA exposure varies by race, ethnicity, income, and education level

In 2015 – 2016 NHANES data, PFAA serum levels varied by racial and ethnic identity. Mexican-Americans had lower median serum concentrations of five PFAS than non-Hispanic whites or non-Hispanic blacks. Participants who self-identied as Asian had on average higher levels of PFOS and several other PFAAs (See Figures 42 and 43). Figure 42 shows differences in serum PFOS, which were the most pronounced. Similar demographic findings were reported in an earlier NHANES survey (Nelson et al., 2012).

In other studies, black Americans had lower PFAA levels than non-Hispanic whites. Kingsley et al. (2018) reported that non-Hispanic black women had 18% lower serum PFOA and 43% lower serum PFHxS concentrations than non-Hispanic whites in a study of pregnant women in Cincinnati, Ohio. Serum PFOS and PFNA were also lower, but the difference was not statistically significant (Kingsley et al., 2018). In Project Viva—a study of children aged 6 – 10 years born in the Boston area—children of black mothers had lower levels of PFOA, PFOS, PFHxS, and 2-(N-methyl-perfluorooctane sulfonamido) acetic acid (Me-PFOSA-AcOH), but not PFNA, compared with children of white mothers, even after adjusting for maternal concentration during pregnancy (Harris et al., 2017). It is not clear what factors underlie the differences observed, but income level, dietary habits, and use of consumer products such as stain repellents appear to contribute (Boronow et al., 2019; Kingsley et al., 2018). See Section 7.3 Pathways of exposure for more information.

Figure 42. Demographics of PFOS serum levels in non-Hispanic whites, non-Hispanic blacks, Mexican-Americans, all Hispanics, and Asians (CDC - NHANES, 2015-2016).

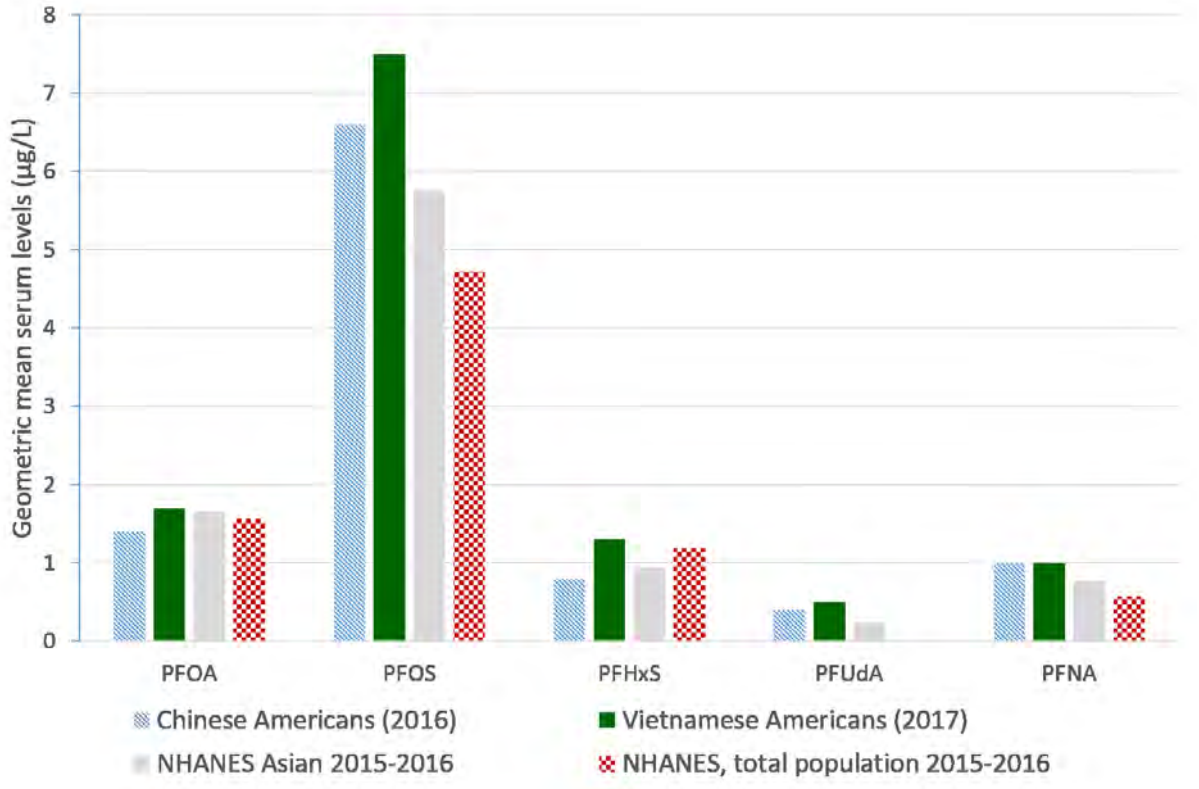


Notes:

- The red line represents the health-protective limit for human exposure recommended by New Jersey (22.5 µg/L), New Hampshire (23.6 µg/L), and Washington (23.6 µg/L) in their recommendations for drinking water limits for PFOS (New Hampshire Department of Environmental Services, 2019; New Jersey Drinking Water Quality Institute, 2018; Health, 2021).

The California Environmental Contaminant Biomonitoring Program investigated risk factors for elevated PFAAs in two Asian subgroups in the Asian Pacific Islander Community Exposures (ACE) Study (Biomonitoring California, 2019a, 2019b). This study recruited about 100 ethinic Chinese and 100 ethnic Vietnamese participants in San Francisco and San Jose areas in 2016 – 2017. Both subgroups in their study had even higher levels of PFOS than NHANES Asians at the mean and 95th percentile (see Figure 43). PFAAs serum levels were significantly associated with demographic factors such as age, sex, U.S. residency, birth country, household income, and language. Specficially, higher PFAA levels were associated with a smaller portion of life spent in the U.S., presumably reflecting more time spent in countries where industrial manufacturing and emissions have continued (Xie et al., 2013). Researchers concluded that California's regional immigration and racial and ethnic patterns may contribute to differences in PFAAs observed across the statewide surveys of PFAS (Attfield, 2018).

Figure 43. Geometric mean PFAAs serum levels (µg/L) in Asian subgroups from the ACE Study in California, compared to national norms as reported in CDC NHANES 2015 – 16. (Attfield, 2018; Biomonitoring California, 2019a, 2019b; CDC - NHANES, 2015 – 2016).



The most recent U.S. Census estimates for Washington state demographics estimate 8.3% of state residents are Asian and 3.7% are black or African-American (U.S. Census Bureau, 2018). If the distribution of serum PFOS in the state is similar to national norms, approximately 10% of Asian and 5% of African-American residents in Washington state would have PFOS serum levels that exceed health-based protective levels recommended by New Jersey (22.5 µg/L), New Hampshire (23.6 µg/L) and Washington (23.6 µg/L) (New Hampshire Department of Environmental Services, 2019; New Jersey Drinking Water Quality Institute, 2018; Health, 2021). No information was located for relative levels of PFAS in serum in U.S. or Northwest tribal populations.

Scientists don't know yet how social and economic determinants (e.g., race, ethnicity, income, education) are exactly linked with the environment, health, and well-being. Scientists believe that these associations could result from differences in socioeconomic factors, which may influence exposure and specific health outcomes.

Among a cohort of pregnant women living in eastern Massachusetts, PFAA serum levels were higher in women who were younger, less educated (but higher income), and had less educated partners (Sagiv et al., 2015). A meta-analysis confirmed that socioeconomic status (defined by income) is an important determinant of PFAS blood levels in people. This study looked at human biomonitoring markers of PFAS exposure with education and income. The study showed

consistently that a higher income is associated with higher PFAS concentrations (Buekers et al., 2018). The authors concluded that with PFAS it appears that a low socioeconomic status is not associated with an increased chemical burden.

7.2.2 Populations with elevated PFAS exposure

Occupational exposures

Manufacturing workers and those working with PFAS products

A number of occupational exposure studies of PFAAs in workers at fluorosurfactant and fluoropolymer manufacturing facilities were reviewed by ATSDR (ATSDR, 2018b). Compared to people with environmental exposures, concentrations reported in workers during the 1990s and 2000s were typically much higher (i.e., 800 – 10,000 µg/L for PFOA, 800 – 2,440 µg/L for PFOS, 200 – 1,850 µg/L for PFHxS).

Some professional ski waxers heat and handle PFAS-containing glide waxes during the professional competition season. Several European investigations have documented their high airborne exposure to PFAS in workspace and personal air. These studies have also shown increased serum levels of PFAS associated with this work (Freberg et al., 2010; Freberg et al., 2014; Nilsson et al., 2013; Nilsson et al., 2010; Russell et al., 2013).

Exposure information is limited or lacking for other workers. Tanner et al. (2018) reported that in a cohort of older adults in upstate New York, those who had worked in industries known to use PFAS had higher serum PFOS and PFOA than workers who did not work in those industries (Tanner et al., 2018). Workers who may be expected to have higher exposures include those who manufacture or handle PFAS-treated paper, carpets, leather, apparel, furniture, and individuals who install carpets or provide professional carpet care services, or other retail exposures.

For example, indoor air concentrations of 14 PFAS (Fluorotelomer alcohols [FTOH]: 4:2 FTOH, 6:2 FTOH, 8:2 FTOH, 10:2 FTOH, 12:2 FTOH; fluorotelomer acrylates [FTAC]: 6:2 FTA, 8:2 FTA, 10:2 FTA; perfluorinated sulfonamido ethanols and perfluorinated sulfonamides: EtFOSA, MeFBSA, MeFOSA, N-Methyl perfluorooctane sulfonamido-ethanol [MeFOSE], MeFBSE, N-Ethyl perfluorooctane sulfonamidoethanol [EtFOSE]) were measured in various settings, with the highest concentrations in stores selling outdoor equipment, a furniture shop, and a carpet shop (Langer et al., 2010). Schlummer et al. (2013) found higher air concentrations of FTOH in carpet shops and stores selling outdoor textiles than Langer et al. (2010). A study of PFAS-containing outdoor jackets in Germany showed that the jackets emitted FTOHs. The study estimated that inhalation of FTOHs by jacket retail workers would result in PFAS exposures similar to levels of dietary intake at the time (Knepper et al., 2014). Table 67 below summarizes occupational exposure estimates.

Table 67. Occupational exposure estimates (Langer et al., 2010).

Occupation	Average total PFAS air concentrations (nanogram/cubic meter) [ng/m^3]	Average exposure to total PFAS (ng/ kg body weight-day)
Retail trade workers in furniture and carpeting stores	187	11.84
Retail trade workers in sporting goods stores	351	22.23

Firefighters

Firefighters may have contact with PFAS in class B foams (also referred to as aquous film forming foam (AFFF) when extinguishing flammable liquid fires or during training exercises. Firefighter turnout gear may also shed or emit PFAS during normal use and cleaning (Peaslee et al., 2020). Finally, firefighters may be exposed to PFAS in smoke and dust from burning building materials. For example, serum collected from first responders after the World Trade Center collapse had 2-fold higher concentrations of PFOA and PFHxS compared to the U.S. general population. Higher exposure to PFNA, PFHxS, and PFOA was associated with work in areas that had higher exposure to dust and smoke (Tao et al., 2008).

PFAS serum levels were higher among firefighters compared to the general population in several studies (California, 2016; Dobraca et al., 2015; Jin et al., 2011; Shaw et al., 2013). A 2010 – 2011 study of 200 California firefighters showed slightly higher mean serum levels for PFOS, PFOA, and PFHxS compared to national norms for the study period (California, 2016, 2017b). A 2014 – 2015 PFAS biomonitoring study in a female cohort of firefighters and office workers reported higher exposure to PFHxS, PFUnDA, and PFNA in firefighters compared to office workers after controlling for age, race, and ethnicity. The levels of PFHxS, PFDA, and perfluorobutane sulfonic acid (PFBuS) were higher in firefighters and office workers compared to 2013 – 2014 NHANES adult women (Trowbridge et al., 2019).

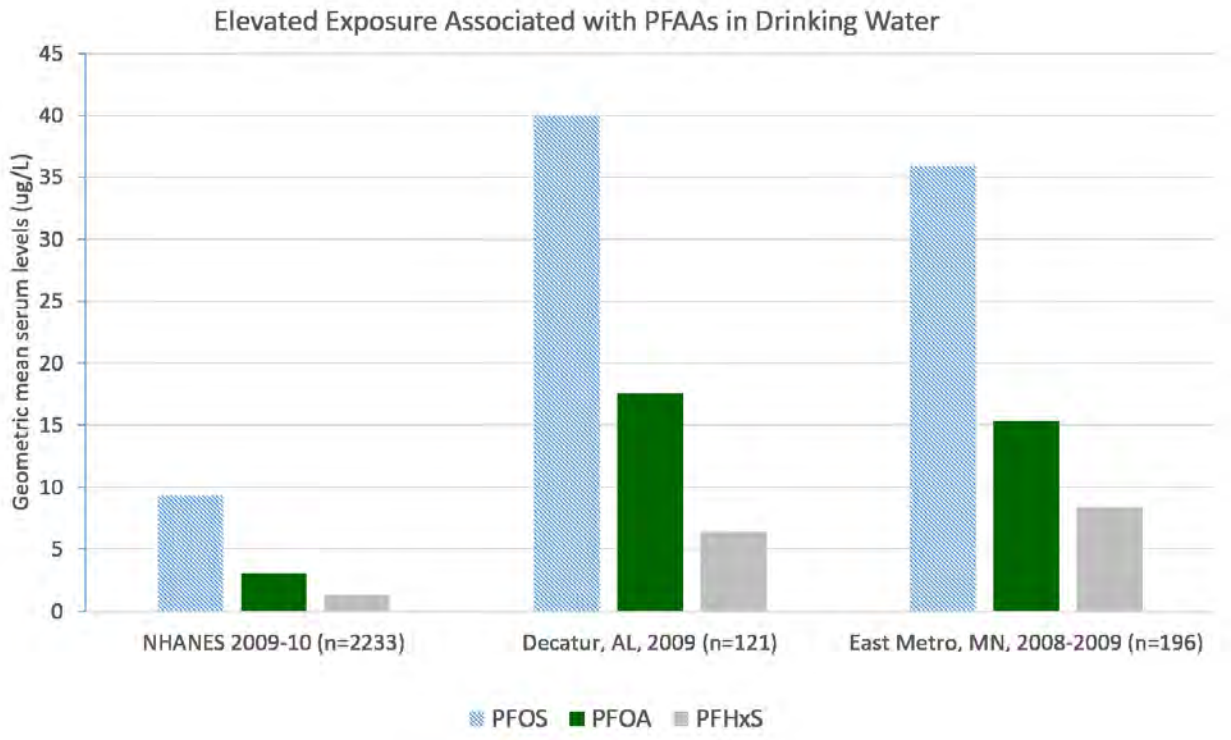
An Australian study of 149 contract firefighters who were required to train every 90 days with AFFF reported that median serum level of PFOS was ten times higher in firefighters than the general population of Australia and Canada. PFHxS was 15 times higher. PFOA, PFNA, PFHpA, and PFDA were not elevated in firefighters relative to the general population. Median serum levels in the group of firefighters studied were 66 µg/L PFOS and 25 µg/L PFHxS. Maximum detections were 391 µg/L PFOS and 277 µg/L PFHxS. Interestingly, study participants who had worked ten years or less (only after the phase out of PFOS-based AFFF) had levels of PFOS that were similar to the general population. A small study by the same research group used non-targeted analysis (quadrupole time-of-flight tandem mass spectrometry) to identify additional novel PFAS that were more frequently detected or unique to the firefighters studied (Rotander, Karrman, et al., 2015; Rotander, Toms, et al., 2015)

A small occupational exposure study in Finland analyzed 12 PFAS in the serum of eight firefighters after each of three training sessions with AFFF and simulated aircraft fires. Serum concentrations of PFHxS and PFNA were, on average, slightly higher in serum after the training sessions. Neither of these PFAS were ingredients in the foam being used, but may have been metabolites of precursor PFAS or from another part of the process (Laitinen et al., 2014).

Communities with PFAS contamination in drinking water

A large number of U.S. drinking water supply wells have tested positive for PFAS since testing began in 2013 (Environmental Working Group (EWG), 2020b). Below, we highlight three examples of communities with drinking water contamination that also had serum testing. Figure 44 shows the average community concentrations of serum PFAAs in two communities in which drinking water was impacted by industrial emissions and waste practices.

Figure 44. Elevated serum PFAAs levels (µg/L) in communities with drinking water impacted by industrial PFAS sources compared to the U.S. general population (ATSDR, 2013; CDC - NHANES, 2017; Minnesota Department of Health, 2020).



In Decatur, Alabama, a PFAS manufacturer reported in 2007 that it had been unknowingly discharging PFCAs into the Decatur Utilities Dry Creek Wastewater Treatment Plant (WWTP). Sewage sludge from that facility had been applied repeatedly as a soil amendment to about 5,000 acres of privately owned agricultural fields (176 fields on 35 farms). Between 2007 – 2009, EPA investigators detected PFAAs in the Decatur Utilities biosolids and in surface water, groundwater, and drinking water at and near the site of land application. PFAS concentrations in drinking water were not fully reported. Three out of 20 private wells had PFOA and PFOS

concentrations above the EPA provisional health advisory level at the time. Maximum detected levels were 365 ng/L PFOS and 2,200 ng/L PFOA. The public water system reported 155 ng/L PFOA in finished water in 2006 and 70 ng/L PFOA in finished water in 2010.

In April 2010, ATSDR tested serum samples from 153 people who lived and worked in the affected area. Median serum PFAA concentrations of 121 residents served by the public water system were 18.1 µg/L PFOA, 39.3 µg/L PFOS, and 7.4 µg/L PFHxS (Figure 44). Median levels were higher in nine residents served by private wells with detectable PFAS in the water: 30.8 µg/L PFOA, 60.8 µg/L PFOS, and 8.3 µg/L PFHxS (ATSDR, 2013).

The East Metro, a suburb of Saint Paul, Minnesota, is part of a larger area of Washington County, Minnesota with groundwater impacted by PFOS, PFOA, and PFHxS. This larger area is 150 square miles and affects the water supply of 140,000 Minnesotans. The sources of contamination are a large PFAS manufacting facility in Cottage Grove and disposal sites at Oakdale, Woodbury, Cottage Grove, and Lake Elmo—where the plant had disposed of wastes in the 1950s, 1960s, and 1970s (Minnesota Department of Health (MDH), 2019). Drinking water contamination in the East Metro was discovered in 2004, and water filtration to remove PFAAs was developed and installed in 2006. PFOA and PFOS levels in municipal wells ranged from non-detect to 900 ng/L. In private wells, the levels ranged from non-detect to 2,200 ng/L for PFOA and non-detect to 3,500 ng/L for PFOS (MDH, 2020).

MDH conducted a community exposure assessment in the East-Metro Area in 2008 in a random sample of residents with impacted drinking water. Mean and maximum levels detected in the 196 residents tested (Figure 44) were:

- PFOA
  - Mean 15.4 µg/L
  - Max 177 µg/L
- PFOS
  - Mean 35.9 µg/L
  - Max 448 µg/L
- PFHxS
  - Mean 8.4 µg/L
  - Max 316 µg/L

PFBA and PFBS were also detected in 28% and 23% of the samples, respectively. MDH conducted additional biomonitoring in 2010 and 2014 to confirm that water filters were working to reduce exposure. Over the six years of follow-up, average individual levels of PFOS went down by 45%, PFOA by 59%, and PFHxS by 34% (MDH, 2020).

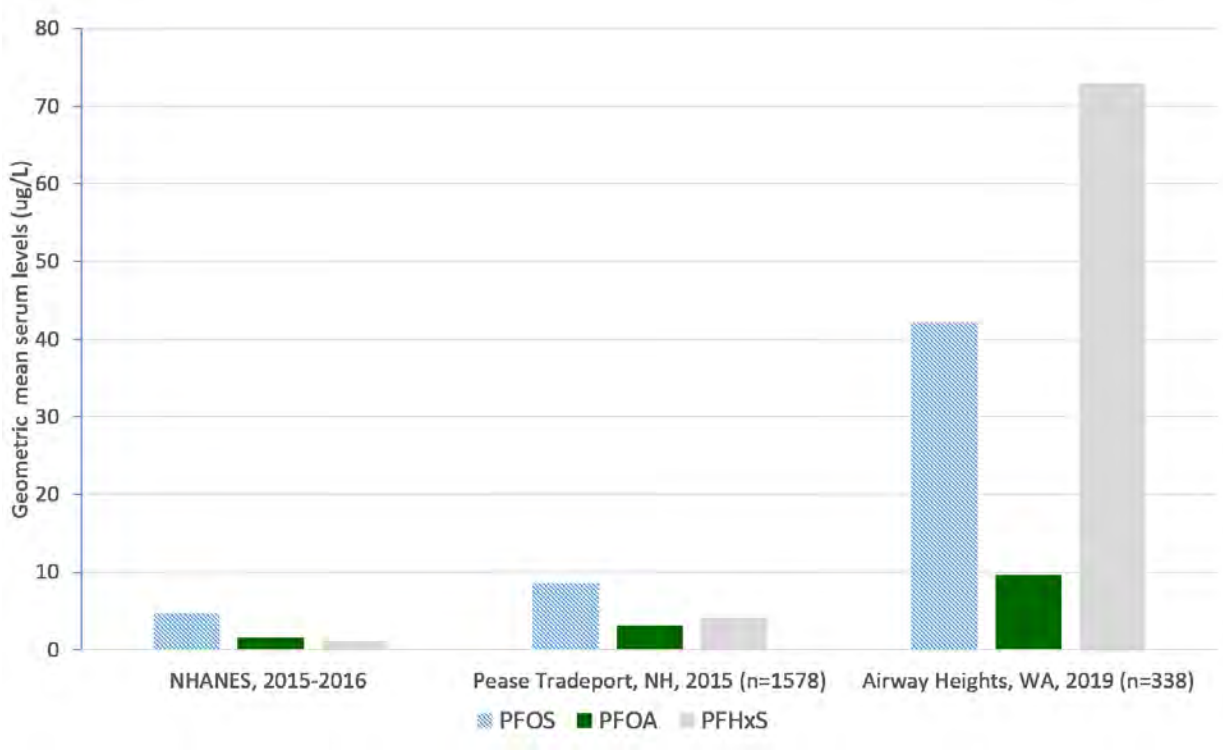
Biomonitoring studies have also documented elevated PFAS exposure in communities where firefighting foam contaminated their residential drinking water with PFAS. Figure 45 shows the mean serum concentrations in two communities compared to national norms.

At Pease International Tradeport in Portsmouth, New Hampshire, PFAAs were reported in three production wells of a public drinking water system in May 2014. The Tradeport was developed on the site of the former Pease Air Force Base and contains more than 250 businesses, public offices, restaurants, and childcare facilities employing more than 9,500

individuals. The suspected contamination source was firefighting foam used at the former base. Levels of PFAS detected were highest in the Haven well—PFOS (2,500 ng/L), PFOA (350 ng/L), and PFHxS (830 ng/L)—prompting the city to shut down the well. Two other wells had lower levels of these PFAS, but concentrations exceeded the 2016 EPA advisory level for PFOA and PFOS. These wells were fitted with PFAS filtration systems in 2016 (New Hampshire Department of Health and Human Services (NHDHHS), 2016).

Between April and October 2015, the NHDHHS conducted blood testing in 1,578 individuals who had lived on, worked on, or attended child care at Pease Tradeport. Three PFAAs were significantly elevated relative to national norms (Figure 44). Maximum serum levels detected were 95.6 µg/L for PFOS, 32 µg/L for PFOA, 116 µg/L for PFHxS, 5.2 µg/L for PFNA, and 5.6 µg/L for PFDeA. Six percent of the participants reported current or past experience as a firefighter, and may have had occupational exposure as well. Firefighters had significantly higher levels of PFOS and PFHxS compared to other participants (NHDHHS, 2016).

Figure 45. Geometric mean serum levels (µg/L) in samples collected from people who lived, worked or received childcare at Pease Tradeport in New Hampshire and Airway Heights, Washington. Levels are compared to national norms as measured by the CDC NHANES for the same time period.



The City of Airway Heights, Washington, near Fairchild Air Force Base, was selected to participate in a national exposure assessment of eight communities known to have had PFAS in their drinking water. PFAS in firefighting foam used at the base is the key suspected source of the water contamination (see Section 7.4.3 for more information about this site). Serum levels measured in study participants, 2.5 years after the contamination was removed from community drinking water, were elevated for PFOS, PFHxS, and PFOA (See Figure 45). The study is being conducted by the Agency for Toxic Substances and Disease Registry (ATSDR, 2020a).

The mean serum levels of PFHxS and PFOS reported in the Airway Heights exposure assessment are higher than those reported by other U.S. studies of communities exposed to PFAS via drinking water (ATSDR, 2020b) and lower than serum levels measured in residents of Ronneby, Sweden (Li et al., 2018).

In Ronneby, Sweden, 2013, high levels of PFOS and PFHxS (8,000 ng/L PFOS, 1,700 ng/L PFHxS) were found in the drinking water from one of the two waterworks supplying the municipality (population 28,000 residents). The primary source of drinking water contamination was also firefighting foam. In follow-up biomonitoring studies, median serum levels were 228 µg/L (PFHxS), 245 µg/L (PFOS), and 21 µg/L (PFOA) in a large group of residents (n=3418) exposed to contaminated water at home for at least one year during 2005 – 2013 (Li et al 2018).

7.3 Sources and pathways for human exposure

The primary pathways of human exposure to PFAAs are:

Non-point or diffuse sources:

- Dietary exposure to PFAS in the global environment.
- Eating foods that have been in contact with PFAS-coated food papers.
- Swallowing or inhaling indoor dust and air in homes, offices, and other buildings with PFAS-containing materials, such as treated carpets, furniture, or hard surfaces.
- Contact with consumer products that contain PFAS ingredients such as certain cleaning products, cosmetics, carpet treatments, car washes, waterproofing sprays, and dental floss.

Local sources around a release site:

- Drinking contaminated water.
- Eating fish and shellfish or wild game and wild plants from contaminated areas.
- Eating crops or animal products (meat, eggs, milk) from farms with contaminated soils, water, or feed.

Work exposures:

- Making or processing PFAS-containing materials on the job.
- Using PFAS-containing products on the job (e.g., firefighters).
- Working with or near PFAS-treated textiles such as apparel, carpets, or building materials.

7.3.1 Drinking water

Drinking water has been a significant source of human exposure in areas where significant PFAS contamination has occurred (see Section 7.2.2). Ingestion is the primary route of absorption from drinking water since the ionic forms of PFAAs found in water are not readily absorbed through skin (ATSDR, 2018b). Drinking water may be contributing to background exposures as well. Low levels of eight PFAAs (PFOS, PFOA, PFHxS, PFNA, PFHpA, perfluoro-n-pentanoic acid (PFPeA), PFUnDA, and PFDoDA) were detectable at very low levels in more than 30% of the archived U.S. tap water samples from 1990. Even these low levels of PFOA and PFNA in tap water (0.57 ng/L and 0.13 ng/L, respectively) were associated with higher plasma concentrations of PFOA and PFNA in household members. The authors estimated that tap water explained about 20% of residents' exposure for these two compounds (Hu et al., 2019).

According to Hu et al. (2016), the most significant two risk factors for detection of six PFAS in U.S. public drinking water systems in EPA's Unregulated Contaminant Monitoring Survey (UCMR3) were:

- Proximity to military fire training areas that used PFAS-containing products.
- Proximity to industrial sites that made or used PFAS.

More information about drinking water contamination is presented in Appendix 4: Fate and Transport.

Several large studies of long-term human exposure to PFOA in community drinking water have observed that average serum levels in the population are about 100 times the drinking water concentration (i.e., serum: drinking water ratio of 100:1) (Pitter et al., 2020; Post et al., 2012; Post et al., 2013). PFOS in community drinking water is estimated to result in average serum concentrations 172 times the chronic concentration in drinking water (Egeghy & Lorber, 2011; New Jersey Drinking Water Quality Institute, 2018).

These approximate ratios were also observed in a recent study of California teachers who lived in zip codes with detectable but modest drinking water levels of PFOS and PFOA as measured in the UCMR3 study (Hurley et al., 2016). Serum levels in any specific community are likely to relate to:

- How long the drinking water has been contaminated.
- Timing of serum sampling relative to when the exposure occurred.
- Individual consumption and use patterns of drinking water.
- Co-exposure to food.
- Consumer products.
- Other unknown sources.

7.3.2 Food

Food is another primary way most people are thought to be exposed to the PFAAs commonly detected in human serum (ATSDR, 2015; Jain, 2018; Poothong et al., 2020). In the U.S. and Canada, PFOA and PFOS were detected in some snack foods, vegetables, oils and butter, meat, dairy products, wild and farmed fish, shellfish, fast food, and microwave popcorn (Schecter et al., 2010; Tittlemier et al., 2007). In two small recent surveys by the Federal Drug Administration (FDA), few detections of 16 PFAS were reported in a wide variety of foods in the U.S. food supply. The exception was detection of PFOS (86 – 87 pg/g) in ground turkey and tilapia.

More extensive testing for PFAS in the food supply has occurred in Europe. The EFSA Panel on Contaminants in the Food Chain recently assessed more than 69,433 analytical results for 26 PFAS in common foods sampled across 16 countries of the European Union (EU). Many samples were below the analytical detection limits for the PFAS tested. Of the samples that were positive, fish, meat, and eggs generally had the highest concentrations. Vegetables and fruits had low concentrations but frequent detections. The EFSA panel concluded that fish and other seafood, eggs, meat, and fruit were important contributors to chronic exposure of PFOS and PFOA in Europeans. Vegetables and drinking water were also important contributors to chronic PFOA exposure. The same key dietary contributors emerged when they considered combined exposure to PFOA, PFNA, PFHxS, and PFOS (EFSA, 2018, 2020).

Two large U.S. dietary studies based on CDC NHANES data found that higher fish and shellfish consumption were associated with higher serum levels of PFAAs (Christensen et al., 2017; Susmann et al., 2019). In Susmann et al. (2019), higher levels of serum PFNA, PFDA, and PFOS were associated with fish consumption reported in the past 24 hours, 7 days, or 30 days and with seafood consumption in the past 12 months. Shellfish consumption reported for these same recall periods was associated with higher serum levels of PFNA and PFDA.

This study also found that serum PFAAs were positively associated with consumption of popcorn, fast food, and pizza, and were inversely associated with the number of food meals eaten at home (Susmann et al., 2019). Similar findings were reported in another dietary exposure study of California children and adults. Positive associations were found between PFAS serum concentrations and consumption of butter and margarine, fish, meat products, and microwave popcorn (Wu et al., 2015). PFAAs in fast food wrappers, non-stick baking paper, grease-proof take-out containers, and microwave popcorn bags can migrate out of the paper into food (Begley et al., 2008; Begley et al., 2005; European Commission and Cordis, 2012; Geueke, 2016)

At contaminated sites, food raised for human consumption could have elevated PFAS. Site investigations and research studies have demonstrated that when PFAAs are present in soil, drinking water, irrigation water, or animal feed, they can transfer to livestock and food crops. Shorter chain PFCAs appear most likely to accumulate in plants (Ghisi et al., 2019). Long-chain perfluoroalkane sulfonic acids (PFSAs) and PFCAs are the most likely to accumulate in animals. The degree of uptake and accumulation depends on the PFAA, the plant or animal species, and the level of contamination. For example, low levels of PFAAs in soil did not cause significant

uptake in vegetables in a Minnesota garden study (Scher et al., 2018). PFAA uptake has been observed in:

- Chicken meat and eggs (Australian Government Department of Defense, 2017; Yeung et al., 2009; Yoo et al., 2009).
- Beef cattle and other livestock (Lupton et al., 2012, 2014; Numata et al., 2014).
- Dairy animals and their milk products (Kowalczyk et al., 2012; Kowalczyk et al., 2013; Maine Department of Environmental Protection, 2017).
- Fish (Hansen et al., 2016).
- Cereals (wheat, rye, oats) (Liu et al., 2019; Stahl et al., 2009).
- Vegetable crops (Bizkarguenaga et al., 2016; Lechner & Knapp, 2011; Liu et al., 2019).

See Appendix 6: PFAS Ecotoxicology, Section 6.2 Bioaccumulation, about uptake in plants, fish, birds, and other animals, and Appendix 8: Biosolids, Section 8.6 Literature review of biosolids land application effects, regarding uptake by plants from biosolids application, for more information.

7.3.3 Consumer products

Contact with consumer products is a potential source of human exposure to some PFAS. Dipersable products such as waterproofing sprays and carpet cleaners may be inhaled, swallowed, or absorbed across the skin. Cosmetics and personal care products are applied directly to the skin. Durable products such as nonstick pans, hard surface sealants, and waterproof outdoor gear may release PFAS as they age. Young children may suck directly on treated surfaces and fabrics, or swallow PFAS on their hands during normal hand-to-mouth exploration. We review the types of consumer products that contain PFAS extensively in Section 3.3, Consumer products, along with the evidence for human exposure from these items.

Indoor dust and air have been sampled as an aggregate measure of human exposure to PFAS emitted or shed from consumer products and building materials. People inhale and ingest contaminated air and dust, leading to human exposure to PFAS.

Carpets and carpet care treatments

Carpets have been routinely treated with PFAS-based protectants to make them resistant to stains and easier to clean (see Appendix 3: Sources and Uses, Section 3.3.2 PFAS in a typical home). Several investigations have attempted to characterize human exposure to PFAS from treated carpets and carpet care products. Karaskova et al. (2016) found that the combined concentrations of 20 PFAS on carpeted floors was higher than other floor types (Karaskova et al., 2016). Several other studies have also observed higher concentrations of various PFAS in the indoor environment in homes and offices with carpet (Fraser et al., 2013; Gewurtz et al., 2009; Kubwabo et al., 2005). Because children spend more time on or near the floor and have relatively high respiration rates and frequent hand-to-mouth activity, they have higher exposures to contaminated air and house dust, and have more direct skin and mouth contact with carpet. Karaskova et al. (2016), Tian et al. (2016), Shoeib et al. (2011), and Trudel et al. (2008) have found that house dust is an important PFAS exposure route for toddlers.

Studies show that children with carpets in their bedrooms have higher concentrations of PFOS, PFHxS, and Me-PFOSA-AcOH in their bodies than children with other types of bedroom flooring (Harris et al., 2017). Boronow et al. (2019) found that women living in homes with treated carpet had higher exposure to PFAS, PFNA, and PFDeA.

In a Canadian study, a home where carpets had been treated approximately eight times with Scotchgard carpet protection formulations over 15 years had elevated levels of PFHxS, PFOS, and PFOA in house dust (2,780 nanograms per gram [ng/g], 1,090 ng/g, and 550 ng/g dust respectively). Serum levels of family members were also elevated (PFHxS ranged 27.5 – 423 µg/L, PFOS ranged 15.2 – 108 µg/L, and PFOA ranged 2.40 – 9.23 µg/L). The authors concluded that the ingestion or inhalation of household dust was the likely pathway of their elevated exposure (Beesoon et al., 2012).

A 2016 Danish Environmental Protection Agency (DEPA) study estimated the potential PFAS exposure to young children from five children's rugs (intended for those younger than 15 years old) that tested positive for organofluorine content in a survey of 21 rugs. PFOA and 6:2 fluorotelomer sulfonic acid (6:2 FTSA) were the primary PFAS detected in further targeted analysis. Using worst case assumptions about ingestion of carpet dust by toddlers, DEPA estimated 0.05 ng/kg-day exposure to PFOA with all other PFAS contributing another 0.04 ng/kg-day. This was well below the Danish screening value at the time (TDI of 30 nanograms per kilogram per day [ng/kg-day]) and is also below Washington state's recommended reference dose (RfD) for PFOA of 3 ng/kg-day (DEPA, 2016). It is important to note that their targeted analysis only measured a small percentage of the total organofluorine content present.

Apparel

PFAS are used to provide dirt repellency and durable water repellency to rain gear, snow gear, shoes and boots, synthetic and real leather, and other clothing including children's bibs, hats, mittens, rain and snowsuits (DEPA, 2015, Commission for Environmental Cooperation [CEC], 2017; Kotthoff et al., 2015; Gremmel et al., 2016). After market sprays may also be applied to apparel to boost water and dirt repellency. An earlier study reported that children who wore waterproof clothing more frequently had higher concentrations of PFOS and PFNA in their serum (Clara et al., 2008).

Several studies have investigated potential exposure to PFAS from apparel. A study by the CEC, investigated the presence and migration of PFAS in a range of 137 textile items purchased across Canada, Mexico, and the United States during the summer 2017 (CEC, 2017). Most of the items were performance apparel such as rain gear and sports attire but waterproof children's bedding and bibs were also included. PFCAs were the most frequently detected PFAS tested and both PFHxA and PFOA were detected in more than 40% of items. Both short-chain and long-chain PFCAs, PFSAs, fluorotelomer carboxylic acids (FTCA), fluorotelomer sulfonic acids (FTSA), and fluorotelomer unsaturated acids (FTUA) were detected in the materials tested. Investigation into release of PFAS from fabrics showed that water-soluble PFAS (PFBA, PFHxA, PFOA, PFBS, 6:2 FTS, 6:2 FTCA, 6:2 FTUA) were most likely to be released into wash water in the laundering scenario. Similarly, PFAS with shorter chain lengths and higher water solubility were most prone to migrate from the children's material into artificial saliva and from sports fabrics into artificial sweat (CEC, 2017).

Migration of PFAS from children's textiles into laundry water and artificial saliva was also documented in a study by the DEPA (DEPA, 2015). This study was conducted earlier when C8 chemistry predominated in the market. Compared to the amount of PFCAs in the materials measurable by solvent extraction, about 6% of the total PFCAs in treated fabrics migrated to artificial saliva and about 12% was released from the material during the laundering scenario (DEPA, 2015). The DEPA used oral and dermal estimates from their studies and air emission data from other studies to estimate an upper-end daily uptake of PFAS from children's clothes which was 0.55 ng/kg-day for a four-year-old (DEPA, 2015). This can be compared to Washington state's recommended reference dose (RfD) for PFOA of 3 ng/kg-day.

Neither study measured airborne emissions of volatile PFAS such as fluorotelomer alcohols (FTOH). Volatile PFAS have been measured in PFAS treated apparel (reviewed in DEPA 2015) and have been measured in emissions from treated apparel (Knepper et al., 2014). Their release from fabrics can actually increase over time as the material ages, presumably because of degradation of side-chain polymers (van der Veen et al., 2020). Several indoor air studies show that higher FTOHs in indoor air correlate with higher serum levels of PFAA in occupants (Shoeib et al., 2011; Makey et al., 2017; Fraser et al., 2012; Poothong et al., 2020). Inhalation of volatile PFAS may be the predominant pathway of exposure to PFAS in apparel.

Cosmetics and personal care products

Polymeric and non-polymeric PFAS ingredients are used in sunscreens, creams and lotions, foundation and concealers, shampoos, nail polish, eye makeup, and denture cleaners (DEPA, 2018; Geueke, 2016). Although none of the cosmetic ingredients listed in two surveys were PFCAs, testing by Fujii et al. (2013) and the DEPA (2018) showed that the majority of cosmetics with PFAS ingredients did contain a range of PFCAs (C6 – C14). As identified in Appendix 1: Chemistry, Section 1.1.1 PFAS terminology, C6 represents a PFAS with a carbon chain length of 6, and so on. Presumably these occur as breakdown products of precursors or residuals from ingredient manufacturing. The listed ingredients with the highest levels of measured PFCAs were ammonium C6 – 16 perfluoroalkyl ethyl phosphate and C9 – C15 fluoroalcohol phosphate. Sunscreens and foundation had the highest measured PFCA levels. PFOA concentrations in a couple of samples exceeded the EU limit of 25 ng/g (DEPA, 2018; Fujii et al., 2013).

The DEPA conducted a human risk assessment based on the above survey results. DEPA used PFOA as the reference chemical because data on skin absorption and toxicity were available. They assumed 2% absorption across skin for ionic PFOA and 70% dermal absorption for neutral PFOA. Their risk assessment did not find a likely risk to consumers from any given product, even using conservative assumptions (DEPA, 2018). However, if they had used EFSA's 2018 TDI of 6 nanograms per kilogram (ng/kg) per week for PFOA as a screening level, most of their dermal exposure estimates from single products were just below or considerably above (up to 35 times higher) that screening level.

Indoor air and dust

As certain consumer products degrade by abrasion and normal wear and tear, they may contribute to PFAS levels in indoor dust and air. Indoor air is inhaled by occupants and indoor dust is both inhaled and swallowed, especially by young children who crawl on the floor and engage in hand-to-mouth activity.

In 2000 – 2001, a number of PFAS were measured in U.S. indoor dust samples collected from 112 homes and ten day-care centers in North Carolina and Ohio. PFOA, PFOS, and PFHxA were the most commonly detected (median concentrations in indoor dust were 142, 201, and 54.2 ng/g, respectively). Some dust samples had very high concentrations of PFOS and PFHxS (up to 12,100 and 35,700 ng/g respectively) (Strynar & Lindstrom, 2008). Lower mean concentrations of PFAA were detected in indoor dust samples from 152 homes in Vancouver, Canada. PFOA, PFOS, and FOSE were prominent in dust samples. 8:2 FTOH had a mean level of 88 ng/g dust and 2.9 nanograms per cubic meter (ng/m^3) in air.

Exposure estimates in this study shows that air, rather than dust, was the primary exposure pathway in adults whereas in toddlers, dust was a significant pathway of exposure (Shoeib et al., 2011). In another exposure assessment, PFOA, PFOS, and PFNA measured in serum of pregnant women in Vancouver, Canada in 2007 – 2008 correlated with precursor chemicals measured in the indoor air of participants' homes. Specifically, positive associations were discovered between airborne 10:2 FTOH and serum PFOA and PFNA, and between airborne N-methyl perfluorooctane sulfonamido ethanol (N-MeFOSE) and serum PFOS (Makey et al., 2017). The median PFOA levels in dust observed in the U.S. and Canada are higher than the levels found in European countries (D'Hollander et al., 2010). This may be due to differences in PFAS use and sources.

PFOA, PFOS, and PFHxS were also routinely detected in indoor dust from homes, offices, and vehicles in Boston, Massachusetts in 2009 (Fraser et al., 2013). Another Boston study sampled PFAS in air in 30 offices in seven buildings, and compared this to serum levels in 31 office occupants. This Boston study detected a range of newer PFAS in more than 90% of the indoor air samples of offices, and reported maximum levels of 70 ng/m^3 for 8:2 FTOH, 12.6 ng/m^3 for 10:2 FTOH, and 11 ng/m^3 for 6:2 FTOH (Fraser et al., 2012). Collectively, FTOHs in air significantly predicted PFOA in serum of office workers ($p < 0.001$) and explained approximately 36% of the variation in serum PFOA concentrations. PFOS in serum was not associated with air levels of perfluorooctane sulfonamides (PFOSAs) or N-ethyl perfluorooctane sulfonamido ethanols (N-EtFOSEs). The compounds 8:2 FTOH and 10:2 FTOH are precursors to PFOA, and represent a potential inhalation pathway.

Norwegian investigators also reported significant positive associations between household dust and air levels of certain PFAS and the serum PFAS concentrations in occupants. This study collected indoor air, dust, duplicate diet, and blood samples in 2013 – 2014 as part of a study to examine various pathways of PFAS exposure in 61 adults in the Oslo area. Air intakes of 10:2 FTOH were associated with serum PFUnDA, 8:2 FTOH inhalation correlated with serum PFNA, and MeFOSE and EtFOSE inhalation correlated with whole blood PFOSA. Air intake of 6:2 FTOH was not associated with measured serum PFCAs. Dust samples of PFOA and PFNA were also associated with serum levels. The authors estimated that PFAAs in dust contributed to 2% of

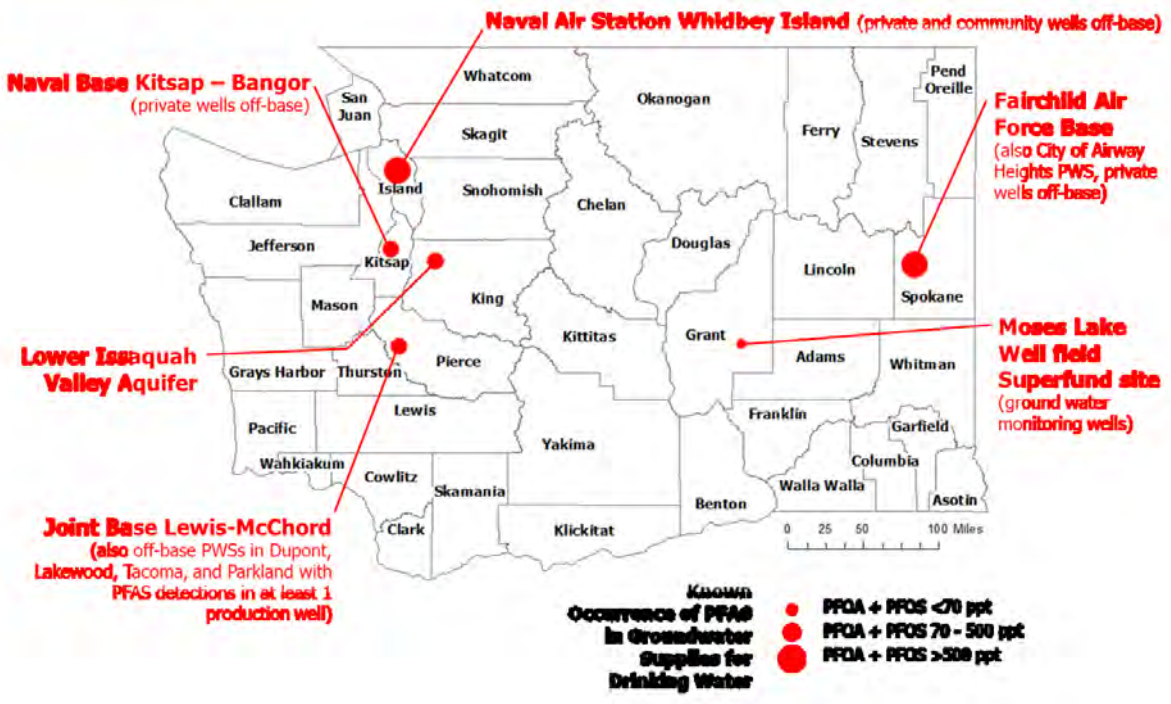
median exposures and PFAAs in indoor air contributed about 3% to median exposures in study participants. Specific individuals in the study, however, had much higher estimated contributions from household dust and indoor air (Poothong et al., 2020).

7.4 Known areas of PFAS contamination in drinking water aquifers in Washington state

Comprehensive testing for PFAS in drinking water has not been conducted yet in Washington state. Available data shows PFAS contamination in groundwater supplies used for drinking in five main areas of the state (Figure 46). Where levels exceeded the lifetime health advisory level for PFOA and PFOS of 0.07 µg/L set by EPA in 2016, water systems and the military have taken action to meet the federal health advisory.

In Figure 46, red dots indicate that at least one private or public well had detectable levels of PFOA and PFOS. The size of the dot indicates the maximum concentration detected. Detections of PFOA and PFOS by specific public water systems is provided in Table 68. The data shown in Figure 46 are from voluntary testing by the Navy, Air Force, and Army, and from proactive voluntary testing by public water systems. In addition, the Moses Lake Well Field superfund site, a former military facility, reported PFAS in groundwater monitoring wells in 2016.

Figure 46. Known areas of PFAS contamination in drinking water supplies.



The primary source suspected in these areas is a firefighting foam called AFFF that contained PFAS. Additional sources of PFAS at contaminated drinking water sites may be uncovered by ongoing investigations. Available state data are presented below with a summary of actions taken in each area.

7.4.1 Lower Issaquah Valley Aquifer, 2015 – 2020

As part of EPA's UCMR3 testing, the City of Issaquah discovered PFOS, PFHxS, and smaller amounts of PFOA, PFNA, PFBS, and PFHpA in a shallow production well in their PWS. PFOS concentration in the affected well ranged from 0.4 – 0.6 µg/L and PFHxS ranged from 0.20 – 0.24 µg/L. Concentrations of other PFAS were less than 0.03 µg/L. Water from this well was blended in a ratio of 1:4 with a deeper adjacent well that was PFAS-free before it entered the distribution system. After blending, the water level did not exceed the 2009 provisional EPA health advisory, which was 0.4 µg/L for PFOA and 0.2 µg/L for PFOS (EPA, 2009).

In November 2015, additional sampling across the Issaquah system detected PFOS at 0.106 µg/L at the entry point of the two blended wells, and levels ranging from 0.068 – 0.038 µg/L in more distant areas of the distribution system. At each site, PFHxS was present at about half the PFOS concentration.

In January 2016, the city shut down the impacted well and eventually invested over $600,000 to install a granular activated carbon (GAC) treatment system in May 2016. Since June 2016, the treatment system has been effective at removing PFOA and PFOS from the shallow well and is routinely tested for performance. In late 2019, PFOS and PFHxS contamination began to appear in the deeper well, with levels reaching 0.04 µg/L for PFOS and 0.02 µg/L for PFHxS by early 2021. The City plans to take that deeper well offline later in 2021 and expand its treatment system to remove PFAS from both wells.

The city has investigated the potential sources of contamination and concluded that the likely source was the Eastside Fire and Rescue headquarters, about a mile up gradient. Soil samples in a firefighting training area at the headquarters contained PFOA and PFOS from firefighting foam.

One monitoring well and two drinking water production wells operated by nearby Sammamish Plateau Water system were also found to contain PFOS up to 35 ppt and PFHxS up to 30 ppt (Sammamish Plateau Water, 2016, 2018; Tuchscherer, 2021). Currently these wells are offline and the water district is seeking funding to design and install GAC treatment to remove PFAS from these wells.

7.4.2 NAS Whidbey Island, 2016 – 2020

In 2016, the NAS Whidbey Island began offering PFAS water testing in off-base drinking water wells located within one mile from potential or known release sites of AFFF on the base. Water results were compared to the 2016 EPA health advisory level for PFOA and PFOS. Subsequent sampling rounds have "stepped out" in a half-mile radius in the direction of groundwater flow from exceedances of PFOS and/or PFOA in drinking water.

In October 2018, the Navy identified PFAS in a stormwater drain near Hangar 6 at Ault Field and in an associated stormwater drainage system that empties into Clover Valley Stream and Dugualla Bay. As a result of this new information, the Navy expanded its off-base drinking water sampling near Ault Field, specifically within one-half mile of Clover Valley Stream and Dugualla Bay. No exceedance of the EPA health advisory was identified.

As of May 2020, the Navy has tested a total of 281 private or community drinking water wells as part of this investigation. PFOS or PFOA were detected in 26 wells (9%). Sixteen of these wells exceeded the EPA health advisory level. Eight are near the Outlying Landing Field (OLF) southeast of the Town of Coupeville, two are near Ault Field in Oak Harbor, and six are near a former Navy disposal site used from the 1960s to 1990s for industrial and household wastes (referred to as Area 6). See Figure 47 for a map with these locations.

Figure 47. Arial map of NAS Whidbey Island.

While PFOS was the leading PFAS detected near Ault Field and Area 6, contamination near OLF was dominated by PFOA. The Navy continues to conduct biannual sampling of all drinking water

wells with PFAS detections. It also monitors wells adjacent to properties with wells above the EPA health advisory. The Navy provides bottled water to residents whose results for PFOA or PFOS exceed the EPA health advisory until a long-term solution is developed and implemented. Long-term solutions may include connecting homes to a nearby public water system, installing whole house filtration systems, and installing a new drinking water well.

In addition to private wells, two Group A public water systems in the area were found to have PFAS detections. One of these systems is the Town of Coupeville's water system, which is located near OLF. Coupeville's water system blends water from multiple wells, most of which are not impacted, so tap water has remained below the EPA health advisory for PFOA and PFOS (Hinds, 2017). Water testing results from two specific wells in March 2019 showed PFOA concentrations ranged from 0.022 – 0.061 µg/L (Anatek Labs Inc., 2019). Detectable levels of PFHxS and PFHpA were also present (see Table 68). To address PFOA above the EPA's health advisory in eight private wells, the Navy recently installed a granulated activated carbon treatment system to remove PFAS from Coupeville's contaminated well and then connected these private well owners to the town's water system (Department of Navy [DON], 2018). The treatment system is routinely tested to ensure that the water is below EPA's health advisory level for PFOA and PFOS.

The second Group A public water system with PFOA and PFOS combined above the EPA health advisory is a mobile home park south of Area 6. The long-term solution being conducted for this system is connection to the Oak Harbor Water System (DON, 2020). The Navy also sampled the Admiral's Cove Water District and the Crockett Lake Water District. Both water districts had no detections of PFOS and PFOA at the time of sampling. At least 12 small public water systems on Whidbey Island tested their wells independently from the Navy's testing for PFAS. None reported detections.

The Navy has conducted a number of public meetings where they have presented health information and answered questions about the drinking water investigation. The Navy continues to make progress on its on-base PFAS source investigation and is implementing a policy regarding removal, disposal, and replacement of legacy AFFF. No firefighting training is occurring on base with PFAS-containing foams. The NAS Whidbey Island PFAS website[148] contains additional information about the on-base and off-base PFAS investigations.

[148] https://navfac.navy.mil/NASWIPFAS

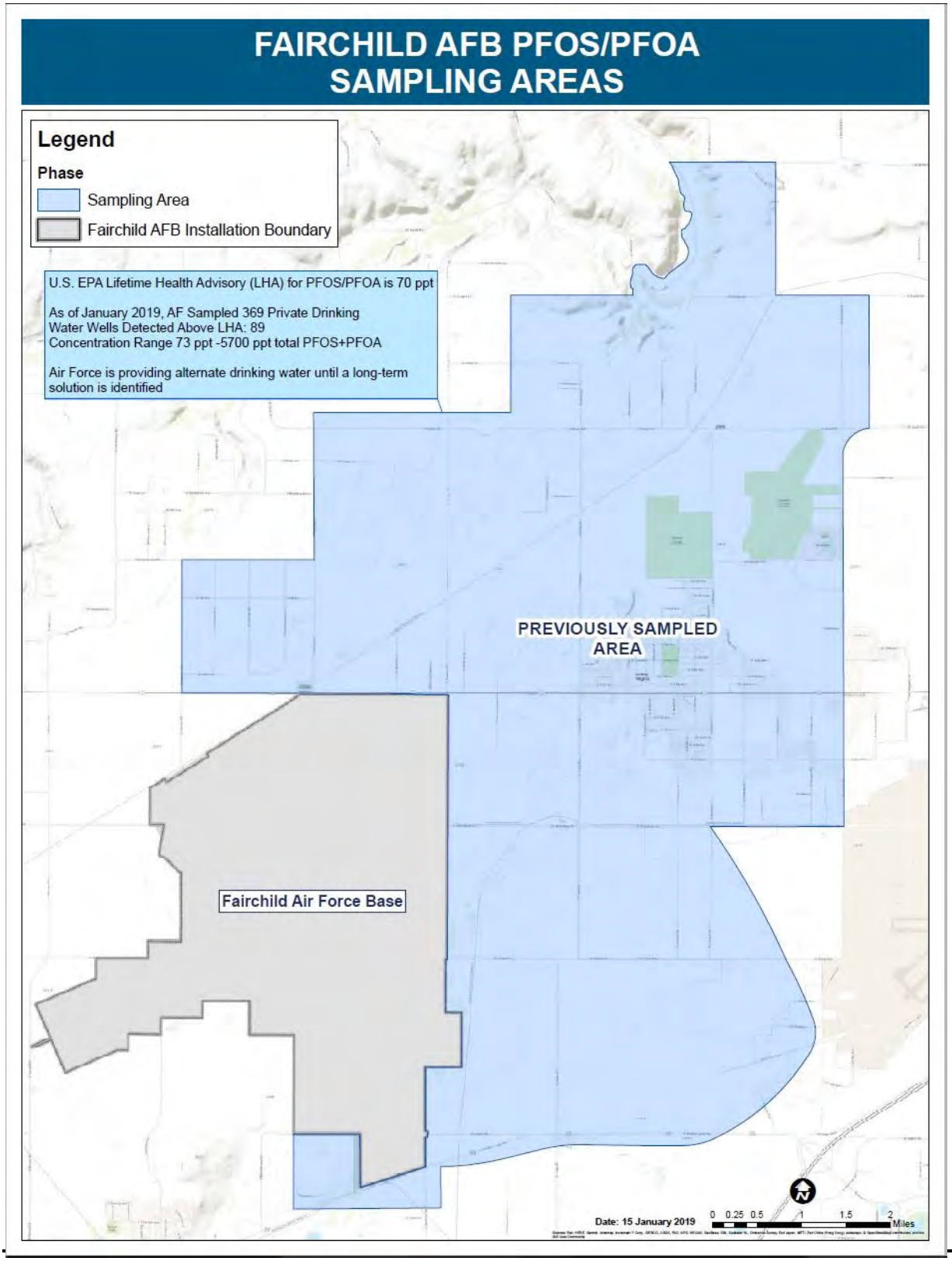
7.4.3 Fairchild Air Force Base, 2017 – 2019

Fairchild Air Force Base (AFB) detected PFAS in groundwater monitoring wells on the base, in monitoring directed by the Department of Defense (DOD). Drinking water on the base comes from three wells located several miles northeast of the base near the Spokane River, and a well located on the southern tip of the base. These wells are not contaminated with PFOS or PFOA. Based on groundwater monitoring results, Fairchild AFB conducted off-base testing for PFAS in public and private drinking water wells in several phases. They detected PFAS in private wells east of the base, municipal wells for the City of Airway Heights northeast of the base, and other community and private wells to the north and northeast of the base.

As of January 2020, the Air Force has tested 372 private residential drinking water wells. One hundred and sixty nine (169) residential wells had detectable levels of PFAS and 88 of those wells currently exceed the EPA health advisory level for PFOA and PFOS (Mark Loucks, 2020). The maximum detected level of PFOA and PFOA combined was 5,700 ppt total in a private well. The Air Force policy is to immediately notify well owners and provide bottled water if levels for PFOS and PFOA in drinking water exceed the EPA health advisory level. Bottled water is provided until a long-term solution is developed and implemented. According to a January 2020 progress report, the Fairchild AFB has installed 78 residential GAC treatment systems on impacted residential wells. Where a GAC filtration system is not feasible, the Air Force is connecting private wells to the City of Airway Heights water system (Fairchild AFB, 2018; Mark Loucks, 2020).

The Air Force sampled four municipal wells, two from the City of Medical Lake and two from the City of Airway Heights. Only the two Airway Heights wells had detectable levels of PFAS (see Table 68). The concentration of PFOS and PFOA in the Airway Heights wells were 1.1 – 1.2 µg/L PFOS and 0.3 – 0.32 µg/L PFOA in the affected wells. These levels are about 17 times higher than the EPA health advisory level for PFOS and PFOA.

Figure 48. Sampling area for private wells around the Fairchild Air Force Base (Fairchild Air Force Base, 2019).



In response to PFAS detection in April 2017, the City of Airway Heights public water system closed their contaminated wells and used an emergency intertie with the City of Spokane to flush their system with clean water. Flushing included draining reservoirs and water towers. During the flushing, the city warned residents west of Hayford Road to not drink or cook with water from city pipes, and Fairchild AFB provided bottled water to city residents. After testing throughout the water system confirmed that PFAS were sufficiently flushed, the water system resumed delivery with water from the City of Spokane. The city added another connection to the City of Spokane to supply drinking water and the Air Force installed a treatment system on municipal well #9 to supplement the Airway Heights water supply during high-demand summer and fall months. This system was operational in the Fall of 2018 (Fairchild AFB, 2018).

According to Fairchild AFB, the base has transitioned to a safer foam that is based on C6 fluorochemistry. Fairchild no longer uses AFFF during live fire training. Fire trucks on base are outfitted with a test system that prevents any foam discharge during equipment testing. AFFF use is limited to emergency responses with immediate containment requirements. The Strategic Environmental Research and Development Program (SERDP), Environmental Security Technology Certification Program (ESTCP) is funding research on new fluorine-free firefighting foam formulations that can meet the military's performance requirements (Mil-Spec), and are readily biodegradable (Ananth, 2018; Payne, 2018; Tsang, 2018).

7.4.4 Joint Base Lewis-McChord

The Army's Fort Lewis facility and the Air Force's McChord Field facility are operated as a joint military base, the Joint Base Lewis-McChord (JBLM), but have separate water systems.

Fort Lewis Water System

Fort Lewis monitored seven drinking water sources as part of the UCMR3 monitoring. PFOA was detected at 0.051 µg/L in one well and PFHpA at 0.013 µg/L in another. Subsequent testing in November 2016 confirmed the previous detections in those two wells and showed PFOA concentration in the Fort Lewis well #17 at 0.071 µg/L, which is just above the health advisory level (Lynn, 2017). Well #17 was taken out of service in August 2015 but was monitored for PFAS until 2019. According to a Freedom of Information Act request, Army drinking water testing in 2018 detected 0.144 µg/L total PFAS concentration at well #17 Fort Lewis with seven PFAAs detected (PFBS, PFHpA, PFHxS, PFHxA, PFNA, PFOS, PFOA) (Environmental Working Group, 2020). JBLM plans to decommission well #17.

The November 2016 testing also revealed additional wells with PFAS contamination. The primary source of drinking water (Sequalitchew Springs and infiltration gallery) for the main base generally has 0.015 – 0.020 µg/L of PFOS and PFOA combined. In addition, a well that serves the military golf course near DuPont had levels just above the EPA health advisory level. Bottled water was supplied at that facility, and point-of-use treatment devices are now used to reduce exposure to PFAAs.

McChord Field

McChord Field was not involved in UCMR3 monitoring because the population served by its water system at that time was below 10,000. In the November 2016 monitoring, PFOS and small amounts of PFOA were reported in two drinking water wells serving McChord Field at combined concentrations of 0.250 and 0.216 µg/L (Lynn, 2017). According to a Freedom of Information Act request, Army testing in 2017 detected a total PFAS concentration of 0.303 µg/L with five PFAAs detected (PFBS, PFHpA, PFHxS, PFOS, and PFOA) (Environmental Working Group, 2020). Both wells that contained PFOS and PFOA above the advisory level were shut down in 2017. In early 2020, JBLM installed GAC filtration systems on these two wells and two other wells with lower levels of PFAS that supply drinking water to McChord Field and the housing units for McChord.

JBLM staff believes contamination came from firefighting foam used through the early 1990s for firefighter training at several locations associated with McChord Field's runway and Fort Lewis's Gray Army Airfield, as well as other potential sources such as landfills. According to JBLM staff, use of foams containing PFAS was discontinued more than 20 years ago.

Yakima Training Center

Another military site managed by JBLM, the Yakima Training Center, detected no PFAS in drinking water on-base in November 2016. These wells draw from deep aquifers. Site investigation around potential AFFF release sites in 2021 showed elevated levels of PFAS in shallow onsite monitoring wells near the Selah Airstrip. The Army plans to offer sampling of offsite drinking water wells starting in late 2021 to investigate this further.

7.4.5 City of Lakewood

As part of the UCMR3 monitoring, the Lakewood Water District tested five of its drinking water wells drawing from three different aquifers, and no PFAS were detected at that time. Because of detections in late 2016 at McChord Field just east of Lakewood, the water district began proactively monitoring for PFAS in their water system starting in spring of 2017 using lower reporting limits than were used in UCMR3. Initially only trace levels of PFOS and PFHxS were detected in the two wells at the Ponders well field just west of McChord Field. The concentrations gradually increased and Lakewood removed these wells from service in summer 2018 and installed GAC treatment at the Ponders wellfield in late 2019. In 2021, Lakewood is in the process of designing GAC treatment to install at its Scotts well field northwest of McChord Field. Lakewood's shallow J-wells north of McChord Field also have low levels of PFOS and PFHxS. All six of these Lakewood wells with detectable levels of PFAS tap into the shallower aquifers near McChord Field. Lakewood continues to monitor the 31 wells in its system and to update its water customers about the issue (Lakewood Water District, 2019a, 2019b).

7.4.6 City of DuPont

As part of UCMR3 testing, the City of DuPont detected levels of PFOA (~ 0.03 µg/L) in two wells in the southwest area of its distribution system. PFOA and PFOS were not detected in the three wells serving the north and east areas of the distribution system. Between October 2018 and January 2020, DuPont was proactive in conducting follow-up monitoring for PFAS. January 2020 results show PFOA concentrations of 0.010 – 0.015 µg/L and PFOS concentrations of 0.005 – 0.009 µg/L at two Bell Hill wells. October 2019 results at two Hoffman Hill wells show PFOA levels were 0.027 – 0.050 µg/L and PFOS levels were 0.010 – 0.013 µg/L.

Because of blending, the combined concentration of PFOA and PFOS entering the water system from these well fields is lower: 0.014 µg/L for Bell Hill and 0.029 µg/L for Hoffman Hills. Although these levels are below the EPA health advisory level, they are above the respective draft State Action Levels. The City of DuPont hired an engineering consulting firm to investigate the hydrology of the wells and options for next steps (City of Dupont, 2020). The City recently received funding to design and install GAC treatment to remove PFAS from the Hoffman Hill wells.

7.4.7 City of Tacoma

Tacoma Public Utilities tested its South Tacoma Wellfield as part of the UCMR3 monitoring and did not detect PFAS at that time. In late summer 2018, Tacoma Public Utilities tested for PFAS in some of the individual wells at the southern end of its South Tacoma Wellfield. This was a proactive effort to understand if PFAS existed in its water sources near JBLM. One of the wells sampled (Well 10C) draws from a shallow aquifer and was used exclusively as a source of nonfluoridated drinking water by customers who collected water in their own containers at the well site. Combined PFOA and PFOS levels in this well exceeded the EPA health advisory level. Tacoma notified customers and closed the well. Tacoma's Green River source, which serves all Tacoma Water customers with the vast majority of their drinking water, showed no detections of PFAS (Tacoma Public Utilities, 2018).

7.4.8 Parkland Light and Water Company

Parkland Light and Water Company tested its drinking water wells as part of the UCMR3 monitoring. No PFAS were detected at that time. Because of detections in late 2016 at McChord Field just west of Parkland, Parkland began proactively monitoring for PFAS starting in the spring of 2017. Levels of PFOS and PFOA well below EPA's Health Advisory have been detected in two of Parkland's wells located within a mile of the runway at McChord Field. These two wells draw from a very shallow but extremely productive aquifer apparently flowing mostly from the southeast. Parkland continues to monitor these wells.

7.4.9 Naval Base Kitsap-Bangor

In 2019, the Navy identified 23 historical sites where firefighting foam may have been released on Naval Base Kitsap-Bangor. The base drinking water supply was tested in the UCMR3 with no PFAS detected. Based on groundwater flow in the area, the Navy invited private well owners in adjacent communities to participate in free voluntary testing for PFAS (DON, 2021). Results have been reported to the private well owners. Two private wells southwest of the base had PFOS and PFOA combined in excess of the EPA health advisory level. These households were immediately provided bottled water for drinking and cooking until a long-term solution can be put into place. Seventy two percent of the private wells had no detectable PFAS. Twenty seven percent of tested wells had detections of PFAS below the EPA Health Advisory level. Most of these wells (95%) had PFAS levels that were also below June 2021 draft recommendations for Washington State Action Levels for five PFAS in Group A public drinking water systems (DON, 2021). PFAS contamination was not detected in two nearby PWS (Silverdale and Kitsap PWS) (Farley, 2020).

7.4.10 Washington state testing summary

Table 68 reports the results outlined above from various testing sites in Washington. This testing was completed under the UCMR3, through voluntary testing by branches of the Armed Services at military sites, and via voluntary follow-up testing by PWS.

Because water from multiple wells is often blended before distribution, the PFAS results shown may not represent the water concentration delivered to taps. The results shown here also represent the levels of PFAS detected in the water before mitigation action was taken.

Table 68. Results of PFAS testing of drinking water in Washington state for PFAS.

Source of testing information	Year	Public drinking water systems, private wells with PFAS detections	PFOA + PFOS combined (µg/L)	Total PFAS measured (µg/L)	PFAS detected	Mitigation action
EPA UCMR3 [a]	2013 to 2015	Issaquah Water System – Well #4	0.490 [c]	0.796	PFOS PFHxS PFHpA PFOA PFNA PFBS	GAC filter installed 2016
City of Issaquah	2016 to 2021	Issaquah Water System – Well #4	ND	ND	N/A	Continued monitoring of the filtered well

Source of testing information	Year	Public drinking water systems, private wells with PFAS detections	PFOA + PFOS combined (µg/L)	Total PFAS measured (µg/L)	PFAS detected	Mitigation action
City of Issaquah	2020 to 2021	Issaquah Water System – Well #5	Up to 0.04	Up to 0.06	PFOS PFHxS	GAC filter to be installed
Sammamish Plateau Water and Sewer District	2016 to 2021	Sammamish Plateau Water and Sewer District	Up to 0.04	Up to 0.09	PFOS PFHxS PFNA PFOA PFBS	Blending; wells removed from service until GAC filter can be installed
EPA UCMR3 [a]	2013 to 2015	City of DuPont Water System (two wells)	0.030	0.030	PFOA	Follow-up monitoring
City of DuPont	2018 to 2019	City of DuPont Water system (four wells)	0.014 – 0.060 [d]	Not reported	PFOA PFOS PFHxS	Blending; GAC filter to be installed
EPA UCMR3 [a]	2013 to 2015	JBLM - Lewis (two wells)	0.051	0.013 – 0.051	PFOA PFHpA	Follow-up monitoring
JBLM [b]	2016 to 2018	Ft. Lewis (five wells)	0.015 – 0.071	up to 0.144	PFOA PFOS PFHxS PFHpA PFBS PFHxA PFNA	One well above health advisory level was not active and has not been returned to service
JBLM [b]	2016 to 2018	McChord Field (four wells)	0.216 – 0.250	up to 0.303	PFOA PFOS PFHxS PFHpA PFBS	Wells removed from service until GAC filters installed (2020)
City of Lakewood	2018 to 2019	Lakewood Water District (6 wells)	0.017 – 0.063	Not reported	PFOS PFOA PFHxS	GAC filters installed (2019)

Source of testing information	Year	Public drinking water systems, private wells with PFAS detections	PFOA + PFOS combined (µg/L)	Total PFAS measured (µg/L)	PFAS detected	Mitigation action
City of Tacoma	2018 to 2019	Tacoma Public Utilities (1 well)	Not reported	Not reported	Not reported	Well removed from service
Parkland Light and Water Company	2017 to 2019	Parkland Light and Water – Well #9	0.007 – 0.042	Not reported	PFOS PFOA PFHxS	Follow-up monitoring
NAS Whidbey Island [b]	2016 to 2019	Town of Coupeville, Evergreen Mobile Home Park, Group B wells, and 20 private wells	0.006 – 7.74 [e]	0.004 – 9.9	PFOS PFOA PFHxS PFHxA PFHpA PFNA PFBS	Bottled water or PUR filter provided when tap water is above health advisory level until long-term solution installed
Town of Coupeville	Mar. 2019	Town of Coupeville water system (one well)	0.022 – 0.061 [f]	0.035 – 0.139	PFOA PFHxS PFHpA	GAC filters installed (July 2019)
Fairchild AFB [b]	2017 to 2019	City of Airway Heights (two wells)	1.4 – 1.5	Not reported	PFOS PFHxS 6:2 FTS PFHxA PFOA	Bottled water provided until Spokane City water was provided or GAC filters installed
Fairchild AFB [b]	2017 to 2019	88 private wells	0.073 – 5.7	Not reported	Not reported	Bottled water provided until GAC filters or other long-term solution installed
Fairchild AFB [b]	2017 to 2019	78 private wells	LOD – 0.070	Not reported	Not reported	Continued monitoring

Source of testing information	Year	Public drinking water systems, private wells with PFAS detections	PFOA + PFOS combined (µg/L)	Total PFAS measured (µg/L)	PFAS detected	Mitigation action
Naval Base Kitsap-Bangor	2020 to 2021	2 private wells	>0.070	Not reported	Not reported	Bottled water provided until long-term solution can be put into place.
Naval Base Kitsap-Bangor	2020 to 2021	93 private wells	LOD—0.070	Not reported	Not reported	Monitoring

Notes:

- a = EPA's UCMR3 directed 132 public water systems in Washington to test six perfluoroalkyl acids (PFAAs). The systems included all 113 large Group A systems that serve more than 10,000 people and 19 smaller systems. The systems tested cover 94% of Washington residents served by public water systems. PFOS, PFOA, PFNA, PFBS, PFHxS, and PFHpA were measured using EPA Method 537 with reporting limits between 0.02 and 0.04 µg/L.
- b = Military bases with fire training areas or a history of AFFF use have been testing drinking water on and off bases in response to a directive from the DOD (DOD, 2016a, 2016b; DOD Environment, 2018). This is a voluntary effort that is following the EPA lifetime health advisory for PFOS and PFOA combined of 0.070 µg/L. When a private well or public water system exceeds this level, the military has provided alternative water immediately. The military has also installed or paid for filtration of private wells and public water systems.
- c = This Issaquah well was blended 1:4 with an uncontaminated well before distribution, so the concentration of PFOA and PFOS combined at the nearest businesses was closer to 0.10 µg/L. Levels were lower still in other parts of the Issaquah water system.
- d = Because of blending, the concentration entering the water distribution system from impacted well fields is lower (0.014 - 0.028 µg/L for PFOS and PFOA combined).
- e = Results reported show the range of concentrations measured across all wells tested by NAS Whidbey. The maximum detections were in private wells. Independent sampling by the Town of Coupeville water results are shown separately.
- f = Because of blending, PFAS concentrations in distributed tap water were lower.

7.5 Public health advice

7.5.1 EPA health advice for PFOS and PFOA in drinking water

In 2016, EPA established a Lifetime Health Advisory of 0.070 µg/L for PFOA and PFOS combined in drinking water. A lifetime health advisory level is a concentration in daily drinking water considered to be without risk of adverse health effects over a lifetime of exposure, including in sensitive populations. EPA health advisories are non-regulatory and non-enforceable standards.

The EPA advisory was based on an evaluation of the studies of PFOA and PFOS in laboratory animals and considered studies of human populations exposed to PFAS. For both compounds, EPA identified developmental effects in rodents as the most sensitive endpoint in animal experiments thought to be relevant to humans. For both PFOA and PFOS there are large differences between humans and laboratory animals in how external dose (the amount of intake) translates into internal dose (the amount in blood and organs). Humans retain PFOA and PFOS much longer than laboratory rats and mice, which leads to a higher internal dose in humans given the same external dose. EPA used toxicokinetic modelling to derive equivalent human doses for exposure levels in rodents associated with minimal to no observable adverse developmental effects. Uncertainty factors were applied to derive a RfD of 20 nanograms per kilogram of body weight per day for each compound (EPA, 2016b, 2016c).

EPA assumed that significant PFOA and PFOS exposure occurs through non-drinking water sources and apportioned a default of 20% of the Reference Dose to come from drinking water. They also assumed 90th percentile drinking water intake rate for lactating women for their ingestion rate. For an average sized woman, this ingestion rate is 3.8 liters (L) of tap water consumed daily in beverages and foods (see Table 69).

Table 69. 2016 Lifetime Health Advisory Levels for two PFAS in drinking water established by EPA Office of Water (EPA, 2016a).

PFAS	RfD[a] (ng/kg-day)	Basis	Relative source contribution[b]	Drinking water ingestion rate	Lifetime Health Advisory Level in drinking water (µg/L)
PFOA	20	Developmental effects in mice	20%	0.054 L/kg-day [c]	0.070
PFOS	20	Developmental effects in rats	20%	0.054 L/kg-day [c]	0.070

Notes:

- a = RfD is the reference dose which is a health protective value for chronic oral consumption.
- b = Relative Source Contribution is the proportion of the RfD allocated to drinking water sources under the Safe Drinking Water Act.
- c = This ingestion rate is the 90th percentile intake by lactating women from the 2011 EPA Exposure Factors Handbook.

There are no enforceable federal drinking water standards for PFAS. In early 2021, EPA announced its regulatory determination to develop maximum contaminant levels (MCLs) for PFOA and PFOS. The process of establishing MCLs takes at least three to four years before regulations are adopted. Recent MCLs have taken considerably longer.

7.5.2 Washington Department of Health advice for PFAAs in drinking water

Since 2016, a large number of additional research studies have been published on the toxicity of various PFAS found in drinking water. Comprehensive federal assessments by the ATSDR, the National Toxicology Program, and several state assessments using more recent data have added significantly to the evidence base for health advisories and regulations (see Section 7.2 health concerns). In 2019, Health reviewed this newer data and recommended taking action at lower concentrations of PFOA and PFOS in drinking water (above 10 ppt PFOA and 15 ppt PFOS). Health also reviewed the evidence available to support health-based values for the other most commonly reported PFAS in state drinking water supplies. In all, Health recommended state action levels for five PFAS (PFOS, PFOA, PFHxS, PFNA, and PFBS). These draft recommendations support rulemaking being conducted by the SBOH to address PFAS contamination in drinking water. A draft rule and the draft state action levels were posted in November 2019 for public review and an informal comment period. Health also held three stakeholder workshops in December 2019 to engage regulated (Group A) public water systems. A proposed rule was filed[149] in August 2021 with the SALs shown in Table 70. Rule adoption is expected in late 2021.

Table 70. Proposed State Action Levels (SALs) for Washington public drinking water systems.

PFAS	Allowable daily intake[a] (ng/kg-day)	Basis	Relative source contribution[b]	Drinking water ingestion rate	SAL in drinking water[c] (µg/L)
PFOA	3	Developmental effects in mice.	50%	MDH model[d]	0.010
PFOS	3	Immune effects in mice. Also protective of developmental effects in rats.	20% Adults 50% Children	MDH model[d]	0.015
PFNA	2.5	Developmental effects in mice.	50%	MDH model w/ MDHHS inputs[e]	0.009
PFHxS	9.7	Reduced thyroid hormone (T4) in rats (developmental concern).[f]	50%	MDH model[d]	0.065

[149] https://www.doh.wa.gov/CommunityandEnvironment/DrinkingWater/RegulationandCompliance/RuleMaking

PFAS	Allowable daily intake[a] (ng/kg-day)	Basis	Relative source contribution[b]	Drinking water ingestion rate	SAL in drinking water[c] (µg/L)
PFBS	300	Reduced thyroid hormone (T4) in mice (developmental concern).[f]	20%	0.174 L/kg-day[g]	345

Notes:

- a = such a reference dose which is a health protective value for chronic oral consumption.
- b = RSC is the proportion of the allowable daily intake allocated to drinking water sources.
- c = SALs are State Action Levels for Group A public water systems developed for consideration by Washington State Board of Health.
- d = The MDH Model is the Minnesota Department of Health 2019 peer-reviewed toxicokinetic model for infant intake of bioaccumulative PFAS in drinking water. It includes age-specific drinking water ingestion rates as well as placental and lactational transfer pathways from mother to child.
- e = MDHHS inputs are from the Michigan Department of Health and Human Services 2019 recommended public health screening levels for four PFAS in drinking water.
- f = Thyroxine (T4) is a thyroid hormone.
- g = This ingestion rate is the 95th percentile intake by infants (aged birth to 1 year) from the 2019 EPA Exposure Factors Handbook.

The proposed draft public health advice reflects our best judgement for protecting Washington state residents while we continue to follow advancements in PFAS research. For details of how Health developed the SAL values, please see the technical documentation available on the rulemaking website.[150] There is a very active research effort to understand the human health impacts of exposure to various PFAS. Health researchers continue to study health outcomes in human populations with elevated exposures. EPA is using rapid toxicity-screening tools to investigate potential biological activities of 75 compounds that are representative of the various classes of PFAS chemistry. Industry and independent scientists are publishing new findings regularly in peer-reviewed scientific literature.

[150] https://www.doh.wa.gov/CommunityandEnvironment/DrinkingWater/RegulationandCompliance/RuleMaking

7.5.3 Drinking water health advisories and MCLs set by other states

A number of states use the EPA Health Advisories for PFOS and PFOA to guide public health advice for drinking water. Other states have developed independent advisories for PFAS in drinking water (Connecticut, California, Illinois, Maine, Minnesota, North Carolina, and Ohio). At least seven states have established enforceable state standards for PFOS, PFOA, and/or other PFAAs in drinking water (New Jersey, Vermont, Massachusetts, Michigan, California, New York, New Hampshire). Some states—like Vermont, Connecticut, and Massachusetts—have set a value for the total of five to six PFAS in drinking water (ITRC, 2020c). The ITRC maintains a current listing of state and international standards and guidance values[151] for PFAAs in groundwater, drinking water, and surface water/effluent wastewater. We refer readers to this resource for the most current information.

7.5.4 Washington state assessment and advice for PFAS contaminants in recreational fish

Recreational and subsistence fishers, and tribal communities that consume fish from urban waters and areas downstream of WWTP discharges may have higher exposures to PFAS that accumulate in fish. Serum of fish and shellfish consumers who participated in CDC NHANES in 2007 – 2014 had higher levels of several PFAS (Christensen et al., 2017). Researchers determined that consumers of fish and shellfish are at higher risk of exposure to certain PFAS than non-consumers. In Washington, PFOS was the primary PFAS detected in Ecology surveys in Washington freshwater fish in fillets (see Appendix 5: Environmental Occurrence, Section 5.1.7 Freshwater fish).

International studies indicate that some PFAAs—such as PFOS, PFHxS, and PFOA—can reach very high levels in serum of fishermen who eat fish from industrially impacted areas (G. W. Olsen, 2015a). A recent study also identified a number of novel PFAS in fish from the Yangtze River and Tandxun Lake, China (including six sulfonate classes, two amine classes, one carboxylate class, and one *N*-heterocycle class) (Liu et al., 2018). The discovery of these PFAS in fish demonstrates bioavailability and the potential for bioaccumulation for these compounds or their precursors. A study examined the association of PFAS with diet and drinking water in reproductive-aged Chinese women. Intake of freshwater fish, marine fish, shrimp, and crab was positively associated with plasma PFAS concentrations, whereas higher intake of soy products was associated with lower plasma PFAS levels (Zhou et al., 2019).

Several states with localized surface water contamination have developed fish advisories. In Minnesota, fish tissue with more than 800 ng/g PFOS in edible parts are listed as *do not eat*, fish with 40 – 800 ng/g have various recommended consumption restrictions, and fish with less than 40 ng/g have no suggested consumption limits. New Jersey issued a consumption advisory for 12 species of fish that were found to contain chemicals belonging to the PFAS family (Hurdle, 2018). Michigan has developed Eat Safe Fish Guidelines for PFOS across numerous water bodies (Michigan Government, 2018). These guidelines are set to be protective for

[151] https://pfas-1.itrcweb.org/fact-sheets/

everyone including children, pregnant and breastfeeding women, and people with existing health problems such as cancer or diabetes.

The Great Lakes Consortium for Fish Consumption Advisories released Best Practice for Perfluorooctane Sulfonate (PFOS) Guidelines[152] in November 2019. The guidance is voluntary for states that border the Great Lakes, but is intended to promote consistency in fish consumption advice. The best practices meal advice categories for all populations are:

- PFOS in fish (microgram per kilogram [µg/kg]): ≤ 10, Meal frequency: Unrestricted.
- PFOS in fish (µg/kg): > 10 – 20, Meal frequency: 2 meals per week.
- PFOS in fish (µg/kg): > 20 – 50, Meal frequency: 1 meal per week.
- PFOS in fish (µg/kg): > 50 – 200, Meal frequency: 1 meal per month.
- PFOS in fish (µg/kg): > 200, Meal frequency: Do not eat.

There are currently no fish consumption advisories for PFAS in Washington. In 2018, Health determined provisional health-based screening levels for PFOS and PFOA based on the 2016 EPA RfDs. The provisional screening levels were 23 ng/g and 8 ng/g for the general population and high consumers, respectively. Health reviewed fish data collected by Ecology in 2008 and 2016 and found that some fillet tissue contained PFOS concentrations in excess of these values. Specifically, PFOS was detected in Washington freshwater fish at levels up to 87 ng/g in fillets (see Appendix 5: Environmental Occurrence, Section 5.1.7 Freshwater fish). Health requested additional data to provide an adequate basis for a fish consumption advisory. That data was collected by Ecology and provided to Health in 2019. Health is re-evaluating its screening levels in consideration of the lower recommended oral intake recently recommended as part of Health's proposed drinking water advice. Health is also collecting PFAS data on the most common types of fish sold in Washington to inform advice to consumers.

7.5.5 International health guidance values

German human biomonitoring commission (HBM Commission)

In 2017, the German Human Biomonitoring Commission (HBM commission) derived health-related guidance values in blood plasma for PFOA and PFOS. The "HBM I" value represents the concentration of a substance in human biological material at which, and below, there is no risk of adverse health effects, and no need for action. Based on an assessment of literature on human epidemiological studies, and on animal studies, the HBM commission derived an HBM I value of 2 nanograms per milliliter (ng/mL) for PFOA and 5 ng/mL for PFOS (Apel et al., 2017).

French Agency for Food, Environmental, and Occupational Health and Safety

In 2017, the French Agency for Food, Environmental, and Occupational Health and Safety (ANSES) developed human reference doses (toxicity reference values [TRVs]) for PFBA, PFHxS, PFBS, and PFHxA based on studies conducted in laboratory animals (Table 71) (ANSES, 2017). TRVs are established for a given critical effect, and are specific to a substance, a duration of exposure (acute, subchronic or chronic), and a route of exposure (oral, inhalation, etc.).

[152] https://www.health.state.mn.us/communities/environment/fish/docs/consortium/bestpracticepfos.pdf

Table 71. Toxicity reference values developed by ANSES (ANSES, 2017).

Chemical	Critical effect and study	Critical concentration	Uncertainty factor (UF)	Toxicity reference value (TRV) (mg/kg-day)
PFBA	Hepatic effects Butenhoff et al., 2012	NOAEL = 6 mg/kg-d HED = 1.764 mg/kg-d	75	0.024
PFHxS	Hepatic effects Butenhoff et al., 2012	NOAEL = 1 mg/kg-d HED = 0.289 mg/kg-d	75	0.004
PFBS	Renal effects (Hyperplasia tubular) Lieder et al., 2009b	BMD 10% = 24 mg/kg-d HED = 6.06 mg/kg-d	75	0.08
PFHxA	Renal effects (papillary necrosis & tubular degeneration) Klaunig et al., 2015	NOAEL = 30 mg/kg-d HED = 7.91 mg/kg-d	25	0.32

Notes:

- LOAEL: Lowest-observed-adverse-effect level.
- NOAEL: No-observed-adverse-effect level.
- BMD: Benchmark dose.
- HED: Human equivalent dose.

European Food Safety Authority

In 2018, the EFSA issued a provisional scientific opinion on tolerable weekly intakes of PFOA and PFOS (EFSA, 2018). EFSA derived their estimates from serum measurements in human observational studies.

After an extensive review of epidemiological evidence, they selected the outcomes with the strongest evidence for a causal association with PFOS and PFOA. These were increased serum cholesterol, decreased antibody response to vaccines, and lower birthweight for PFOS; and increased serum cholesterol, elevated liver enzyme (ALT), and decreased birth weight for PFOA. They then used physiologically based pharmacokinetic (PBPK) modelling to estimate the dietary intake that would produce that serum level over a lifetime of continuous exposure. For children, they used maternal serum levels and models of maternal transfer during gestation and breastfeeding to target children's serum levels at five years old (EFSA, 2018).

- PFOS: Serum levels associated with a 5% change in total cholesterol or birthweight ranged from 21 – 25 µg/L. The serum level for vaccine response was lower, 10.5 µg/L. EFSA recommended a tolerable daily intake of 1.8 – 2.0 ng/kg bw-day based on the cholesterol endpoint.

- PFOA: Serum levels associated with a 5% change in total cholesterol ranged from 9.2 – 9.4 µg/L, for increase in liver enzyme was 21 µg/L, and for birth weight ranged from 4.4 – 10.6 µg/L. EFSA recommended a tolerable daily intake of 0.4 – 2.0 ng/kg bw-day.

In February 2020, EFSA proposed a tolerable weekly intake (TWI) of 8 ng/kg bw-day for PFOS, PFNA, and PFHxS combined (EFSA, 2020). This reflects an updated evaluation of recent scientific findings and use of new Agency guidance for assessing combined exposure to multiple chemicals (EFSA, 2019). The TWI is based on effects in the immune system seen in animals (PFOA, PFOS) and associations between the sum of PFOS, PFOA, PFHxS, and PFNA in serum, reduced titers of antibodies to diptheria and tetnus in 5-year-old children in the Faroe Islands, and reduced antibody titers against haemophilus influenza type b (Hib) in 1-year-old children in a study from Germany. The proposed EFSA opinion is undergoing public review and comment.

7.6 Health equity and environmental justice (EJ)

We added this section to the CAP in response to stakeholder requests. We acknowledge the importance of health equity and EJ considerations during CAP development and implementation of CAP recommendations. The section reviews the limited information we have related to the intersection of exposure to PFAS and vulnerable and historically overburdened communities. It is by no means a comprehensive assessment of EJ or of population characteristics as they relate to PFAS. Instead, it is meant to offer a snapshot of our current state of knowledge.

Our consideration of overburdened communities in the CAP focuses on the meaning related to EJ concerns. This is reflected, for example, in the definitions provided by the state Environmental Justice Task Force (Environmental Justice Task Force, 2020) and, most recently, in the Washington State Legislature's Engrossed Second Substitute Senate Bill (E2SSB) 5141,[153] which Governor Inslee signed into law on May 17, 2021 (Washington State Legislature, 2021):

- Environmental Justice Task Force: "Overburdened communities" are communities who experience disproportionate environmental harms and risks due to exposures, greater vulnerability to environmental hazards, or cumulative impacts from multiple stressors.
- E2SSB 5141: "Overburdened community" means a geographic area where vulnerable populations face combined, multiple environmental harms and health impacts, and includes, but is not limited to, highly impacted communities as defined in RCW 19.405.020.[154]

[153] http://lawfilesext.leg.wa.gov/biennium/2021-22/Pdf/Bills/Session%20Laws/Senate/5141-S2.SL.pdf?q=20210702115844
[154] https://app.leg.wa.gov/RCW/default.aspx?cite=19.405.020

7.6.1 Population demographics and exposure to PFAS

Section 7.2.1 Trends and demographics of PFAA exposure, and 7.2.2 Populations with elevated PFAS exposure, identify population groups that have been studied to evaluate whether certain communities bear greater exposures to PFAS or could be more susceptible to effects of such exposures. Section 7.2.2 considered populations, including indigenous people, whose PFAS dietary intake may be exacerbated by PFAS bioaccumulated in fish or found in other natural resources that are subsistence-gathered.

However, our knowledge of potential impacts specific to EJ communities is currently limited for several reasons. Our knowledge about areas of contamination currently focuses on the limited number of areas where drinking water impacts have been identified (see Section 7.4 Known areas of PFAS contamination in drinking water aquifers in Washington state). Future drinking water testing—either under the fifth Unregulated Contaminant Monitoring Survey (UCMR5, see Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency) or under monitoring requirements that are proposed to be adopted by the SBOH as part of their adoption of SALs for certain PFAS (see Section 7.5.2 Washington Department of Health advice for PFAA's in drinking water)—may identify additional locations where PFAS are present in drinking water, and locations where applicable advisories or standards are exceeded. Discoveries of areas with impacted drinking water could lead us to uncover new PFAS release sites, additional localized contamination of surface waters and soils, and exposures of concern related to consumption of local fish and other wildlife, livestock, native plants or crops.

Our knowledge of potential impacts to recreational, tribal, or subsistence fishers is also limited. Ecology has conducted several surveys of PFAS in different waterbodies of the state (see Appendix 5: Environmental Occurrence, Section 5.1.4 Surface water). PFAS detected in the waterbody correlated with PFAS in the resident fish with variation by species noted. PFAS was higher in urban lakes than rural lakes and higher in waters that receive effluent from WWTPs. Work is underway to fill data gaps for Puget Sound fish and for the most commonly purchased fish in Washington state markets. Health is developing public health advice for PFAS in fish and will consider EJ by prioritizing impacted populations and engaging in tailored outreach (see the section: What else are we doing about PFAS?).

We lack information about potential commercial and industrial release sources. Use and discharge of PFAS from these facilities has not been reportable in our state. We will seek to identify these under Recommendation 2.3.

Earlier modelling studies based on UCMR3 data indicated that proximity to industrial PFAS use PFAS manufacturing sites and military fire training areas were significant risk factors for PFAS in drinking water (Hu et al., 2016). Data being collected nationwide support these models as potential release sources are identified and further characterized. For example, the California State Water Resources Control Board is collecting data to identify the presence of PFAS in public water systems and characterize potential releases from bulk fuel terminals and refineries, publicly owned treatment works, chrome platers, landfills, and airports. The data will provide insights that can be used to guide and prioritize implementation of CAP recommendations (California State Water Resources Control Board, 2021a; 2021b).

7.6.2 Available tools to assist in identifying and characterizing EJ impacts

Comments on the Draft CAP suggested that the CAP include a detailed screening of known and suspected areas of PFAS contamination against available tools such as EPA's EJ Screen and the Washington Environmental Health Disparities Map (WEHDM). The WEHDM tool provides an Environmental Health Disparities Ranking (EHDR) based on a combination of four environmental and societal indicators:

- Environmental exposures.
- Environmental effects.
- Socioeconomic factors.
- Presence of sensitive populations.

The tool was developed aiming to (University of Washington, 2019):

- Rank environmental health risks by census tracks to identify communities burdened by cumulative impacts of pollution.
- Identify and monitor trends in environmental health indicators by census tract over time, providing useful, data-driven insights for communities, policymakers, government leaders, and others.

Although the tool's rankings represent environmental risk, they do not depict the concept of environmental burden. The tool's developers also identified its limitations:

- The tool relies on currently available statewide data, and does not characterize the full scope of environmental risks and health impacts experienced by people living in Washington.
- Although the rankings provide a common scale to compare various issues at a community level and assess the cumulative impact of indicators across communities, the tool does not show the numeric difference between each rank.
- The map should not be used to diagnose a community health issue, to label a community or to impute risk factors and exposures for specific individuals.
- Environmental risk factors vary depending on a community's characteristics, such as rural or urban communities.

Using the WEHDM, we conducted a high-level survey of census tracts generally including known areas of drinking water contamination and suspected locations of release. We acknowledge two important data gaps:

- We do not have access to specific locations where contaminated drinking water may have been supplied (to individual households for example). In several cases, it was clearly identified that only certain water wells within an overall supply system were compromised (see Table 68 for example).
- We do not have specific information about hydrological factors that influence the direction of groundwater contamination dispersal from the source. It is possible that large portions of the local census tract are upgradient from the release site and not exposed.

Therefore, looking at census tracts in all directions around a known release location can significantly overestimate the size of the exposed population. Our survey resulted in the following broad conclusions:

- EHDR data reflected existing disparities in communities affected by PFAS contamination of their drinking water supplies. For example, urbanized areas located northwards of JBLM (City of Tacoma, Spanaway) reflect the long-term urban and industrial history in this portion of Pierce County, and therefore exhibit high EHDRs across multiple indicators.
- Certain communities, especially those with longer historical term urban and industrial development, already bear cumulative environmental and health equity burdens.
- Rural communities, though exposed to different historical disparities, can also be subject to cumulative burdens.
- EHDRs may less reflect effects of industrial pollution, but populations may still be affected as a result of socioeconomic factors or sensitivity based on the presence of major transportation corridors or exposure to agricultural activities.

These conclusions emphasize that it is essential that any future work to implement CAP recommendations consider co-existing community exposure to pollution and environmental burdens, identify the specific sub-communities most affected, and create tailored approaches to inform these populations and prioritize mitigation actions affecting them.

7.7 Data gaps and recommendations

7.7.1 Data gaps

Further information on the following would reduce uncertainty about toxicity and health effects:

- Testing PFNA and PFHxS for immune system toxicity including antibody response to antigens.
- Investigation into developmental impacts of PFOA in mouse mammary glands to include testing of other PFAS, other animal models, and prospective human studies in exposed communities.
- Mechanistic investigations into underlying activity of PFAS compounds in mammals.
- Further toxicity testing on other PFAS that are detected in drinking water and in human biomonitoring.
- Further investigation into potential interactions within mixtures of PFAS (additive, antagonistic, synergistic effects).
- Prospective and longitudinal studies in human populations.

Further information on the following would improve exposure assessment:

- Better characterization of human exposure to PFAS in environmental media such as drinking water and in human serum. Both expanded panels of targeted analysis and nontargeted analysis methods would be helpful.

- Wider and more comprehensive PFAS testing in U.S. foods and pathway investigations into plant and animal uptake of various PFAS from soil, feed, and water.
  - For example, PFOS was frequently detected in freshwater fish in the state, but we know little about PFAS in marine fish and shellfish. Biomonitoring surveys have indicated that self-reported consumption of fish and shellfish are associated with serum levels of certain PFAS in the general populations, making this an important data gap to fill.
- Additional studies on the relative contribution of sources other than food are needed, especially for those PFAS present in the highest concentrations in indoor air and house dust. Information needed includes:
  - PFAS transfer from products to indoor air, dust and surfaces.
  - Studies of inhalation, dermal, and oral exposure associated with household products containing PFAS.
  - The levels of dermal exposure from household products containing PFAS.
  - Mitigation measures that can reduce PFAS levels in homes, house dust, and indoor air, including the availability of safer alternatives.
- Studies on half-life of PFAS in humans by gender and lifestage.
- Prospective and longitudinal studies in human populations.

7.7.2 Recommendations

Recommendation 1.0: Ensure drinking water is safe.

Protecting public health by ensuring safe drinking water is a fundamental responsibility of the Health Office of Drinking Water (ODW).

There are three types of drinking water systems in Washington:

- Group A water systems serve 85% of state residents.[155] They service more than 15 connections or more than 25 people. There are 4,105 Group A systems in the state. ODW primarily regulates these public water systems.
- Group B public water systems are smaller and serve 1.5% of state residents. The local health department usually oversees these systems. Group B systems have few testing requirements for continued operation.
- Private wells serve 13.5% of state residents. Private wells are only regulated in their design and installation, and regulatory overview is by local health departments. Chemical testing is not usually required.

Less than 10% of all Group A systems in the state have been tested for PFAS. This includes water testing done by the DOD, voluntary testing by public water systems, and testing done under EPA's third unregulated contaminant monitoring rule (UCMR3). However, those that have been tested serve most water customers in the state. The percentage of Group B and private wells tested for PFAS is even lower. A water test is required to determine whether PFAS are in drinking water, because PFAS are tasteless and odorless at levels of public health concern.

[155] https://www.doh.wa.gov/DataandStatisticalReports/EnvironmentalHealth/DrinkingWaterSystemData/DataDownload

Because testing and treating for PFAS in drinking water is expensive, exposures to PFAS-contaminated water may be disproportionately borne by populations who do not have the financial means to test for and remove these contaminants.

The following additional actions are recommended to ensure drinking water is safe.

Recommendation 1.1: Identify funding for PFAS drinking water mitigation.

State agencies, the Washington State Legislature, and water systems should work together to fund PFAS drinking water mitigation. These costs should be reimbursed by responsible parties under applicable laws. Once PFAS water contaminants are classified as hazardous substances by the federal government or meet the definition of hazardous substance under the state of Washington's statutes or rules, they can be addressed under the state Model Toxics Control Act (MTCA) framework.

Existing resources

Drinking Water State Revolving Fund is an EPA-funded loan program administered by Health. The loans are used to:

- Improve drinking water infrastructure.
- Finance the cost of installing treatment or other infrastructure improvements over a number of years.

Drinking Water State Revolving Fund can provide emergency loans in the event a water system is issued a “Do Not Use” order by the Department of Health as a result of PFAS contamination. The program recently funded a reservoir project for the City of Spokane to allow Spokane to provide reliable water service to Airway Heights. Airway Heights has PFAS in their wells and is now relying on the City of Spokane for its water.

EPA provides funding to Health’s Office of Drinking Water for set-aside activities and source water protections. We can use these funds in limited circumstances to defray costs of additional water testing.

Other funding programs in the state could be tapped for loans or grants to help with costs of new infrastructure in response to PFAS contamination:

- Public Works Assistance Account overseen by Public Works Board.
- Community Development Block Grant overseen by Department of Commerce.
- Rural Development loans and grants overseen by the U.S. Department of Agriculture.

Public water systems can pursue reimbursement from potentially liable parties under the state MTCA when PFAS are concluded to be hazardous substances under MTCA. Even under MTCA, water systems may have to carry costs long-term or permanently because:

- The process of identifying responsible parties and being reimbursed can take years.
- Responsible parties may be difficult, if not impossible, to determine.
- The potentially liable party could be a local entity under the same public administration as the water utility (for example, a local fire station).
- Legal costs to the affected water system operator to pursue liable parties can also be significant.

Privately owned water systems regulated by the Washington state Utilities and Transportation Commission (defined in RCW 80.04.010(30),[156] and having 100 or more connections or charging more than $557 per year per customer) may have fewer options to secure funding, being primarily limited to the Drinking Water State Revolving Fund.

In each of these cases, the costs borne by the water system would be long-term or permanent.

Recommendation 1.2: Provide technical support for site characterization, source investigation and mitigation at contaminated sites.

Ecology and Health will continue to develop expertise and provide technical assistance and guidance to drinking water purveyors, local jurisdictions, and responsible parties to address PFAS contamination and conduct cleanup actions.

Those actions include:

- Ecology will continue to collaborate with involved parties at PFAS contamination sites in the state. These efforts will help to better understand the sources, composition, and distribution of PFAS contamination in soil and water. Identification and evaluation of appropriate cleanup actions and their costs will be informed by this work. This work is being done within Ecology's existing resources.
- Health will continue to provide water systems with advice and assistance to understand the mitigation options and guide voluntary action on unregulated PFAS until the rulemaking for PFAS in drinking water is complete. To-date, technical assistance has focused on public water systems near military bases with PFAS detections in groundwater. Department of Health continues to include local health departments in outreach and guidance. This work is being done within Health's existing resources.
- Ecology will look at using Safe Drinking Water Action Grants (a category of Remedial Action Grants for Local Governments) to help address PFAS-contaminated drinking water, once Maximum Contaminant Levels (MCLs) have been promulgated for the PFAS compounds of concern or site specific cleanup levels have been established.
- Ecology plans to investigate PFAS contamination in groundwater and surface water. These efforts would support local health departments, cities, counties, and other public entities in Washington when PFAS contamination is discovered. Initial investigation efforts could identify areas at high risk of contamination. This could include areas where trainings or firefighting activities used large quantities of PFAS-containing AFFF, or where spills released the foam. Ecology could prioritize funding for site-specific assessments and groundwater testing. Funding for this action is estimated below.
- Ecology plans to consider the number of people impacted, the concentration of the PFAAs in the drinking water, and vulnerable populations present when prioritizing mitigation and cleanup activities. Ecology may use mapping tools such as Environmental Justice (EJ) screen and the Information by Location (IBL) tool in the Washington Tracking Network (WTN) portal to characterize the demographics of the population served by impacted drinking water.

[156] https://app.leg.wa.gov/rcw/default.aspx?cite=80.04.010

- Ecology may seek to obtain chemical identities from products and at contaminated sites to find chemical "fingerprints" useful in identifying source locations. Analytical methods may not yet be developed to obtain all the required data.

Recommendation 1.3: Support biomonitoring and other studies to help answer important health questions.

Health should continue to find opportunities for Washington residents to participate in exposure and health studies. These studies help answer important community and public health questions about PFAS exposure and health outcomes. For example, Health requested and supports inclusion of Airway Heights as one of eight sites in the ATSDR's PFAS Exposure Assessment study. We also applied for but were not awarded a cooperative agreement to include a Washington site in the ATSDR Multisite PFAS Health Study.

State agencies should also support investigations into sources and pathways of PFAS contamination in food, drinking water, and the indoor environment and pursue policies to mitigate and reduce these sources of human exposure over time.

Supplement 1: Summary of Primary Health Concerns by PFAA

Table 72. Health-based values for oral intake of different types PFAA chemicals according to various government agencies and authoritative bodies.

Type of PFAA chemical	Authoritative body responsible for value (year)	Health-based value for subchronic/chronic oral intake (ng/kg-day)
PFOA	EPA RfD (2016)	20
PFOA	ATSDR MRL (2021)	2
PFOA	NJ DWQI RfD (2017)	2
PFOA	NH DES RfD (2019)	6.1
PFOA	MI SAW TV (2019)	3.9
PFOA	CA OEHHA ADD (2019)	0.45
PFOS	EPA RfD (2016)	20
PFOS	ATSDR MRL (2021)	2
PFOS	NJ DWQI RfD (2018)	1.8
PFOS	NH DES (2019)	3
PFOS	MDH RfD (2019)	3.1
PFOS	MI SAW TV (2019)	2.89
PFOS	CA OEHHA ADD (2019)	1.8
PFNA	ATDSR MRL (2021)	3
PFNA	NJ DWQI RfD (2015)	0.74
PFNA	NH DES (2019)	4.3
PFNA	MI SAW TV (2019)	2.2
PFHxS	ATDSR MRL (2021)	20
PFHxS	MDH RfD (2019)	9.7
PFHxS	NH DES RfD (2019)	4
PFHxS	MI SAW TV (2019)	9.7
PFBS	EPA RfD (2021)	300
PFBS	MDH RfD (2017)	430
PFBS	MI SAW TV (2019)	300
PFBS	CA OEHHA ADD (2021)	600
PFHxA	MI SAW TV (2019)	83,000
GenX	MI SAW TV (2019)	77
GenX	EPA (2018)	80
PFBA	MDH (2018)	2,900

Notes:

- EPA RfD (2016d, 2016e, 2018, 2021). The Environmental Protection Agency Office of Water developed RfDs for PFOA and PFOS in 2016 to support drinking water health advisories. The Agency issued a draft chronic RfD for GenX in 2018 and a final RfD for PFBS in April 2021. An RfD is an EPA estimate, with uncertainty or safety factors built in,

of the daily lifetime dose of a substance that is unlikely to cause harm in humans. RfDs are based on non-cancer endpoints (EPA, 2016a, 2018b).

- ATSDR MRL (2021). The Agency for Toxic Substances and Disease Registry released a draft Toxicological Profile for PFAS in 2018 that included Minimal Risk Levels (MRLs) for four PFAAs. An MRL is an ATSDR estimate of daily human exposure to a hazardous substance at or below which that substance is unlikely to pose a measurable risk of harmful noncancerous effects. PFAS MRLs are screening values for intermediate duration oral exposures of more than 14 days and less than a year (Agency for Toxic Substances and Disease Registry (ATSDR), 2021).
- NJ DWQI RfD (2015 – 18). The New Jersey Drinking Water Quality Institute develops technical recommendations and supporting documentation for drinking water standards in the state of New Jersey. They developed target serum levels and RfDs for PFNA, PFOS, and PFOS (New Jersey, 2017; New Jersey Drinking Water Quality Institute, 2015; NJDWQI, 2018).
- MI SAW TV (2019). Michigan Science Advisory Workgroup (SAW) developed toxicity values (TVs) corresponding to serum concentrations expected to have minimal or no risk for humans with daily chronic exposure. The toxicity values were developed to support drinking water regulation in the state (Michigan Science Advisory Workgroup, 2019).
- CA OEHHA ADD (2019, 2021). The State of California, Office of Environmental Health Hazard Assessment developed Acceptable Daily Doses (ADD) for PFOA and PFOS in support of drinking water notification and removal levels. ADDs are developed for noncancer endpoints and are estimates of the maximum daily dose of a chemical that can be consumed by humans for an entire lifetime without toxic effects (CalEPA OEHHA, 2019, 2021).
- MDH RfD (2017-19). Minnesota Department of Health developed RfDs for PFOS, PFHxS, PFBA and PFBS in support of state drinking water guidance. This is part of their program to develop health-based values for emerging contaminants (MDH, 2017; Minnesota Department of Health (MDH), 2017, 2019).
- NH DES RfD (2019). New Hampshire Department of Environmental Services developed target serum values and RfDs for PFOS, PFOA, PFNA, and PFHxS to support state drinking water standards (New Hampshire Department of Environmental Services, 2019).

PFOA

The primary effects observed in laboratory animals following PFOA exposure are:

- Liver toxicity (L. Biegel, Hurtt, Frame, O'Conner, & Cook, 2001; J. Butenhoff, G. Kennedy, S. Frame, J. O'Connor, & R. York, 2004; Loveless, Hoban, Sykes, Frame, & Everds, 2008; Perkins, Butenhoff, Kennedy, & Palazzolo, 2004).
- Immunotoxicity (J. DeWitt, Copeland, Strynar, & Luebke, 2008; Q Yang, Xie, & Depierre, 2000; Q. Yang, Xie, Eriksson, Nelson, & DePierre, 2001).
- Reproductive and developmental toxicity (B. D. Abbott, 2015; J. Butenhoff et al., 2004; Lau et al., 2006; Macon et al., 2011; White et al., 2011; C. Wolf et al., 2007).
- Altered thyroid hormones (National Toxicology Program (NTP), 2019b).

The strongest and most consistent associations between PFOA exposure and adverse health effects in humans are:

- Elevated serum cholesterol (Lau, 2015; New Jersey Drinking Water Quality Institute (NJDWQI) Health Effects Subcommittee, 2016).
- Reduced birth weight (Johnson et al., 2014; Meng et al., 2018).
- Reduced antibody response to vaccines (National Toxiciology Program, 2016).
- Increased serum liver enzymes (Gallo et al., 2012; C. Y. Lin et al., 2010; G. Olsen et al., 2007; Sakr et al., 2007; Yamaguchi et al., 2013).

Studies also report associations between PFOA exposure and:

- Altered development of reproductive tissue and delayed puberty (Di Nisio A, 2018; Lopez-Espinosa et al., 2011).
- Higher serum uric acid (Geiger, Xiao, & Shankar, 2013; Shankar, Xiao, & Ducatman, 2011b; Steenland, Tinker, Shankar, & Ducatman, 2010)
- Altered thyroid hormone levels and thyroid disorders (Jain, 2013; Knox, Jackson, Frisbee, Javins, & Ducatman, 2011; G. W. Olsen, Burris, Burlew, & Mandel, 2003; Wen et al., 2013).
- Pregnancy-induced hypertension and preeclampsia (Savitz, Stein, Bartell, et al., 2012; Savitz, Stein, Elston, et al., 2012; C. Stein, Savitz, & Dougan, 2009).
- Ulcerative colitis (Steenland et al., 2015; Steenland et al., 2013).

PFOA is not considered genotoxic or mutagenic, but studies in laboratory animals have reported increased incidence of tumors in liver, testicular, and pancreatic tissues as well as ovarian tubular hyperplasia (Biegel et al., 2001; Butenhoff et al., 2012; EPA, 2016a; NTP, 2020). PFOA exposure has been positively associated with increased incidence of kidney and/or testicular cancers in some epidemiological studies (Barry et al., 2013; Shearer et al., 2020; Vieira et al., 2013). Studies of the general population have looked for but not found associations between serum PFOA levels and a range of human cancers (Bonefeld-Jorgensen et al., 2014; Eriksen et al., 2009; Hardell et al., 2014; Innes et al., 2014). The following cancer classifications have been applied to PFOA:

- “Suggestive evidence” of carcinogenic potential in humans (EPA, 2016c).
- Group 2B, possibly carcinogenic to humans (IARC, 2017).

PFOS

The primary types of toxicity observed in experimental animals exposed to PFOS are:

- Developmental toxicity (Lau et al., 2003; Luebker, Case, et al., 2005; Luebker, York, Hansen, Moore, & Butenhoff, 2005).
- Immune suppression (G. Dong et al., 2009; G. H. Dong et al., 2011; Guruge et al., 2009; Peden-Adams et al., 2008; Zheng, Dong, Jin, & He, 2009).
- Liver and kidney toxicity (Cui, Zhou, Liao, Fu, & Jiang, 2009; A. M. Seacat et al., 2003; Xing et al., 2016).
- Disruption of thyroid and other hormones (S. C. Chang et al., 2008; L. Li et al., 2018; Wan et al., 2011; Yu et al., 2009; Zhao et al., 2014).

Limited studies in rats and mice also report:

- Degenerative changes in male reproductive tissue (Lopez-Doval et al., 2014; Wan et al., 2011; Zhao et al., 2014).
- Signs of altered neurodevelopment (changes in motor activity and habituation response) (Johansson, Fredriksson, & Eriksson, 2008; Y. Wang, Liu, Zhang, Zhao, & Quan, 2015)
- Altered glucose metabolism following prenatal exposures. (Lv et al., 2013; Wan, Zhao, Leung, & Wong, 2014).

The most consistent findings from human epidemiological studies are positive associations between serum PFOS and:

- Higher serum cholesterol (Frisbee et al., 2010; Nelson et al., 2010; G. W. Olsen et al., 2003; Steenland, Tinker, Frisbee, Ducatman, & Vaccarino, 2009).
- Reduced antibody response to vaccines (J. C. DeWitt, Blossom, & Schaider, 2019; National Toxicology Program (NTP), 2016).
- Reduced birth weight (Koustas et al., 2014).

Other endpoints of concern with less evidence include:

- Elevated uric acid (Geiger et al., 2013; Steenland et al., 2010).
- Altered energy metabolism and glucose intolerance (Domazet, Grontved, Timmermann, Nielsen, & Jensen, 2016; Lin, Chen, Lin, & Lin, 2009; Liu et al., 2018).
- Altered hormone levels (Ballesteros et al., 2017; Kim et al., 2018; Webster et al., 2016).
- Thyroid disease (Melzer et al., 2010; Webster, Venners, Mattman, & Martin, 2014; Wen et al., 2013).
- Chronic kidney disease (Shankar, Xiao, & Ducatman, 2011a; Steenland et al., 2010).

PFOS does not appear to be mutagenic or genotoxic but chronic rodent studies observed liver, thyroid and mammary gland tumors (J. L. Butenhoff, Chang, et al., 2012). Data relevant to cancer risk of PFOS are limited. In terms of cancer classifications, for PFOS, there is “suggestive evidence” of carcinogenic potential in humans (EPA, 2016b).

PFNA

The general types of rodent toxicity observed with PFNA are similar to PFOA:

- Liver toxicity (Das et al., 2015; Mertens et al., 2010; National Toxicology Program (NTP), 2019b; Stump et al., 2008; J. Wang, Yan, Zhang, Zhang, & Dai, 2015).
- Male reproductive toxicity (Y. Feng et al., 2009; National Toxicology Program (NTP), 2019b; Singh & Singh, 2019a, 2019b).
- Female reproductive toxicity (Stump et al., 2008; C. J. Wolf et al., 2010).
- Developmental toxicity (Das et al., 2015; Rogers et al., 2014; Rosen, 2010; C. J. Wolf et al., 2010).
- Immunotoxicity (X. Fang et al., 2009; X. Fang, Feng, Wang, & Dai, 2010; X Fang et al., 2008; National Toxicology Program (NTP), 2019b).
- Thyroid hormone alterations (National Toxicology Program (NTP), 2019b).

Epidemiological studies relevant to PFNA provide limited evidence of an association between PFNA exposure and increased serum cholesterol, but not with other lipid alterations (HDL, LDL, triglycerides) (Agency for Toxic Substances and Disease Registry (ATSDR), 2018b; NJDWQI, 2015) and small associations between serum PFNA and some liver function biomarkers (Jain & Ducatman, 2019; Nian et al., 2019; Salihovic et al., 2018).

Investigations of PFNA and immune endpoints in humans reported associations between higher PFNA exposure and:

- Decreased antibody response to a vaccine (Granum et al., 2013; Kielsen et al., 2016).
- Higher number of reported respiratory infections or common cold in children (Granum et al., 2013; Impinen et al., 2018).
- Asthma in children (G. H. Dong et al., 2013). Asthma and allergic diseases were not associated with PFNA in a number of other studies (Granum et al., 2013; Humblet et al., 2014; Impinen et al., 2019; Impinen et al., 2018).

Other associations between PFNA exposure measures and reproductive and developmental outcomes have been reported in epidemiological studies (Meng et al., 2018; Sagiv et al., 2018) including:

- Gestational diabetes (Rahman et al., 2019).
- Increased risk of miscarriage (Jensen et al., 2015).
- Lower birth weights (Sagiv et al., 2018).
- Altered timing of puberty onset for boys and girls (Ernst et al., 2019).
- Altered bone mineral density in girls at 17 years old (Jeddy et al., 2018).
- Lower levels of sex hormones and insulin-like growth factor (IGF-1) in boys and girls six to nine years old (Lopez-Espinosa, Mondal, Armstrong, Eskenazi, & Fletcher, 2016).

PFHxS

The liver is the primary target of PFHxS toxicity in rodent studies. Effects observed include increased liver weight, hepatocellular hypertrophy, altered lipid metabolism, steatosis, and necrosis (Bijland et al., 2011; J. L. Butenhoff, Chang, et al., 2009; S. Chang et al., 2018). Several studies have reported thyroid cell damage and reduced T4 and T3 thyroid hormone levels in rodent studies (J. L. Butenhoff, Chang, et al., 2009; NTP, 2018; Ramhoj et al., 2018).

Reproductive and developmental effects have been reported in some studies such as reduced litter size (S. Chang et al., 2018) and reduced birth weight (Ramhoj et al., 2018), but have not been consistently observed. One study reported altered spontaneous behavior and habituation in adult mice that had received a single dose of PFHxS on postnatal day ten (Viberg, Lee, & Eriksson, 2013). A key data gap is the lack of immune toxicity testing in animal studies.

According to ATSDR's 2018 draft assessment, the weight-of-evidence for epidemiological studies supports associations between PFHxS exposure and liver damage (as evidenced by increases in serum enzymes and decreases in serum bilirubin levels) and decreased antibody response to vaccines (Agency for Toxic Substances and Disease Registry (ATSDR), 2018b). There is also limited and somewhat inconsistent evidence of associations between higher PFHxS exposure and increased risk of hyperactivity in children (K Hoffman, Webster, Weisskopf, Weinberg, & Vieira, 2010; C. R. Stein & Savitz, 2011) and reduced T4 levels in pregnant women and male infants (Ballesteros et al., 2017; Preston et al., 2018).

The carcinogenicity of PFHxS has not been investigated.

Perfluoroheptanoic acid (PFHpA)

There is very limited data in laboratory animals to assess PFHpA. *In vitro* studies showed that PFHpA is as biologically active as PFOA in activating PPARα, however this activity was not evident *in vivo*, probably because PFHpA was rapidly excreted and did not accumulate in the rodent liver (Goecke-Flora & Reo, 1996; HSDB, 2016; Kudo, Bandai, Suzuki, Katakura, & Kawashima, 2000; Kudo et al., 2001; Ohmori, Kudo, Katayama, & Kawashima, 2003). People do not excrete PFHpA as rapidly as rodents. In a study of 11 professional ski waxers, it took between 31 and 123 days after exposure ceased for their individual serum level of PFHpA to drop by half (Russell, Himmelstein, & Buck, 2015). A study of Chinese adults reported a longer estimated half-life in human serum (1.5 years) (Zhang, Beesoon, Zhu, & Martin, 2013).

Studies in humans are limited. Fu et al. (2014) reported no association between PFHpA in serum of adults and increased total cholesterol and LDL cholesterol at environmental exposure levels (Fu et al., 2014). Epidemiological studies investigating immune toxicity did not find associations between serum PFHpA levels and diphtheria or tetanus antibody levels in adults (Kudo et al., 2001), or risk of asthma diagnosis, eczema, or wheezing in children (Smit et al., 2015). Mattsson et al. (2015) reported that the risk of coronary artery disease was higher in individuals with serum PFHpA levels in the 3rd quartile of exposure, but not the 4th (highest) exposure quartile. Nian et al. (2020) reported that maternal plasma level of PFHpA early in pregnancy was associated with reduced free androgen index in baby's cord blood at birth in the large prospective Shanghai Birth Cohort.

PFHxA

Liver effects observed in 90-day rat studies with PFHxA were generally mild and required higher doses than PFOA (Chengelis, Kirkpatrick, Radovsky, & Shinohara, 2009; DuPont, 2007; Loveless et al., 2009). As discussed in Hall et al. (2012), these liver effects may not be relevant to humans (Hall et al., 2012). Effects on kidney and tubular degeneration observed in rodents (Klaunig et al., 2015) served as the basis for Michigan's enforceable limit of 400 µg/L PFHxA in drinking water (SAW, 2019).

Thyroid effects were observed only at very high doses in rats (DuPont, 2007; Loveless et al., 2009). In reproductive and developmental toxicity studies, PFOA-like effects were seen but at much higher doses (National Industrial Chemicals Notification and Assessment Scheme (NICNAS), 2015, 2017). A cancer study in rodents of PFHxA was negative for tumors (Klaunig et al., 2015).

Limited human evidence has been reported (Luz et al., 2019). Four cross-sectional human epidemiology studies provide some evidence of statistical associations between serum PFHxA levels and testosterone (Zhou et al., 2016), thyroid antibody markers (Li, Cheng, Xie, & Zeng, 2017), and Gilbert's syndrome (Fan, Ducatman, & Zhang, 2014).

The FluoroCouncil supported a comprehensive review of available toxicological data in 2019. The authors recommended a chronic RfD of 0.25 mg/kg-day and a drinking water screening value of 1400 µg/L for PFHxA (Anderson et al., 2019; Luz et al., 2019).

PFBS

In rodent testing, PFBS reduced thyroid hormones and produced kidney toxicity such as hyperplasia, developmental toxicity including delayed growth and maturation, hypertrophy in liver tissue, increased serum liver enzymes, and altered lipids and hematological profiles (X. Feng et al., 2017; Lieder, York, Hakes, Chang, & Butenhoff, 2009; York, 2002, 2003; Lieder, Chang, et al., 2009; Bijland et al., 2011; 3M Company, 2001; National Toxicology Program (NTP), 2019a). Data gaps include lack of immune toxicity studies, chronic toxicity studies, and cancer testing in laboratory animals (EPA, 2021).

EPA conducted a structured review of studies that investigated adverse effects of PFBS. This included 19 epidemiological studies that met EPA criteria for data quality. PFBS levels in serum were positively associated in at least one study with the following outcomes: adiposity in girls but not boys, asthma, serum cholesterol, cardiovascular disease and hypertensive disorders of pregnancy. Evidence from these human studies was considered equivocal by EPA evaluators (EPA, 2021).

PFBA

Toxicity observed in laboratory mice and rats:

- Mild liver toxicity (J. L. Butenhoff, Bjork, et al., 2012; Crebelli et al., 2019; Foreman et al., 2009).
- Mild thyroid toxicity (increased thyroid weight, hyperplasia, and hypertrophy of the follicular epithelium).
- Decreased thyroid hormone (T4) levels and decreased serum cholesterol (Bjork & Wallace, 2009; J. L. Butenhoff, Bjork, et al., 2012).

Males were more sensitive than females. In a reproductive and developmental study in mice, litter loss was observed at high doses. Despite liver enlargement in dams and pups, no effects on maternal, fetal, or pup weight gain were noted. Mouse offspring exposed to PFBA prenatally had significant delays in eye opening and a slight delay in onset of puberty (Das et al., 2008). PFBA was less developmentally toxic than PFOA presumably because of its more rapid elimination from the mouse. The health-based value for subchronic or chronic intake of PFBA from Minnesota Department of Health is 2,900 ng/kg-day (MDH, 2018).

Studies of health effects of PFBA in humans are lacking. A recent study in the Danish population reported an association between detectable PFBA in plasma and severity of Coronovirus disease 2019 (COVID-19). No other PFAS were similarly associated (Grandjean et al., 2020).

References

3M Company, & 3M Corporate Toxicology. (2001). *A 28-day oral (gavage) toxicity study of T-7485 in Sprague-Dawley rats. (Study Number: 132-007)*.

Abbott, B. D. (2015). Developmental Toxicity. In J. C. DeWitt (Ed.), *Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances* (pp. 203–218). Springer International Publishing.

Abbott, B. D., Wolf, C. J., Schmid, J. E., Das, K. P., Zehr, R. D., Helfant, L., Nakayama, S., Lindstrom, A. B., Strynar, M. J., & Lau, C. (2007). Perfluorooctanoic Acid Induced Developmental Toxicity in the Mouse is Dependent on Expression of Peroxisome Proliferator Activated Receptor-alpha. *Toxicological Sciences*, *98*, 571–581. https://doi.org/10.1093/toxsci/kfm110

Abraham, K., Mielke, H., Fromme, H., Völkel, W., Menzel, J., Peiser, M., Zepp, F., Willich, S. N., & Weikert, C. (2020). Internal exposure to perfluoroalkyl substances (PFASs) and biological markers in 101 healthy 1-year-old children: associations between levels of perfluorooctanoic acid (PFOA) and vaccine response. *Archives of Toxicology*, *94*, 2131–2147. https://doi.org/10.1007/s00204-020-02715-4

Agence nationale de sécurité sanitaire, de l'alimentation, de l'environnement, & et du travail (ANSES). (2017). *Elaboration de VTR chronique par voie orale pour l'acide per-fluorohexanoique (PFHxA)* (E. Agence Nationale de Securite Sanitaire Alimentation Travall (ed.)). ANSES. https://www.anses.fr/fr/system/files/SUBSTANCES2015SA0127Ra.pdf

Agency for Toxic Substances and Disease Registry (ATSDR). (2013). *Exposure investigation Report - Perfluorochemical Serum Sampling In the vicinity of Decatur, Alabama Morgan, Lawrence, and Limestone Counties*. Division of Community Health Investigation, Agency for Toxics Substance and Disease Registry. http://www.atsdr.cdc.gov/HAC/pha/Decatur/Perfluorochemical_Serum Sampling.pdf

Agency for Toxic Substances and Disease Registry (ATSDR). (2015). *Frequently Asked Questions: Perfluorinated Compounds* (Division of Community Health Investigations Science Support Branch (ed.)). ATSDR.

Agency for Toxic Substances and Disease Registry (ATSDR). (2015). *Draft Toxicological Profile for Perfluoroalkyls*. http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=237

Agency for Toxic Substances and Disease Registry (ATSDR). (2018). *ATSDR's Minimal Risk Levels (MRLs) and Environmental Media Evaluation Guides (EMEGs) for PFAS*. ATSDR. https://www.atsdr.cdc.gov/pfas/mrl_pfas.html

Agency for Toxic Substances and Disease Registry (ATSDR). (2020a). *Spokane County (WA) near Fairchild Air Force Base*. Retrieved from https://www.atsdr.cdc.gov/pfas/communities/Spokane-County-WA.html

Agency for Toxic Substances and Disease Registry (ATSDR). (2020b). CDC/ATSDR PFAS Exposure Assessment Community Level Results. Spokane County (WA) near Fairchild AirForce Base. June 2020. Retrieved from https://www.atsdr.cdc.gov/pfas/docs/factsheet/CDC_ATSDR-PFAS-EA-Spokane-County-Community-Level-Results-Fact-Sheet-H.pdf

Agency for Toxic Substances and Disease Registry (ATSDR). (2021). *Toxicological profile for Perfluoroalkyls.* May 2021. Retrieved from https://www.atsdr.cdc.gov/ToxProfiles/tp200.pdf

Ananth, R. (2018). *Fluorine-free Foams with Oleophobic Surfactants and Additives for Effective Pool Fire Suppression* (U.S. Naval Research Laboratory (ed.)). Strategic Environmental Research and Development Program (SERDP), Environmental Security Technology Certification Program (ESTCP). https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2739/WP-2739

Anatek Labs Inc. (2019). *Analytical Results Report for The Town of Coupeville*. https://townofcoupeville.org/wp-content/uploads/2019/04/TOC-Test-Results-March-2019.pdf

Anderson, J.K., Luz, A.L., Goodrum, P., & Durda, J. (2019). Perfluorohexanoic acid toxicity, part II: Application of human health toxicity value for risk characterization. *Regulatory Toxicology and Pharmacology, 103,* 10 – 20. https://doi.org/10.1016/j.yrtph.2019.01.020.

Andersson, E. M., Scott, K., Xu, Y., Li, Y., Olsson, D. S., Fletcher, T., & Jakobsson, K. (2019). High exposure to perfluorinated compounds in drinking water and thyroid disease. A cohort study from Ronneby, Sweden. *Environmental Research*, *176*, 108540. https://doi.org/10.1016/j.envres.2019.108540

Apel, P., Angerer, J., Wilhelm, M., & Kolossa-Gehring, M. (2017). New HBM values for emerging substances, inventory of reference and HBM values in force, and working principles of the German Human Biomonitoring Commission. *International Journal of Hygiene and Environmental Health*, *220*, 152–166. https://doi.org/10.1016/j.ijheh.2016.09.007

Attfield, K. (2018). *Serum PFAS levels and their predictors in San Francisco Bay Area Asian and Pacific Islander Communities - Biomonitoring California Scientific Guidance Panel Meeting*. California Department of Health. https://biomonitoring.ca.gov/sites/default/files/downloads/Attfield08222018.pdf

Australian Government Department of Defense. (2017). *PFAS in Chicken Eggs - 2017 Study Findings. RAAF Base Williamtown, Stage 2B Environmental Investigation*. https://www.defence.gov.au/Environment/PFAS/docs/Williamtown/FactSheets/20171205WilliamtownChickenEggStudy.pdf

Ballesteros, V., Costa, O., Iñiguez, C., Fletcher, T., Ballester, F., & Lopez-Espinosa, M.-J. (2017). Exposure to perfluoroalkyl substances and thyroid function in pregnant women and children: A systematic review of epidemiologic studies. *Environment International*, *99*, 15–28. https://doi.org/10.1016/j.envint.2016.10.015

Barry, V., Winquist, A., & Steenland, K. (2013). Perfluorooctanoic Acid (PFOA) Exposures and Incident Cancers among Adults Living Near a Chemical Plant. *Environmental Health Perspectives*, *121*, 1313–1318. https://doi.org/10.1289/ehp.1306615

Bartell, S. M., Calafat, A. M., Lyu, C., Kato, K., Ryan, P. B., & Steenland, K. (2010). Rate of Decline in Serum PFOA Concentrations after Granular Activated Carbon Filtration at Two Public Water Systems in Ohio and West Virginia. *Environmental Health Perspectives*, *118*, 222–228. https://doi.org/10.1289/ehp.0901252

Bassler, J., Ducatman, A., Elliott, M., Wen, S., Wahlang, B., Barnett, J., & Cave, M. C. (2019). Environmental perfluoroalkyl acid exposures are associated with liver disease characterized by apoptosis and altered serum adipocytokines. *Environmental Pollution*, *247*, 1055–1063. https://doi.org/10.1016/j.envpol.2019.01.064

Beesoon, S., Genuis, S. J., Benskin, J. P., & Martin, J. W. (2012). Exceptionally High Serum Concentrations of Perfluorohexanesulfonate in a Canadian Family are Linked to Home Carpet Treatment Applications. *Environmental Science & Technology*, *46*, 12960–12967. https://doi.org/10.1021/es3034654

Begley, T. H., Hsu, W., Noonan, G., & Diachenko, G. (2008). Migration of fluorochemical paper additives from food-contact paper into foods and food simulants. *Food Additives & Contaminants: Part A*, *25*, 384–390. https://doi.org/10.1080/02652030701513784

Begley, T. H., White, K., Honigfort, P., Twaroski, M. L., Neches, R., & Walker, R. A. (2005). Perfluorochemicals: Potential sources of and migration from food packaging. *Food Additives and Contaminants*, *22*, 1023–1031. https://doi.org/10.1080/02652030500183474

Benninghoff, A. D., Orner, G. A., Buchner, C. H., Hendricks, J. D., Duffy, A. M., & Williams, D. E. (2012). Promotion of Hepatocarcinogenesis by Perfluoroalkyl Acids in Rainbow Trout. *Toxicological Sciences*, *125*, 69–78. https://doi.org/10.1093/toxsci/kfr267

Biegel, L. B., Hurtt, M. E., Frame, S. R., O'Connor, J. C., & Cook, J. C. (2001). Mechanisms of Extrahepatic Tumor Induction by Peroxisome Proliferators in Male CD Rats. *Toxicological Sciences*, *60*, 44–55. https://doi.org/10.1093/toxsci/60.1.44

Biegel, L. B., Liu, R. C. M., Hurtt, M. E., & Cook, J. C. (1995). Effects of Ammonium Perfluorooctanoate on Leydig-Cell Function: In Vitro, in Vivo, and ex Vivo Studies. *Toxicology and Applied Pharmacology*, *134*, 18–25. https://doi.org/10.1006/taap.1995.1164

Bijland, S., Rensen, P. C. N., Pieterman, E. J., Maas, A. C. E., van der Hoorn, J. W., van Erk, M. J., Havekes, L. M., Willems van Dijk, K., Chang, S.-C., Ehresman, D. J., Butenhoff, J. L., & Princen, H. M. G. (2011). Perfluoroalkyl Sulfonates Cause Alkyl Chain Length–Dependent Hepatic Steatosis and Hypolipidemia Mainly by Impairing Lipoprotein Production in APOE*3-Leiden CETP Mice. *Toxicological Sciences*, *123*, 290–303. https://doi.org/10.1093/toxsci/kfr142

Biomonitoring California. (2019). *Project Results for Asian/Pacific Islander Community Exposures (ACE) Project - ACE 1*. https://biomonitoring.ca.gov/results/projects/2751

Biomonitoring California. (2019). *Project Results for Asian/Pacific Islander Community Exposures (ACE) Project - ACE 2*. Office of Environmental Health Hazard Assessment,. https://biomonitoring.ca.gov/results/projects/2750

Bizkarguenaga, E., Zabaleta, I., Mijangos, L., Iparraguirre, A., Fernández, L. A., Prieto, A., & Zuloaga, O. (2016). Uptake of perfluorooctanoic acid, perfluorooctane sulfonate and perfluorooctane sulfonamide by carrot and lettuce from compost amended soil. *Science of The Total Environment*, *571*, 444–451. https://doi.org/10.1016/j.scitotenv.2016.07.010

Bjork, J. A., & Wallace, K. B. (2009). Structure-Activity Relationships and Human Relevance for Perfluoroalkyl Acid–Induced Transcriptional Activation of Peroxisome Proliferation in Liver Cell Cultures. *Toxicological Sciences*, *111*, 89–99. https://doi.org/10.1093/toxsci/kfp093

Bonefeld-Jørgensen, E. C., Long, M., Fredslund, S. O., Bossi, R., & Olsen, J. (2014). Breast cancer risk after exposure to perfluorinated compounds in Danish women: a case–control study nested in the Danish National Birth Cohort. *Cancer Causes & Control*, *25*, 1439–1448. https://doi.org/10.1007/s10552-014-0446-7

Boronow, K. E., Brody, J. G., Schaider, L. A., Peaslee, G. F., Havas, L., & Cohn, B. A. (2019). Serum concentrations of PFASs and exposure-related behaviors in African American and non-Hispanic white women. *Journal of Exposure Science & Environmental Epidemiology*, *29*, 206–217. https://doi.org/10.1038/s41370-018-0109-y

Buekers, J., Colles, A., Cornelis, C., Morrens, B., Govarts, E., & Schoeters, G. (2018). Socio-Economic Status and Health: Evaluation of Human Biomonitored Chemical Exposure to Per- and Polyfluorinated Substances across Status. *International Journal of Environmental Research and Public Health*, *15*, 2818. https://doi.org/10.3390/ijerph15122818

Butenhoff, J. L., Chang, S. C., Olsen, G. W., & Thomford, P. J. (2012). Chronic dietary toxicity and carcinogenicity study with potassium perfluorooctanesulfonate in Sprague Dawley rats. *Toxicology*, *293*, 1–15. https://doi.org/10.1016/j.tox.2012.01.003

Butenhoff, J. L., Bjork, J. A., Chang, S.-C., Ehresman, D. J., Parker, G. A., Das, K., Lau, C., Lieder, P. H., van Otterdijk, F. M., & Wallace, K. B. (2012). Toxicological evaluation of ammonium perfluorobutyrate in rats: Twenty-eight-day and ninety-day oral gavage studies. *Reproductive Toxicology*, *33*, 513–530. https://doi.org/10.1016/j.reprotox.2011.08.004

Butenhoff, J. L., Chang, S.-C., Ehresman, D. J., & York, R. G. (2009). Evaluation of potential reproductive and developmental toxicity of potassium perfluorohexanesulfonate in Sprague Dawley rats. *Reproductive Toxicology*, *27*, 331–341. https://doi.org/10.1016/j.reprotox.2009.01.004

Butenhoff, J. L., Ehresman, D. J., Chang, S.-C., Parker, G. A., & Stump, D. G. (2009). Gestational and lactational exposure to potassium perfluorooctanesulfonate (K+PFOS) in rats: Developmental neurotoxicity. *Reproductive Toxicology*, *27*, 319–330. https://doi.org/10.1016/j.reprotox.2008.12.010

Butenhoff, J. L., Kennedy, G. L., Frame, S. R., O'Connor, J. C., & York, R. G. (2004). The reproductive toxicology of ammonium perfluorooctanoate (APFO) in the rat. *Toxicology*, *196*, 95–116. https://doi.org/10.1016/j.tox.2003.11.005

Butenhoff, J., Costa, G., Elcombe, C., Farrar, D., Hansen, K., Iwai, H., Jung, R., Kennedy, G., Lieder, P., Olsen, G., & Thomford, P. (2002). Toxicity of ammonium perfluorooctanoate in male cynomolgus monkeys after oral dosing for 6 months. *Toxicological Sciences : An Official Journal of the Society of Toxicology*, *69*, 244–257. https://doi.org/10.1093/toxsci/69.1.244

C8 Science Panel. (2012). *C8 Probable Link Reports*. http://www.c8sciencepanel.org/prob_link.html

Calafat, A. M., Kato, K., Hubbard, K., Jia, T., Botelho, J. C., & Wong, L.-Y. (2019). Legacy and alternative per- and polyfluoroalkyl substances in the U.S. general population: Paired serum-urine data from the 2013–2014 National Health and Nutrition Examination Survey. *Environment International*, *131*, 105048. https://doi.org/10.1016/j.envint.2019.105048

Calafat, A. M., Wong, L.-Y., Kuklenyik, Z., Reidy, J. A., & Needham, L. L. (2007). Polyfluoroalkyl Chemicals in the U.S. Population: Data from the National Health and Nutrition Examination Survey (NHANES) 2003–2004 and Comparisons with NHANES 1999–2000. *Environmental Health Perspectives*, *115*, 1596–1602. https://doi.org/10.1289/ehp.10598

California Office of Environmental Health Hazard Assessment (OEHHA). (2019). *Notification Level Recommendations, Perfluorooctanoic Acid and Perfluorooctane Sulfonate in Drinking Water*. California Environmental Protection Agency. https://oehha.ca.gov/water/notification-level/notification-level-recommendations-perfluorooctanoic-acid-pfoa

California Office of Environmental Health Hazard Assessment (OEHHA). (2021). Notification Level Recommendation for Perfluorobutane Sulfonic Acid (PFBS) in Drinking Water. January 2021. Retrieved from https://oehha.ca.gov/media/downloads/water/chemicals/nl/pfbsnl011321.pdf

California State Water Resources Control Board. (2021a). PFAS General Order 2020-003-DDW, August 27, 2020, and General Order DW-2021-0001-DDW, February 16, 2021. Retrieved from https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/pfas_ddw_general_order/

California State Water Resources Control Board. (2021b). Non-Drinking Water PFAS Information and Resources, Investigative Orders. Retrieved from https://www.waterboards.ca.gov/pfas/non_drinking_water.html

Caverly Rae, J. M., Craig, L., Slone, T. W., Frame, S. R., Buxton, L. W., & Kennedy, G. L. (2015). Evaluation of chronic toxicity and carcinogenicity of ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)-propanoate in Sprague–Dawley rats. *Toxicology Reports*, *2*, 939–949. https://doi.org/http://dx.doi.org/10.1016/j.toxrep.2015.06.001

Centers for Disease Control (CDC) and Prevention, & NHANES, C. D. C.-. (2019). *Fourth National Report on Human Exposure to Environmental Chemicals, Uptaded Tables, January 2019, Volume One* (Vol. 1). U.S. Department of Health and Human Services. file:///S:/EPH/EPHS/SAT/Toxicology/PFAS chemical action plan/Journal articles/2019/NHANES 2019-FourthReport_UpdatedTables_Volume1_Jan2019-508.pdf

Centers for Disease Control and Prevention (CDC – NHANES). (2017). *Fourth National Report on Human Exposure to Environmental Chemicals - Updated Tables, January 2017*. Center for Disease Control and Prevention, National Health and Nutrition Examination Survey. https://www.cdc.gov/exposurereport/

Centers for Disease Control and Prevention (CDC – NHANES). (2019). *Fourth Report on Human Exposure to Environmental Chemicals, Updated Tables, (January 2019)*. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. https://www.cdc.gov/exposurereport/

Chang, S.-C., Das, K., Ehresman, D. J., Ellefson, M. E., Gorman, G. S., Hart, J. A., Noker, P. E., Tan, Y.-M., Lieder, P. H., Lau, C., Olsen, G. W., & Butenhoff, J. L. (2008). Comparative Pharmacokinetics of Perfluorobutyrate in Rats, Mice, Monkeys, and Humans and Relevance to Human Exposure via Drinking Water. *Toxicological Sciences*, *104*, 40–53. https://doi.org/10.1093/toxsci/kfn057

Chang, S.-C., Thibodeaux, J. R., Eastvold, M. L., Ehresman, D. J., Bjork, J. A., Froehlich, J. W., Lau, C., Singh, R. J., Wallace, K. B., & Butenhoff, J. L. (2008). Thyroid hormone status and pituitary function in adult rats given oral doses of perfluorooctanesulfonate (PFOS). *Toxicology*, *243*, 330–339. https://doi.org/10.1016/j.tox.2007.10.014

Chang, S., Butenhoff, J. L., Parker, G. A., Coder, P. S., Zitzow, J. D., Krisko, R. M., Bjork, J. A., Wallace, K. B., & Seed, J. G. (2018). Reproductive and developmental toxicity of potassium perfluorohexanesulfonate in CD-1 mice. *Reproductive Toxicology*, *78*, 150–168. https://doi.org/10.1016/j.reprotox.2018.04.007

Chengelis, C. P., Kirkpatrick, J. B., Radovsky, A., & Shinohara, M. (2009). A 90-day repeated dose oral (gavage) toxicity study of perfluorohexanoic acid (PFHxA) in rats (with functional observational battery and motor activity determinations). *Reproductive Toxicology*, *27*, 342–351. https://doi.org/10.1016/j.reprotox.2009.01.006

Christensen, K. Y., Raymond, M., Blackowicz, M., Liu, Y., Thompson, B. A., Anderson, H. A., & Turyk, M. (2017). Perfluoroalkyl substances and fish consumption. *Environmental Research*, *154*, 145–151. https://doi.org/10.1016/j.envres.2016.12.032

Christensen, K. Y., Maisonet, M., Rubin, C., Holmes, A., Calafat, A. M., Kato, K., Flanders, W. D., Heron, J., McGeehin, M. A., & Marcus, M. (2011). Exposure to polyfluoroalkyl chemicals during pregnancy is not associated with offspring age at menarche in a contemporary British cohort. *Environment International*, *37*, 129–135. https://doi.org/10.1016/j.envint.2010.08.007

City of Dupont. (2020). *PFCs - Frequently Asked Questions*. Retrieved from https://www.dupontwa.gov/502/PFCs

Clara, M., Scharf, S., Weiss, S., Gans, O., & Scheffknecht, C. (2008). Emissions of perfluorinated alkylated substances (PFAS) from point sources—identification of relevant branches. *Water Science and Technology*, *58*, 59–66. https://doi.org/10.2166/wst.2008.641

Conley, J., Lambright, C., Evans, N., McCord, J., Strynar, M., Hill, D., Medlock-Kakaley, E., Wilson, V., & Gray, L. (2021). Hexafluoropropylene oxide-dimer acid (HFPO-DA or GenX) alters maternal and fetal glucose and lipid metabolism and produces neonatal mortality, low birthweight, and hepatomegaly in the Sprague-Dawley rat. *Environment international, 146,* 106 – 204. https://doi.org/10.1016/j.envint.2020.106204

Convertino, M., Church, T. R., Olsen, G. W., Liu, Y., Doyle, E., Elcombe, C. R., Barnett, A. L., Samuel, L. M., MacPherson, I. R., & Evans, T. R. J. (2018). Stochastic Pharmacokinetic-Pharmacodynamic Modeling for Assessing the Systemic Health Risk of Perfluorooctanoate (PFOA). *Toxicological Sciences*, *163*, 293–306. https://doi.org/10.1093/toxsci/kfy035

Corsini, E., Luebke, R. W., Germolec, D. R., & DeWitt, J. C. (2014). Perfluorinated compounds: Emerging POPs with potential immunotoxicity. *Toxicology Letters*, *230*, 263–270. https://doi.org/10.1016/j.toxlet.2014.01.038

Corton, J. C., Peters, J. M., & Klaunig, J. E. (2018). The PPARα-dependent rodent liver tumor response is not relevant to humans: addressing misconceptions. *Archives of Toxicology*, *92*, 83–119. https://doi.org/10.1007/s00204-017-2094-7

Crebelli, R., Caiola, S., Conti, L., Cordelli, E., De Luca, G., Dellatte, E., Eleuteri, P., Iacovella, N., Leopardi, P., Marcon, F., Sanchez, M., Sestili, P., Siniscalchi, E., & Villani, P. (2019). Can sustained exposure to PFAS trigger a genotoxic response? A comprehensive genotoxicity assessment in mice after subacute oral administration of PFOA and PFBA. *Regulatory Toxicology and Pharmacology*, *106*, 169–177. https://doi.org/10.1016/j.yrtph.2019.05.005

Cui, L., Zhou, Q., Liao, C., Fu, J., & Jiang, G. (2009). Studies on the Toxicological Effects of PFOA and PFOS on Rats Using Histological Observation and Chemical Analysis. *Archives of Environmental Contamination and Toxicology*, *56*, 338–349. https://doi.org/10.1007/s00244-008-9194-6

D'Hollander, W., Roosens, L., Covaci, A., Cornelis, C., Reynders, H., Campenhout, K. Van, Voogt, P. de, & Bervoets, L. (2010). Brominated flame retardants and perfluorinated compounds in indoor dust from homes and offices in Flanders, Belgium. *Chemosphere*, *81*, 478–487. https://doi.org/10.1016/j.chemosphere.2010.07.043

Dalsager, L., Christensen, N., Husby, S., Kyhl, H., Nielsen, F., Høst, A., Grandjean, P., & Jensen, T. K. (2016). Association between prenatal exposure to perfluorinated compounds and symptoms of infections at age 1–4years among 359 children in the Odense Child Cohort. *Environment International*, *96*, 58–64. https://doi.org/10.1016/j.envint.2016.08.026

Darrow, L. A., Groth, A. C., Winquist, A., Shin, H.-M., Bartell, S. M., & Steenland, K. (2016). Modeled Perfluorooctanoic Acid (PFOA) Exposure and Liver Function in a Mid-Ohio Valley Community. *Environmental Health Perspectives*, *124*, 1227–1233. https://doi.org/10.1289/ehp.1510391

Das, K. P., Wood, C. R., Lin, M. T., Starkov, A. A., Lau, C., Wallace, K. B., Corton, J. C., & Abbott, B. D. (2017). Perfluoroalkyl acids-induced liver steatosis: Effects on genes controlling lipid homeostasis. *Toxicology*, *378*, 37–52. https://doi.org/10.1016/j.tox.2016.12.007

Das, K. P., Grey, B. E., Zehr, R. D., Wood, C. R., Butenhoff, J. L., Chang, S.-C., Ehresman, D. J., Tan, Y.-M., & Lau, C. (2008). Effects of Perfluorobutyrate Exposure during Pregnancy in the Mouse. *Toxicological Sciences*, *105*, 173–181. https://doi.org/10.1093/toxsci/kfn099

Das, K. P., Grey, B. E., Rosen, M. B., Wood, C. R., Tatum-Gibbs, K. R., Zehr, R. D., Strynar, M. J., Lindstrom, A. B., & Lau, C. (2015). Developmental toxicity of perfluorononanoic acid in mice. *Reproductive Toxicology*, *51*, 133–144. https://doi.org/10.1016/j.reprotox.2014.12.012

Department of Defense (DOD). (2016). *Testing DOD Drinking Water for Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA) - Policy*. DOD. https://www.denix.osd.mil/army-pfas/the-army-addresses-pfos-pfoa/the-army-addresses-pfos-and-pfoa/testing-dod-drinking-water-for-perfluorooctane-sulfonate-and-perfluorooctanoic-acid-contamination/

Department of Defense (DOD). (2016). *Perfluorinated Compound (PFC) Contamination Assessment*. Department of Defense. https://www.denix.osd.mil/army-pfas/the-army-addresses-pfos-pfoa/the-army-addresses-pfos-and-pfoa/perfluorinated-compound-pfc-contamination-assessment1/

Department of Defense (DOD) Environment. (2018). *Army PFAS Fact Sheet*. DENIX DOD Environment, Safety and Occupational Health Network and Information Exchange. Retrieved from https://www.denix.osd.mil/army-pfas/home/homepage-documents/may-9-pfas-factsheet/

Department of Navy (DON). (2018). Final Action Memorandum, Town of Coupeville – Navy Water System Improvements, Coupeville, Naval Air Station Whidbey Island, Outlying Landing Field, Coupeville, Washington, July 2018.

Department of Navy (DON). (2020). Final Action Memorandum, Ault Field and Area 6 Drinking Water, Naval Air Station Whidbey Island, Oak Harbor, Washington, June 2020.

Department of Navy (DON). (2021). Naval Base Kitsap-Bangor PFAS Virtual Open House. Retrived from https://www.navybangorpfas.com/index.html

DeWitt, J. C., Blossom, S. J., & Schaider, L. A. (2019). Exposure to per-fluoroalkyl and polyfluoroalkyl substances leads to immunotoxicity: epidemiological and toxicological evidence. *Journal of Exposure Science & Environmental Epidemiology*, *29*, 148–156. https://doi.org/10.1038/s41370-018-0097-y

DeWitt, J. C., Copeland, C. B., Strynar, M. J., & Luebke, R. W. (2008). Perfluorooctanoic Acid–Induced Immunomodulation in Adult C57BL/6J or C57BL/6N Female Mice. *Environmental Health Perspectives*, *116*, 644–650. https://doi.org/10.1289/ehp.10896

Di Nisio, A., Sabovic, I., Valente, U., Tescari, S., Rocca, M. S., Guidolin, D., Dall'Acqua, S., Acquasaliente, L., Pozzi, N., Plebani, M., Garolla, A., & Foresta, C. (2019). Endocrine Disruption of Androgenic Activity by Perfluoroalkyl Substances: Clinical and Experimental Evidence. *The Journal of Clinical Endocrinology & Metabolism*, *104*, 1259–1271. https://doi.org/10.1210/jc.2018-01855

Dobraca, D., Israel, L., McNeel, S., Voss, R., Wang, M., Gajek, R., Park, J.-S., Harwani, S., Barley, F., She, J., & Das, R. (2015). Biomonitoring in California Firefighters. *Journal of Occupational and Environmental Medicine*, *57*, 88–97. https://doi.org/10.1097/JOM.0000000000000307

Domazet, S. L., Grøntved, A., Timmermann, A. G., Nielsen, F., & Jensen, T. K. (2016). Longitudinal Associations of Exposure to Perfluoroalkylated Substances in Childhood and Adolescence and Indicators of Adiposity and Glucose Metabolism 6 and 12 Years Later: The European Youth Heart Study. *Diabetes Care*, *39*, 1745–1751. https://doi.org/10.2337/dc16-0269

Dong, G.-H., Liu, M.-M., Wang, D., Zheng, L., Liang, Z.-F., & Jin, Y.-H. (2011). Sub-chronic effect of perfluorooctanesulfonate (PFOS) on the balance of type 1 and type 2 cytokine in adult C57BL6 mice. *Archives of Toxicology*, *85*, 1235–1244. https://doi.org/10.1007/s00204-011-0661-x

Dong, G.-H., Zhang, Y.-H., Zheng, L., Liu, W., Jin, Y.-H., & He, Q.-C. (2009). Chronic effects of perfluorooctanesulfonate exposure on immunotoxicity in adult male C57BL/6 mice. *Archives of Toxicology*, *83*, 805–815. https://doi.org/10.1007/s00204-009-0424-0

Ducatman, A., Zhang, J., & Fan, H. (2015). Prostate-Specific Antigen and Perfluoroalkyl Acids in the C8 Health Study Population. *Journal of Occupational and Environmental Medicine*, *57*, 111–114. https://doi.org/10.1097/JOM.0000000000000319

DuPont. (2007). *Sodium Perfluorohexanoate: 90-Day Gavage Study in Rats with One-generation Reproduction Evaluation (Study No. 19715, July 2007)*. E.I. du Pont de Nemours and Company (Unpublished report). https://www.daikinchemicals.com/library/pb_common/pdf/sustainability/PFHxA/90day_004.pdf

Egeghy, P. P., & Lorber, M. (2011). An assessment of the exposure of Americans to perfluorooctane sulfonate: A comparison of estimated intake with values inferred from NHANES data. *Journal of Exposure Science & Environmental Epidemiology*, *21*, 150–168. https://doi.org/10.1038/jes.2009.73

Emmett, E. A., Shofer, F. S., Zhang, H., Freeman, D., Desai, C., & Shaw, L. M. (2006). Community Exposure to Perfluorooctanoate: Relationships Between Serum Concentrations and Exposure Sources. *Journal of Occupational and Environmental Medicine*, *48*, 759–770. https://doi.org/10.1097/01.jom.0000232486.07658.74

Environmental Justice Task Force. (2020). Report to the Washington State Governor and Legislature; Recommendations for Prioritizing EJ in Washington State Government. Fall 2020. Retrieved from https://healthequity.wa.gov/Portals/9/Doc/Publications/Reports/EJTF%20Report_FINAL(1).pdf

Environmental Working Group (EWG). (2020). *Freedom of Information Request for PFAS Detections on U.S. Army Bases, 2016-2019*. https://cdn3.ewg.org/sites/default/files/u352/EWG_PFASTable-Army_C01.pdf?_ga=2.221565720.1036667099.1568130417-1210461551.1568130417

Environmental Working Group (EWG). (2020). *Mapping the PFAS Contamination Crisis: New Data Show 1,582 Sites in 49 States*. https://www.ewg.org/interactive-maps/pfas_contamination/

Eriksen, K. T., Sorensen, M., McLaughlin, J. K., Lipworth, L., Tjonneland, A., Overvad, K., & Raaschou-Nielsen, O. (2009). Perfluorooctanoate and Perfluorooctanesulfonate Plasma Levels and Risk of Cancer in the General Danish Population. *JNCI Journal of the National Cancer Institute*, *101*, 605–609. https://doi.org/10.1093/jnci/djp041

Ernst, A., Brix, N., Lauridsen, L. L. B., Olsen, J., Parner, E. T., Liew, Z., Olsen, L. H., & Ramlau-Hansen, C. H. (2019). Exposure to Perfluoroalkyl Substances during Fetal Life and Pubertal Development in Boys and Girls from the Danish National Birth Cohort. *Environmental Health Perspectives*, *127*, 017004. https://doi.org/10.1289/EHP3567

European Commission and Cordis. (2012). *Final Report Summary - PERFOOD (PERFluorinated Organics in Our Diet)*. https://cordis.europa.eu/project/rcn/91268/reporting/en

European Food Safety Authority (EFSA). (2020). *Draft scientific opinion on risks to human health related to the presence of perfluoroalkyl substances in food*. https://www.efsa.europa.eu/sites/default/files/consultation/consultation/PFAS_Draft_Opinion_for_public_consultation_Part_I.pdf

European Food Safety Authority (EFSA). (2020). *Public consultation on the draft scientific opinion on the risks to human health related to the presence of perfluoroalkyl substances in food*. European Food Safety Authority. https://www.efsa.europa.eu/en/consultations/call/public-consultation-draft-scientific-opinion-risks-human-health

Fairchild Air Force Base. (2018). *Restoration Advisory Board (RAB) Meeting Agenda*. Air Force.

Fairchild Airforce Base. (2019). *Fairchild AFB PFOS/PFOA Sampling Area*. https://www.fairchild.af.mil/PFOS-PFOA-INFO/

Fan, H., Ducatman, A., & Zhang, J. (2014). Perfluorocarbons and Gilbert syndrome (phenotype) in the C8 Health Study Population. *Environmental Research*, *135*, 70–75. https://doi.org/10.1016/j.envres.2014.08.011

Fang, X., Feng, Y., Wang, J., & Dai, J. (2010). Perfluorononanoic acid-induced apoptosis in rat spleen involves oxidative stress and the activation of caspase-independent death pathway. *Toxicology*, *267*(1–3), 54–59. https://doi.org/10.1016/j.tox.2009.10.020

Fang, X., Feng, Y., Shi, Z., & Dai, J. (2009). Alterations of Cytokines and MAPK Signaling Pathways are Related to the Immunotoxic Effect of Perfluorononanoic Acid. *Toxicological Sciences*, *108*, 367–376. https://doi.org/10.1093/toxsci/kfp019

Fang, X., Zhang, L., Feng, Y., Zhao, Y., & Dai, J. (2008). Immunotoxic Effects of Perfluorononanoic Acid on BALB/c Mice. *Toxicological Sciences*, *105*, 312–321. https://doi.org/10.1093/toxsci/kfn127

Farley, J. (2020, March 10). Well near Bangor found to have potentially dangerous levels of contamination. *Kitsap Sun*. https://www.kitsapsun.com/story/news/2020/03/10/well-near-bangor-found-have-potentially-dangerous-levels-contamination/5011073002/

Fei, C., McLaughlin, J. K., Lipworth, L., & Olsen, J. (2009). Maternal levels of perfluorinated chemicals and subfecundity. *Human Reproduction*, *24*, 1200–1205. https://doi.org/10.1093/humrep/den490

Feng, X., Cao, X., Zhao, S., Wang, X., Hua, X., Chen, L., & Chen, L. (2017). Exposure of Pregnant Mice to Perfluorobutanesulfonate Causes Hypothyroxinemia and Developmental Abnormalities in Female Offspring. *Toxicological Sciences*, *155*, 409–419. https://doi.org/10.1093/toxsci/kfw219

Feng, Y., Shi, Z., Fang, X., Xu, M., & Dai, J. (2009). Perfluorononanoic acid induces apoptosis involving the Fas death receptor signaling pathway in rat testis. *Toxicology Letters*, *190*, 224–230. https://doi.org/10.1016/j.toxlet.2009.07.020

Foreman, J. E., Chang, S.-C., Ehresman, D. J., Butenhoff, J. L., Anderson, C. R., Palkar, P. S., Kang, B.-H., Gonzalez, F. J., & Peters, J. M. (2009). Differential Hepatic Effects of Perfluorobutyrate Mediated by Mouse and Human PPAR-α. *Toxicological Sciences*, *110*, 204–211. https://doi.org/10.1093/toxsci/kfp077

Fraser, A. J., Webster, T. F., Watkins, D. J., Nelson, J. W., Stapleton, H. M., Calafat, A. M., Kato, K., Shoeib, M., Vieira, V. M., & McClean, M. D. (2012). Polyfluorinated Compounds in Serum Linked to Indoor Air in Office Environments. *Environmental Science & Technology*, *46*, 1209–1215. https://doi.org/10.1021/es2038257

Fraser, A. J., Webster, T. F., Watkins, D. J., Strynar, M. J., Kato, K., Calafat, A. M., Vieira, V. M., & McClean, M. D. (2013). Polyfluorinated compounds in dust from homes, offices, and vehicles as predictors of concentrations in office workers' serum. *Environment International*, *60*, 128–136. https://doi.org/10.1016/j.envint.2013.08.012

Frawley, R. P., Smith, M., Cesta, M. F., Hayes-Bouknight, S., Blystone, C., Kissling, G. E., Harris, S., & Germolec, D. (2018). Immunotoxic and hepatotoxic effects of perfluoro- n -decanoic acid (PFDA) on female Harlan Sprague–Dawley rats and B 6 C 3 F 1 /N mice when administered by oral gavage for 28 days. *Journal of Immunotoxicology*, *15*, 41–52. https://doi.org/10.1080/1547691X.2018.1445145

Freberg, B. I., Olsen, R., Daae, H. L., Hersson, M., Thorud, S., Ellingsen, D. G., & Molander, P. (2014). Occupational Exposure Assessment of Airborne Chemical Contaminants Among Professional Ski Waxers. *The Annals of Occupational Hygiene*, *58*, 601–611. https://doi.org/10.1093/annhyg/meu015

Freberg, B. I., Haug, L. S., Olsen, R., Daae, H. L., Hersson, M., Thomsen, C., Thorud, S., Becher, G., Molander, P., & Ellingsen, D. G. (2010). Occupational Exposure to Airborne Perfluorinated Compounds during Professional Ski Waxing. *Environmental Science & Technology*, *44*, 7723–7728. https://doi.org/10.1021/es102033k

Frisbee, S. J., Brooks, A. P., Maher, A., Flensborg, P., Arnold, S., Fletcher, T., Steenland, K., Shankar, A., Knox, S. S., Pollard, C., Halverson, J. A., Vieira, V. M., Jin, C., Leyden, K. M., & Ducatman, A. M. (2009). The C8 Health Project: Design, Methods, and Participants. *Environmental Health Perspectives*, *117*, 1873–1882. https://doi.org/10.1289/ehp.0800379

Frisbee, S. J., Shankar, A., Knox, S. S., Steenland, K., Savitz, D. A., Fletcher, T., & Ducatman, A. M. (2010). Perfluorooctanoic Acid, Perfluorooctanesulfonate, and Serum Lipids in Children and Adolescents. *Archives of Pediatrics & Adolescent Medicine*, *164*, 860–869. https://doi.org/10.1001/archpediatrics.2010.163

Fu, Y., Wang, T., Fu, Q., Wang, P., & Lu, Y. (2014). Associations between serum concentrations of perfluoroalkyl acids and serum lipid levels in a Chinese population. *Ecotoxicology and Environmental Safety*, *106*, 246–252. https://doi.org/10.1016/j.ecoenv.2014.04.039

Fujii, Y., Harada, K. H., & Koizumi, A. (2013). Occurrence of perfluorinated carboxylic acids (PFCAs) in personal care products and compounding agents. *Chemosphere*, *93*, 538–544. https://doi.org/10.1016/j.chemosphere.2013.06.049

Gallo, V., Leonardi, G., Genser, B., Lopez-Espinosa, M.-J., Frisbee, S. J., Karlsson, L., Ducatman, A. M., & Fletcher, T. (2012). Serum Perfluorooctanoate (PFOA) and Perfluorooctane Sulfonate (PFOS) Concentrations and Liver Function Biomarkers in a Population with Elevated PFOA Exposure. *Environmental Health Perspectives*, *120*, 655–660. https://doi.org/10.1289/ehp.1104436

Geiger, S. D., Xiao, J., & Shankar, A. (2013). Positive Association Between Perfluoroalkyl Chemicals and Hyperuricemia in Children. *American Journal of Epidemiology*, *177*, 1255–1262. https://doi.org/10.1093/aje/kws392

Geueke, B. (2016). FPF Dossier: Per- and polyfluoroalkyl substances (PFASs). *Food Packaging Forum*. https://doi.org/10.5281/zenodo.57198

Ghisi, R., Vamerali, T., & Manzetti, S. (2019). Accumulation of perfluorinated alkyl substances (PFAS) in agricultural plants: A review. *Environmental Research*, *169*, 326–341. https://doi.org/10.1016/j.envres.2018.10.023

Girardi, P., & Merler, E. (2019). A mortality study on male subjects exposed to polyfluoroalkyl acids with high internal dose of perfluorooctanoic acid. *Environmental Research*, *179*, 108743. https://doi.org/10.1016/j.envres.2019.108743

Gleason, J. A., Post, G. B., & Fagliano, J. A. (2015). Associations of perfluorinated chemical serum concentrations and biomarkers of liver function and uric acid in the US population (NHANES), 2007–2010. *Environmental Research*, *136*, 8–14. https://doi.org/10.1016/j.envres.2014.10.004

Goecke-Flora, C. M., & Reo, N. V. (1996). Influence of Carbon Chain Length on the Hepatic Effects of Perfluorinated Fatty Acids. A 19 F- and 31 P-NMR Investigation. *Chemical Research in Toxicology*, *9*, 689–695. https://doi.org/10.1021/tx950217k

Goudarzi, H., Miyashita, C., Okada, E., Kashino, I., Chen, C.-J., Ito, S., Araki, A., Kobayashi, S., Matsuura, H., & Kishi, R. (2017). Prenatal exposure to perfluoroalkyl acids and prevalence of infectious diseases up to 4 years of age. *Environment International*, *104*, 132–138. https://doi.org/10.1016/j.envint.2017.01.024

Graber, J. M., Alexander, C., Laumbach, R. J., Black, K., Strickland, P. O., Georgopoulos, P. G., Marshall, E. G., Shendell, D. G., Alderson, D., Mi, Z., Mascari, M., & Weisel, C. P. (2019). Per and polyfluoroalkyl substances (PFAS) blood levels after contamination of a community water supply and comparison with 2013–2014 NHANES. *Journal of Exposure Science & Environmental Epidemiology*, *29*, 172–182. https://doi.org/10.1038/s41370-018-0096-z

Grandjean, P., Andersen, E. W., Budtz-Jørgensen, E., Nielsen, F., Mølbak, K., Weihe, P., & Heilmann, C. (2012). Serum Vaccine Antibody Concentrations in Children Exposed to Perfluorinated Compounds. *JAMA*, *307*, 391–397. https://doi.org/10.1001/jama.2011.2034

Grandjean, P., Heilmann, C., Weihe, P., Nielsen, F., Mogensen, U. B., & Budtz-Jørgensen, E. (2017). Serum Vaccine Antibody Concentrations in Adolescents Exposed to Perfluorinated Compounds. *Environmental Health Perspectives*, *125*, 077018. https://doi.org/10.1289/EHP275

Grandjean, P., Heilmann, C., Weihe, P., Nielsen, F., Mogensen, U. B., Timmermann, A., & Budtz-Jørgensen, E. (2017). Estimated exposures to perfluorinated compounds in infancy predict attenuated vaccine antibody concentrations at age 5-years. *Journal of Immunotoxicology*, *14*, 188–195. https://doi.org/10.1080/1547691X.2017.1360968

Grandjean, P., Timmermann, C., Kruse, M., Nielsen, F., Vinholt, P., Boding, L., Heilmann, C., & Mølbak, K. (2020). Severity of COVID-19 at elevated exposure to perfluorinated alkylates. *PloS one*, *15*, 1 – 12. https://doi.org/10.1371/journal.pone.0244815

Granum, B., Haug, L. S., Namork, E., Stølevik, S. B., Thomsen, C., Aaberge, I. S., van Loveren, H., Løvik, M., & Nygaard, U. C. (2013). Pre-natal exposure to perfluoroalkyl substances may be associated with altered vaccine antibody levels and immune-related health outcomes in early childhood. *Journal of Immunotoxicology*, *10*, 373 – 379. https://doi.org/10.3109/1547691X.2012.755580

Gremmel, C., Frömel, T., & Knepper, T.P. (2016). Systematic determination of perfluoroalkyl and polyfluoroalkyl substances (PFASs) in outdoor jackets. *Chemosphere, 160*, 173-180. https://doi.org/10.1016/j.chemosphere.2016.06.043

Guruge, K. S., Hikono, H., Shimada, N., Murakami, K., Hasegawa, J., Yeung, L. W. Y., Yamanaka, N., & Yamashita, N. (2009). Effect of perfluorooctane sulfonate (PFOS) on influenza A virus-induced mortality in female B6C3F1 mice. *The Journal of Toxicological Sciences*, *34*, 687–691. https://doi.org/10.2131/jts.34.687

Gyllenhammar, I., Benskin, J. P., Sandblom, O., Berger, U., Ahrens, L., Lignell, S., Wiberg, K., & Glynn, A. (2018). Perfluoroalkyl Acids (PFAAs) in Serum from 2–4-Month-Old Infants: Influence of Maternal Serum Concentration, Gestational Age, Breast-Feeding, and Contaminated Drinking Water. *Environmental Science & Technology*, *52*, 7101–7110. https://doi.org/10.1021/acs.est.8b00770

Hall, A. P., Elcombe, C. R., Foster, J. R., Harada, T., Kaufmann, W., Knippel, A., Küttler, K., Malarkey, D. E., Maronpot, R. R., Nishikawa, A., Nolte, T., Schulte, A., Strauss, V., & York, M. J. (2012). Liver Hypertrophy. *Toxicologic Pathology*, *40*(7), 971–994. https://doi.org/10.1177/0192623312448935

Hansen, S., Vestergren, R., Herzke, D., Melhus, M., Evenset, A., Hanssen, L., Brustad, M., & Sandanger, T. M. (2016). Exposure to per- and polyfluoroalkyl substances through the consumption of fish from lakes affected by aqueous film-forming foam emissions — A combined epidemiological and exposure modeling approach. The SAMINOR 2 Clinical Study. *Environment International*, *94*, 272–282. https://doi.org/10.1016/j.envint.2016.05.030

Hardell, E., Kärrman, A., van Bavel, B., Bao, J., Carlberg, M., & Hardell, L. (2014). Case–control study on perfluorinated alkyl acids (PFAAs) and the risk of prostate cancer. *Environment International*, *63*, 35–39. https://doi.org/10.1016/j.envint.2013.10.005

Hardisty, J. F., Willson, G. A., Brown, W. R., McConnell, E. E., Frame, S. R., Gaylor, D. W., Kennedy, G. L., & Butenhoff, J. L. (2010). Pathology Working Group review and evaluation of proliferative lesions of mammary gland tissues in female rats fed ammonium perfluorooctanoate (APFO) in the diet for 2 years. *Drug and Chemical Toxicology*, *33*, 131–137. https://doi.org/10.3109/01480541003667610

Harris, M. H., Rifas-Shiman, S. L., Calafat, A. M., Ye, X., Mora, A. M., Webster, T. F., Oken, E., & Sagiv, S. K. (2017). Predictors of Per- and Polyfluoroalkyl Substance (PFAS) Plasma Concentrations in 6–10 Year Old American Children. *Environmental Science & Technology*, *51*, 5193–5204. https://doi.org/10.1021/acs.est.6b05811

Hinds, K. K. (2017). *Limited Update Water System Plan*. Town of Coupeville. https://townofcoupeville.org/wp-content/uploads/2017/08/limited-update-water-system-plan-2017.pdf

Hoffman, K., Webster, T. F., Bartell, S. M., Weisskopf, M. G., Fletcher, T., & Vieira, V. M. (2011). Private Drinking Water Wells as a Source of Exposure to Perfluorooctanoic Acid (PFOA) in Communities Surrounding a Fluoropolymer Production Facility. *Environmental Health Perspectives*, *119*, 92–97. https://doi.org/10.1289/ehp.1002503

Hoffman, K., Webster, T. F., Weisskopf, M. G., Weinberg, J., & Vieira, V. M. (2010). Exposure to Polyfluoroalkyl Chemicals and Attention Deficit/Hyperactivity Disorder in U.S. Children 12–15 Years of Age. *Environmental Health Perspectives*, *118*, 1762–1767. https://doi.org/10.1289/ehp.1001898

Hu, X. C., Andrews, D. Q., Lindstrom, A. B., Bruton, T. A., Schaider, L. A., Grandjean, P., Lohmann, R., Carignan, C. C., Blum, A., Balan, S. A., Higgins, C. P., & Sunderland, E. M. (2016). Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Military Fire Training Areas, and Wastewater Treatment Plants. *Environmental Science & Technology Letters*, *3*, 344–350. https://doi.org/10.1021/acs.estlett.6b00260

Hong, S., Lee, S., Yang, J., Lee, J., Jung, K., Seok, J., Kim, S., Nam, K., Jeong, J., Lee, J., & Oh, J. (2020). Orally Administered 6:2 Chlorinated Polyfluorinated Ether Sulfonate (F-53B) Causes Thyroid Dysfunction in Rats. *Toxics, 8,* 54. https://doi.org/10.3390/toxics8030054

Hu, X. C., Tokranov, A. K., Liddie, J., Zhang, X., Grandjean, P., Hart, J. E., Laden, F., Sun, Q., Yeung, L. W. Y., & Sunderland, E. M. (2019). Tap Water Contributions to Plasma Concentrations of Poly- and Perfluoroalkyl Substances (PFAS) in a Nationwide Prospective Cohort of U.S. Women. *Environmental Health Perspectives*, *127*, 067006. https://doi.org/10.1289/EHP4093

Huang, M., Jiao, J., Zhuang, P., Chen, X., Wang, J., & Zhang, Y. (2018). Serum polyfluoroalkyl chemicals are associated with risk of cardiovascular diseases in national US population. *Environment International*, *119*, 37–46. https://doi.org/10.1016/j.envint.2018.05.051

Huang, R., Chen, Q., Zhang, L., Luo, K., Chen, L., Zhao, S., Feng, L., & Zhang, J. (2019). Prenatal exposure to perfluoroalkyl and polyfluoroalkyl substances and the risk of hypertensive disorders of pregnancy. *Environmental Health*, *18*, 5. https://doi.org/10.1186/s12940-018-0445-3

Humblet, O., Diaz-Ramirez, L. G., Balmes, J. R., Pinney, S. M., & Hiatt, R. A. (2014). Perfluoroalkyl Chemicals and Asthma among Children 12–19 Years of Age: NHANES (1999–2008). *Environmental Health Perspectives*, *122*, 1129–1133. https://doi.org/10.1289/ehp.1306606

Hurdle, J. (2018, July 20). New Jersey issues first advisories for consumption of fish containing PFAS chemicals - State scientists recommend health limits for 12 species. *StateImpact Pennsylvania*. https://stateimpact.npr.org/pennsylvania/2018/07/20/new-jersey-issues-first-advisories-for-consumption-of-fish-containing-pfas-chemicals/

Hurley, S., Houtz, E., Goldberg, D., Wang, M., Park, J.-S., Nelson, D. O., Reynolds, P., Bernstein, L., Anton-Culver, H., Horn-Ross, P., & Petreas, M. (2016). Preliminary Associations between the Detection of Perfluoroalkyl Acids (PFAAs) in Drinking Water and Serum Concentrations in a Sample of California Women. *Environmental Science & Technology Letters*, *3*, 264–269. https://doi.org/10.1021/acs.estlett.6b00154

Impinen, A., Longnecker, M. P., Nygaard, U. C., London, S. J., Ferguson, K. K., Haug, L. S., & Granum, B. (2019). Maternal levels of perfluoroalkyl substances (PFASs) during pregnancy and childhood allergy and asthma related outcomes and infections in the Norwegian Mother and Child (MoBa) cohort. *Environment International*, *124*, 462–472. https://doi.org/10.1016/j.envint.2018.12.041

Impinen, A., Nygaard, U. C., Lødrup Carlsen, K. C., Mowinckel, P., Carlsen, K. H., Haug, L. S., & Granum, B. (2018). Prenatal exposure to perfluoroalkyl substances (PFASs) associated with respiratory tract infections but not allergy- and asthma-related health outcomes in childhood. *Environmental Research*, *160*, 518–523. https://doi.org/10.1016/j.envres.2017.10.012

Innes, K. E., Wimsatt, J. H., Frisbee, S., & Ducatman, A. M. (2014). Inverse association of colorectal cancer prevalence to serum levels of perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) in a large Appalachian population. *BMC Cancer*, *14*, 45. https://doi.org/10.1186/1471-2407-14-45

International Agency for Research on Cancer (IARC). (2016). IARC Monographs on the Identification of Carcinogenic Hazards to Humans - Perfluorooctanoic Acid. *World Health Organization*, *110*. https://monographs.iarc.fr/wp-content/uploads/2018/06/mono110-01.pdf

International Agency for Research on Cancer (IARC). (2017). Some Chemicals Used as Solvents and in Polymer Manufacture: IARC Monographs on the Identification of Carcinogenic Hazards to Humans. *World Health Organization*, *110*. https://monographs.iarc.fr/wp-content/uploads/2018/06/mono110-01.pdf

Interstate Technology & Regulatory Council (ITRC). (2020). *Regulations, Guidance, and Advisories for Per- and Polyfluoroalkyl Substances (PFAS); Tables 4 and 5*. https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_Regulations_April2020.pdf

Interstate Technology & Regulatory Council (ITRC). (2020). *PFAS Fact Sheets*. ITRC. https://pfas-1.itrcweb.org/fact-sheets/

Interstate Technology & Regulatory Council (ITRC). (2020). *History and Use of Per- and Polyfluoroalkl Substances (PFAS)*. https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_History_and_Use_April2020.pdf

Jain, R. B. (2013). Association between thyroid profile and perfluoroalkyl acids: Data from NHNAES 2007–2008. *Environmental Research*, *126*, 51–59. https://doi.org/10.1016/j.envres.2013.08.006

Jain, R. B. (2018). Contribution of diet and other factors to the observed levels of selected perfluoroalkyl acids in serum among US children aged 3-11 years. *Environmental Research*, *161*, 268–275. https://doi.org/10.1016/j.envres.2017.11.018

Jain, R. B. (2013). Effect of Pregnancy on The Levels of Selected Perfluoroalkyl Compounds for Females Aged 17–39 Years: Data From National Health and Nutrition Examination Survey 2003–2008. *Journal of Toxicology and Environmental Health, Part A*, *76*, 409–421. https://doi.org/10.1080/15287394.2013.771547

Jain, R. B., & Ducatman, A. (2019). Selective Associations of Recent Low Concentrations of Perfluoroalkyl Substances With Liver Function Biomarkers. *Journal of Occupational and Environmental Medicine*, *61*, 293–302. https://doi.org/10.1097/JOM.0000000000001532

Jeddy, Z., Tobias, J. H., Taylor, E. V, Northstone, K., Flanders, W. D., & Hartman, T. J. (2018). Prenatal concentrations of perfluoroalkyl substances and bone health in British girls at age 17. *Archives of Osteoporosis*, *13*, 84. https://doi.org/10.1007/s11657-018-0498-5

Jensen, T. K., Andersen, L. B., Kyhl, H. B., Nielsen, F., Christesen, H. T., & Grandjean, P. (2015). Association between Perfluorinated Compound Exposure and Miscarriage in Danish Pregnant Women. *PLOS ONE*, *10*, e0123496. https://doi.org/10.1371/journal.pone.0123496

Jin, C., Sun, Y., Islam, A., Qian, Y., & Ducatman, A. (2011). Perfluoroalkyl Acids Including Perfluorooctane Sulfonate and Perfluorohexane Sulfonate in Firefighters. *Journal of Occupational and Environmental Medicine*, *53*, 324–328. https://doi.org/10.1097/JOM.0b013e31820d1314

Jin, R., McConnell, R., Catherine, C., Xu, S., Walker, D. I., Stratakis, N., Jones, D. P., Miller, G. W., Peng, C., Conti, D. V, Vos, M. B., & Chatzi, L. (2020). Perfluoroalkyl substances and severity of nonalcoholic fatty liver in Children: An untargeted metabolomics approach. *Environment International*, *134*, 105220. https://doi.org/10.1016/j.envint.2019.105220

Johansson, N., Fredriksson, A., & Eriksson, P. (2008). Neonatal exposure to perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) causes neurobehavioural defects in adult mice. *NeuroToxicology*, *29*, 160–169. https://doi.org/10.1016/j.neuro.2007.10.008

Johnson, P. I., Sutton, P., Atchley, D. S., Koustas, E., Lam, J., Sen, S., Robinson, K. A., Axelrad, D. A., & Woodruff, T. J. (2014). The Navigation Guide—Evidence-Based Medicine Meets Environmental Health: Systematic Review of Human Evidence for PFOA Effects on Fetal Growth. *Environmental Health Perspectives*, *122*, 1028–1039. https://doi.org/10.1289/ehp.1307893

Kang, Q., Gao, F., Zhang, X., Wang, L., Liu, J., Fu, M., Shiyi Zhang, S., Wan, Y., Shen, H., & Hu, J. (2020). Nontargeted identification of per- and polyfluoroalkyl substances in human follicular fluid and their blood-follicle transfer. *Environment International, 139,* 105 – 686, https://doi.org/10.1016/j.envint.2020.105686

Kennedy, G. L., & Symons, J. M. (2015). Carcinogenicity of Perfluoroalkyl Compounds. In J. C. DeWitt (Ed.), *Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances* (pp. 265–304). Springer International Publishing Switzerland, 2015. https://doi.org/10.1007/978-3-319-15518-0_12

Kielsen, K., Shamim, Z., Ryder, L. P., Nielsen, F., Grandjean, P., Budtz-Jørgensen, E., & Heilmann, C. (2016). Antibody response to booster vaccination with tetanus and diphtheria in adults exposed to perfluorinated alkylates. *Journal of Immunotoxicology*, *13*, 270–273. https://doi.org/10.3109/1547691X.2015.1067259

Kim, M. J., Moon, S., Oh, B.-C., Jung, D., Ji, K., Choi, K., & Park, Y. J. (2018). Association between perfluoroalkyl substances exposure and thyroid function in adults: A meta-analysis. *PLOS ONE*, *13*, e0197244. https://doi.org/10.1371/journal.pone.0197244

Kingsley, S. L., Eliot, M. N., Kelsey, K. T., Calafat, A. M., Ehrlich, S., Lanphear, B. P., Chen, A., & Braun, J. M. (2018). Variability and predictors of serum perfluoroalkyl substance concentrations during pregnancy and early childhood. *Environmental Research*, *165*, 247–257. https://doi.org/10.1016/j.envres.2018.04.033

Klaunig, J. E., Babich, M. A., Baetcke, K. P., Cook, J. C., Corton, J. C., David, R. M., DeLuca, J. G., Lai, D. Y., McKee, R. H., Peters, J. M., Roberts, R. A., & Fenner-Crisp, P. A. (2003). PPARα Agonist-Induced Rodent Tumors: Modes of Action and Human Relevance. *Critical Reviews in Toxicology*, *33*, 655–780. https://doi.org/10.1080/713608372

Klaunig, J. E., Shinohara, M., Iwai, H., Chengelis, C. P., Kirkpatrick, J. B., Wang, Z., & Bruner, R. H. (2015). Evaluation of the Chronic Toxicity and Carcinogenicity of Perfluorohexanoic Acid (PFHxA) in Sprague-Dawley Rats. *Toxicologic Pathology*, *43*, 209–220. https://doi.org/10.1177/0192623314530532

Knepper, T., Fromel, T., Gremmel, C., van Driezum, I., Weil, H., Vestergren, R., & Cousins, I. (2014). Understanding exposure pathways of per- and polyfluoroalkyl substances (PFAS) via use of PFAS containing products—Risk estimation for man and environment. *Federal Ministry of the Environment,* edition 2014.

Knox, S. S., Jackson, T., Frisbee, S. J., Javins, B., & Ducatman, A. M. (2011). Perfluorocarbon exposure, gender and thyroid function in the C8 Health Project. *The Journal of Toxicological Sciences*, *36*, 403–410. https://doi.org/10.2131/jts.36.403

Knutsen, H. K., Alexander, J., Barregård, L., Bignami, M., Brüschweiler, B., Ceccatelli, S., Cottrill, B., Dinovi, M., Edler, L., Grasl-Kraupp, B., Hogstrand, C., Hoogenboom, L. (Ron), Nebbia, C. S., Oswald, I. P., Petersen, A., Rose, M., Roudot, A., Vleminckx, C., Vollmer, G., … Schwerdtle, T. (2018). Risk to human health related to the presence of perfluorooctane sulfonic acid and perfluorooctanoic acid in food. *EFSA Journal*, *16*, 284. https://doi.org/10.2903/j.efsa.2018.5194

Koskela, A., Koponen, J., Lehenkari, P., Viluksela, M., Korkalainen, M., & Tuukkanen, J. (2017). Perfluoroalkyl substances in human bone: concentrations in bones and effects on bone cell differentiation. *Scientific Reports*, *7*, 6841. https://doi.org/10.1038/s41598-017-07359-6

Koustas, E., Lam, J., Sutton, P., Johnson, P. I., Atchley, D. S., Sen, S., Robinson, K. A., Axelrad, D. A., & Woodruff, T. J. (2014). The Navigation Guide—Evidence-Based Medicine Meets Environmental Health: Systematic Review of Nonhuman Evidence for PFOA Effects on Fetal Growth. *Environmental Health Perspectives*, *122*, 1015–1027. https://doi.org/10.1289/ehp.1307177

Kowalczyk, J., Ehlers, S., Fürst, P., Schafft, H., & Lahrssen-Wiederholt, M. (2012). Transfer of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) From Contaminated Feed Into Milk and Meat of Sheep: Pilot Study. *Archives of Environmental Contamination and Toxicology*, *63*, 288–298. https://doi.org/10.1007/s00244-012-9759-2

Kowalczyk, J., Ehlers, S., Oberhausen, A., Tischer, M., Fürst, P., Schafft, H., & Lahrssen-Wiederholt, M. (2013). Absorption, Distribution, and Milk Secretion of the Perfluoroalkyl Acids PFBS, PFHxS, PFOS, and PFOA by Dairy Cows Fed Naturally Contaminated Feed. *Journal of Agricultural and Food Chemistry*, *61*, 2903–2912. https://doi.org/10.1021/jf304680j

Kristensen, S. L., Ramlau-Hansen, C. H., Ernst, E., Olsen, S. F., Bonde, J. P., Vested, A., Halldorsson, T. I., Becher, G., Haug, L. S., & Toft, G. (2013). Long-term effects of prenatal exposure to perfluoroalkyl substances on female reproduction. *Human Reproduction*, *28*, 3337–3348. https://doi.org/10.1093/humrep/det382

Kudo, N., Bandai, N., Suzuki, E., Katakura, M., & Kawashima, Y. (2000). Induction by perfluorinated fatty acids with different carbon chain length of peroxisomal beta-oxidation in the liver of rats. *Chemico-Biological Interactions*, *124*, 119–132. https://doi.org/10.1016/s0009-2797(99)00150-7

Kudo, N., Suzuki, E., Katakura, M., Ohmori, K., Noshiro, R., & Kawashima, Y. (2001). Comparison of the elimination between perfluorinated fatty acids with different carbon chain length in rats. *Chemico-Biological Interactions*, *134*, 203–216. https://doi.org/10.1016/s0009-2797(01)00155-7

Kvalem, H. E., Nygaard, U. C., Lødrup Carlsen, K. C., Carlsen, K. H., Haug, L. S., & Granum, B. (2020). Perfluoroalkyl substances, airways infections, allergy and asthma related health outcomes – implications of gender, exposure period and study design. *Environment International*, *134*, 105259. https://doi.org/10.1016/j.envint.2019.105259

Laitinen, J. A., Koponen, J., Koikkalainen, J., & Kiviranta, H. (2014). Firefighters' exposure to perfluoroalkyl acids and 2-butoxyethanol present in firefighting foams. *Toxicology Letters*, *231*, 227–232. https://doi.org/10.1016/j.toxlet.2014.09.007

Lakewood Water District. (2019). *Lakewood Wells and PFAS: Staff Talking Points (12/20/2019)*. https://www.lakewoodwater.org/sites/default/files/fileattachments/lakewood_water_district/page/4391/12-20-2019_fact_sheet_update.pdf

Lakewood Water District. (2019). *PFAS Topics*. https://www.lakewoodwater.org/lwd/page/pfas-topics

Lau, C., Thibodeaux, J. R., Hanson, R. G., Rogers, J. M., Grey, B. E., Stanton, M. E., Butenhoff, J. L., & Stevenson, L. A. (2003). Exposure to Perfluorooctane Sulfonate during Pregnancy in Rat and Mouse. II: Postnatal Evaluation. *Toxicological Sciences*, *74*, 382–392. https://doi.org/10.1093/toxsci/kfg122

Lau, C. (2015). Perfluorinated Compounds: An Overview. In J. C. DeWitt (Ed.), *Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances* (pp. 1–21). Humana Press. https://doi.org/10.1007/978-3-319-15518-0_1

Lau, C., Anitole, K., Hodes, C., Lai, D., Pfahles-Hutchens, A., & Seed, J. (2007). Perfluoroalkyl Acids: A Review of Monitoring and Toxicological Findings. *Toxicological Sciences*, *99*, 366–394. https://doi.org/10.1093/toxsci/kfm128

Lau, C., Thibodeaux, J. R., Hanson, R. G., Narotsky, M. G., Rogers, J. M., Lindstrom, A. B., & Strynar, M. J. (2006). Effects of Perfluorooctanoic Acid Exposure during Pregnancy in the Mouse. *Toxicological Sciences*, *90*, 510–518. https://doi.org/10.1093/toxsci/kfj105

Lechner, M., & Knapp, H. (2011). Carryover of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) from Soil to Plant and Distribution to the Different Plant Compartments Studied in Cultures of Carrots (Daucus carota ssp. Sativus), Potatoes (Solanum tuberosum), and Cucu. *Journal of Agricultural and Food Chemistry*, *59*, 11011–11018. https://doi.org/10.1021/jf201355y

Li, L., Li, X., Chen, X., Chen, Y., Liu, J., Chen, F., Ge, F., Ye, L., Lian, Q., & Ge, R.-S. (2018). Perfluorooctane sulfonate impairs rat Leydig cell development during puberty. *Chemosphere*, *190*, 43–53. https://doi.org/10.1016/j.chemosphere.2017.09.116

Li, Y., Cheng, Y., Xie, Z., & Zeng, F. (2017). Perfluorinated alkyl substances in serum of the southern Chinese general population and potential impact on thyroid hormones. *Scientific Reports*, *7*, 43380. https://doi.org/10.1038/srep43380

Li, Y., Barregard, L., Xu, Y., Scott, K., Pineda, D., Lindh, C. H., Jakobsson, K., & Fletcher, T. (2020). Associations between perfluoroalkyl substances and serum lipids in a Swedish adult population with contaminated drinking water. *Environmental Health*, *19*, 33. https://doi.org/10.1186/s12940-020-00588-9

Li, Y., Fletcher, T., Mucs, D., Scott, K., Lindh, C. H., Tallving, P., & Jakobsson, K. (2018). Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water. *Occupational and Environmental Medicine*, *75*, 46–51. https://doi.org/10.1136/oemed-2017-104651

Lieder, P. H., Chang, S.-C., York, R. G., & Butenhoff, J. L. (2009). Toxicological evaluation of potassium perfluorobutanesulfonate in a 90-day oral gavage study with Sprague–Dawley rats. *Toxicology*, *255*, 45–52. https://doi.org/10.1016/j.tox.2008.10.002

Lieder, P. H., York, R. G., Hakes, D. C., Chang, S.-C., & Butenhoff, J. L. (2009). A two-generation oral gavage reproduction study with potassium perfluorobutanesulfonate (K+PFBS) in Sprague Dawley rats. *Toxicology*, *259*, 33–45. https://doi.org/10.1016/j.tox.2009.01.027

Lin, C.-Y., Chen, P.-C., Lin, Y.-C., & Lin, L.-Y. (2009). Association Among Serum Perfluoroalkyl Chemicals, Glucose Homeostasis, and Metabolic Syndrome in Adolescents and Adults. *Diabetes Care*, *32*, 702–707. https://doi.org/10.2337/dc08-1816

Lin, C.-Y., Lin, L.-Y., Chiang, C.-K., Wang, W.-J., Su, Y.-N., Hung, K.-Y., & Chen, P.-C. (2010). Investigation of the Associations Between Low-Dose Serum Perfluorinated Chemicals and Liver Enzymes in US Adults. *American Journal of Gastroenterology*, *105*, 1354–1363. https://doi.org/10.1038/ajg.2009.707

Liu, G., Dhana, K., Furtado, J. D., Rood, J., Zong, G., Liang, L., Qi, L., Bray, G. A., DeJonge, L., Coull, B., Grandjean, P., & Sun, Q. (2018). Perfluoroalkyl substances and changes in body weight and resting metabolic rate in response to weight-loss diets: A prospective study. *PLOS Medicine*, *15*, e1002502. https://doi.org/10.1371/journal.pmed.1002502

Liu, Y., Qian, M., Ma, X., Zhu, L., & Martin, J. W. (2018). Nontarget Mass Spectrometry Reveals New Perfluoroalkyl Substances in Fish from the Yangtze River and Tangxun Lake, China. *Environmental Science & Technology*, *52*, 5830–5840. https://doi.org/10.1021/acs.est.8b00779

Liu, Z., Lu, Y., Song, X., Jones, K., Sweetman, A. J., Johnson, A. C., Zhang, M., Lu, X., & Su, C. (2019). Multiple crop bioaccumulation and human exposure of perfluoroalkyl substances around a mega fluorochemical industrial park, China: Implication for planting optimization and food safety. *Environment International*, *127*, 671–684. https://doi.org/10.1016/j.envint.2019.04.008

López-Doval, S., Salgado, R., Pereiro, N., Moyano, R., & Lafuente, A. (2014). Perfluorooctane sulfonate effects on the reproductive axis in adult male rats. *Environmental Research*, *134*, 158–168. https://doi.org/10.1016/j.envres.2014.07.006

Lopez-Espinosa, M.-J., Fletcher, T., Armstrong, B., Genser, B., Dhatariya, K., Mondal, D., Ducatman, A., & Leonardi, G. (2011). Association of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) with Age of Puberty among Children Living near a Chemical Plant. *Environmental Science & Technology*, *45*, 8160–8166. https://doi.org/10.1021/es1038694

Lopez-Espinosa, M.-J., Mondal, D., Armstrong, B. G., Eskenazi, B., & Fletcher, T. (2016). Perfluoroalkyl Substances, Sex Hormones, and Insulin-like Growth Factor-1 at 6–9 Years of Age: A Cross-Sectional Analysis within the C8 Health Project. *Environmental Health Perspectives*, *124*, 1269–1275. https://doi.org/10.1289/ehp.1509869

Lopez-Espinosa, M.-J., Mondal, D., Armstrong, B., Bloom, M. S., & Fletcher, T. (2012). Thyroid Function and Perfluoroalkyl Acids in Children Living Near a Chemical Plant. *Environmental Health Perspectives*, *120*, 1036–1041. https://doi.org/10.1289/ehp.1104370

Loukes, M. (2020). *Fairchild AFB Update, PFOA/PFOS provided to the Restoration Advisory Board January 23, 2020*.

Loveless, S. E., Hoban, D., Sykes, G., Frame, S. R., & Everds, N. E. (2008). Evaluation of the Immune System in Rats and Mice Administered Linear Ammonium Perfluorooctanoate. *Toxicological Sciences*, *105*, 86–96. https://doi.org/10.1093/toxsci/kfn113

Loveless, S. E., Slezak, B., Serex, T., Lewis, J., Mukerji, P., O'Connor, J. C., Donner, E. M., Frame, S. R., Korzeniowski, S. H., & Buck, R. C. (2009). Toxicological evaluation of sodium perfluorohexanoate. *Toxicology*, *264*, 32–44. https://doi.org/10.1016/j.tox.2009.07.011

Luebker, D. J., Case, M. T., York, R. G., Moore, J. A., Hansen, K. J., & Butenhoff, J. L. (2005). Two-generation reproduction and cross-foster studies of perfluorooctanesulfonate (PFOS) in rats. *Toxicology*, *215*, 126–148. https://doi.org/10.1016/j.tox.2005.07.018

Luebker, D. J., York, R. G., Hansen, K. J., Moore, J. A., & Butenhoff, J. L. (2005). Neonatal mortality from in utero exposure to perfluorooctanesulfonate (PFOS) in Sprague–Dawley rats: Dose–response, and biochemical and pharamacokinetic parameters. *Toxicology*, *215*, 149–169. https://doi.org/10.1016/j.tox.2005.07.019

Lupton, S. J., Huwe, J. K., Smith, D. J., Dearfield, K. L., & Johnston, J. J. (2014). Distribution and Excretion of Perfluorooctane Sulfonate (PFOS) in Beef Cattle (Bos taurus). *Journal of Agricultural and Food Chemistry*, *62*, 1167–1173. https://doi.org/10.1021/jf404355b

Lupton, S. J., Huwe, J. K., Smith, D. J., Dearfield, K. L., & Johnston, J. J. (2012). Absorption and Excretion of 14 C-Perfluorooctanoic Acid (PFOA) in Angus Cattle (Bos taurus). *Journal of Agricultural and Food Chemistry*, *60*, 1128–1134. https://doi.org/10.1021/jf2042505

Luz, A. L., Anderson, J. K., Goodrum, P., & Durda, J. (2019). Perfluorohexanoic acid toxicity, part I: Development of a chronic human health toxicity value for use in risk assessment. *Regulatory Toxicology and Pharmacology*, *103*, 41–55. https://doi.org/10.1016/j.yrtph.2019.01.019

Lv, Z., Li, G., Li, Y., Ying, C., Chen, J., Chen, T., Wei, J., Lin, Y., Jiang, Y., Wang, Y., Shu, B., Xu, B., & Xu, S. (2013). Glucose and lipid homeostasis in adult rat is impaired by early-life exposure to perfluorooctane sulfonate. *Environmental Toxicology*, *28*, 532–542. https://doi.org/10.1002/tox.20747

Lynn, A. (2017, March 2). 3 JBLM Wells Shut After Unacceptable Levels of Chemicals Found in Water. *The News Tribune*. https://www.thenewstribune.com/news/local/military/article136098683.html#:~:text=Joint Base Lewis-McChord has,officials announced the action Thursday.

Macon, M. B., Villanueva, L. R., Tatum-Gibbs, K., Zehr, R. D., Strynar, M. J., Stanko, J. P., White, S. S., Helfant, L., & Fenton, S. E. (2011). Prenatal Perfluorooctanoic Acid Exposure in CD-1 Mice: Low-Dose Developmental Effects and Internal Dosimetry. *Toxicological Sciences*, *122*, 134–145. https://doi.org/10.1093/toxsci/kfr076

Maine Department of Environmental Protection. (2017). *Stone Farm, Arundel. Sample Collection - Data Summary Report. June 15, 2017*. https://kkw.org/wp-content/uploads/2018/02/DEP-Phase-2-study.pdf

Maisonet, M., Terrell, M. L., McGeehin, M. A., Christensen, K. Y., Holmes, A., Calafat, A. M., & Marcus, M. (2012). Maternal Concentrations of Polyfluoroalkyl Compounds during Pregnancy and Fetal and Postnatal Growth in British Girls. *Environmental Health Perspectives*, *120*, 1432–1437. https://doi.org/10.1289/ehp.1003096

Makey, C. M., Webster, T. F., Martin, J. W., Shoeib, M., Harner, T., Dix-Cooper, L., & Webster, G. M. (2017). Airborne Precursors Predict Maternal Serum Perfluoroalkyl Acid Concentrations. *Environmental Science & Technology*, *51*, 7667–7675. https://doi.org/10.1021/acs.est.7b00615

Mamsen, L. S., Björvang, R. D., Mucs, D., Vinnars, M.-T., Papadogiannakis, N., Lindh, C. H., Andersen, C. Y., & Damdimopoulou, P. (2019). Concentrations of perfluoroalkyl substances (PFASs) in human embryonic and fetal organs from first, second, and third trimester pregnancies. *Environment International*, *124*, 482–492. https://doi.org/10.1016/j.envint.2019.01.010

Marks, K. J., Cutler, A. J., Jeddy, Z., Northstone, K., Kato, K., & Hartman, T. J. (2019). Maternal serum concentrations of perfluoroalkyl substances and birth size in British boys. *International Journal of Hygiene and Environmental Health*, *222*, 889–895. https://doi.org/10.1016/j.ijheh.2019.03.008

Mattsson, K., Rignell-Hydbom, A., Holmberg, S., Thelin, A., Jönsson, B. A., Lindh, C. H., Sehlstedt, A., & Rylander, L. (2015). Levels of perfluoroalkyl substances and risk of coronary heart disease: Findings from a population-based longitudinal study. *Environmental Research*, *142*, 148–154. https://doi.org/10.1016/j.envres.2015.06.033

Melzer, D., Rice, N., Depledge, M. H., Henley, W. E., & Galloway, T. S. (2010). Association between Serum Perfluorooctanoic Acid (PFOA) and Thyroid Disease in the U.S. National Health and Nutrition Examination Survey. *Environmental Health Perspectives*, *118*, 686–692. https://doi.org/10.1289/ehp.0901584

Meng, Q., Inoue, K., Ritz, B., Olsen, J., & Liew, Z. (2018). Prenatal Exposure to Perfluoroalkyl Substances and Birth Outcomes; An Updated Analysis from the Danish National Birth Cohort. *International Journal of Environmental Research and Public Health*, *15*, 1832. https://doi.org/10.3390/ijerph15091832

Mertens, J. J. W. M., Sved, D. W., Marit, G. B., Myers, N. R., Stetson, P. L., Murphy, S. R., Schmit, B., Shinohara, M., & Farr, C. H. (2010). Subchronic Toxicity of S-111-S-WB in Sprague Dawley Rats. *International Journal of Toxicology*, *29*, 358–371. https://doi.org/10.1177/1091581810370372

Miaz, L. T., Plassmann, M. M., Gyllenhammar, I., Bignert, A., Sandblom, O., Lignell, S., Glynn, A., & Benskin, J. P. (2020). Temporal trends of suspect- and target-per/polyfluoroalkyl substances (PFAS), extractable organic fluorine (EOF) and total fluorine (TF) in pooled serum from first-time mothers in Uppsala, Sweden, 1996–2017. *Environmental Science: Processes & Impacts*, *22*, 1071–1083. https://doi.org/10.1039/C9EM00502A

Michigan PFAS Action Response Team. (2018). *PFAS Response - Taking Action, Protecting Michigan - Wildlife*. Michigan Department of Environment, Great Lakes, and Energy; Michigan.Gov. https://www.michigan.gov/pfasresponse/0,9038,7-365-86512---,00.html

Michigan Science Advisory Workgroup. (2019). Health-based Drinking water Value Recommendations for PFAS in Michigan. *Michigan PFAS Action Response Team*. https://www.michigan.gov/documents/pfasresponse/Health-Based_Drinking_Water_Value_Recommendations_for_PFAS_in_Michigan_Report_659258_7.pdf

Minnesota Department of Health (MDH). (2017). *Health Based Guidance for Water. Toxicological Summary for perfluorobutane sulfate*. Health Risk Assessment Unit, Environmental Health Division. https://www.health.state.mn.us/communities/environment/risk/docs/guidance/gw/pfbssummary.pdf

Minnesota Department of Health (MDH). (2020). *PFAS Biomonitoring in the East Metro*. https://www.health.state.mn.us/communities/environment/biomonitoring/projects/pfas.html

Minnesota Department of Health (MDH). (2019). *Toxicological Summary for Perfluorohexane sulfonate* (E. H. D. Health Risk Assessment Unit (ed.); Issue April 2019). Minnesota Department of Health.

Minnesota Department of Health (MDH). (2017). *PFBA and Drinking Water*. Minnesota Department of Health. https://www.health.state.mn.us/communities/environment/risk/docs/guidance/gw/pfbainfo.pdf

Minnesota Department of Health (MDH). (2019). *History of perfluoroalkyl substances (PFAS) in Minnesota*. https://www.health.state.mn.us/communities/environment/hazardous/topics/history.html#2019

Mogensen, U. B., Grandjean, P., Heilmann, C., Nielsen, F., Weihe, P., & Budtz-Jørgensen, E. (2015). Structural equation modeling of immunotoxicity associated with exposure to perfluorinated alkylates. *Environmental Health*, *14*, 47. https://doi.org/10.1186/s12940-015-0032-9

Mondal, D., Lopez-Espinosa, M.-J., Armstrong, B., Stein, C. R., & Fletcher, T. (2012). Relationships of Perfluorooctanoate and Perfluorooctane Sulfonate Serum Concentrations between Mother–Child Pairs in a Population with Perfluorooctanoate Exposure from Drinking Water. *Environmental Health Perspectives*, *120*, 752–757. https://doi.org/10.1289/ehp.1104538

Mora, A. M., Fleisch, A. F., Rifas-Shiman, S. L., Woo Baidal, J. A., Pardo, L., Webster, T. F., Calafat, A. M., Ye, X., Oken, E., & Sagiv, S. K. (2018). Early life exposure to per- and polyfluoroalkyl substances and mid-childhood lipid and alanine aminotransferase levels. *Environment International*, *111*, 1–13. https://doi.org/10.1016/j.envint.2017.11.008

More, S. J., Bampidis, V., Benford, D., Bennekou, S. H., Bragard, C., Halldorsson, T. I., Hernández-Jerez, A. F., Koutsoumanis, K., Naegeli, H., Schlatter, J. R., Silano, V., Nielsen, S. S., Schrenk, D., Turck, D., Younes, M., Benfenati, E., Castle, L., Cedergreen, N., Hardy, A., … Hogstrand, C. (2019). Guidance on harmonised methodologies for human health, animal health and ecological risk assessment of combined exposure to multiple chemicals. *EFSA Journal*, *17*, 5634. https://doi.org/10.2903/j.efsa.2019.5634

Nakayama, S. F., Isobe, T., Iwai-Shimada, M., Kobayashi, Y., Nishihama, Y., Taniguchi, Y., Sekiyama, M., Michikawa, T., Yamazaki, S., Nitta, H., Oda, M., Mitsubuchi, H., Sanefuji, M., Ohga, S., Mise, N., Ikegami, A., Suga, R., & Shimono, M. (2020). Poly- and perfluoroalkyl substances in maternal serum: Method development and application in Pilot Study of the Japan Environment and Children's Study. *Journal of Chromatography A*, *1618*, 460933. https://doi.org/10.1016/j.chroma.2020.460933

National Center for Biotechnology Information. (2016). *PubChem Compound Summary for CID 67818, Perfluoroheptanoic acid*. NIH - US National Library of Medicine. https://pubchem.ncbi.nlm.nih.gov/compound/67818

National Industrial Chemicals Notification and Assessment Scheme (NICNAS). (2017). *Human Health Tier II Assessment for Short-Chain Perfluorocarboxylic Acids and their Direct Precursors*. Australian Government. https://www.nicnas.gov.au/chemical-information/imap-assessments/imap-assessments/tier-ii-environment-assessments/short-chain-perfluorocarboxylic-acids-and-their-direct-precursors

National Industrial Chemicals Notification and Assessment Scheme (NICNAS). (2015). *IMAP Tier II Human Health Assessment for Short Chain Perfluorocarboxylic acids and their Direct Precursors* (NICNAS (ed.)). https://www.industrialchemicals.gov.au/sites/default/files/Short-chain perfluorocarboxylic acids and their direct precursors_ Environment tier II assessment.pdf

National Toxiciology Program (NTP). (2016). *NTP Monograph on immunotoxicity associated with exposure to perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS)*. National Toxicology Program, U.S. Department of Health and Human Services. https://ntp.niehs.nih.gov/ntp/ohat/pfoa_pfos/pfoa_pfosmonograph_508.pdf

National Toxicology Program (NTP). (2019). *NTP Technical Report on the Toxicity Studies of Perfluoroalkyl Carboxylates (Perfluorohexanoic Acid, Perfluorooctanoic Acid, Perfluorononanoic Acid, and Perfluorodecanoic Acid) Administered by Gavage to Sprague Dawley Rats* (August 201). U.S. Department of Health and Human Services.

National Toxicology Program (NTP). (2020). NTP Technical Report on the Toxicology and Carcinogenesis Studies of Perfluorooctanoic Acid (CAS No. 335-67-1) Administered in Feed to Sprague Dawley Rats. Technical Report 598. Retrieved from https://ntp.niehs.nih.gov/ntp/htdocs/lt_rpts/tr598_508.pdf

National Toxicology Program (NTP). (2018). *28-Day Evaluation of the Toxicity (C06100) of Perfluorohexane sulfonate potassium salt (PFHSKslt) (3871-99-6) in Harlan Sprague-Dawley Rats Exposed via Gavage*. Chemical Effects in Biological Systems (CEBS). Research Triangle Park, NC (USA): National Toxicology Program (NTP). https://manticore.niehs.nih.gov/cebssearch/test_article/3871-99-6

National Toxicology Program (NTP). (2019). *NTP Technical Report on the Toxicity Studies of Perfluoroalkyl Sulfonates (Perfluorobutane Sulfonic Acid, Perfluorohexane Sulfonate Potassium Salt, and Perfluorooctane Sulfonic Acid) Administered by Gavage to Sprague Dawley Rats* (P. H. Service (ed.); August 201). U.S. Department of Health and Human Services.

National Toxicology Program (NTP). (2016). *Systematic Review of Immunotoxicity Associated with Exposure to Perfluorooctanoic acid (PFOA) or Perfluoroctane Sulfonate (PFOS)*. National Toxicology Program, U.S. Department of Health and Human Services. http://ntp.niehs.nih.gov/ntp/about_ntp/monopeerrvw/2016/july/draftsystematicreviewimmunotoxicityassociatedpfoa_pfos_508.pdf

Negri, E., Metruccio, F., Guercio, V., Tosti, L., Benfenati, E., Bonzi, R., La Vecchia, C., & Moretto, A. (2017). Exposure to PFOA and PFOS and fetal growth: a critical merging of toxicological and epidemiological data. *Critical Reviews in Toxicology*, *47*, 489–515. https://doi.org/10.1080/10408444.2016.1271972

Nelson, J. W., Hatch, E. E., & Webster, T. F. (2010). Exposure to Polyfluoroalkyl Chemicals and Cholesterol, Body Weight, and Insulin Resistance in the General U.S. Population. *Environmental Health Perspectives*, *118*, 197–202. https://doi.org/10.1289/ehp.0901165

Nelson, J. W., Scammell, M. K., Hatch, E. E., & Webster, T. F. (2012). Social disparities in exposures to bisphenol A and polyfluoroalkyl chemicals: a cross-sectional study within NHANES 2003-2006. *Environmental Health*, *11*, 10. https://doi.org/10.1186/1476-069X-11-10

New Hampshire Department of Environmental Services. (2019). *Technical Background Report for the June 2019 Proposed Maximum Contaminant Levels (MCLs) and Ambient Groundwater Quality Standards (AGQSs) for Perfluorooctane sulfonic Acid (PFOS), Perfluorooctanoic Acid (PFOA), Perfluorononanoic Acid (PFNA), and Perfluor*. https://www.des.nh.gov/organization/commissioner/pip/publications/documents/r-wd-19-29.pdf

New Hampshire Department of Health and Human Services. (2016). *PFAS PFC Blood Testing Program: April 2015-October 2015* . https://www.dhhs.nh.gov/dphs/pfcs/blood-testing.htm

New Jersey. (2017). *Maximum Contaminant Level Recommendation for Perfluorooctanoic Acid in Drinking Water - Basis and Background* (New Jersey Drinking Water Quality Institute (ed.)). New Jersey. http://www.nj.gov/dep/watersupply/pdf/pfoa-recommend.pdf

New Jersey Drinking Water Quality Institute (NJDWQI). (2015). *Health-based Maximum Contaminant Level Support Document: Perfluorononanoic acid (PFNA)*. New Jersey Drinking Water Quality Institute Health Effects Subcommittee. http://www.state.nj.us/dep/watersupply/pdf/he-response.pdf

New Jersey Drinking Water Quality Institute (NJDWQI). (2015). *Health-Based Maximum Contaminant Level Support Document: Perfluorononanoic Acid (PFNA): Vol. June 22,* (N. J. D. W. Q. I. H. E. Subcommittee (ed.)). https://www.nj.gov/dep/watersupply/pdf/pfna-health-effects.pdf

New Jersey Drinking Water Quality Institute (NJDWQI). (2018). *Health-Based Maximum Contaminant Level Support Document: PFOS*. https://www.state.nj.us/dep/watersupply/pdf/pfos-recommendation-appendix-a.pdf.

New Jersey Drinking Water Quality Institute (NJDWQI) Health Effects Subcommittee. (2016). *Public Review Draft - Health-Based Maximum Contaminant Level Support Document: Perfluorooctanoic Acid (PFOA)*. NJDWQI. http://www.nj.gov/dep/watersupply/pdf/pfoa-hb--mcl-public-review-draftwithappendices.pdf

New Jersey Drinking Water Quality Institute (NJDWQI) Health Effects Subcommittee. (2018). *Health-Based Maximun Contaminant Level Support Document: Perfluorooctane Sulfonate (PFOS)* (Issue June 5, 2018). New Jersey Drinking Water Quality Institute, Health Effects Subcommittee.

Ngo, H. T., Hetland, R. B., Sabaredzovic, A., Haug, L. S., & Steffensen, I.-L. (2014). In utero exposure to perfluorooctanoate (PFOA) or perfluorooctane sulfonate (PFOS) did not increase body weight or intestinal tumorigenesis in multiple intestinal neoplasia (Min/+) mice. *Environmental Research*, *132*, 251–263. https://doi.org/10.1016/j.envres.2014.03.033

Nian, M., Li, Q.-Q., Bloom, M., Qian, Z. (Min), Syberg, K. M., Vaughn, M. G., Wang, S.-Q., Wei, Q., Zeeshan, M., Gurram, N., Chu, C., Wang, J., Tian, Y.-P., Hu, L.-W., Liu, K.-K., Yang, B.-Y., Liu, R.-Q., Feng, D., Zeng, X.-W., & Dong, G.-H. (2019). Liver function biomarkers disorder is associated with exposure to perfluoroalkyl acids in adults: Isomers of C8 Health Project in China. *Environmental Research*, *172*, 81–88. https://doi.org/10.1016/j.envres.2019.02.013

Nian, M., Luo, K., Luo, F., Aimuzi, R., Huo, X., Chen, Q., Tian, Y., & Zhang, J. (2020). Association between Prenatal Exposure to PFAS and Fetal Sex Hormones: Are the Short-Chain PFAS Safer? *Environmental Science & Technology, 54*, 8291 − 8299. https://doi.org/10.1021/acs.est.0c02444

Nilsson, H., Kärrman, A., Rotander, A., van Bavel, B., Lindström, G., & Westberg, H. (2013). Biotransformation of fluorotelomer compound to perfluorocarboxylates in humans. *Environment International*, *51*, 8–12. https://doi.org/10.1016/j.envint.2012.09.001

Nilsson, H., Kärrman, A., Westberg, H., Rotander, A., van Bavel, B., & Lindström, G. (2010). A Time Trend Study of Significantly Elevated Perfluorocarboxylate Levels in Humans after Using Fluorinated Ski Wax. *Environmental Science & Technology*, *44*, 2150–2155. https://doi.org/10.1021/es9034733

Numata, J., Kowalczyk, J., Adolphs, J., Ehlers, S., Schafft, H., Fuerst, P., Müller-Graf, C., Lahrssen-Wiederholt, M., & Greiner, M. (2014). Toxicokinetics of Seven Perfluoroalkyl Sulfonic and Carboxylic Acids in Pigs Fed a Contaminated Diet. *Journal of Agricultural and Food Chemistry*, *62*, 6861–6870. https://doi.org/10.1021/jf405827u

Ohmori, K., Kudo, N., Katayama, K., & Kawashima, Y. (2003). Comparison of the toxicokinetics between perfluorocarboxylic acids with different carbon chain length. *Toxicology*, *184*, 135–140. https://doi.org/10.1016/S0300-483X(02)00573-5

Olsen, G. W. (2015). PFAS Biomonitoring in Higher Exposed Populations. In *Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances* (pp. 77–125). Springer International Publishing. https://doi.org/10.1007/978-3-319-15518-0_4

Olsen, G. W. (2015). PFAS Biomonitoring in Higher Exposed Populations - Chapter 4. In *Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances* (pp. 77–125). Springer International Publishing. https://doi.org/10.1007/978-3-319-15518-0_4

Olsen, G. W., Chang, S. C., Noker, P. E., Gorman, G. S., Ehresman, D. J., Lieder, P. H., & Butenhoff, J. L. (2009). A comparison of the pharmacokinetics of perfluorobutanesulfonate (PFBS) in rats, monkeys and humans. *Toxicology*, *256*, 65–74.

Olsen, G. W., Church, T. R., Larson, E. B., van Belle, G., Lundberg, J. K., Hansen, K. J., Burris, J. M., Mandel, J. H., & Zobel, L. R. (2004). Serum concentrations of perfluorooctanesulfonate and other fluorochemicals in an elderly population from Seattle, Washington. *Chemosphere*, *54*(11), 1599–1611. https://doi.org/10.1016/j.chemosphere.2003.09.025

Olsen, G. W., Mair, D. C., Lange, C. C., Harrington, L. M., Church, T. R., Goldberg, C. L., Herron, R. M., Hanna, H., Nobiletti, J. B., Rios, J. A., Reagen, W. K., & Ley, C. A. (2017). Per- and polyfluoroalkyl substances (PFAS) in American Red Cross adult blood donors, 2000–2015. *Environmental Research*, *157*, 87–95. https://doi.org/10.1016/j.envres.2017.05.013

Olsen, G. W., Burris, J. M., Burlew, M. M., & Mandel, J. H. (2003). Epidemiologic assessment of worker serum perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) concentrations and medical surveillance examinations. *Journal of Occupational and Environmental Medicine*, *45*, 260–270. https://doi.org/10.1097/01.jom.0000052958.59271.10

Olsen, G. W., Burris, J. M., Ehresman, D. J., Froehlich, J. W., Seacat, A. M., Butenhoff, J. L., & Zobel, L. R. (2007). Half-Life of Serum Elimination of Perfluorooctanesulfonate,Perfluorohexanesulfonate, and Perfluorooctanoate in Retired Fluorochemical Production Workers. *Environmental Health Perspectives*, *115*, 1298–1305. https://doi.org/10.1289/ehp.10009

Olsen, G. W., Burris, J. M., Ehresman, D. J., Froehlich, J. W., Seacat, A. M., Butenhoff, J. L., & Zobel, L. R. (2007). Half-Life of Serum Elimination of Perfluorooctanesulfonate,Perfluorohexanesulfonate, and Perfluorooctanoate in Retired Fluorochemical Production Workers. *Environmental Health Perspectives*, *115*, 1298–1305. https://doi.org/10.1289/ehp.10009

Olsen, G., Church, T., Hansen, K., Burris, J., Butenhoff, J., Mandel, J., & Zobel, L. (2004). Quantitative Evaluation of Perfluorooctanesulfonate (PFOS) and Other Fluorochemicals in the Serum of Children. *Journal of Children's Health*, *2*, 53–76. https://doi.org/10.1080/15417060490447378

Patlewicz, G., Richard, A. M., Williams, A. J., Grulke, C. M., Sams, R., Lambert, J., Noyes, P. D., DeVito, M. J., Hines, R. N., Strynar, M., Guiseppi-Elie, A., & Thomas, R. S. (2019). A Chemical Category-Based Prioritization Approach for Selecting 75 Per- and Polyfluoroalkyl Substances (PFAS) for Tiered Toxicity and Toxicokinetic Testing. *Environmental Health Perspectives*, *127*, 014501. https://doi.org/10.1289/EHP4555

Payne, J. (2018). *Fluorine-Free Aqueous Film Forming Foam* (N. Foam (ed.)). Strategic Environmental Research and Development Program (SERDP), Environmental Security Technology Certification Program (ESTCP). https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2738/WP-2738

Peaslee, G., Wilkinson, J., McGuinness, S., Tighe, M., Caterisano, N., Lee, S., Gonzales, A., Roddy, M., Mills, S., & Mitchell, K. (2020), Another pathway for firefighter exposure to per- and polyfluoroalkyl substances: Firefighter textiles. *Environmental Science & Technology Letters, 7,* 594 – 598. https://doi.org/10.1021/acs.estlett.0c00410

Peden-Adams, M. M., Keller, J. M., EuDaly, J. G., Berger, J., Gilkeson, G. S., & Keil, D. E. (2008). Suppression of Humoral Immunity in Mice following Exposure to Perfluorooctane Sulfonate. *Toxicological Sciences*, *104*, 144–154. https://doi.org/10.1093/toxsci/kfn059

Pérez, F., Nadal, M., Navarro-Ortega, A., Fàbrega, F., Domingo, J. L., Barceló, D., & Farré, M. (2013). Accumulation of perfluoroalkyl substances in human tissues. *Environment International*, *59*, 354–362. https://doi.org/10.1016/j.envint.2013.06.004

Perkins, R. G., Butenhoff, J. L., Kennedy, G. L., & Palazzolo, M. J. (2004). 13-Week Dietary Toxicity Study of Ammonium Perfluorooctanoate (APFO) in Male Rats. *Drug and Chemical Toxicology*, *27*, 361–378. https://doi.org/10.1081/DCT-200039773

Pitter, G., Da Re, F., Canova, C., Barbieri, G., Zare Jeddi, M., Daprà, F., Manea, F., Zolin, R., Bettega, A. M., Stopazzolo, G., Vittorii, S., Zambelli, L., Martuzzi, M., Mantoan, D., & Russo, F. (2020). Serum Levels of Perfluoroalkyl Substances (PFAS) in Adolescents and Young Adults Exposed to Contaminated Drinking Water in the Veneto Region, Italy: A Cross-Sectional Study Based on a Health Surveillance Program. *Environmental Health Perspectives*, *128*, 027007. https://doi.org/10.1289/EHP5337

Poothong, S., Papadopoulou, E., Padilla-Sánchez, J. A., Thomsen, C., & Haug, L. S. (2020). Multiple pathways of human exposure to poly- and perfluoroalkyl substances (PFASs): From external exposure to human blood. *Environment International*, *134*, 105244. https://doi.org/10.1016/j.envint.2019.105244

Post, G. B., Cohn, P. D., & Cooper, K. R. (2012). Perfluorooctanoic acid (PFOA), an emerging drinking water contaminant: A critical review of recent literature. *Environmental Research*, *116*, 93–117. https://doi.org/10.1016/j.envres.2012.03.007

Post, G. B., Louis, J. B., Lippincott, R. L., & Procopio, N. A. (2013). Occurrence of Perfluorinated Compounds in Raw Water from New Jersey Public Drinking Water Systems. *Environmental Science & Technology*, *47*, 13266–13275. https://doi.org/10.1021/es402884x

Preston, E. V, Webster, T. F., Oken, E., Claus Henn, B., McClean, M. D., Rifas-Shiman, S. L., Pearce, E. N., Braverman, L. E., Calafat, A. M., Ye, X., & Sagiv, S. K. (2018). Maternal Plasma per- and Polyfluoroalkyl Substance Concentrations in Early Pregnancy and Maternal and Neonatal Thyroid Function in a Prospective Birth Cohort: Project Viva (USA). *Environmental Health Perspectives*, *126*, 027013. https://doi.org/10.1289/EHP2534

Qiu, Z., Qu, K., Luan, F., Liu, Y., Zhu, Y., Yuan, Y., Li, H., Zhang, H., Hai, Y., & Zhao, C. (2020). Binding specificities of estrogen receptor with perfluorinated compounds: A cross species comparison. *Environment International*, *134*, 105284. https://doi.org/10.1016/j.envint.2019.105284

Rahman, M. L., Zhang, C., Smarr, M. M., Lee, S., Honda, M., Kannan, K., Tekola-Ayele, F., & Buck Louis, G. M. (2019). Persistent organic pollutants and gestational diabetes: A multi-center prospective cohort study of healthy US women. *Environment International*, *124*, 249–258. https://doi.org/10.1016/j.envint.2019.01.027

Raleigh, K. K., Alexander, B. H., Olsen, G. W., Ramachandran, G., Morey, S. Z., Church, T. R., Logan, P. W., Scott, L. L. F., & Allen, E. M. (2014). Mortality and cancer incidence in ammonium perfluorooctanoate production workers. *Occupational and Environmental Medicine*, *71*, 500–506. https://doi.org/10.1136/oemed-2014-102109

Ramhøj, L., Hass, U., Boberg, J., Scholze, M., Christiansen, S., Nielsen, F., & Axelstad, M. (2018). Perfluorohexane Sulfonate (PFHxS) and a Mixture of Endocrine Disrupters Reduce Thyroxine Levels and Cause Antiandrogenic Effects in Rats. *Toxicological Sciences*, *163*, 579–591. https://doi.org/10.1093/toxsci/kfy055

Rappazzo, K., Coffman, E., & Hines, E. (2017). Exposure to Perfluorinated Alkyl Substances and Health Outcomes in Children: A Systematic Review of the Epidemiologic Literature. *International Journal of Environmental Research and Public Health*, *14*, 691. https://doi.org/10.3390/ijerph14070691

Rebholz, S. L., Jones, T., Herrick, R. L., Xie, C., Calafat, A. M., Pinney, S. M., & Woollett, L. A. (2016). Hypercholesterolemia with consumption of PFOA-laced Western diets is dependent on strain and sex of mice. *Toxicology Reports*, *3*, 46–54. https://doi.org/10.1016/j.toxrep.2015.11.004

Rice, P. A., Aungst, J., Cooper, J., Bandele, O., & Kabadi, S. V. (2020). Comparative analysis of the toxicological databases for 6:2 fluorotelomer alcohol (6:2 FTOH) and perfluorohexanoic acid (PFHxA). *Food & Chemical Toxicology, 138*, 111 – 210. https://doi.org/10.1016/j.fct.2020.111210

Rogers, J. M., Ellis-Hutchings, R. G., Grey, B. E., Zucker, R. M., Norwood, J., Grace, C. E., Gordon, C. J., & Lau, C. (2014). Elevated Blood Pressure in Offspring of Rats Exposed to Diverse Chemicals During Pregnancy. *Toxicological Sciences*, *137*, 436–446. https://doi.org/10.1093/toxsci/kft248

Rosen Schmid, J.E., Zehr, D., Das, K., Ren, H., Abbot, B.D., Lau, C., Corton, C., M. B. (2010). Toxicogenomic profiling of perfluorononanoic acid in wild-type and PPAR alpha-null mice. *The Toxicologist*, *47*(114), 23. https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=216614

Roswall, N., Larsen, S. B., Sørensen, M., Tjønneland, A., & Raaschou-Nielsen, O. (2018). Perfluorooctanoate and Perfluorooctanesulfonate plasma concentrations and survival after prostate and bladder cancer in a population-based study. *Environmental Epidemiology*, *2*, e018. https://doi.org/10.1097/EE9.0000000000000018

Rotander, A., Kärrman, A., Toms, L.-M. L., Kay, M., Mueller, J. F., & Gómez Ramos, M. J. (2015). Novel Fluorinated Surfactants Tentatively Identified in Firefighters Using Liquid Chromatography Quadrupole Time-of-Flight Tandem Mass Spectrometry and a Case-Control Approach. *Environmental Science & Technology*, *49*, 2434–2442. https://doi.org/10.1021/es503653n

Rotander, A., Toms, L.-M. L., Aylward, L., Kay, M., & Mueller, J. F. (2015). Elevated levels of PFOS and PFHxS in firefighters exposed to aqueous film forming foam (AFFF). *Environment International*, *82*, 28–34. https://doi.org/10.1016/j.envint.2015.05.005

Russell, M. H., Himmelstein, M. W., & Buck, R. C. (2015). Inhalation and oral toxicokinetics of 6:2 FTOH and its metabolites in mammals. *Chemosphere*, *120*, 328–335. https://doi.org/10.1016/j.chemosphere.2014.07.092

Russell, M. H., Nilsson, H., & Buck, R. C. (2013). Elimination kinetics of perfluorohexanoic acid in humans and comparison with mouse, rat and monkey. *Chemosphere*, *93*(10), 2419–2425. https://doi.org/10.1016/j.chemosphere.2013.08.060

Sagiv, S. K., Rifas-Shiman, S. L., Fleisch, A. F., Webster, T. F., Calafat, A. M., Ye, X., Gillman, M. W., & Oken, E. (2018). Early-Pregnancy Plasma Concentrations of Perfluoroalkyl Substances and Birth Outcomes in Project Viva: Confounded by Pregnancy Hemodynamics? *American Journal of Epidemiology*, *187*, 793–802. https://doi.org/10.1093/aje/kwx332

Sagiv, S. K., Rifas-Shiman, S. L., Webster, T. F., Mora, A. M., Harris, M. H., Calafat, A. M., Ye, X., Gillman, M. W., & Oken, E. (2015). Sociodemographic and Perinatal Predictors of Early Pregnancy Per- and Polyfluoroalkyl Substance (PFAS) Concentrations. *Environmental Science & Technology*, *49*, 11849–11858. https://doi.org/10.1021/acs.est.5b02489

Sakr, C. J., Kreckmann, K. H., Green, J. W., Gillies, P. J., Reynolds, J. L., & Leonard, R. C. (2007). Cross-Sectional Study of Lipids and Liver Enzymes Related to a Serum Biomarker of Exposure (ammonium perfluorooctanoate or APFO) as Part of a General Health Survey in a Cohort of Occupationally Exposed Workers. *Journal of Occupational and Environmental Medicine*, *49*, 1086–1096. https://doi.org/10.1097/JOM.0b013e318156eca3

Salihovic, S., Stubleski, J., Kärrman, A., Larsson, A., Fall, T., Lind, L., & Lind, P. M. (2018). Changes in markers of liver function in relation to changes in perfluoroalkyl substances - A longitudinal study. *Environment International*, *117*, 196–203. https://doi.org/10.1016/j.envint.2018.04.052

Sammamish Plateau Water. (2016). *Perfluorooctanoic Acid (PFOA), Perfluorooctane Sulfonate (PFOS) Questions and Answers*. Sammamish Plateau Water System. https://spwater.org/DocumentCenter/View/593/PFOA-Questions-and-Answers-Revised-with-PFOS-5-4-16?bidId=

Sammamish Plateau Water. (2018). *PFCs in Drinking Water - Keeping your water safe from PFCs*. Retrieved from https://spwater.org/345/PFCs-in-Drinking-Water

Savitz, D. A., Stein, C. R., Bartell, S. M., Elston, B., Gong, J., Shin, H.-M., & Wellenius, G. A. (2012). Perfluorooctanoic Acid Exposure and Pregnancy Outcome in a Highly Exposed Community. *Epidemiology*, *23*, 386–392. https://doi.org/10.1097/EDE.0b013e31824cb93b

Savitz, D. A., Stein, C. R., Elston, B., Wellenius, G. A., Bartell, S. M., Shin, H.-M., Vieira, V. M., & Fletcher, T. (2012). Relationship of Perfluorooctanoic Acid Exposure to Pregnancy Outcome Based on Birth Records in the Mid-Ohio Valley. *Environmental Health Perspectives*, *120*, 1201–1207. https://doi.org/10.1289/ehp.1104752

Schecter, A., Colacino, J., Haffner, D., Patel, K., Opel, M., Päpke, O., & Birnbaum, L. (2010). Perfluorinated Compounds, Polychlorinated Biphenyls, and Organochlorine Pesticide Contamination in Composite Food Samples from Dallas, Texas, USA. *Environmental Health Perspectives*, *118*, 796–802. https://doi.org/10.1289/ehp.0901347

Schecter, A., Malik-Bass, N., Calafat, A. M., Kato, K., Colacino, J. A., Gent, T. L., Hynan, L. S., Harris, T. R., Malla, S., & Birnbaum, L. (2012). Polyfluoroalkyl Compounds in Texas Children from Birth through 12 Years of Age. *Environmental Health Perspectives*, *120*, 590–594. https://doi.org/10.1289/ehp.1104325

Scher, D. P., Kelly, J. E., Huset, C. A., Barry, K. M., Hoffbeck, R. W., Yingling, V. L., & Messing, R. B. (2018). Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. *Chemosphere*, *196*, 548–555. https://doi.org/10.1016/j.chemosphere.2017.12.179

Seacat, A. M. (2002). Subchronic Toxicity Studies on Perfluorooctanesulfonate Potassium Salt in Cynomolgus Monkeys. *Toxicological Sciences*, *68*, 249–264. https://doi.org/10.1093/toxsci/68.1.249

Seacat, A. M., Thomford, P. J., Hansen, K. J., Clemen, L. A., Eldridge, S. R., Elcombe, C. R., & Butenhoff, J. L. (2003). Sub-chronic dietary toxicity of potassium perfluorooctanesulfonate in rats. *Toxicology*, *183*, 117–131. https://doi.org/10.1016/S0300-483X(02)00511-5

Seo, S.-H., Son, M.-H., Choi, S.-D., Lee, D.-H., & Chang, Y.-S. (2018). Influence of exposure to perfluoroalkyl substances (PFASs) on the Korean general population: 10-year trend and health effects. *Environment International*, *113*, 149–161. https://doi.org/10.1016/j.envint.2018.01.025

Shankar, A., Xiao, J., & Ducatman, A. (2011). Perfluoroalkyl Chemicals and Chronic Kidney Disease in US Adults. *American Journal of Epidemiology*, *174*, 893–900. https://doi.org/10.1093/aje/kwr171

Shankar, A., Jie Xiao, & Alan Ducatman. (2011). Perfluoroalkyl chemicals and elevated serum uric acid in US adults. *Clinical Epidemiology*, *3*, 251. https://doi.org/10.2147/CLEP.S21677

Shankar, A., Xiao, J., & Ducatman, A. (2012). Perfluorooctanoic Acid and Cardiovascular Disease in US Adults. *Archives of Internal Medicine*, *172*, 1397. https://doi.org/10.1001/archinternmed.2012.3393

Shaw, S. D., Berger, M. L., Harris, J. H., Yun, S. H., Wu, Q., Liao, C., Blum, A., Stefani, A., & Kannan, K. (2013). Persistent organic pollutants including polychlorinated and polybrominated dibenzo-p-dioxins and dibenzofurans in firefighters from Northern California. *Chemosphere*, *91*, 1386–1394. https://doi.org/10.1016/j.chemosphere.2012.12.070

Shearer, J., Callahan, C., Calafat, A., Huang, W., Jones, R., Sabbisetti, V., Freedman, N., Sampson, J., Silverman, D., Purdue, M., & Hofmann, J. (2021). Serum Concentrations of Per- and Polyfluoroalkyl Substances and Risk of Renal Cell Carcinoma, *Journal of the National Cancer Institute*, *113,* 580 – 587, https://doi.org/10.1093/jnci/djaa143

Shi, G., Guo, H., Sheng, N., Cui, Q., Pan, Y., Wang, J., Guo, Y., & Dai, J. (2018). Two-generational reproductive toxicity assessment of 6:2 chlorinated polyfluorinated ether sulfonate (F-53B, a novel alternative to perfluorooctane sulfonate) in zebrafish. *Environmental pollution (Barking, Essex : 1987)*, *243*(Pt B), 1517–1527. https://doi.org/10.1016/j.envpol.2018.09.120

Shi, Z., Zhang, H., Liu, Y., Xu, M., & Dai, J. (2007). Alterations in Gene Expression and Testosterone Synthesis in the Testes of Male Rats Exposed to Perfluorododecanoic Acid. *Toxicological Sciences*, *98*, 206–215. https://doi.org/10.1093/toxsci/kfm070

Shin, H.-M., Vieira, V. M., Ryan, P. B., Detwiler, R., Sanders, B., Steenland, K., & Bartell, S. M. (2011). Environmental Fate and Transport Modeling for Perfluorooctanoic Acid Emitted from the Washington Works Facility in West Virginia. *Environmental Science & Technology*, *45*, 1435–1442. https://doi.org/10.1021/es102769t

Shoeib, M., Harner, T., M. Webster, G., & Lee, S. C. (2011). Indoor Sources of Poly- and Perfluorinated Compounds (PFCS) in Vancouver, Canada: Implications for Human Exposure. *Environmental Science & Technology*, *45*, 7999–8005. https://doi.org/10.1021/es103562v

Singh, S., & Singh, S. K. (2019). Prepubertal exposure to perfluorononanoic acid interferes with spermatogenesis and steroidogenesis in male mice. *Ecotoxicol Environ Saf*, *170*, 590–599. https://doi.org/10.1016/j.ecoenv.2018.12.034

Singh, S., & Singh, S. K. (2019). Chronic exposure to perfluorononanoic acid impairs spermatogenesis, steroidogenesis and fertility in male mice. *Journal of Applied Toxicology*, *39*, 420–431. https://doi.org/10.1002/jat.3733

Smit, L. A. M., Lenters, V., Høyer, B. B., Lindh, C. H., Pedersen, H. S., Liermontova, I., Jönsson, B. A. G., Piersma, A. H., Bonde, J. P., Toft, G., Vermeulen, R., & Heederik, D. (2015). Prenatal exposure to environmental chemical contaminants and asthma and eczema in school-age children. *Allergy*, *70*, 653–660. https://doi.org/10.1111/all.12605

Stahl, T., Heyn, J., Thiele, H., Hüther, J., Failing, K., Georgii, S., & Brunn, H. (2009). Carryover of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) from Soil to Plants. *Archives of Environmental Contamination and Toxicology*, *57*, 289–298. https://doi.org/10.1007/s00244-008-9272-9

Starling, A. P., Engel, S. M., Richardson, D. B., Baird, D. D., Haug, L. S., Stuebe, A. M., Klungsoyr, K., Harmon, Q., Becher, G., Thomsen, C., Sabaredzovic, A., Eggesbo, M., Hoppin, J. A., Travlos, G. S., Wilson, R. E., Trogstad, L. I., Magnus, P., & Longnecker, M. P. (2014). Perfluoroalkyl Substances During Pregnancy and Validated Preeclampsia Among Nulliparous Women in the Norwegian Mother and Child Cohort Study. *American Journal of Epidemiology*, *179*, 824–833. https://doi.org/10.1093/aje/kwt432

Starling, A. P., Engel, S. M., Whitworth, K. W., Richardson, D. B., Stuebe, A. M., Daniels, J. L., Haug, L. S., Eggesbø, M., Becher, G., Sabaredzovic, A., Thomsen, C., Wilson, R. E., Travlos, G. S., Hoppin, J. A., Baird, D. D., & Longnecker, M. P. (2014). Perfluoroalkyl substances and lipid concentrations in plasma during pregnancy among women in the Norwegian Mother and Child Cohort Study. *Environment International*, *62*, 104–112. https://doi.org/10.1016/j.envint.2013.10.004

State of California. (2017). *Biomonitoring California - Project Results for Measuring Analytes in Maternal Archived Samples (MAMAS)*. Biomonitoring California. http://biomonitoring.ca.gov/results/projects/2157

State of California. (2017). *Perfluorochemicals (PFCs) - Biomonitoring California Information*. Biomonitoring California. https://biomonitoring.ca.gov/chemicals/perfluorochemicals-pfcs

State of California. (2016). *Project Results for Firefighter Occupational Exposures (FOX) Project*. Biomonitoring California. Retrieved from https://biomonitoring.ca.gov/results/projects/410

Steenland, K., Fletcher, T., Stein, C., Bartell, S., Darrow, L., Lopez-Espinosa, M., Ryan, P., & Savitz, D. (2020). Review: Evolution of evidence on PFOA and health following the assessments of the C8 Science Panel, *Environment International*, *145*, 106 – 125. https://doi.org/10.1016/j.envint.2020.106125

Steenland, K., Tinker, S., Frisbee, S., Ducatman, A., & Vaccarino, V. (2009). Association of Perfluorooctanoic Acid and Perfluorooctane Sulfonate With Serum Lipids Among Adults Living Near a Chemical Plant. *American Journal of Epidemiology*, *170*, 1268–1278. https://doi.org/10.1093/aje/kwp279

Steenland, K., & Woskie, S. (2012). Cohort Mortality Study of Workers Exposed to Perfluorooctanoic Acid. *American Journal of Epidemiology*, *176*, 909–917. https://doi.org/10.1093/aje/kws171

Steenland, K., Barry, V., & Savitz, D. (2018). Serum Perfluorooctanoic Acid and Birthweight. *Epidemiology*, *29*, 765–776. https://doi.org/10.1097/EDE.0000000000000903

Steenland, K., Jin, C., MacNeil, J., Lally, C., Ducatman, A., Vieira, V., & Fletcher, T. (2009). Predictors of PFOA Levels in a Community Surrounding a Chemical Plant. *Environmental Health Perspectives*, *117*, 1083–1088. https://doi.org/10.1289/ehp.0800294

Steenland, K., Kugathasan, S., & Barr, D. B. (2018). PFOA and ulcerative colitis. *Environmental Research*, *165*, 317–321. https://doi.org/10.1016/j.envres.2018.05.007

Steenland, K., Tinker, S., Shankar, A., & Ducatman, A. (2010). Association of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) with Uric Acid among Adults with Elevated Community Exposure to PFOA. *Environmental Health Perspectives*, *118*, 229–233. https://doi.org/10.1289/ehp.0900940

Steenland, K., Zhao, L., & Winquist, A. (2015). A cohort incidence study of workers exposed to perfluorooctanoic acid (PFOA). *Occupational and Environmental Medicine*, *72*, 373–380. https://doi.org/10.1136/oemed-2014-102364

Steenland, K., Zhao, L., Winquist, A., & Parks, C. (2013). Ulcerative Colitis and Perfluorooctanoic Acid (PFOA) in a Highly Exposed Population of Community Residents and Workers in the Mid-Ohio Valley. *Environmental Health Perspectives*, *121*, 900–905. https://doi.org/10.1289/ehp.1206449

Stein, C. R., Savitz, D. A., & Dougan, M. (2009). Serum Levels of Perfluorooctanoic Acid and Perfluorooctane Sulfonate and Pregnancy Outcome. *American Journal of Epidemiology*, *170*, 837–846. https://doi.org/10.1093/aje/kwp212

Stein, C. R., McGovern, K. J., Pajak, A. M., Maglione, P. J., & Wolff, M. S. (2016). Perfluoroalkyl and polyfluoroalkyl substances and indicators of immune function in children aged 12–19 y: National Health and Nutrition Examination Survey. *Pediatric Research*, *79*, 348–357. https://doi.org/10.1038/pr.2015.213

Stein, C. R., & Savitz, D. A. (2011). Serum Perfluorinated Compound Concentration and Attention Deficit/Hyperactivity Disorder in Children 5–18 Years of Age. *Environmental Health Perspectives*, *119*, 1466–1471. https://doi.org/10.1289/ehp.1003538

Strynar, M. J., & Lindstrom, A. B. (2008). Perfluorinated Compounds in House Dust from Ohio and North Carolina, USA. *Environmental Science & Technology*, *42*, 3751–3756. https://doi.org/10.1021/es7032058

Stump, D. G., Holson, J. F., Murphy, S. R., Farr, C. H., Schmit, B., & Shinohara, M. (2008). An oral two-generation reproductive toxicity study of S-111-S-WB in rats. *Reproductive Toxicology*, *25*, 7–20. https://doi.org/10.1016/j.reprotox.2007.10.002

Susmann, H. P., Schaider, L. A., Rodgers, K. M., & Rudel, R. A. (2019). Dietary Habits Related to Food Packaging and Population Exposure to PFASs. *Environmental Health Perspectives*, *127*, 107003. https://doi.org/10.1289/EHP4092

Tacoma Public Utilities. (2018). *Testing for PFAS and Keeping Tacoma's Drinking Water Safe*. TPU. https://www.mytpu.org/tacomawater/testing-pfas-keeping.htm

Tanner, E. M., Bloom, M. S., Wu, Q., Kannan, K., Yucel, R. M., Shrestha, S., & Fitzgerald, E. F. (2018). Occupational exposure to perfluoroalkyl substances and serum levels of perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) in an aging population from upstate New York: a retrospective cohort study. *International Archives of Occupational and Environmental Health*, *91*, 145–154. https://doi.org/10.1007/s00420-017-1267-2

Tao, L., Kannan, K., Aldous, K. M., Mauer, M. P., & Eadon, G. A. (2008). Biomonitoring of Perfluorochemicals in Plasma of New York State Personnel Responding to the World Trade Center Disaster. *Environmental Science & Technology*, *42*, 3472–3478. https://doi.org/10.1021/es8000079

Taylor, K. W., Hoffman, K., Thayer, K. A., & Daniels, J. L. (2014). Polyfluoroalkyl Chemicals and Menopause among Women 20–65 Years of Age (NHANES). *Environmental Health Perspectives*, *122*, 145–150. https://doi.org/10.1289/ehp.1306707

Temkin, A. M., Hocevar, B. A., Andrews, D. Q., Naidenko, O. V, & Kamendulis, L. M. (2020). Application of the Key Characteristics of Carcinogens to Per and Polyfluoroalkyl Substances. *International Journal of Environmental Research and Public Health*, *17*, 1668. https://doi.org/10.3390/ijerph17051668

The Danish Environmental Protection Agency (DEPA). (2018). *Risk assessment of fluorinated substances in cosmetic products*. Ministry of Environment and Food Denmark Environmental Protection Agency. https://www2.mst.dk/Udgiv/publications/2018/10/978-87-93710-94-8.pdf

The Danish Environmental Protection Agency (DEPA). (2016). *Survey and risk assessment of chemical substances in rugs for children - Survey of chemical substances in consumer products*. Ministry of Environment and Food of Denmark Environmental Protection Agency. https://www2.mst.dk/Udgiv/publications/2016/08/978-87-93435-98-8.pdf

The Danish Environmental Protection Agency (DEPA). (2015). *Polyfluoroalkyl substances (PFASs) in textiles for children – Survey of chemical substances in consumer products.* Ministry of Environment and Food, The Danish Environmental Protection Agency. https://www2.mst.dk/Udgiv/publications/2015/04/978-87-93352-12-4.pdf

Thibodeaux, J. R., Hanson, R. G., Rogers, J. M., Grey, B. E., Barbee, B. D., Richards, J. H., Butenhoff, J. L., Stevenson, L. A., & Lau, C. (2003). Exposure to Perfluorooctane Sulfonate during Pregnancy in Rat and Mouse. I: Maternal and Prenatal Evaluations. *Toxicological Sciences*, *74*, 369–381. https://doi.org/10.1093/toxsci/kfg121

Thomford, P. J. (2002). *104-Week Dietary Chronic Toxicity and Carcinogenicity Study with Perfluorooctane Sulfonic Acid Potassium Salt (PFOS; T-6295) in Rats. Final Reportt, 3M T-6295 (Covance Study No. 6329-183): Vols. I–IX*. 3M.

Tittlemier, S. A., Pepper, K., Seymour, C., Moisey, J., Bronson, R., Cao, X.-L., & Dabeka, R. W. (2007). Dietary Exposure of Canadians to Perfluorinated Carboxylates and Perfluorooctane Sulfonate via Consumption of Meat, Fish, Fast Foods, and Food Items Prepared in Their Packaging. *Journal of Agricultural and Food Chemistry*, *55*, 3203–3210. https://doi.org/10.1021/jf0634045

Trowbridge, J., Gerona, R. R., Lin, T., Rudel, R. A., Bessonneau, V., Buren, H., & Morello-Frosch, R. (2020). Exposure to Perfluoroalkyl Substances in a Cohort of Women Firefighters and Office Workers in San Francisco. *Environmental Science & Technology*, *54*, 3363–3374. https://doi.org/10.1021/acs.est.9b05490

Tsang, J. (2018). *Novel Fluorine-Free Replacement For Aqueous Film Forming Foam* (Naval Air Warfare Center Weapons Division (ed.)). Strategic Environmental Research and Development Program (SERDP), Environmental Security Technology Certification Program (ESTCP). Retrieved from https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Waste-Reduction-and-Treatment-in-DoD-Operations/WP-2737

Tuchscherer, A. (2021). Email from from Andy Tuchscherer, Sammamish Plateau Water, to Steve Hulsman, Department of Health. Sample results for all wells with charts. May 21, 2021.

U.S. Census Bureau. (2018). *U.S. Census 5 year ACS*. https://data.census.gov/cedsci/table?q=B03002&g=0400000US53&tid=ACSDT5Y2018.B03002

U.S. Environmental Protection Agency (EPA). (2009). *Provisional Health Advisories for Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS)*. Environmental Protection Agency. https://www.epa.gov/sites/production/files/2015-09/documents/pfoa-pfos-provisional.pdf

U.S. Environmental Protection Agency (EPA). (2016a). *Drinking Water Health Advisories for PFOA and PFOS - Health Advisories*. U.S. Environmental Protection Agency. https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos

U.S. Environmental Protection Agency (EPA). (2016b). *Health Effects Support Document for Perfluorooctane Sulfonate (PFOS)*. Environmental Protection Agency. https://www.epa.gov/sites/production/files/2016-05/documents/pfos_hesd_final_508.pdf

U.S. Environmental Protection Agency (EPA). (2016c). *Health Effects Support Document for Perfluorooctanoic Acid (PFOA)* (pp. 1 – 322). U.S. Environmental Protection Agency. https://www.epa.gov/sites/production/files/2016-05/documents/pfoa_hesd_final-plain.pdf

U.S. Environmental Protection Agency (EPA). (2016d). *Drinking Water Health Advisory of Perfluoroctane Sulfonate (PFOS)*. Environmental Protection Agency. https://www.epa.gov/sites/production/files/2016-05/documents/pfos_health_advisory_final_508.pdf

U.S. Environmental Protection Agency (EPA). (2016e). *Drinking Water Health Advisory for Perfluorooctanoic Acid (PFOA)* (p. 103). Environmental Protection Agency. https://www.epa.gov/sites/production/files/2016-05/documents/pfoa_health_advisory_final-plain.pdf

U.S. Environmental Protection Agency (EPA). (2018). *Technical Fact Sheet: Draft Toxicity Assessments for GenX Chemicals and PFBS*. U.S. Environmental Protection Agency. https://www.epa.gov/sites/production/files/2018-12/documents/tech_fact_sheet_genx_pfbs_draft_tox_assess_final_508.pdf

U.S. Environmental Protection Agency (EPA). (2021). Human Health Toxicity Values for Perfluorobutane Sulfonic Acid (CASRN 375-73-5) and Related Compound Potassium Perfluorobutane Sulfonate (CASRN 29420-49-3). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-20/345F, 2021. Retrieved from https://ofmpub.epa.gov/eims/imageupdown.download?p_image_id=262

U.S. Food and Drug Administration (FDA). (2020). Authorized Uses of PFAS in Food Contact Applications. Per and Polyfluoroalkyl Substances. Market Phase-Out of Certain Short-Chain PFAS. Retrieved from https://www.fda.gov/food/chemical-contaminants-food/authorized-uses-pfas-food-contact-applications

University of Washington. (2019). Deparmtent of Environmental & Occupational Health Sciences. Washington environmental health disparities map comparing environmental health risk factors across communities. Retrieved from https://deohs.washington.edu/sites/default/files/images/Washington_Environmental_Health_Disparities_Map.pdf

van der Veen, I., Hanning, A-C., Stare, A., Leonards, P. E.G., de Boer, J., & Weiss, J.M. (2020). The effect of weathering on per- and polufluoroalkyl substances (PFASs) from durable water repellent (DWR) clothing. *Chemosphere, 249.* https://doi.org/10.1016/j.chemosphere.2020.126100

Velez, M. P., Arbuckle, T. E., & Fraser, W. D. (2015). Maternal exposure to perfluorinated chemicals and reduced fecundity: the MIREC study. *Human Reproduction*, *30*, 701–709. https://doi.org/10.1093/humrep/deu350

Verner, M.-A., Loccisano, A. E., Morken, N.-H., Yoon, M., Wu, H., McDougall, R., Maisonet, M., Marcus, M., Kishi, R., Miyashita, C., Chen, M.-H., Hsieh, W.-S., Andersen, M. E., Clewell, H. J., & Longnecker, M. P. (2015). Associations of Perfluoroalkyl Substances (PFAS) with Lower Birth Weight: An Evaluation of Potential Confounding by Glomerular Filtration Rate Using a Physiologically Based Pharmacokinetic Model (PBPK). *Environmental Health Perspectives*, *123*, 1317–1324. https://doi.org/10.1289/ehp.1408837

Vested, A., Ramlau-Hansen, C. H., Olsen, S. F., Bonde, J. P., Kristensen, S. L., Halldorsson, T. I., Becher, G., Haug, L. S., Ernst, E. H., & Toft, G. (2013). Associations of in Utero Exposure to Perfluorinated Alkyl Acids with Human Semen Quality and Reproductive Hormones in Adult Men. *Environmental Health Perspectives*, *121*, 453–458. https://doi.org/10.1289/ehp.1205118

Viberg, H., Lee, I., & Eriksson, P. (2013). Adult dose-dependent behavioral and cognitive disturbances after a single neonatal PFHxS dose. *Toxicology*, *304*, 185–191. https://doi.org/10.1016/j.tox.2012.12.013

Vieira, V. M., Hoffman, K., Shin, H.-M., Weinberg, J. M., Webster, T. F., & Fletcher, T. (2013). Perfluorooctanoic Acid Exposure and Cancer Outcomes in a Contaminated Community: A Geographic Analysis. *Environmental Health Perspectives*, *121*, 318–323. https://doi.org/10.1289/ehp.1205829

Wan, H. T., Zhao, Y. G., Wong, M. H., Lee, K. F., Yeung, W. S. B., Giesy, J. P., & Wong, C. K. C. (2011). Testicular Signaling Is the Potential Target of Perfluorooctanesulfonate-Mediated Subfertility in Male Mice1. *Biology of Reproduction*, *84*, 1016–1023. https://doi.org/10.1095/biolreprod.110.089219

Wan, H. T., Zhao, Y. G., Leung, P. Y., & Wong, C. K. C. (2014). Perinatal Exposure to Perfluorooctane Sulfonate Affects Glucose Metabolism in Adult Offspring. *PLoS ONE*, *9*, e87137. https://doi.org/10.1371/journal.pone.0087137

Wang, J., Yan, S., Zhang, W., Zhang, H., & Dai, J. (2015). Integrated Proteomic and miRNA Transcriptional Analysis Reveals the Hepatotoxicity Mechanism of PFNA Exposure in Mice. *Journal of Proteome Research*, *14*, 330–341. https://doi.org/10.1021/pr500641b

Wang, Y., Adgent, M., Su, P.-H., Chen, H.-Y., Chen, P.-C., Hsiung, C. A., & Wang, S.-L. (2016). Prenatal Exposure to Perfluorocarboxylic Acids (PFCAs) and Fetal and Postnatal Growth in the Taiwan Maternal and Infant Cohort Study. *Environmental Health Perspectives*, *124*, 1794–1800. https://doi.org/10.1289/ehp.1509998

Wang, Y., Liu, W., Zhang, Q., Zhao, H., & Quan, X. (2015). Effects of developmental perfluorooctane sulfonate exposure on spatial learning and memory ability of rats and mechanism associated with synaptic plasticity. *Food and Chemical Toxicology*, *76*, 70–76. https://doi.org/10.1016/j.fct.2014.12.008

Washington Department of Health (DOH). (2021). *Recommended State Action Levels for Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water: Approach, Methods and Supporting Information, August 2021.* WDOH Office of Environmental Public Health Sciences. https://www.doh.wa.gov/Portals/1/Documents/Pubs/331-673.pdf

Washington State Legislature. (2021). Engrossed Second Substitute Senate Bill 5141, Chapter 314, Laws of 2021, 67th Legislature 2021 Regular Session. Environmental Justice – Various Provisions. Effective date: July 25, 2021. Retrieved from http://lawfilesext.leg.wa.gov/biennium/2021-22/Pdf/Bills/Session%20Laws/Senate/5141-S2.SL.pdf?q=20210702115844

Webster, G. M., Rauch, S. A., Marie, N. S., Mattman, A., Lanphear, B. P., & Venners, S. A. (2016). Cross-Sectional Associations of Serum Perfluoroalkyl Acids and Thyroid Hormones in U.S. Adults: Variation According to TPOAb and Iodine Status (NHANES 2007–2008). *Environmental Health Perspectives*, *124*, 935–942. https://doi.org/10.1289/ehp.1409589

Webster, G. M., Venners, S. A., Mattman, A., & Martin, J. W. (2014). Associations between Perfluoroalkyl acids (PFASs) and maternal thyroid hormones in early pregnancy: A population-based cohort study. *Environmental Research*, *133*, 338–347. https://doi.org/10.1016/j.envres.2014.06.012

Wen, L.-L., Lin, L.-Y., Su, T.-C., Chen, P.-C., & Lin, C.-Y. (2013). Association Between Serum Perfluorinated Chemicals and Thyroid Function in U.S. Adults: The National Health and Nutrition Examination Survey 2007–2010. *The Journal of Clinical Endocrinology & Metabolism*, *98*, E1456–E1464. https://doi.org/10.1210/jc.2013-1282

White, S. S., Kato, K., Jia, L. T., Basden, B. J., Calafat, A. M., Hines, E. P., Stanko, J. P., Wolf, C. J., Abbott, B. D., & Fenton, S. E. (2009). Effects of perfluorooctanoic acid on mouse mammary gland development and differentiation resulting from cross-foster and restricted gestational exposures. *Reproductive Toxicology*, *27*, 289–298. https://doi.org/10.1016/j.reprotox.2008.11.054

White, S. S., Stanko, J. P., Kato, K., Calafat, A. M., Hines, E. P., & Fenton, S. E. (2011). Gestational and Chronic Low-Dose PFOA Exposures and Mammary Gland Growth and Differentiation in Three Generations of CD-1 Mice. *Environmental Health Perspectives*, *119*, 1070–1076. https://doi.org/10.1289/ehp.1002741

Whitworth, K. W., Haug, L. S., Baird, D. D., Becher, G., Hoppin, J. A., Skjaerven, R., Thomsen, C., Eggesbo, M., Travlos, G., Wilson, R., & Longnecker, M. P. (2012). Perfluorinated Compounds and Subfecundity in Pregnant Women. *Epidemiology*, *23*, 257–263. https://doi.org/10.1097/EDE.0b013e31823b5031

Wikström, S., Lin, P.-I., Lindh, C. H., Shu, H., & Bornehag, C.-G. (2020). Maternal serum levels of perfluoroalkyl substances in early pregnancy and offspring birth weight. *Pediatric Research*, *87*, 1093–1099. https://doi.org/10.1038/s41390-019-0720-1

Winquist, A., Lally, C., Shin, H.-M., & Steenland, K. (2013). Design, Methods, and Population for a Study of PFOA Health Effects among Highly Exposed Mid-Ohio Valley Community Residents and Workers. *Environmental Health Perspectives*, *121*, 893–899. https://doi.org/10.1289/ehp.1206450

Winquist, A., & Steenland, K. (2014). Perfluorooctanoic Acid Exposure and Thyroid Disease in Community and Worker Cohorts. *Epidemiology*, *25*, 255–264. https://doi.org/10.1097/EDE.0000000000000040

Wolf, C. J., Fenton, S. E., Schmid, J. E., Calafat, A. M., Kuklenyik, Z., Bryant, X. A., Thibodeaux, J., Das, K. P., White, S. S., Lau, C. S., & Abbott, B. D. (2006). Developmental Toxicity of Perfluorooctanoic Acid in the CD-1 Mouse after Cross-Foster and Restricted Gestational Exposures. *Toxicological Sciences*, *95*, 462–473. https://doi.org/10.1093/toxsci/kfl159

Wolf, C. J., Zehr, R. D., Schmid, J. E., Lau, C., & Abbott, B. D. (2010). Developmental Effects of Perfluorononanoic Acid in the Mouse Are Dependent on Peroxisome Proliferator-Activated Receptor-Alpha. *PPAR Research*, *2010*, 1–11. https://doi.org/10.1155/2010/282896

Wu, X. (May), Bennett, D. H., Calafat, A. M., Kato, K., Strynar, M., Andersen, E., Moran, R. E., Tancredi, D. J., Tulve, N. S., & Hertz-Picciotto, I. (2015). Serum concentrations of perfluorinated compounds (PFC) among selected populations of children and Adults in California. *Environmental Research*, *136*, 264–273. https://doi.org/10.1016/j.envres.2014.09.026

Xie, S., Wang, T., Liu, S., Jones, K. C., Sweetman, A. J., & Lu, Y. (2013). Industrial source identification and emission estimation of perfluorooctane sulfonate in China. *Environment International*, *52*, 1–8. https://doi.org/10.1016/j.envint.2012.11.004

Xing, J., Wang, G., Zhao, J., Wang, E., Yin, B., Fang, D., Zhao, J., Zhang, H., Chen, Y. Q., & Chen, W. (2016). Toxicity assessment of perfluorooctane sulfonate using acute and subchronic male C57BL/6J mouse models. *Environmental Pollution*, *210*, 388–396. https://doi.org/10.1016/j.envpol.2015.12.008

Xu, Y., Fletcher, T., Pineda, D., Lindh, C., Nilsson, C., Glynn, A., Vogs, C., Norström, K., Lilja, K., Jakobsson, K., & Li, Y. (2020). Serum Half-Lives for Short- and Long-Chain Perfluoroalkyl Acids after Ceasing Exposure from Drinking Water Contaminated by Firefighting Foam. *Environmental Health Perspectives*, *128*, 770 – 774. https://doi.org/10.1289/EHP6785

Xu, Y., Li, Y., Scott, K., Lindh, C., Jakobsson, K., Fletcher, T., Ohlsson, B., & Andersson, E. (2019). Ulcerative colitis, Crohn's disease and other inflammatory bowel disease in a population with high exposure to per- and polyfluoroalkyl substances through drinking water. *Environmental Epidemiology*, *3*, 449. https://doi.org/10.1097/01.EE9.0000611064.79086.2f

Yamaguchi, M., Arisawa, K., Uemura, H., Katsuura-Kamano, S., Takami, H., Sawachika, F., Nakamoto, M., Juta, T., Toda, E., Mori, K., Hasegawa, M., Tanto, M., Shima, M., Sumiyoshi, Y., Morinaga, K., Kodama, K., Suzuki, T., Nagai, M., & Satoh, H. (2013). Consumption of seafood, serum liver enzymes, and blood levels of PFOS and PFOA in the Japanese population. *Journal of Occupational Health*, *55*, 184–194. https://doi.org/10.1539/joh.12-0264-oa

Yang, Q., Xie, Y., & Depierre, J. W. (2000). Effects of peroxisome proliferators on the thymus and spleen of mice. *Clinical and Experimental Immunology*, *122*, 219–226. https://doi.org/10.1046/j.1365-2249.2000.01367.x

Yang, Q., Xie, Y., Eriksson, A. M., Nelson, B. D., & DePierre, J. W. (2001). Further evidence for the involvement of inhibition of cell proliferation and development in thymic and splenic atrophy induced by the peroxisome proliferator perfluoroctanoic acid in mice33Abbreviations: PFOA, perfluorooctanoic acid; PP, peroxisome prolif. *Biochemical Pharmacology*, *62*, 1133–1140. https://doi.org/10.1016/S0006-2952(01)00752-3

Ye, X., Kato, K., Wong, L.-Y., Jia, T., Kalathil, A., Latremouille, J., & Calafat, A. M. (2018). Per- and polyfluoroalkyl substances in sera from children 3 to 11 years of age participating in the National Health and Nutrition Examination Survey 2013–2014. *International Journal of Hygiene and Environmental Health*, *221*, 9–16. https://doi.org/10.1016/j.ijheh.2017.09.011

Ye, X., Kato, K., Wong, L.-Y., Jia, T., Kalathil, A., Latremouille, J., & Calafat, A. M. (2018). Per- and polyfluoroalkyl substances in sera from children 3 to 11 years of age participating in the National Health and Nutrition Examination Survey 2013–2014. *International Journal of Hygiene and Environmental Health*, *221*, 9–16. https://doi.org/10.1016/j.ijheh.2017.09.011

Yeung, L. W. Y., Loi, E. I. H., Wong, V. Y. Y., Guruge, K. S., Yamanaka, N., Tanimura, N., Hasegawa, J., Yamashita, N., Miyazaki, S., & Lam, P. K. S. (2009). Biochemical Responses and Accumulation Properties of Long-Chain Perfluorinated Compounds (PFOS/PFDA/PFOA) in Juvenile Chickens (Gallus gallus). *Archives of Environmental Contamination and Toxicology*, *57*, 377–386. https://doi.org/10.1007/s00244-008-9278-3

Yeung, L. W. Y., & Mabury, S. A. (2016). Are humans exposed to increasing amounts of unidentified organofluorine? *Environmental Chemistry*, *13*, 102. https://doi.org/10.1071/EN15041

Yoo, H., Guruge, K. S., Yamanaka, N., Sato, C., Mikami, O., Miyazaki, S., Yamashita, N., & Giesy, J. P. (2009). Depuration kinetics and tissue disposition of PFOA and PFOS in white leghorn chickens (Gallus gallus) administered by subcutaneous implantation. *Ecotoxicology and Environmental Safety*, *72*, 26–36. https://doi.org/10.1016/j.ecoenv.2007.09.007

York, R. G. (2002). Oral (gavage) developmental toxicity study of potassium perfluorobutane sulfonate (PFBS) in rats. (Argus Research Protocol Number 418023). In *3M Corporate Toxicology*.

York, R. G. (2003). Oral (gavage) two -generation (one litter per generation) reproduction study of perfluorobutane sulfonate (PFBS) in rats. (Argus Research Protocol Number 418021). In *Argus Research* (p. 84).

Yu, W.-G., Liu, W., Jin, Y.-H., Liu, X.-H., Wang, F.-Q., Liu, L., & Nakayama, S. F. (2009). Prenatal and Postnatal Impact of Perfluorooctane Sulfonate (PFOS) on Rat Development: A Cross-Foster Study on Chemical Burden and Thyroid Hormone System. *Environmental Science & Technology*, *43*, 8416–8422. https://doi.org/10.1021/es901602d

Zhang, Y., Beesoon, S., Zhu, L., & Martin, J. W. (2013). Biomonitoring of Perfluoroalkyl Acids in Human Urine and Estimates of Biological Half-Life. *Environmental Science & Technology*, *47*, 10619–10627. https://doi.org/10.1021/es401905e

Zhao, B., Li, L., Liu, J., Li, H., Zhang, C., Han, P., Zhang, Y., Yuan, X., Ge, R. S., & Chu, Y. (2014). Exposure to Perfluorooctane Sulfonate In Utero Reduces Testosterone Production in Rat Fetal Leydig Cells. *PLoS ONE*, *9*, e78888. https://doi.org/10.1371/journal.pone.0078888

Zheng, L., Dong, G.-H., Jin, Y.-H., & He, Q.-C. (2009). Immunotoxic changes associated with a 7-day oral exposure to perfluorooctanesulfonate (PFOS) in adult male C57BL/6 mice. *Archives of Toxicology*, *83*, 679–689. https://doi.org/10.1007/s00204-008-0361-3

Zhou, W., Zhao, S., Tong, C., Chen, L., Yu, X., Yuan, T., Aimuzi, R., Luo, F., Tian, Y., & Zhang, J. (2019). Dietary intake, drinking water ingestion and plasma perfluoroalkyl substances concentration in reproductive aged Chinese women. *Environment International*, *127*, 487–494. https://doi.org/10.1016/j.envint.2019.03.075

Zhou, Y., Hu, L.-W., Qian, Z. (Min), Chang, J.-J., King, C., Paul, G., Lin, S., Chen, P.-C., Lee, Y. L., & Dong, G.-H. (2016). Association of perfluoroalkyl substances exposure with reproductive hormone levels in adolescents: By sex status. *Environment International*, *94*, 189–195. https://doi.org/10.1016/j.envint.2016.05.018

Zhu, Y., Qin, X.-D., Zeng, X.-W., Paul, G., Morawska, L., Su, M.-W., Tsai, C.-H., Wang, S.-Q., Lee, Y. L., & Dong, G.-H. (2016). Associations of serum perfluoroalkyl acid levels with T-helper cell-specific cytokines in children: By gender and asthma status. *Science of The Total Environment*, *559*, 166–173. https://doi.org/10.1016/j.scitotenv.2016.03.187

List of acronyms

General acronyms

Table 73. Acronyms found in the health appendix.

Acronym	Definition
ACE	Asian Pacific Islander Community Exposures
ADj. BMD	Adjustment benchmark dose
AFB	Air Force Base
AFFF	Aqueous film forming foam
ALT	Elevated liver enzyme
ANSES	French Agency for Food, Environmental and Occupational Health and Safety
ATSDR	Agency for Toxic Substances and Disease Registry
BMD	Benchmark dose
COVID-19	Coronavirus disease 2019
CDC	Centers for Disease Control and Prevention
CEC	Commission for Environmental Cooperation
DOD	United States Department of Defense
DEPA	Danish Environmental Protection Agency
E2SSB	Engrossed Second Substitute Senate Bill
Ecology	Washington State Department of Ecology
EFSA	European Food Safety Authority
EHDR	Environmental Health Disparities Ranking
EJ	Environmental Justice
EPA	United States Environmental Protection Agency
ERα	Estrogen receptor alpha
ESTCP	Environmental Security Technology Certification Program
EU	European Union
FDA	United States Food and Drug Administration
Health	Washington Department of Health
HED	Human equivalent dose
HBM commission	German Human Biomonitoring Commission
Hib	Haemophilus influenza type b
IARC	International Agency for Research on Cancer
IBL	Information by Location, a tool used in Washington Tracking Network
IgE	Immunoglobulin E
ITRC	Interstate Technology & Regulatory Council
JBLM	Joint Base Lewis-McChord
L	Liter
LDL	low-density lipoprotein

Acronym	Definition
LOAEL	Lowest observed adverse effect level
µg/L	Microgram per liter
µg/kg	Microgram per kilogram
MAMAS	Measuring Analytes in Maternal Archived Samples
MCL	Maximum contaminant level
MDH	Minnesota Department of Health
Mil-spec	Military performance requirements
MTCA	Model Toxics Control Act
NAS	Naval Air Station
ng/g	Nanogram per gram
ng/kg	Nanogram per kilogram
ng/kg-day	Nanogram per kilogram per day
ng/mL	Nanogram per milliliter
ng/m^3	Nanogram per cubic meter
NHANES	CDC National Health and Nutrition Examination Survey
NHDHHS	New Hampshire Department of Health and Human Services
NIEHS	National Institute of Environmental Health Sciences
NOAEL	No observed adverse effect level
NTP	National Toxicology Program
OLF	Outlying Landing Field
PBPK	Physiologically based pharmacokinetic
PPARα	Peroxisome proliferator-activated receptor alpha
Ppt	Parts per trillion
PSA	Prostate specific antigen
PWS	Public drinking water system
RfD	Reference dose
SBOH	State Board of Health
SERDP	Strategic Environmental Research and Development Program
TRV	Toxicity reference values
TSH	Thyroid simulating hormone
TWI	Tolerable weekly intake
T3	Triidothyonine
T4	Thyroxine
UCMR3	Third Unregulated Contaminant Monitoring Survey
UCMR5	Fifth Unregulated Contaminant Monitoring Survey
WEHDM	Washington Environmental Health Disparities Map
WTN	Washington Tracking Network
WWTP	Wastewater treatment plant

Chemical names

Table 74. Chemical name acronyms found in the health appendix, excluding the acronyms in the table above.

Acronym	Chemical name
6:2 FTCA	6:2 fluorotelomer carboxylic acid
6:2 FTOH	6:2 fluorotelomer alcohol
6:2 FTS	6:2 fluorotelomer sulfonate
6:2 FTSA	6:2 fluorotelomer sulfonic acid
6:2 FTUA	6:2 fluorotelomer unsaturated acid
APFO	Ammonium perfluorooctanoate
EtFOSA	N-Ethyl perfluorooctane sulfonamide
EtFOSE	N-Ethyl perfluorooctane sulfonamidoethanol
FTAC	Fluorotelomer acrylate
FTCA	Fluorotelomer carboxylic acid
FTOH	Fluorotelomer alcohol
FTSA	Fluorotelomer sulfonic acid
FTUA	Fluorotelomer unsaturated acid
HFPO-DA(GenX)	Hexafluoropropylene oxide dimer acid
MeFBSA	N-Methyl perfluorobutane sulfonamide
MeFBSE	N-Methyl perfluorobutane sulfonamide ethanol
MeFOSE	N-Methyl perfluorooctane sulfonamido ethanol
MeFOSA	N-Methyl perfluorooctane sulfonamide
Me-PFOSA-AcOH	2-(N-methyl-perfluorooctane sulfonamido) acetic acid
N-EtFOSEs	Perfluorooctane sulfonamido ethanols
N-MeFOSE	N-Methyl perfluorooctane sulfonamido ethanol
PFAA	Perfluorinated alkyl acid
PFAS	Per- and polyfluoroalkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonic acid
PFBuS	Perfluorobutane sulfonic acid
PFCA	Perfluoro-carboxylic acid
PFDA	Perfluorodecanoic acid
PFDeA	Perfluorodecanoic acid
PFDoDA	Perfluorododecanoic acid
PFHxA	Perfluorohexanoic acid
PFHpA	Perfluoroheptanoic acid
PFHxS	Perfluorohexane sulfonate
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOSA	Perfluorooctane sulfonamide

Acronym	Chemical name
PFPeA	Perfluoro-n-pentanoic acid
PFSA	Perfluoro- sulfonic acid
PFUnDA	Perfluoroundecanoic acid

Appendix 8: Biosolids

8.0 Overview

8.0.1 Findings

Biosolids are nutrient- and organic-rich residuals from wastewater treatment. They are land applied on agricultural fields as a soil amendment and fertilizer under a regulated program. Washington's biosolids rule incorporates federal standards, and requires permitting specific sites and approval of application rates and procedures.

An extensive risk assessment was conducted by the U.S. Environmental Protection Agency (EPA) prior to the promulgation of the federal biosolids rule. Three National Sewage Sludge Surveys have been conducted to assess contaminants in biosolids thought to pose risks to human health and the environment. Per- and polyfluoroalkyl substances (PFAS) were not evaluated under the initial risk assessment or the sewage sludge surveys, even though PFAS compounds were widely used throughout the period.

Biosolids PFAS concentrations in the scientific literature have been measured using a variety of methods, although the dense organic matrix has made accurate and precise results difficult to obtain. EPA is currently validating specific methods for PFAS analysis suitable for biosolids and soil. Completion of the validation process is expected sometime in 2020.

Scientific studies evaluating PFAS from land-applied biosolids have investigated results of extremely high application rates, biosolids contaminated by direct industrial production, or used artificial spiking of PFAS compounds. These conditions are not reflective of the rates, likely concentration, or availability of PFAS in Washington biosolids under current rules.

Worldwide, concentrations of the two most common PFAS, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), in biosolids have trended downward following reduced production of these congeners. Since there is no known industrial production of PFAS in Washington, biosolids exposure pathways in Washington are primarily from homes and consumer products. Secondary manufacturers may be a source of some contamination in municipal waste streams, but primary exposure is largely from consumer products. Reduction of PFAS in consumer products will lower direct PFAS exposure and the indirect concentrations that may occur in Washington biosolids. Currently, no data exists for PFAS in Washington biosolids.

Several states in the U.S. are considering setting PFAS contaminant levels in soil and biosolids. A PFAS task force in Maine developed PFAS biosolids standards of low ppb for PFOS, PFOA, and perfluoro butane sulfonate (PFBS). Leaching models used in the calculations of these limits use impractical values for parameters such as the fraction of organic carbon in soil (F_{OC}) and degree of molecular sorption (K_{OC}). This can result in calculating unrealistically low soil contaminant limits.

Adoption of extremely low regulatory limits for soil PFAS could have adverse consequences for organics and residual recycling. Such limits could interfere with established goals and benefits

of recycling programs, but may not provide demonstrated risk-reduction for human health and the environment.

Risk assessment of PFAS in land-applied biosolids requires a baseline dataset for PFAS that includes:

- Assessment of concentrations in Washington biosolids.
- Measurement of soil concentrations directly attributable to land-applied biosolids under conditions that mimic current state rules.
- Evaluation of contaminant modeling that uses realistic values for input parameters.
- A review of exposure pathways.

8.0.2 Introduction

This appendix presents information regarding the presence of PFAS in biosolids produced as a result of wastewater treatment. It reviews the evolution of how state and federal regulations address PFAS in biosolids, discusses the lack of accredited analytical methods to measure PFAS in biosolids, and presents current knowledge regarding biosolids PFAS concentration trends. Impacts of PFAS-contaminated biosolids application are reviewed and placed into the context of typical biosolids recycling and use in the state.

8.1 Background

Amendments to the Federal Water Pollution Control Act of 1948, now known as the Clean Water Act (CWA), set the creation of wastewater treatment across the U.S. in motion. Large scale construction of wastewater treatment plants (WWTPs) that included secondary treatment was initiated in 1972 when these facilities were nationally funded under a grant program administered by EPA.

One of the primary functions of wastewater treatment is to remove solids from the influent. Treatment plants utilize a variety of engineering designs, but most employ some sort of biological treatment whereby aquatic bacteria consume (i.e., digest) the organic constituents in the influent. The biological and organic floc—along with mineral and some chemical constituents—is settled out of the wastewater prior to discharge of effluent. These solids are typically high in organic matter and mechanically dewatered. Some facilities in arid climates air-dry the solids as a primary method of dewatering or in addition to a mechanical process.

In Washington, biosolids are land applied for their nutrient and soil amending properties. Land application of biosolids is conducted primarily in conjunction with commercial farming operations across the state. Washington State Department of Ecology (Ecology) approves individual biosolids applications on an agronomic basis—matching nitrogen needs of the crop with that supplied by biosolids. Analysis of both soil and biosolids is required by rule to calculate site-specific rates on permitted fields in advance of application.

8.2 Federal and state regulations

EPA administers the federal biosolids rule (40 Code of Federal Regulations (CFR) Part 503), under which specific sampling, analysis, and management is required of WWTP residuals. Requirements under the federal rule were developed during extensive scientific review and risk analysis conducted by EPA over a multi-year period preceding the adoption of the federal rule in February 1993. Under federal rules, the solids generated by wastewater treatment are called "sewage sludge."

Washington regulation (Chapter 173-308[157] Washington Administrative Code (WAC)—Biosolids Management) differentiates between wastewater solids that meet the regulatory standards to allow land application, classified as "biosolids," and solids not meeting the standards, defined as "sewage sludge." Washington law requires that biosolids are land applied to the greatest extent possible, but that sewage sludge be disposed in a landfill. Based on etimates derived from Annual Report data compiled by Ecology (2017), currently about 85 – 90% of biosolids generated in Washington are land applied.

Washington's biosolids rule adopts all the standards in the federal rule regarding sampling and analysis of WWTP solids, but analysis for PFAS is not required. The Washington rule imposes additional management criteria related to:

- Land application, site evaluation, and permitting.
- Development of management plans that govern the land application procedures.
- Ongoing oversight and approval of application rates and operations.

8.3 Biosolids risk assessment: Rule development, national surveys, and National Research Council

EPA developed the federal rule after undertaking a substantive nine-year evaluation of sewage sludge land application. The process included an "extensive multi-pathway risk assessment for evaluating and setting limits to manage pollutants in biosolids" (EPA, 1995). It involved making a list of pollutants, developing risk-assessment methodologies, determining pollutant limits, defining management practices, and issuing the rule.

In 1984, EPA identified a list of 200 potential pollutants in wastewater residuals for evaluation. Included in this list were a range of toxic organics such as dioxins, furans, polyaromatic hydrocarbons, pesticides, and herbicides. A scientific panel reviewed this list and made a recommendation that approximately 50 of these pollutants be evaluated for further study (EPA, 1995). The evaluation considered toxicity, occurrence, and fate and effects of the pollutants, with a focus on pathways of exposure.

In 1988, EPA conducted the first National Sewage Sludge Survey (NSSS) (EPA, 1992b) to develop a reliable database in support of the final Part 503 biosolids regulation. Samples were collected from 180 Publically Owned Treatment Works (POTWs). These samples were analyzed for more

[157] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308

than 400 pollutants according to analytical protocols adapted specifically for the matrix of biosolids. EPA also reviewed the operational practices of 462 POTWs that utilized secondary treatment.

Following the initial survey, two subsequent NSSS have been conducted. In 2007, the survey prioritized an evaluation of dioxins (EPA, 2007), and a Targeted NSSS published in 2009 focused on pharmaceuticals and personal care products (EPA, 2009). Although in wide use at the time, neither PFAS as a chemical class, nor the specific congeners PFOS and PFOA were evaluated.

The National Research Council (NRC) has twice reviewed the federal rule, 40 CFR Part 503. In 1996 the NRC released "Use of Reclaimed Water and Sludge in Food Crop Production" and in 2002 reviewed the science and methodology underlying the health and environmental standards entitled "Biosolids Applied to Land: Advancing Standards and Practices." Both studies concluded that the federal rule was protective of human health and the environment, but PFAS substances were not specifically part of these evaluations. The 2002 NRC review stated that "there is no documented scientific evidence that the Part 503 rule has failed to protect public health."

Pursuant to the CWA Section 405(d), EPA must review the biosolids regulations every two years. They are directed to identify additional toxic pollutants that show sufficient evidence of harm and establish management practices protective of human health and the environment. An international study in 2011 stated that research on organic contaminants in biosolids has been undertaken for more than 30 years, and the increasing body of evidence demonstrates that the majority of compounds studied do not place human health at risk when biosolids are land applied on farmland (Clarke & Smith, 2011). The study cautions that "continued vigilance in assessing 'emerging' organic contaminants in sludge is necessary to support and ensure the long-term sustainability and security of the beneficial agricultural route for biosolids management."

8.4 PFAS analysis methods for biosolids

The required analytical methods and analytes for WWTP residuals in the U.S. are specified by EPA in the federal rule (40 CFR Part 503) and incorporated into the Washington state rule (Chapter 173-308[158] WAC). Municipalities are required to test their biosolids for a range of chemical parameters including nutrients and regulated metals, but PFAS is not a required analyte. The frequency of testing is determined by the quantity of biosolids the facility generates, with larger facilities required to conduct more frequent testing.

Regulatory analysis of biosolids in Washington state is required to be conducted by Ecology-accredited laboratories. WWTP residuals in Washington state are considered sewage sludge until they are analyzed by accredited labs using specified methods with the results meeting minimum standards. Residuals meeting the standards in the Washington rule are deemed biosolids and are required to be beneficially used.

[158] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308

Wastewater residuals are a dense organic matrix and have proved difficult to accurately analyze. EPA spent considerable time developing the appropriate methodologies required in the federal rule in order to achieve accurate and consistent results. Laboratories often commit the analytical error of conducting biosolids analyses using methods developed for water and wastewater (EPA, 1992a).

As identified in Appendix 2: Analytical Methods, Section 2.1, EPA has developed Method 537 for analyzing PFOS, PFOA, and 12 other PFAS in drinking water (EPA, 2018a). Some U.S. labs are analyzing biosolids using modified procedures based on EPA Method 537, but guidelines are inconsistent and results have not been validated (Personal communication, Elizabeth Resek, Biosolids Program Lead at EPA, 2018). Ecology's lab accreditation unit at Manchester Environmental Laboratory has performed a technical review of one laboratory in Washington for analysis of a limited number of PFAS compounds in solids and chemical materials using a modified 537 method. Manchester has also recognized the accreditation of the National Environmental Laboratory Accreditation Program (NELAP) for a few other Washington laboratories for PFAS analysis in the solids and chemical materials matrix using modified 537 methods (Personal Communication, Rebecca Wood, Unit Supervisor of Laboratory Accreditation Unit, Manchester Environmental Laboratory, Washington Department of Ecology, 2018). Such accreditation ensures that the procedures are being appropriately followed, not that the method provides accurate and consistent results when analyzing biosolids.

EPA is in the process of validating a different procedure for analyzing biosolids and soil for PFAS—SW-846. Phase I was carried out in the winter of 2017 for 24 PFAS in various media. Phase II of this process was conducted in the fall of 2018 and several external labs are in the process of validating these procedures for public review (EPA, 2018a). It is unlikely that EPA will have finalized its approval of method(s) for PFAS analysis in biosolids before 2020 (Beecher & Brown, 2018; Personal communication, Elizabeth Resek, Biosolids Program Lead at EPA, 2018).

Separate from the SW-846 analysis procedures being reviewed by EPA is another analysis method for PFAS—Total Oxidizable Precursor (TOP) assay. This method uses a chemical oxidation pretreatment. While a number of commercial labs offer the TOP assay, the oxidation can be more or less aggressive depending on the details of the procedure (Masunaga, 2017). Also, there is no currently settled methodology or agreed-upon best approach. TOP is not an EPA method, but is the only commercialized screening tool to measure the presence of PFAA (perfluoroalkyl acid) precursors.

8.5 PFAS concentration and trends in biosolids

The concentrations of PFOS and PFOA in biosolids have been reported from a variety of sources outside of Washington state (Arvaniti & Stasinakis, 2015; Loganathan et al., 2007; Sepulvado et al., 2011; Ulrich et al., 2016; Venkatesan & Halden, 2013; Zareitalabad et al., 2013). The literature reports PFOA concentrations from 7 – 219 nanograms per gram (ng/g) and PFOS from less than 2.5 – 990 ng/g. PFOS is often reported as the most abundant among the PFAS compounds (Arvaniti & Stasinakis, 2015; Sepulvado et al., 2011). Four WWTPs in Washington had effluent analysis for PFOS and PFOA, but this review did not include an analysis of biosolids for these compounds (Furl & Meredith, 2010).

In general, the chemistry of biosolids is reflective of the chemistry of people's daily lives, as is the dust in homes (Haug et al., 2011; Hundal, Lakhwinder, Kumar, & Basta, 2011). Washington residents are exposed to PFAS from carpets, food packaging, personal care products and cosmetics, surface coatings on textiles, paints, lubricants, waterproof fabric, ski wax, and a wide variety of other sources. Therefore, it would not be surprising if there were trace amounts in Washington biosolids.

Industrial sources of perfluoroalkylates can influence concentrations of these compounds in biosolids when a WWTP receives influent directly from industries that work with fluorotelomer compounds. A WWTP in Decatur, Alabama received discharge from industries that conducted electrochemical fluorination and worked with a variety of fluorotelomer compounds and perfluoroalkylates (Washington et al., 2010). The data for PFOA concentrations from Decatur sewage sludge are fragmentary, but show high levels in 2005 and 2006: 528 ng/g and 683 ng/g in 2005, and 1,875 ng/g in 2006. Subsequent to significant reduction from industrial discharges, the concentration of PFOA in the Decatur biosolids decreased markedly. The reported PFOA concentrations in biosolids were 50 ng/g and 128 ng/g in 2007, and 27 ng/g and 32 ng/g in 2008 (Washington et al., 2010).

Washington state does not have commercial production of PFAS compounds, although secondary manufacturing using PFAS chemicals may occur within the state (see Appendix 1: Chemistry, Section 1.3). This suggests that there may be some industrial discharge, but the vast majority of perfluorinated compounds in Washington municipal wastewater would originate from domestic sources—our homes and consumer products. Contamination such as that identified in Alabama biosolids is highly unlikely to occur in Washington.

A trend of decreasing concentrations of PFOA and PFOS is observed across a broad spectrum of data characterizing biosolids using a variety of analytical methods. A review of sewage sludge in Germany evaluated perfluoroalkyl acids (PFAAs) concentration from 4,981 samples from 1,165 WWTPs collected between 2008 and 2013 (Ulrich et al., 2016). Seventy-one WWTPs had samples exceeding a European Union (EU) precautionary level of 125 ng/g, but this occurred with decreasing frequency over time. The exceedances decreased from 6% in 2008 to 0.8% in 2013. During the same timeframe, WWTPs uncontaminated with PFOS and PFOA increased by 32%. In the samples evaluated, PFOS was found in 41% and PFOA in 7%. Forty-seven percent of WWTPs showed clear decreases over time and 16% showed an increasing trend. The total load of PFAAs in sewage sludge was reduced by more than 90% during this time period. These reductions are likely the result of the decreased production of PFOS and PFOA.

In 2013, archived samples of biosolids from the NSSS from 2001 were combined into five composite samples and analyzed for PFOA and PFOS. The average concentration of PFOS was 276 – 430 ng/g, and PFOA was 12 – 56 ng/g (Venkatesan & Halden, 2013). These archived NSSS samples represented 94 WWTPs in 32 states, but did not include Washington state. A summary of PFAS compounds in sewage sludge from 2005 to 2015 monitoring data worldwide was compiled by carbon chain length at concentrations of ng/g (Arvaniti & Stasinakis, 2015). With few exceptions, these more recent samples are lower for PFOS and PFOA than the composite results from samples in the EPA NSSS of 2001. A reduction in PFOS and PFOA levels in human blood (Calafat et al., 2007) was also observed in data compiled from the National Health and

Nutrition Examination Surveys (NHANES). They conclude this is "most likely related to discontinuation in 2002 of industrial production of PFOS and related perfluorooctanesulfonyl fluoride compounds."

8.6 Literature review of biosolids land application effects

In the case from Decatur, Alabama referenced above, biosolids were land applied to about 2,000 hectares (ha) of agricultural fields for more than a decade (Washington et al., 2010). The elevated levels of PFAS in the biosolids generated concern that land application may constitute a pathway to contaminate surface and groundwater. In order to evaluate this risk, EPA collected some initial soil samples in 2007 from Decatur land application sites and from nearby background fields that did not receive biosolids. Results indicated the presence of high concentrations of several fluorotelomer alcohols (FTOHs) and PFAS in soil. After collection of these initial soil samples and public drinking water samples, EPA collected an expanded set of soil samples in 2009 to more accurately characterize the extent of contamination in and around the land application sites. These land application activities and the subsequent EPA review have received widespread coverage in news reports and have been noted in a variety of websites (Fluoride Action Network, 2009; Northwestern University, n.d.; Renner, 2009).

The soil from sludge-applied fields in Alabama had PFAS concentrations that were higher than the background field samples. The highest PFOA concentrations from sludge-applied fields were less than or equal to 320 ng/g, and PFOS were less than or equal to 410 ng/g (Washington et al., 2010). Annual application rates of Decatur biosolids for a five-year period between 2002 and 2006 averaged approximately 32 Megagram per hectare (Mg/ha) ranging from 14.9 – 60 Mg/ha. These amounts are well above Washington's mean application rate of 6.95 Mg/ha calculated from 809 regulatory approvals for land application of biosolids for Alfalfa or grass hay, barley, canola, corn, hops, sunflowers, triticale, and wheat over the years 2010 – 2017, for which data are available (Severtson, 2017). The minimum Decatur rate exceeds all but six of the 809 Washington approvals. The six higher land application rates approved in Washington were for lagoon biosolids that contained significant amount of mineral material (sand) and low nitrogen (N) content. From the perspective of an agronomic evaluation, application rates used for the Decatur biosolids would have likely resulted in excessive N accumulations and leaching of nitrate. Such rates would be unlikely to receive regulatory approval in Washington.

Sepulvado et al. (2011) land applied municipal biosolids from Chicago to investigate questions about the fate of perfluorochemicals (Sepulvado et al., 2011). This investigation indicated four significant results:

- Concentrations of PFAS in soil increased linearly with increasing biosolids loading rate (PFOS = 2 – 483 ng/g).
- Desorption experiments suggested the leaching potential of perfluorochemicals decreased with increasing carbon chain length.
- Previously derived organic carbon partition coefficients may not be accurate predictors of the desorption of long-chain PFAS compounds.
- Trace levels of short-chain PFAS were detected in soil cores below the level of incorporation.

The Chicago biosolids in the Sepulvado et al. (2011) study were land applied at very high cumulative loading rates. Their long-term plots had applications over 32 years amounting to 553 Mg/ha (low rate), 1,109 Mg/ha (medium rate), and 2,218 Mg/ha (high rate) (Sepulvado et al., 2011). Although the PFAS soil concentrations were linearly correlated with application rates, the loading rates in the Sepulvado et al. (2011) study were significantly higher than the mean Washington agronomic rate of 6.95 Mg/ha. It would require 79, 159, and 319 years of annual applications respectively at Washington's average application rate to achieve similar cumulative loading.

However, most fields in Washington do not have biosolids applied annually. On a wheat-fallow, rotation applications are made every other year at most, and commonly every four years. Applications on alternate years would require a minimum of 158 years to achieve the lowest cumulative biosolids loading in the Sepulvado et al. (2011) study. These were biosolids likely to have higher levels of PFOS and PFOA than Washington biosolids, due to the dates when they were produced and potential industrial contamination.

In a spiked soil study, Stahl et al. (2009) reported bioaccumulation and that PFOA and PFOS at very high concentrations can result in diminished growth of spring wheat. However, spiked-soil studies are known to create results not seen in field investigations with typical agronomic application rates. Studies by Blaine et al. (2013) and Pannu et al. (2012) showed that biosolids amended spiked-soil studies can show artificially greater accumulation in plants and earthworms as compared to samples grown in field soils (Blaine et al., 2013; Pannu, O'Connor, & Toor, 2012). Similarly, regarding metal uptake, Brown et al. (1998) demonstrated that "significantly less cadmium (Cd) was taken up by lettuce grown on biosolids-amended soil than lettuce grown on soil amended with equivalent rates of a Cd salt."

Negative impacts on crop growth are not representative of yield data from biosolids applications in Washington state. Results from a long-term Washington State University study evaluating biosolids applications to winter wheat and canola have shown significant long-term yield **increases** from biosolids applications compared with the control or mineral fertilizer additions (Cogger et al., 2013). This is despite the fact that there are likely to be trace amounts of PFAS in the biosolids. However, there are no PFAS soil concentration data from this site nor has EPA addressed agricultural soil concentration limits to date.

In a widely distributed greenhouse and field study of plant uptake of perfluoroalkyl acids (PFAAs) from biosolids, Blaine et al. (2013) looked at PFAA concentrations in lettuce *(Lactuca sativa)* and tomato *(Lycopersicon lycopersicum)* grown in biosolids-amended soils. The greenhouse portion of the study used industrially impacted biosolids, biosolids from a long-term application site, as well as "clean" soil. They calculated bioaccumulation factors (BAFs), looking at concentrations in soil relative to plant concentrations primarily from the greenhouse portion of the trial. They conclude that the "study confirms that the bioaccumulation of PFAAs from biosolids-amended soils depends strongly on PFAA concentrations, soil properties, the type of crop, and analyte."

In the Blaine et al. (2013) field scale trial using lettuce and tomato, and a full-scale field study with corn, the plant concentrations were below the level of quantification (LOQ) for all treatments except the 4x agronomic rate (100 Mg/ha), which is 14 times the average

application rate in Washington. Given the results of the Blaine et al. (2013) study, it is highly unlikely that grain would exhibit concentrations above the LOQ as a result of agronomic applications in Washington, where PFOS and PFOA concentrations are likely to be very low due to lack of industrial production.

The Blaine et al. (2013) greenhouse study shows how small-scale investigations into bioaccumulation can differ significantly from regulated, field-scale applications in Washington. The study used three types of soil: control, "industrially impacted," and "municipal." The industrial soil was created by adding a 10% (dry weight) biosolids compost and the municipal soil originated from cumulative applications of municipal biosolids that totaled 1,654 Mg/ha. The industrially impacted soil had PFOA concentrations of 78.5 ng/g and PFOS concentrations of 49.7 ng/g. The municipal soil had PFOA concentrations of 14.9 ng/g and PFOS concentrations of 319.5 ng/g.

In both cases, soil concentrations are orders of magnitude higher than would realistically result in Washington state from agronomic biosolids applications. Indeed, it would be impossible to reach the PFAS soil concentrations seen in the Blaine et al. (2013) study if initial biosolids concentrations are significantly lower than those modeled. Tables 76 and 77 show the time necessary to reach such concentrations—using biosolids PFAS concentration data from the literature, combined with the mean Washington biosolids application rate. Actual PFAS concentrations in Washington biosolids are likely to be significantly lower than these values.

Table 75. Estimates of the time needed to reach Blaine et al. (2013) municipal soil concentrations from annual applications of biosolids using various concentration estimates and mean Washington application rate in megagrams per hectare (6.95 Mg/ha).

Biosolids PFOS/PFOA concentration (µg/kg)	Biosolids application rate[18] (Mg/ha)	PFOS/PFOA applied per application-dry weight (µg)	Soil depth (cm)	Soil weight (kg/ha)	Calculated soil conc. (µg/kg)	Blaine et al. (2013) municipal soil conc. (µg/kg)	Years to reach soil levels*
PFOS: 19 PFOA: 10 (Ulrich, 2016)	6.95	PFOS: 132,050 PFOA: 69,500	15	2,000,000	PFOS: 0.066 PFOA: 0.035	PFOS: 319.5 PFOA: 14.9	PFOS: 4,841 PFOA: 426
PFOA: 32 (Washington et al., 2010)	6.95	220,400	15	2,000,000	PFOA: 0.110	PFOA: 14.9	PFOS: 135
PFOS: 403 PFOA: 34 (EPA, 2001)	6.95	PFOS: 2,800,850 PFOA: 236,300	15	2,000,000	PFOS: 1.400 PFOA: 0.118	PFOS: 319.5 PFOA: 14.9	PFOS: 228 PFOA: 126

Note: * = One application annually, summed empirical amounts only (no degradation or leaching of PFOS or PFOA).

Table 76. Estimates of the time needed to reach Blaine et al. (2013) industrial soil concentrations from annual applications of biosolids using various concentration estimates and mean Washington application rate in megagrams per hectare (6.95 Mg/ha).

Biosolids PFOS/PFOA concentration (µg/kg)	Biosolids application rate[18] (Mg/ha)	PFOS/PFOA applied per application-dry weight (µg)	Soil depth (cm)	Soil weight (kg/ha)	Calculated soil conc. (µg/kg)	Blaine et al. (2013) industrial soil conc. (µg/kg)	Years to reach soil levels*
PFOS: 19 PFOA: 10 (Ulrich, 2016)	6.95	PFOS: 132,050 PFOA: 69,500	15 cm	2,000,000	PFOS: 0.066 PFOA: 0.035	PFOS: 49.7 PFOA: 78.5	PFOS: 753 PFOA: 2,243
PFOA: 32 (Washington et al., 2010)	6.95	220,400	15 cm	2,000,000	0.111	78.5	PFOA: 707
PFOS: 403 PFOA: 34 (EPA, 2001)	6.95	PFOS: 2,800,850 PFOA: 236,300	15 cm	2,000,000	PFOS: 1.400 PFOA: 0.118	PFOS: 49.7 PFOA: 78.5	PFOS: 36 PFOA: 665

Note: * = One application annually, summed empirical amounts only (no degradation or leaching of PFOS or PFOA).

8.7 Factors influencing risk assessment of PFAS in Washington biosolids

8.7.1 PFAS concentration data

PFOS was voluntarily phased-out of production in the U.S. between 2000 and 2002 by its primary producer, 3M Company (EPA, 2016). Since 2006, eight global manufacturers participated in a voluntary phase-out of PFOA by 2015 (EPA, 2018b). Reduced production of PFOS and PFOA is likely the reason for the lower reported concentrations of these chemicals in sewage sludge and biosolids in recent years. The biosolids PFOS and PFOA data in Germany (Ulrich et al., 2016) and locations worldwide using a variety of analytical methods suggest that concentrations of these chemicals are trending downward.

There is currently no PFAS data from biosolids generated in Washington. In June 2018, regulators and officials from major producers of biosolids across the state discussed the issue of PFAS data. There were a number of unresolved issues regarding how samples would be collected, what analysis method(s) would be used, who would pay for any analysis, data use and evaluation, and public dissemination of proprietary analysis results.

PFAS data in the literature from biosolids outside of Washington has been obtained using a variety of analytical methods. The accuracy and precision of these data is uncertain considering that EPA has not concluded its validation of analysis methods in a biosolids or soil matrix. It is "virtually impossible" to correlate PFAS soil data gathered across different states that have used

various sample collection procedures and non-validated analysis methods (Personal communication, Ned Beecher, Northeast Biosolids and Residuals Association, 2019).

Some commercial laboratories are claiming they can measure PFAS in solid matrices (biosolids and soil) at reporting limits as low as 0.2 ng/g (ppb). Claims of such precision in analysis results are suspect, because actual lab results often show reporting limits in the range of 2 – 5 ppb. Different methods also show wide variation in results. For example, Vermont DEC conducted split sample tests comparing a DOD-preferred isotope dilution method (MLA 110) with a modified Method 537 (Weston & Sampson, 2018). When analyzing wastewater, they found differences in results ranging from 10% – 200%. When analyzing wastewater solids, the range of difference between the methods exceeded 300%.

8.7.2 Modeling data

New York and Maine have made attempts at groundwater migration models to estimate leaching of PFAS in soil. The models used to derive soil screening values have not been field-verified for the PFAS chemicals, and there is insufficient published research on soil leaching of biosolids-sourced PFAS to allow for robust understanding of the potential leaching risks.

The sorption of perfluorinated compounds to soil influences their fate and distribution in the environment after land application. There is evidence that PFOS and PFOA persistence in soil is related to carbon-chain length, with longer carbon-chains being more persistent and less mobile in soil (Calafat et al., 2007; Venkatesan & Halden, 2013). Laboratory determined organic-carbon partitioning coefficients (K_{OC}) are often used to predict potential mobility of organic contaminants in the environment. The K_{OC} values can vary based on the method used for calculation (Snyder, O'Connor, & McAvoy, 2010), and derived values appear to differ from gross distribution of PFAS compounds in the environment. Lab-based Log K_{OC} values may overestimate PFOS and PFOA concentrations in water and underestimate soil residence time (Zareitalabad et al., 2013).

Determining K_{OC} values that are reflective of the environmental fate of biosolids-sourced PFAS compounds has proven difficult. It is likely that the database for K_{OC} values for the range of perfluorinated compounds is incomplete and may not provide adequate information to accurately model movement in a soil system.

Given that biosolids are settled out of an aqueous media, PFAS congeners with lower sorption are likely to leave wastewater treatment in the effluent. This may reduce overall PFAS amounts and provide an inherent bias for higher sorption congeners (higher K_{OC}) to remain in biosolids. This may result in reduced mobility of biosolids-sourced PFAS relative to the suite of PFAS congeners found in the WWTP influent. Thus, field-scale studies investigating the transfer or leaching of biosolids-sourced PFAS in natural soil systems are important to evaluate actual mobility and risk from biosolids land application.

Leaching models use a number of factors including the Fraction of Organic Carbon (F_{OC}) in soil and K_{OC}. Small changes in these factors directly affect model outcomes. Alaska Department of Environmental Conservation (ADEC) is currently evaluating soil standards based on a leaching model where the F_{OC} is assumed to be 0.1%. This is an unrealistic value associated with land applied biosolids where PFAS compounds would be land applied in a dense, organic-matter

matrix, and likely be applied to soils with significantly higher organic matter content. The Alaska model also used EPA's lab-based log K_{OC} values, which are not field verified.

ADEC's online calculator run with more realistic inputs for organic content and partitioning coefficients resulted in significantly higher calculated soil PFAS limits (Lono-Batura, Maile, Beecher, Ned, Franciosi, & Riggs, 2018). The State of Maine PFAS task force recently developed screening concentrations of 2.5 ng/g for PFOA, 5.2 ng/g for PFOS, and 1,900 ng/g for PFBS for biosolids that may be land applied. The levels were developed using SESOIL and AT123D models, which are primarily based on the leaching from soil to groundwater pathway (Maine Department of Environmental Protection, 2018). Maine also required all Maine utilities to test the biosolids for three PFAS compounds before any land application can occur. Following the setting of screening levels, representatives from various wastewater utilities wrote a letter to the PFAS task force and requested the screening levels be based on real-world research and not on fate and transport models.

Data and modeling uncertainties inhibit accurate assessment of risk to human health and the environment from biosolids-sourced PFAS land applied at agronomic rates in Washington. Biosolids are applied to less than 1% of state farmland on an annual basis. Applications occur only on permitted fields with rates based on crop type, yield, biosolids nutrient content, and site-specific soil analysis. PFAS in Washington biosolids result primarily from domestic sources and concentrations are likely to be very low. Mean application rates result in soil dilution exceeding 1,000-fold in the top two feet. State regulations regarding site restrictions also limit the pathways of exposure. These conditions, combined with available data, mean we can reasonably expect that health risks directly attributable to biosolids-sourced PFAS from land application in Washington are likely low.

8.8 Biosolids policy discussion

Biosolids management entities include private business, public utilities, and regulatory agencies. Issues regarding contaminants of emerging concern have occurred numerous times. The focus of concern has included a variety of categories such as pesticides, dioxins, PBDEs, antimicrobial compounds, and pharmaceuticals. Typically, the concentrations of these chemicals in biosolids have been very small, and until recent years, analytical techniques did not afford consistent identification and quantification. Current analytical reports on PFAS indicate identifiable concentrations in parts per billion and parts per trillion in a variety of media, drinking water in particular. This has renewed concern over the presence of contaminants in biosolids.

PFAS are nearly ubiquitous in modern society and Washington biosolids will likely show trace concentrations of PFAS. However, trends in the literature regarding PFOS and PFOA concentrations have shown decreases in biosolids, primarily attributed to reduced production. If PFAS concentrations in Washington biosolids largely reflect the domestic exposure people receive from consumer products in their homes, we would expect these concentrations to be low. As such, upstream source reduction—reduced use of products containing these compounds—will be the direct means of lowering PFAS exposure from biosolids for Washingtonians.

Use of hypothetical leaching models with unrealistic input parameters may calculate unachievable soil contaminant concentration limits. Several states are currently considering a variety of PFAS threshold values for soil based on such modeling. Some of these values for PFAS concentrations in soil may exceed local background levels making them unrealistic and to implement as a regulatory standard. Setting unrealistic (and potentially unenforceable) contaminant thresholds undermines public support for regulation.

Very low regulatory limits for PFAS soil concentrations that are widely applicable could have adverse impacts to businesses and municipalities managing biosolids and other residuals. The economic and management impacts would extend to a variety of end-users of biosolids and compost products (CDM Smith, 2020). The perception of risk resulting from extremely low concentrations may not have scientifically demonstrated human health risks and could have adverse impacts on generators. This may result in hesitancy by generators to publicly release their proprietary analytical results that are not required by rule. As such, without field verification data, Ecology will be cautious of implementing low calculated contaminant thresholds (such as the soil levels being considered in Alaska).

Risk assessment of biosolids land application requires appropriate analytical methods, modeling of biosolids-related contaminant transfer to soil and groundwater, and toxicological data on identified pathways of exposure for Washington residents.

8.9 Data gaps and recommendations

8.9.1 Data gaps

The following data gaps are identified with respect to PFAS in biosolids:

- Washington state has not conducted any biosolids sampling for PFAS with accredited methods, so there is no accredited data on PFAS concentrations in Washington biosolids.
- Background levels of PFAS in regulated land application zones are unknown.
- Soil PFAS concentrations in areas of direct biosolids land application are unknown.
- The source and amount of industrial discharge containing PFAS to municipal WWTPs is unknown.

8.9.2 Recommendations

The information gaps regarding biosolids are significant and currently prevent assessment of risk from PFAS in biosolids land applied in Washington. Any regulatory changes should be founded on defensible data and science-based risk assessments. If scientific modeling is used by Ecology to assess potential PFAS transfer from biosolids to soil or groundwater, realistic model parameters must be used.

Washington biosolids regulation in the near term should ensure sound agronomic land application practices on permitted sites where human exposure is limited. It is premature to add or change regulatory limits given the absence of data from Washington biosolids and problems identified with models and their input parameters.

Based on the analysis conducted in this appendix, we make the following recommendation.

Recommendation 4.3: Evaluate Washington biosolids management.

We recommend the following key steps to address the current data gaps:

- Establish biosolids and soil sample collection and handling methods for PFAS analysis.
- Accredit Washington labs for EPA-validated analysis method(s).
- Use EPA-validated analysis methods for biosolids and soils.
- Conduct credentialed third-party review of raw mass spectrometer PFAS data.
- Investigate land application sites where procedures mimic rates and practices under current state rule (Chapter 173-308[159] WAC).
- Evaluate realistic exposure pathways.
- Evaluate risk modeling with use of realistic input values.
- Collaborate with stakeholders to get accurate and precise biosolids data. Initial results should remain anonymous.
- Compile analysis data with statistical review.

As part of implementation of these steps, Ecology would:

- Allocate staff resources and funding to support biosolids PFAS data collection (sampling and analysis).
- Establish sampling methods and accreditation of laboratories.
- Collaborate with Northwest Biosolids Association, research institutions, and other stakeholders to establish the protocols and procedures.
- Work collaboratively with a variety of generators to analyze biosolids for PFAS using accredited methods and laboratories.
- Collect and analyze preliminary soil samples from biosolids application sites with known histories that mimic current Washington rules.
- Emphasize triplicate sample analysis in order to evaluate the precision of results for all sampling and analysis recommended in this appendix.
- Evaluate the basis of contaminant limits set in other states and Canada. Such an evaluation would include a review of baseline biosolids data, contaminant models and their parameters, pathways of exposure, and level of uncertainty.

[159] https://apps.leg.wa.gov/wac/default.aspx?cite=173-308

References

Arvaniti, O. S., & Stasinakis, A. S. (2015). Review on the occurrence, fate and removal of perfluorinated compounds during wastewater treatment. Science of The Total Environment, 524–525, 81–92. https://doi.org/10.1016/j.scitotenv.2015.04.023

Beecher, N. (2019). Personal communication. Phone call with Peter Severtson, Washington Department of Ecology, and Ned Beecher, Northeast Biosolids and Residuals Association. 2019

Beecher, N., & Brown, S. (2018). Managing Organics In The " PFAS Age ." BioCycle, 59, 31.

Blaine, A. C., Rich, C. D., Hundal, L. S., Lau, C., Mills, M. A., Harris, K. M., & Higgins, C. P. (2013). Uptake of Perfluoroalkyl Acids into Edible Crops via Land Applied Biosolids: Field and Greenhouse Studies. Environmental Science & Technology, 47, 14062–14069. https://doi.org/10.1021/es403094q

Brown, S., Chaney, R., & Angle, J. (1998). The phytoavailability of cadmium to lettuce in long-term biosolids-amended soils. Of Environmental Quality.

Calafat, A. M., Wong, L.-Y., Kuklenyik, Z., Reidy, J. A., & Needham, L. L. (2007). Polyfluoroalkyl Chemicals in the U.S. Population: Data from the National Health and Nutrition Examination Survey (NHANES) 2003–2004 and Comparisons with NHANES 1999–2000. Environmental Health Perspectives, 115, 1596–1602. https://doi.org/10.1289/ehp.10598

CDM Smith. (2020). Cost Analysis of the Impacts on Municipal Utilities and Biosolids Management to Address PFAS Contamination. October 2020. Retrieved from https://www.wef.org/globalassets/assets-wef/3---resources/topics/a-n/biosolids/technical-resources/cost-analysis-of-pfas-on-biosolids---final.pdf

Clarke, B. O., & Smith, S. R. (2011). Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids. Environment International, 37, 226–247. https://doi.org/10.1016/j.envint.2010.06.004

Cogger, C. G., Bary, A. I., Kennedy, A. C., & Fortuna, A.-M. (2013). Long-Term Crop and Soil Response to Biosolids Applications in Dryland Wheat. Journal of Environmental Quality, 42, 1872–1880. https://doi.org/10.2134/jeq2013.05.0109

Estimates derived from 2017 Annual Report data compiled by the Washington State Department of Ecology. (2017).

Fluoride Action Network. (2009). PFOA contaminated sludge spread in Lawrence County. Retrieved from http://fluoridealert.org/news/alabama-pfoa-contaminated-sludge-spread-in-lawrence-county/

Furl, C., & Meredith, C. (2010). Perfluorinated Compounds in Washington Rivers and Lakes, Environmental Assessment Program, Washington State Department of Ecology, Available at https://apps.ecology.wa.gov/publications/documents/1003034.pdf.

Haug, L. S., Huber, S., Schlabach, M., Becher, G., & Thomsen, C. (2011). Investigation on Per- and Polyfluorinated Compounds in Paired Samples of House Dust and Indoor Air from Norwegian Homes. Environmental Science & Technology, 45, 7991–7998. https://doi.org/10.1021/es103456h

Hundal, Lakhwinder S, Kumar, K, Basta, N, C. A. E. (2011). Evaluating Exposure Risk to Trace Organic Chemicals in Biosolids. BioCycle, 52.

Loganathan, B., Sajwan, K., Sinclair, E., Kumar, K., & Kannan, K. (2007). Perfluoroalkyl sulfonates and perfluorocarboxylates in two wastewater treatment facilities in Kentucky and Georgia. Water Research, 41, 4611–4620. https://doi.org/10.1016/J.WATRES.2007.06.045

Lono-Batura, Maile, Beecher, Ned, Franciosi, F, Riggs, M. (2018). Proposed ADEC Amendments to 18 AAC 75-Setting Cleanup Levels for PFAS, available at https://static1.squarespace.com/static/54806478e4b0dc44e1698e88/t/5be06915cd83666b73a1054c/1541433624189/NWBiosolidsNEBRAUSCCWORCComments-AK_DECSoilStndsPFAS-2Nov2018.pdf.

Maine Department of Environmental Protection. (2018). Maine Solid Waste Management Rules: Chapter 418 Beneficial Use of Solid Wastes Appendix A Screening Levels for Beneficial Use. Retrieved from https://www.maine.gov/dep/bep/2018/01-09-18/06-096 Ch. 418 Clean for Adoption.pdf

Masunaga, S. (2017). Effect of Oxidation Time on the Quantification of Total Perfluoroalkyl Acid Precursors by Potassium Persulfate - Hydroxyl Radical Method. SETAC 2017 Poster Session. Retrieved from http://globe.setac.org/wp-content/uploads/2018/07/SETAC-Minneapolis-program-v3-4.pdf

Northwestern University. (n.d.). Per - and Polyfluoroalkyl substances, The social discovery of a class of emerging contaminants. Decatur, Alabama. Retrieved August 14, 2019, from https://pfasproject.com/decatur-alabama/

Pannu, M. W., O'Connor, G. A., & Toor, G. S. (2012). Toxicity and bioaccumulation of biosolids-borne triclosan in terrestrial organisms. Environmental Toxicology and Chemistry, 31, 646–653. https://doi.org/10.1002/etc.1721

Renner, R. (2009). EPA finds record PFOS, PFOA levels in Alabama grazing fields. Environmental Science & Technology, 43, 1245–1246. https://doi.org/10.1021/es803520c

Resek, E. (2018). Personal communication. Phone call with Peter Severtson, Washington Department of Ecology, and Elizabeth Resek, United States Environmental Protection Agency, Biosolids Program Lead. 2018.

Sepulvado, J. G., Blaine, A. C., Hundal, L. S., & Higgins, C. P. (2011). Occurrence and Fate of Perfluorochemicals in Soil Following the Land Application of Municipal Biosolids. Environmental Science & Technology, 45, 8106–8112. https://doi.org/10.1021/es103903d

Severtson. (2017). Washington State Department of Ecology biosolids land application data, GIS data summary.

Snyder, E. H., O'Connor, G. A., & McAvoy, D. C. (2010). Measured physicochemical characteristics and biosolids-borne concentrations of the antimicrobial Triclocarban (TCC). Science of The Total Environment, 408, 2667–2673. https://doi.org/10.1016/j.scitotenv.2010.03.001

Stahl, T., Heyn, J., Thiele, H., Hüther, J., Failing, K., Georgii, S., & Brunn, H. (2009). Carryover of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) from Soil to Plants. Archives of Environmental Contamination and Toxicology, 57, 289–298. https://doi.org/10.1007/s00244-008-9272-9

Ulrich, H., Freier, K. P., & Gierig, M. (2016). Getting on with persistent pollutants: Decreasing trends of perfluoroalkyl acids (PFAAs) in sewage sludge. Chemosphere, 161, 527–535. https://doi.org/10.1016/j.chemosphere.2016.07.048

U.S. Environmental Protection Agency (EPA). (1992a). Biosolids Reference Sheet. Retrieved from https://www.epa.gov/sites/production/files/documents/handbook2.pdf

U.S. Environmental Protection Agency (EPA). (1992b). Final Report, Statistical Support Documentation for the 40 CFR, Part 503, Final Standards for the Use or Disposal of Sewage Sludge, Vol. 1., November 11, 1992. Retrieved from https://www.epa.gov/sites/production/files/2015-04/documents/statistics_1992_support_document_-_biosolids_vol_i.pdf

U.S. Environmental Protection Agency (EPA). (1995). Guide to the Biosolids Risk Assessments for the EPA Part 503 Rule, EPA publication, 832/B-93/005. Retrieved from https://www.epa.gov/sites/production/files/2018-11/documents/guide-biosolids-risk-assessments-part503.pdf

U.S. Environmental Protection Agency (EPA). (2007). U.S. EPA's 2001 National Sewage Sludge Survey, EPA-822-R-07-006. Retrieved from https://www.epa.gov/sites/production/files/2018-11/documents/2001-tnsss-report.pdf

U.S. Environmental Protection Agency (EPA). (2009). Targeted National Sewage Sludge Survey Overview Report. Retrieved from https://nepis.epa.gov/Exe/ZyPDF.cgi/P1005KUR.PDF?Dockey=P1005KUR.PDF

U.S. Environmental Protection Agency (EPA). (2016). Drinking Water Health Advisories for PFOA and PFOS. Retrieved from https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos#:~:text=EPA's health advisory level for,and PFOS in drinking water.

U.S. Environmental Protection Agency (EPA). (2018a). EPA Actions to Address PFAS. Retrieved from https://www.epa.gov/pfas/epa-actions-address-pfas

U.S. Environmental Protection Agency (EPA). (2018b). EPA Fact Sheet: 2010/2015 PFOA Stewardship Program. Retrieved from https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program

Venkatesan, A. K., & Halden, R. U. (2013). National inventory of perfluoroalkyl substances in archived U.S. biosolids from the 2001 EPA National Sewage Sludge Survey. Journal of Hazardous Materials, 252–253, 413–418. https://doi.org/10.1016/j.jhazmat.2013.03.016

Washington, J. W., Yoo, H., Ellington, J. J., Jenkins, T. M., & Libelo, E. L. (2010). Concentrations, Distribution, and Persistence of Perfluoroalkylates in Sludge-Applied Soils near Decatur, Alabama, USA. Environmental Science & Technology, 44, 8390–8396. https://doi.org/10.1021/es1003846

Weston & Sampson. (2018). Wastewater Treatment Facility and Landfill Leachate PFAS Sampling Various Locations, Northern Vermont,. Report to J. Schmelzer, VT DEC, May 3, 2018.

Wood, R. (2018). Personal Communication. Phone call with Peter Severtson, Washington Department of Ecology, and Rebecca Wood, Washington Department of Ecology, Manchester Environmental Laboratory—Laboratory Accreditation Unit Supervisor. 2018.

Zareitalabad, P., Siemens, J., Hamer, M., & Amelung, W. (2013). Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) in surface waters, sediments, soils and wastewater – A review on concentrations and distribution coefficients. Chemosphere, 91, 725–732. https://doi.org/10.1016/j.chemosphere.2013.02.024

List of acronyms

General acronyms

Table 77. Acronyms found in the biosolids appendix.

Acronym	Definition
ADEC	Alaska Department of Environmental Conservation
BAF	Bioaccumulation factor
Cd	Cadmium
CFR	Code of Federal Regulations
cm	Centimeter
CWA	Clean Water Act
Ecology	Washington State Department of Ecology
EPA	United States Environmental Protection Agency
EU	European Union
F_{oc}	Fraction of organic carbon in soil or fraction of organic matter
ha	Hectare
Kg	Kilogram
K_{oc}	Degree of molecular sorption or organic-carbon partitioning coefficient
LOQ	Level of quantification
Mg	Megagram
ng/g	Nanograms per gram
ųg	Microgram
ųg/kg	Microgram per kilogram
NHANES	National Health and Nutrition Examination Surveys
NRC	National Research Council
NSSS	National Sewage Sludge Survey
POTW	Publicly owned treatment works
TOP	Total oxidizable precursor
U.S.	United States
WAC	Washington Administrative Code
WWTP	Wastewater treatment plant

Chemical names

Table 78. Chemical name acronyms found in the biosolids appendix, excluding the acronyms found in the table above.

Acronym	Chemical Name
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
FTOH	Fluorotelomer alcohol
PFAA	Perfluoroalkyl acid
PFAS	Per- and polyfluorinated alkyl substances
PFBS	Perfluoro butane sulfonate
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate

Appendix 9: Regulations

9.0 Overview

9.0.1 Findings

Washington state currently implements the following laws and regulations to reduce per- and polyfluoroalkyl substances (PFAS):

- Chapter 70A.400[160] Revised Code of Washington (RCW): Firefighting Agents and Equipment Toxic Chemical Use Law.
- Chapter 70A.222[161] RCW: Packages Containing Metals and Toxic Chemicals Law.
- Chapter 70A.300[162] RCW and Chapter 173-303[163] Washington Administrative Code (WAC): Dangerous waste regulations.
- Chapter 173-333[164] WAC: Persistent Bioaccumulative Toxics (PBT) Chemical Action Plans (CAPs).
- Chapter 70A.430[165] RCW and Chapter 173-334[166] WAC: Children's Safe Products Act.
- Chapter 70A.350[167] RCW: Pollution Prevention for Healthy People and Puget Sound Act.

The following regulatory activities are in progress to address PFAS risk:

- Chapter 246-290[168] WAC: Considering setting drinking water standards for five PFAS in Group A Public Water Supplies.

Regulatory actions at the federal level include:

- Adopting voluntary phase out and stewardship programs to eliminate perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) from commerce in the U.S.
- Developing recommendations for addressing contaminated groundwater and establishing screening levels for PFOS and PFOA.
- Establishing Lifetime Drinking Water Health Advisory levels for PFOS and PFOA.
- Removing two PFAS from the list of approved substances for oil and water repellants for paper and paperboard for use in contact with food.
- Requiring reporting for certain PFAS under Toxics Release Inventory (TRI).
- Implementing various provisions related to military use of products containing PFAS.

[160] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true
[161] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222&full=true
[162] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.300&full=true
[163] https://apps.leg.wa.gov/wac/default.aspx?cite=173-303
[164] https://apps.leg.wa.gov/wac/default.aspx?cite=173-333
[165] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.430&full=true
[166] https://apps.leg.wa.gov/wac/default.aspx?cite=173-334
[167] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350&full=true
[168] https://apps.leg.wa.gov/wac/default.aspx?cite=246-290

9.0.2 Introduction

This appendix summarizes Washington state laws and regulations that currently apply to PFAS. The Washington State Department of Ecology (Ecology) administers state and federal laws designed to protect Washington's land, air, and water. Additional discussion is provided of drinking water rulemaking currently underway by the Washington State Department of Health (Health), and two executive orders which also address reducing PFAS exposure and risks. Federal regulations and guidance are also discussed. Finally, resources for understanding PFAS regulations elsewhere in the U.S. and other countries are provided.

Regulatory activity surrounding certain PFAS is developing rapidly. It is outside the scope of this CAP to identify all requirements beyond those applicable in Washington state.

9.1 Washington state laws and regulations

Several Washington state laws, regulations, and executive orders apply to specific PFAS or to PFAS as a class, as summarized in Table 79.

Table 79. Washington laws, regulations, and executive orders applicable to PFAS.

Regulation	Responsible agency	Reference
Pollution Prevention for Healthy People and Puget Sound Act Law	Ecology, in consultation with Health	Chapter 70A.350 RCW
Firefighting Agents And Equipment—Toxic Chemical Use Law	Ecology	Chapter 70A.400 RCW
Packages Containing Metals And Toxic Chemicals Law	Ecology	Chapter 70A.222 RCW
Children's Safe Products Act	Ecology, in consultation with Health	Chapter 70A.430 RCW
Dangerous Waste Regulations Rule	Ecology	Chapter 173-303 WAC
Persistent Bioaccumulative Toxins Rule	Ecology, in consultation with Health	Chapter 173-333 WAC
Children's Safe Products Act Reporting Rule	Ecology, in consultation with Health	Chapter 173-334 WAC
Group A Public Water Supplies Rule	Health	Chapter 246-290 WAC
Governor's Executive Order	All state agencies	EO 04-01
Governor's Executive Order	All state agencies	EO 18-01

9.1.1 Washington state laws

Chapter 70A.430 RCW

The Children's Safe Products Act (CSPA), Chapter 70A.430[169] RCW, authorized Ecology, in consultation with Health to develop a list of chemicals of high concern (CHCC) to children and a process for manufacturers to report on the presence of CHCCs in children's products. Manufacturers are required to annually report the presence of listed chemicals present in children's products sold in Washington state. Annual reports include the manufacturer name, product category and component, chemical function, and concentration. The Children's Safe Products Reporting Rule (WAC 173-334-130[170]) included PFOS in the list of CHCCs to children upon initial rule adoption in 2011. PFOA was added to the reporting list in 2017.

Chapter 70A.350 RCW

Chapter 70A.350[171] RCW, implemented through the Safer Products for Washington program,[172] creates a process for Ecology, in consultation with Health, to regulate classes of chemicals in consumer products. The law designates PFAS as a priority chemical class in the first five-year cycle of the program. The law requires Ecology, in consultation with Health, to designate priority chemicals, identify products that contain these chemicals, determine regulatory actions, and, if needed, adopt rules to implement regulatory actions. Chemical restrictions require that safer alternatives are feasible and available.

The law outlines steps that involve stakeholder consultation, legislative reporting, and rulemaking. Ecology published a draft report[173] in January 2020 and a final report[174] in July 2020 recommending priority consumer products for further research, including carpeting and rugs, aftermarket stain and water resistance treatments, and leather and textile furnishings containing PFAS.

Chapter 70A.400 RCW

Firefighting Agents and Equipment Toxic Chemical Use law (Chapter 70A.400[175] RCW) applies restrictions to Class B firefighting foam (i.e., PFAS-containing firefighting foam) and PFAS-containing firefighting personal protective equipment. PFAS in this law is defined as a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom. The law bans the use of PFAS-containing firefighting foam for training purposes by any user as of July 1, 2018. Starting in July 2020, purchase of PFAS-containing firefighting foam is not allowed by most users, including municipal fire departments. Exceptions to the purchase restrictions include federally required purchases (for example, military or federally certified airports), petroleum refineries, and chemical plants. The law requires notification to purchasers of

[169] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.430&full=true
[170] https://apps.leg.wa.gov/wac/default.aspx?cite=173-334-130
[171] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350&full=true
[172] https://ecology.wa.gov/Safer-Products-WA
[173] https://apps.ecology.wa.gov/publications/documents/2004004.pdf
[174] https://apps.ecology.wa.gov/publications/documents/2004019.pdf
[175] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

firefighting personal protective equipment if PFAS is used in that equipment and serves a protective function. Ecology is required to enforce these requirements.

In 2020, the law was amended in three ways (Engrossed Substitute H.B. 2265, 2020). First, the allowance for federal facilities (including Department of Defense (DOD) facilities and airports) to purchase PFAS-containing foam will end two years after federal regulations are amended to allow the use of non-PFAS foams. After that date, federal facilities will be required to use non-PFAS foams that comply with the new federal regulation.

Second, 18 months after the federal regulations change, airports will be required to inform Ecology about their ability to switch to non-PFAS foams and Ecology may provide additional time for them to comply with the non-PFAS foam requirements.

Finally, the restriction on purchases of PFAS-containing foams do not apply to oil terminals, oil refineries, and chemical plants until 2024, and extensions may be approved by Ecology under certain circumstances.

Chapter 70A.222 RCW

Packages Containing Metals and Toxic Chemicals law (Chapter 70A.222[176] RCW) prohibits PFAS in paper or paperboard food packaging where safer alternatives for specific applications have been determined to exist. PFAS in this law is defined as a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom. Ecology is required to identify whether safer alternatives to PFAS in food packaging are available, through the completion of an alternatives assessment. A ban on specific PFAS in food packaging takes effect in January 2022 if Ecology identifies that safer alternatives are available for those food packaging applications. If Ecology does not identify safer alternatives, Ecology must review its analysis annually and resubmit findings to the Legislature. The prohibition for specific food packaging applications takes effect two years after the submittal of Ecology's report.

9.1.2 Washington state rules

Chapter 173-303 WAC

Under state hazardous waste law (Chapter 70A.300[177] RCW), Washington regulates the designation, handling, and disposal of hazardous waste under the state's Dangerous Waste Regulations (WAC 173-303[178]). These regulations include a category of state-only dangerous waste based on either toxicity or persistence. Halogenated organic compounds are state-only persistent wastes. All PFAS are halogenated, therefore any waste containing PFAS at concentrations above 100 parts per million (ppm) designates as a state-only dangerous waste and must be handled and disposed as required by the Dangerous Waste Regulations. Appendix 3: Sources and Uses, Section 3.4.4 Dangerous waste disposal reports, provides a summary of dangerous waste disposal records submitted to Ecology reporting use of firefighting foams.

[176] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222&full=true
[177] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.300&full=true
[178] https://apps.leg.wa.gov/wac/default.aspx?cite=173-303

Chapter 173-333 WAC

Under the authority of 2004 c276, Executive Order (EO) 04-01, and state hazardous waste law (Chapter 70A.300[179] RCW), Ecology adopted a rule outlining the processes for efforts to reduce and phase out the uses, releases, and exposures to PBT chemicals. This rule includes a list of 28 PBT chemicals, chemical groups, or metals of concern to be considered for CAP development. PFOS and its salts are listed as a chemical group on the list of PBT chemicals in this rule. Table 80 summarizes these below.

Table 80. PFOS chemical group and selected salts identified in WAC 173-333-310.[180]

CAS Number	Substance	Formula	R-Group
1763-23-1	Perfluorooctane sulfonic acid (PFOS)	$C_8F_{17}SO_3H$	SO_3H
29081-56-9	Perfluorooctane sulfonic acid, ammonium salt	$C_8H_4F_{17}NO_3S$	SO_3NH_4
70225-14-8	Perfluorooctane sulfonic acid, diethanolamine salt	$C_{12}H_{12}F_{17}NO_5S$	$C_4H_{12}NO_5S$
29457-72-5	Perfluorooctane sulfonic acid, lithium salt	$C_8F_{17}SO_3Li$	SO_3Li
2795-39-3	Perfluorooctane sulfonic acid, potassium salt	$C_8F_{17}SO_3K$	SO_3K

Under the rule, Ecology consults with Health:

- To develop the PBT list.
- In creating a multi-year schedule for preparing caps.
- Regarding all portions of the CAP related to human health exposure.
- On public information materials addressing food safety issues.

Ecology and Health work together on CAP development, collaborating with an external advisory committee to identify, characterize, and evaluate uses and releases of PBTs. CAPs recommend actions to protect human health or the environment, including actions to reduce and phase out uses and releases of the PBT, such as through the use of safer alternatives. Ecology and Health have completed five CAPs: mercury, lead, polyaromatic hydrocarbons, flame retardants, and polychlorinated biphenyls.

[179] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.300&full=true
[180] https://apps.leg.wa.gov/wac/default.aspx?cite=173-333-310

Chapter 173-334 WAC

The Children's Safe Products Act (CSPA) (Chapter 70A.430[181] RCW) authorized Ecology, in consultation with Health to develop a CHCC list and a process for manufacturers to report on the presence of those chemicals in children's products. Ecology is responsible for collecting annual reports from manufacturers, maintaining an online database of reports received, enforcing compliance with the WAC, and taking the lead on administrative processes to revise the CHCC list. Ecology consults with Health during modifications of the CHCC list. The CSPA Reporting Rule chemical list includes PFOS and its salts, and PFOA and related substances in the list of 85 chemicals of high concern to children (WAC 173-334-130[182]). PFOS and its salts was included in the first list of reporting chemicals adopted in rule in 2011. PFOA and related substances was added to the reporting list in 2017.

Manufacturers are required to annually report the presence of PFOS or PFOA in children's products sold in Washington State. Annual reports include the manufacturer name, product category and component, chemical function, and concentration. Appendix 3: Sources and Uses, Section 3.3.1 PFAS in children's products, provides a summary of the PFOS and PFOA reported in children's products.

Chapter 246-290 WAC

In December 2017, the Washington State Board of Health started rulemaking for Chapter 246-290[183] WAC Group A Public Water Supplies, to consider setting a standard for certain PFAS. The draft rule released for public comment in November 2019 included state action levels for five PFAS: PFOA, PFOS, perfluorononanoic acid (PFNA), perfluorohexane sulfonate (PFHxS), and perfluorobutane sulfonate (PFBS). It also included requirements for testing and reporting results to the Department of Health and for public notification, follow-up monitoring, and other actions when PFAS are detected. The rulemaking is intended to improve public health protection by setting a regulatory standard for PFAS chemicals in Washington for Group A public water systems. See Appendix 7: Health for additional information.

9.1.3 Executive orders

EO 04-01

In 2004, Governor Locke issued EO 04-01, requiring Ecology to establish, through rulemaking, specific criteria for use in identifying persistent, toxic chemicals that pose human health or environmental impacts in Washington state, and a clear process for developing chemical action plans to address those impacts (EO 04-01, 2004). Ecology developed Chapter 173-333[184] WAC in response to this EO.

The EO also ordered the Department of General Administration's Office of State Procurement (now called Department of Enterprise Services) to make available for purchase and use by all

[181] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.430&full=true
[182] https://apps.leg.wa.gov/wac/default.aspx?cite=173-334-130
[183] https://apps.leg.wa.gov/wac/default.aspx?cite=246-290
[184] https://apps.leg.wa.gov/wac/default.aspx?cite=173-333

state agencies equipment, supplies, and other products that do not contain persistent, toxic chemicals unless there is no feasible alternative. State agencies were also ordered to reduce the use and purchase of products that contain PBT compounds (EO 04-01, 2004). As a result of the implementation of this EO, several state purchasing efforts have focused on reducing the presence of PBTs in state products. State purchasing preferences efforts related to PFAS have focused on PFAS-free carpet and food packaging (Simcich, 2020).

EO 18-01

In 2018, Governor Inslee issued EO 18-01, including the requirement that state agencies produce simple, clear, and targeted guidance that ensures agency compliance with environmentally preferable purchasing including opportunities for toxics reduction (EO 18-01, 2018).

9.2 Federal

Federal agencies that regulate PFAS include the Environmental Protection Agency (EPA), Food and Drug Administration (FDA), and Agency for Toxic Substances and Disease Registry (ATSDR). DOD is also required to track and reduce PFAS emissions resulting from its activities. The following EPA regulatory actions summarized in the Interstate Technology & Regulatory Council (ITRC) Fact Sheet (ITRC, 2020a) are not repeated in this document (refer to Appendix 7: Health or ITRC for more discussion):

- Lifetime health advisory of 70 nanograms per liter (parts per trillion) under the Safe Drinking Water Act (SDWA).
- Unregulated contaminant monitoring rule data under the SDWA.
- PFAS reported at 14 sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Since issuance of the Draft CAP in the fall of 2020, federal agencies and legislators have placed additional emphasis on acting on PFAS. The summary below primarily identifies adopted legislation and completed regulatory activity. It is not an exhaustive list of planned or ongoing PFAS-related activity by federal agencies.

9.2.1 Environmental Protection Agency

PFAS are not currently regulated under the Resource Conservation and Recovery Act (RCRA), nor the Clean Air Act (CAA) or through numeric standards under the Clean Water Act (CWA). Nevertheless, EPA has initiated various PFAS-related activities as articulated in its 2019 PFAS Action Plan (EPA, 2019a, 2020a). The plan includes four main actions:

- Initiating steps to evaluate the need for a maximum contaminant level (MCL) for PFOA and PFOS.
- Beginning the steps to propose designating PFOA and PFOS as “hazardous substances” through available federal statutory mechanisms.
- Developing groundwater cleanup recommendations for PFOA and PFOS at contaminated sites.

- Developing toxicity values or oral reference doses for Hexafluoropropylene oxide dimer acid (HFPO-DA, also known as GenX) chemicals and PFBS.

The plan also identifies actions related to the development of new analytical methods, promulgating Significant New Use Rules (SNURs), and using enforcement actions to help manage PFAS risk.

Voluntary actions

PFOS voluntary phase-out

The 3M Company, the only U.S. manufacturer of PFOS, voluntarily phased out manufacture and use of PFOS in the U.S. in 2000 (EPA, 2000). 3M substantially completed the phase out of PFOA and PFOS in its products in the U.S. by 2002 (3M, 2020; Rutherford, 2019). These PFAS were further regulated under the Toxic Substances Control Act (TSCA) as described below.

PFOA stewardship program

EPA and eight major fluoropolymer and fluorotelomer manufacturers established a Voluntary PFOA Stewardship Program in 2006. Participants include Arkema, Asahi Glass, Ciba (now BASF), Clariant (now Archroma), Daikin, DuPont, 3M/Dyneon, and Solvay Solexis. Manufacturers agreed to reduce PFOA, precursor chemicals, and related higher homologue chemicals by 95% no later than 2010. The agreement committed companies to work toward eliminating PFOA emissions and products by 2015. All participating companies state that they met the PFOA Stewardship Program goals (EPA, 2018).

Interim recommendations for addressing contaminated groundwater

On December 19, 2019, EPA issued interim recommendations for addressing groundwater contaminated with PFOA and/or PFOS at sites being evaluated and addressed under federal cleanup programs, including programs for cleanup under CERCLA and RCRA (EPA, 2019b). The guidance recommends:

- Using a screening level of 40 parts per trillion (ppt) to determine if PFOA and/or PFOS is present at a site and may warrant further attention.
- Using EPA's PFOA and PFOS Lifetime Drinking Water Health Advisory level of 70 ppt as the preliminary remediation goal (PRG) for contaminated groundwater that is a current or potential source of drinking water, where no state or tribal MCL or other applicable or relevant and appropriate requirements (ARARs) are available or sufficiently protective.

In July 2021, the House of Representatives passed the PFAS Action Act of 2021 (H.R. 2467[185]). As of July 2021, the Senate has not taken up companion legislation. Among other requirements, the PFAS Action Act of 2021 would require EPA to designate PFAS chemicals as hazardous substances under CERCLA within one year of enactment of the legislation.

[185] https://www.congress.gov/bill/117th-congress/house-bill/2467

CERCLA imposes liability on responsible parties for response costs incurred in the cleanup of sites contaminated with hazardous substances. Designating the family of PFAS chemicals as "hazardous substances" would trigger cleanups of contaminated groundwater under CERCLA.

Toxic Substances Control Act

Significant New Use Rules

Under the provisions of TSCA, EPA has issued Significant New Use Rules (SNUR), to require notification regarding use, or restricting the use, of certain PFAS as follows (EPA, 2020d):

- March 11, 2002: SNUR requiring notification to EPA before any future manufacture (including import) of 13 PFAS chemicals specifically included in the voluntary phase out of PFOS by 3M that took place between 2000 and 2002—allowing the continuation of a few specifically limited uses.
- December 9, 2002: SNUR requiring notification to EPA before any future manufacture (including import) of 75 PFAS chemicals specifically included in the voluntary phase out of PFOS by 3M that took place between 2000 and 2002—allowing the continuation of a few specifically limited uses.
- October 9, 2007: SNUR addressing 183 PFAS chemicals believed to no longer be manufactured (including imported) or used in the United States.
- October 22, 2013: SNUR requiring companies to report all new uses (including import) of certain PFOA related chemicals as part of carpets.
- January 2015: EPA proposed a SNUR requiring persons who import a subset of articles containing long-chain perfluoroalkyl carboxylate and perfluoroalkyl sulfonate (LCPFAC) substances (as well as their salts and precursors) to notify EPA (Significant New Use Rule, 2015). The supplement would narrow the application of the LCPFAC SNUR to the subset of articles where the LCPFAC are part of a surface coating.
- March 2, 2020: EPA published its proposed rule in the Federal Register regarding supplementation of its 2015 PFAS SNUR Significant New Use Rule (EPA Supplemental Proposal, 2020). The supplement would require importers to notify EPA at least 90 days before beginning the import of such articles. Upon notification, EPA would begin evaluation of the conditions of use. Manufacturing (including import) or processing for the use would be prohibited until EPA has conducted a review of the notice, made an appropriate determination on the notice, and taken such actions as are required in association with that determination. This SNUR became final in June 2020 (EPA, 2020e).

New Chemical Review

Since 2000, EPA has also reviewed substitutes for PFOA and PFOS and other long-chain PFAS under TSCA Section 5, New Chemical Program Review. EPA reviews the new substances to identify whether the range of toxicity, fate, and bioaccumulation issues that have caused past concerns with PFAS may be present, as well as any issues that may be raised by new chemistries, in order to ensure that the new chemical may not present an unreasonable risk to health or the environment (EPA, 2020f). For those substances allowed to be manufactured or to enter the market, EPA issues TSCA Section 5(e) consent orders. These consent orders establish, for example, conditions on testing, release monitoring, and use specification. As of March and

April 2021, EPA is implementing new review processes to address potential chemical risks, and on issuing low volume exemptions respectively (EPA, 2021b, 2021c).

National Defense Authorization Act (NDAA) for Fiscal Year 2020

The NDAA includes PFAS-related mandates for both EPA and DOD. Section 9.2.4 below addresses DOD requirements.

Effective January 1, 2020, Section 7321 of the NDAA includes 172 PFAS in the TRI, which are subject to TRI reporting due July 2021 for calendar year 2020 data (EPA 2020b; EPA, 2020c). The NDAA establishes TRI manufacturing, processing, and otherwise use reporting thresholds of 100 pounds for each of the listed PFAS. EPA revised the Emergency Planning and Community Right to Know Act (EPCRA) Section 313 list of reportable chemicals in the Code of Federal Regulations (CFR)[186] to include the 172 PFAS in June 2020 (EPA, 2020i). Additionally, the NDAA provides a framework for PFAS to be added automatically to the TRI list on January 1 of the year following certain EPA actions (NDAA Section 7321(c)). For example, the NDAA automatically adds a PFAS to the TRI list in response to the EPA finalizing a toxicity value for it. In June 2021, EPA issued a final rule incorporating three additional PFAS to the TRI list[187] as a result of their being subject to a SNUR under TSCA (EPA, 2021h). Reporting for these three PFAS will be due by July 2022. The NDAA also instructs EPA to consider certain other PFAS for possible addition to the TRI list (EPA, 2020c).

Finally, EPA is directed to issue a "data rule" pursuant to section 8(a) of TSCA by January 1, 2023, requiring PFAS manufacturers to submit existing information concerning the environmental and health effects and estimates of the number of people exposed to each PFAS. EPA initiated rule development on this requirement in July 2021 (EPA, 2021a).

Other regulatory activity

Ecology and Health continue to track ongoing regulatory activity by EPA, including (but not limited to) study results, guidance, data collection, analytical method development, and notices of rulemaking. Recent examples of such activity include:

- EPA recommendations regarding PFAS related conditions in EPA-issued NPDES permits (EPA, 2020g). (It should be noted, however, that these recommendations would not apply to Ecology-issued NPDES permits in Washington state.)
- Draft interim guidance on the destruction and disposal of PFAS and materials containing PFAS (EPA, 2020h).
- EPA studies of PFAS industrial sources and discharges (EPA, 2021d).
- Proposed fifth Unregulated Contaminant Monitoring Rule (UCMR5), which would provide data about 29 PFAS in the nation's drinking water systems sampled during a 12-month period from January 2023 through December 2025 (EPA, 2021e).

[186] https://www.govinfo.gov/content/pkg/FR-2020-06-22/pdf/2020-10990.pdf
[187] https://www.federalregister.gov/documents/2021/06/03/2021-11586/implementing-statutory-addition-of-certain-per--and-polyfluoroalkyl-substances-pfas-to-the-toxics

- Final regulatory determinations to regulate PFOA and PFOS in order to begin the process to propose and promulgate a national primary drinking water standard activity (EPA, 2021f).
- Proposed rulemaking—CWA effluent limitations guidelines and standards for the organic chemicals, plastics, and synthetic fibers point source category (EPA, 2021g).

9.2.2 Food and Drug Administration (FDA)

The FDA regulates the safety of food, drugs, and cosmetics under the Federal Food, Drug, and Cosmetic Act (U.S. Code Title 21, Chapter 9). Ingredients added to food and indirect food additives regulated under the Food, Drug and Cosmetics Act include substances that migrate from food packaging materials (FDA, 2017). Since the 1960s, PFAS have been used as grease-proofing agents for food packaging such as fast-food wrappers, to-go boxes, and pizza boxes.

The FDA currently authorizes the use of PFAS in four application categories (FDA, 2020a):

- Non-stick cookware.
- Gaskets and o-rings used as a resin in forming certain parts used in food processing equipment where chemical and physical durability are necessary.
- As processing aides for manufacturing food contact polymers to reduce build-up on manufacturing equipment.
- As grease-proofing agents in fast food and pet food paper packaging applications.

In 2011, the FDA and several manufacturers reached a voluntary agreement to stop interstate distribution of products containing long-chain PFAS (FDA, 2017). In 2016, because the industry had discontinued the use, two PFAS were removed from the list of approved substances for oil and water repellants for paper and paperboard for use in contact with food (FDA, 2016). In July 2020, the FDA announced the voluntary phase-out of short-chain per- and polyfluoroalkyl substances (PFAS) that contain 6:2 fluorotelomer alcohol (6:2 FTOH) which may be found in certain food contact substances used as grease-proofing agents on paper and paperboard food packaging (FDA, 2020b). Three manufacturers agreed to a three-year phase-out of their sales of compounds that contain 6:2 FTOH for use as food contact substances in the U.S. beginning in 2021. It may take up to 18 months to exhaust existing stocks of products containing these food contact substances from the market following the three-year phase-out.

9.2.3 Agency for Toxic Substances and Disease Registry (ATSDR)

The ATSDR, under the U.S. Department of Health and Human Services, is an advisory health agency, working with other federal agencies, state and local jurisdictions, tribes, and healthcare providers. Its focus includes preventing harmful exposures to hazardous substances using the best science, taking responsive public health actions, and providing trusted health information to prevent harmful exposures and diseases related to toxic substances. In June 2018, ATSDR released a draft Toxicological Profile for 15 PFAS (ATSDR 2018). See Appendix 7: Health for more information.

9.2.4 Department of Defense

The NDAA included PFAS-related provisions related to military use of products containing PFAS chemicals. The legislation included (State Energy & Environmental Impact Center, 2020):

- Phasing out the use of AFFF after October 1, 2024, except where it is used on ships, in emergency responses, and in limited testing and training circumstances.
- Establishing conditions for incineration of AFFF, and how wastes from such destruction are to be managed.
- Requiring blood testing for PFAS chemicals as part of routine physicals for military firefighters.
- Authorizing DOD to temporarily supply uncontaminated water or treated water to agricultural users whose irrigation water is contaminated with PFAS chemicals from military installations, as well as acquire property within the vicinity of an Air Force base that has shown signs of contamination due to activities at the base.
- Promoting cooperation on and monitoring of PFAS contamination in water supplies with local and state governments.
- Requiring EPA to take action on PFAS chemicals under TSCA, and promulgating a rule to require any manufacturer that has produced PFAS chemicals since 2011 to maintain records and report on the production of PFAS chemicals under TSCA. EPA initiated rule development on this requirement in July 2021 (EPA, 2021a).
- Banning the use of PFAS chemicals in packaging of military field food rations after October 1, 2021.

Various branches of DOD have also implemented many initiatives to address PFAS contamination issues. For example, the Department of the Navy is implementing a comprehensive strategy to manage and address PFAS in drinking water on and off Navy installations, cleanup of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) contaminated sites, and destruction of legacy AFFF (DON, 2017). The strategy includes:

- Controlling, removing, and disposing AFFF (DON, 2016). The Department of the Navy intends to remove, dispose, and replace legacy AFFF that contains PFOS or PFOA once environmentally suitable substitutes are certified to meet MIL-SPEC requirements.
- Identifying potential areas of concern from use of AFFF for fire and emergency response and test and training activities.
- Testing for PFOS and PFOA in Navy public water systems to determine if PFAS are known or suspected to have been released within one mile of the water source.

In 2019, DOD established a task force to address PFAS issues related to its installations nationwide (DOD, 2019). The task force has focused on three goals (DOD, 2020):

- Mitigating and eliminating the use of the current AFFF.
- Understanding the impacts of PFAS on human health.
- Fulfilling its cleanup responsibility related to PFAS.

Research is being funded by DOD in many areas—for example, through its environmental research programs, the Strategic Environmental Research and Development Program (SERDP), and the Environmental Security Technology Certification Program (ESTCP) (SERDP, 2020).

9.3 Other U.S. PFAS regulations and advisories

There are many PFAS regulations, advisories, and criteria, and they are changing rapidly. The ITRC fact sheet on regulations and guidance provides a summary. Supplemental tables to this fact sheet are updated to track changes in state and federal criteria and guidance:

- ITRC PFAS regulations, guidance, and advisories fact sheets (ITRC, 2020a).
- ITRC PFAS Basis for PFOA and PFOS Values in Water established by ten U.S. states and Canada (ITRC, 2020b).
- Water and soil tables of regulations, guidance and advisories for PFAS by 23 U.S. states and 12 nations (ITRC, 2020c).

PFAS-related activities in other U.S. States have also been summarized by the Environmental Council of the States (ECOS) and the National Conference of State Legislatures (NCSL) (ECOS, 2020; NCSL, 2020). The EPA website also compiles state PFAS resource information.[188] For example, in addition to developing standards or guidance for certain PFAS in in drinking water, groundwater, surface water, and soil, states have adopted requirements to report the presence of certain PFAS in consumer products, restrict certain PFAS in firefighting foam applications, and implement fish consumption advisories.

9.4 International

ITRC tables described in Section 9.3 above identify international standards or guidance for PFAS in drinking water, groundwater, surface water, and soil. The OECD also maintains a list of PFAS risk reduction strategies, including regulations, implemented by countries around the world.[189]

[188] https://www.epa.gov/pfas/us-state-resources-about-pfas
[189] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/

9.5 Data gaps and recommendations

9.5.1 Data Gaps

There are no data gaps specific to Washington state regulatory activity on PFAS. Additional information collected as a result of CAP recommendations may clarify whether additional regulatory action is required to minimize PFAS risks.

9.5.2 Recommendations

The following is a summary of recommendations in this CAP which may require legislative or agency regulatory action.

- Recommendation 3.3: Propose a ban on sale or import of products containing long-chain PFAAs in Washington state.
- Recommendation 3.3: Consider PFAS as a class when the list of chemicals of high concern to children (WAC 173-334-130[190]) is updated
- Recommendation 4.1: If study results warrant, Ecology could require that domestic or industrial wastewater treatment plants monitor for PFAS.
- Recommendation 4.2: If study results warrant, Ecology could update Chapter 173-350[191] WAC to require PFAS testing of leachate and landfill monitoring.

[190] https://apps.leg.wa.gov/wac/default.aspx?cite=173-334-130
[191] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350

References

3M. (2020). 3M's Commitment to PFAS Stewardship. Retrieved from https://www.3m.com/3M/en_US/pfas-stewardship-us/pfas-history/

Agency for Toxic Substances and Disease Registry (ATSDR). (2018). Toxicological profile for Perfluoroalkyls. (Draft for Public Comment). Retrieved from https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=1117&tid=237

Chapter 70A.222 RCW: Packages Containing Metals and Toxic Chemicals

Chapter 70A.350 RCW: Pollution Prevention for Healthy People and Puget Sound Act

Chapter 70A.400 RCW: Firefighting Agents and Equipment—Toxic Chemical Use

Chapter 70A.430 RCW: Children's Safe Products

Chapter 173-303 WAC: Dangerous Waste Regulations

Chapter 173-333 WAC: Persistent Bio accumulative Toxins

Chapter 173-334 WAC: Children's Safe Products Reporting Rule

Chapter 246-290 WAC: Group A Public Water Supplies Rule

Engrossed Substitute H.B. 2265, 66th Leg., Reg. Sess. (Wash. 2020)

Environmental Council of the States (ECOS). (2020). ECOS White Paper: Processes and Considerations for Setting State PFAS Standards. Retrieved from https://www.ecos.org/documents/ecos-white-paper-processes-and-considerations-for-setting-state-pfas-standards/

Executive Order 04-01: Persistent Toxic Chemicals

Executive Order 18-01: State Efficiency and Environmental Performance

Indirect food additives: paper and paperboard components, 81 Fed. Reg. 83672 (2016) (to be codified at 21 C.F.R pt. 176)

Interstate Technology & Regulatory Council (ITRC). (2020a). Regulations, guidance, and advisories for per- and polyfluoroalkyl substances (PFAS). Retrieved from https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_Regulations_April2020.pdf

Interstate Technology & Regulatory Council (ITRC). (2020b). Basis for PFOA and PFOS Values in Water established by 10 U.S. states and U.S. and Canada. Retrieved from https://pfas-1.itrcweb.org/fact_sheets_page/ITRCPFASBasisTables_March2020.xlsx

Interstate Technology & Regulatory Council (ITRC). (2020c). Water and Soil Tables of Regulations, Guidance and Advisories for PFAS by 23 U.S. states and 12 nations. Retrieved from https://pfas-1.itrcweb.org/wp-content/uploads/2020/06/ITRCPFASWaterandSoilValuesTables_May2020.xlsx

National Defense Authorization Act for Fiscal Year 2020, S. 1790, 116th Cong. (2019)

National Conference of State Legislatures (NCSL). (2020). Per- and polyfluoroalkyl Substances (PFAS) | State Legislation. Accessed 3-20-2020 from https://www.ncsl.org/research/environment-and-natural-resources/per-and-polyfluoroalkyl-substances-pfas-state-laws.aspx

Rutherford, D. (2019). Hearing on "The Devil They Knew: PFAS Contamination and the Need for Corporate Accountability, Part II." Retrieved from https://docs.house.gov/meetings/GO/GO28/20190910/109902/HHRG-116-GO28-20190910-QFR017.pdf

Significant New Use Rule: Long-Chain Perfluoroalkyl Carboxylate and Perfluoroalkyl Sulfonate Chemical Substances, 80 Fed. Reg. 13 (2015) (to be codified at 40 C.F.R. pt. 721)

Significant New Use Rule, Supplemental Proposal: Long-Chain Perfluoroalkyl Carboxylate and Perfluoroalkyl Sulfonate Chemical Substances, 85 Fed. Reg. 42 (2020) (to be codified at 40 C.F.R. pt. 721)

Simcich, T. (2020). Personal Communication. Meeting with Irina Makarow, Washington Department of Ecology, and Tina Simcich, Washington Department of Ecology, Solid Waste Management program. February 28, 2020.

State Energy & Environmental Impact Center. (2020). PFAS Federal Legislation. *NYU School of Law.* Retrieved from https://www.law.nyu.edu/centers/state-impact/press-publications/research-reports/pfas-federal-legislation#a60,

Strategic Environmental Research and Development Program (SERDP), & Environmental Security Technology Certification Program (ESTCP). (2020). SERDP and ESTCP Efforts on PFAS. Retrieved from https://map.serdp-estcp.org/Featured-Initiatives/Per-and-Polyfluoroalkyl-Substances-PFASs/pfas_efforts.pdf

U.S. Department of Defense (DOD). (2019). Per- and Polyfluoroalkyl Substances Task Force. Retrieved from https://media.defense.gov/2019/Aug/09/2002169524/-1/-1/1/PER-AND-POLYFLUOROALKYL-SUBSTANCES-TASK-FORCE.PDF

U.S. Department of Defense (DOD). (2020). Per- and Polyfluoroalkyl Substances (PFAS) Task Force Progress Report March 2020. Retrieved from https://media.defense.gov/2020/Mar/13/2002264440/-1/-1/1/PFAS-TASK-FORCE-PROGRESS-REPORT-MARCH-2020.PDF

U.S. Department of the Navy (DON). (2016). Aqueous Film Forming Foam (AFFF) Control, Removals and Disposal. Retrieved from http://www.secnav.navy.mil/eie/Documents/Aqueous-Film-Forming-Foam-(AFFF)-Control-Removal-and-Disposal-(1).pdf

U.S. Department of the Navy (DON). (2017). Department of the Navy (DON) is implementing a comprehensive strategy to manage and address Perfluorinated Compounds (PFC)/Perfluoroalkyl Substances (PFAS) issues. Retrieved from https://www.secnav.navy.mil/eie/Pages/PFC-PFAS.aspx

U.S. Environmental Protection Agency (EPA). (2000). *EPA and 3M Announce Phase Out of PFOS*. https://archive.epa.gov/epapages/newsroom_archive/newsreleases/33aa946e6cb11f35852568e1005246b4.html

U.S. Environmental Protection Agency (EPA). (2018). Fact Sheet: 2010/2015 PFOA Stewardship Program. Retrieved from https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program

U.S. Environmental Protection Agency (EPA). (2019a). EPA's per- and Polyfluoroalkyl Substances (PFAS) Action Plan. Retrieved from https://www.epa.gov/sites/production/files/2019-02/documents/pfas_action_plan_021319_508compliant_1.pdf

U.S. Environmental Protection Agency (EPA). (2019b). Interim Recommendations to Address Groundwater Contaminated with Perfluorooctanoic Acid and Perfluorooctanesulfonate. Retrieved from https://www.epa.gov/sites/production/files/2019-12/documents/epas_interim_recomendations_for_addressing_groundwater_contaminated_with_pfoa_and_pfos_dec_2019.pdf

U.S. Environmental Protection Agency (EPA). (2020a). EPA PFAS Action Plan: Program Update. Retrieved from https://www.epa.gov/sites/production/files/2020-01/documents/pfas_action_plan_feb2020.pdf

U.S. Environmental Protection Agency (EPA). (2020b). Chemicals Added to the Toxics Release Inventory Pursuant to Section 7321 of the National Defense Authorization Act. Retrieved from https://www.epa.gov/sites/production/files/2020-02/documents/tri_non-cbi_pfas_list_2_19_2020_final_clean.pdf

U.S. Environmental Protection Agency (EPA). (2020c). Addition of Certain PFAS to the TRI by the National Defense Authorization Act. Retrieved on March 20, 2020 from https://www.epa.gov/toxics-release-inventory-tri-program/addition-certain-pfas-tri-national-defense-authorization-act

U.S. Environmental Protection Agency (EPA). (2020d). Risk Management for Per- and Polyfluoroalkyl Substances (PFAS) under TSCA. Retrieved on July 7, 2020 from https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfas

U.S. Environmental Protection Agency (EPA). (2020e). Long-Chain Perfluoroalkyl Carboxylate and Perfluoroalkyl Sulfonate Chemical Substances; Significant New Use Rule (Final). Retrieved from https://www.epa.gov/sites/production/files/2020-06/documents/10010-44_prepubcopy_fr_doc_epa_admin_esign_2020-06-22final.pdf

U.S. Environmental Protection Agency (EPA). (2020f). New Chemicals Program Review of Alternatives for PFOA and Related Chemicals. Retrieved from https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/new-chemicals-program-review-alternatives-pfoa-and

U.S. Environmental Protection Agency (EPA). (2020g). New Interim Strategy will address PFAS through Certain EPA-Issued Wastewater Permits. November 30, 2020. Retrieved from https://www.epa.gov/newsreleases/new-interim-strategy-will-address-pfas-through-certain-epa-issued-wastewater-permits

U.S. Environmental Protection Agency (EPA). (2020h). Draft Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances, December 18, 2020. Retrieved from https://beta.regulations.gov/docket/EPA-HQ-OLEM-2020-0527/document

U.S. Environmental Protection Agency (EPA). (2020i). Implementing Statutory Addition of Certain Per- and Polyfluoroalkyl Substances; Toxic Chemical Release Reporting. Volume 85 Federal Register 37354. Retrieved from https://www.govinfo.gov/content/pkg/FR-2020-06-22/pdf/2020-10990.pdf

U.S. Environmental Protection Agency (EPA. (2021a). Reporting and Recordkeeping for Perfluoroalkyl and Polyfluoroalkyl Substances under Section 8(a) of the Toxic Substances Control Act. June 27, 2021. Rulemaking Docket EPA-HQ-OPPT-2020-0549. Retrieved from https://www.regulations.gov/docket/EPA-HQ-OPPT-2020-0549

U.S. Environmental Protection Agency (EPA). (2021b) Important Updates on EPA's TSCA New Chemicals Program. March 29, 2021. Retrieved from https://www.epa.gov/chemicals-under-tsca/important-updates-epas-tsca-new-chemicals-program

U.S. Environmental Protection Agency (EPA). (2021c). EPA Announces Changes to Prevent Unsafe New PFAS from Entering Market. April 27, 2021. Retrieved from https://www.epa.gov/chemicals-under-tsca/epa-announces-changes-prevent-unsafe-new-pfas-entering-market

U.S. Environmental Protection Agency (EPA). (2021d). Effluent Guidelines Program Plan 14. January 2021. Retrieved from https://www.epa.gov/sites/production/files/2021-01/documents/eg-plan-14_jan-2021.pdf

U.S. Environmental Protection Agency (EPA). (2021e). Fifth Unregulated Contaminant Monitoring Rule. Retrieved from https://www.epa.gov/dwucmr/fifth-unregulated-contaminant-monitoring-rule

U.S. Environmental Protection Agency (EPA). (2021f). Announcement of the Final Regulatory Determinations for Contaminants on the Fourth Drinking Water Contaminant Candidate List. Dockets EPA-HQ-OW-2019-0583 and FRL – 10019-70-OW. March 3, 2021. Retrieved from https://www.federalregister.gov/documents/2021/03/03/2021-04184/announcement-of-final-regulatory-determinations-for-contaminants-on-the-fourth-drinking-water

U.S. Environmental Protection Agency (EPA). (2021g). Advance notice of proposed rulemaking. Clean Water Act Effluent Limitations Guidelines and Standards for the Organic Chemicals, Plastics and Synthetic Fibers Point Source Category. Dockets EPA-HQ-OW-2020-0582 and FRL 10019-06-OW. March 17, 2021. Retrieved from https://www.federalregister.gov/documents/2021/03/17/2021-05402/clean-water-act-effluent-limitations-guidelines-and-standards-for-the-organic-chemicals-plastics-and

U.S. Environmental Protection Agency (EPA). (2021h). Implementing Statutory Addition of Certain Per- and Polyfluoroalkyl Substances (PFAS) to the Toxics Release Inventory Beginning With Reporting Year 2021. Volume 86 Federal Register 29698. Retrieved from https://www.federalregister.gov/documents/2021/06/03/2021-11586/implementing-statutory-addition-of-certain-per--and-polyfluoroalkyl-substances-pfas-to-the-toxics

U.S. Food and Drug Administration (FDA). (2017). Packaging and Food Contact Substances (FCS). Retrieved from https://www.fda.gov/Food/IngredientsPackagingLabeling/PackagingFCS/default.html

U.S. Food and Drug Administration (FDA). (2020a). Authorized uses of PFAS in food contact applications. October 20, 2020. Retrieved from https://www.fda.gov/food/chemical-contaminants-food/authorized-uses-pfas-food-contact-applications

U.S. Food and Drug Administration (FDA). (2020b). FDA Announces the Voluntary Phase-Out by Industry of Certain PFAS Used in Food Packaging. July 31, 2020. Retrieved from https://www.fda.gov/food/cfsan-constituent-updates/fda-announces-voluntary-phase-out-industry-certain-pfas-used-food-packaging

List of acronyms

General acronyms

Table 81. Acronyms found in the regulations appendix.

Acronym	Definition
ARARs	Applicable or relevant and appropriate requirements
ATSDR	United States Agency for Toxic Substances and Disease Registry
CAA	Clean Air Act
CAP	Chemical Action Plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHCC	Chemicals of High Concern to Children
CSPA	Children's Safe Products Act
CWA	Clean Water Act
DOD	United States Department of Defense
Ecology	Washington State Department of Ecology
ECOS	Environmental Council of the States
EO	Executive Order
EPA	United States Environmental Protection Agency
EPCRA	Emergency Planning and Community Right to Know Act
FCN	Food contact notification
FDA	United States Food and Drug Administration
Health	Washington State Department of Health
ITRC	Interstate Technology & Regulatory Council
MCL	Maximum contaminant level
NCSL	National Conference of State Legislatures
NDAA	National Defense Authorization Act
OECD	Organisation for Economic Co-operation and Development
PBT	Persistent Bioaccumulative Toxic
ppm	Parts per million
ppt	Parts per trillion
PRG	Preliminary remediation goal
RCRA	Resource Conservation and Recovery Act
RCW	Revised Code of Washington
SDWA	Safe Drinking Water Act
SNUR	Significant new use rule
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
UCMR5	Fifth Unregulated Contaminant Monitoring Rule
U.S.	United States of America
WAC	Washington Administrative Code

Chemical Names

Table 82. Chemical name acronyms found in the regulations appendix, excluding the acronyms listed in the table above.

Acronym	Chemical Name
6:2 FTOH	6:2 fluorotelomer alcohol
HFPO-DA (GenX)	Hexafluoropropylene oxide dimer acid
LCPFAC	Long-chain perfluoroalkyl carboxylate and perfluoroalkyl sulfonate
PFAS	Per and polyfluorinated alkyl substances
PFBS	Perfluorobutane sulfonate
PFHxS	Perfluorohexane sulfonate
PFNA	Perfluorononanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOA	Perfluorooctanoic acid

Appendix 10: Economic Analysis

10.0 Overview

10.0.1 Findings

Information about the costs of actions to reduce per- and polyfluoroalkyl substance (PFAS) exposure is limited, due to limited understanding about the extent and characteristics of PFAS contamination statewide, and the variability and often site-specific nature of actions considered. Some PFAS contamination is known and well characterized, while overall statewide contamination and associated cleanup actions are likely to be highly variable and require ongoing sampling and testing to fully characterize.

Moreover, the current status of mitigating ongoing impacts of contamination offers limited insight into overall costs of complete cleanup. Similarly, extent and understanding of the human health impacts of PFAS contamination are variable, and testing depends on factors ranging from individual test costs and bulk discounts, to affected population and duration of exposure before mitigation measures are taken. Public involvement and education can take many forms, and depends on the attributes and needs of the affected population. Finally, understanding of known existing sources and potential actions to reduce exposure suffers from limited information that clearly identifies products containing PFAS (or what kinds of PFAS they contain).

In light of these limitations, we have sought to provide what information is available. For some actions, this allowed for full quantification of some potential costs. For others, only illustrative examples were possible. Overall, potential costs of PFAS remediation and exposure mitigation are likely very significant, and beg the question of whether cleanup or ongoing mitigation is most feasible. Characterizing the extent of the problem, such as testing landfill leachate, is less costly, but does not include the costs of any necessary cleanup or other action identified as a result.

The greatest uncertainty in costs surrounds product purchasing, due to limited or absent ability to identify whether current products contain PFAS, and what PFAS-free alternatives are available. Absent testing, we were not able to identify which paints in state contracts contain PFAS. To the extent that shifting to consumer products labeled as more environmentally friendly, such as cleaning products and floor coverings, coincides with a shift away from PFAS-containing products, some products may double in price. Changing purchasing priorities for floor covering purchases in state and municipal contracts could increase costs by millions of dollars.

10.0.2 Introduction

The Persistent Bioaccumulative Toxins rule (Washington Administrative Code (WAC) 173-333(3)[192]) requires that, as part of any Chemical Action Plan (CAP), the Washington State Departments of Ecology (Ecology) and Health (Health) should "identify costs of implementing the recommendations. This may include a qualitative and/or quantitative analysis of the probable benefits and costs of the CAP." This appendix is intended to meet these requirements. Here, we identify and estimate, to the extent possible, the costs of implementing the recommendations of the CAP. Where possible, we identify the resulting costs and benefits of implementing the recommendations.

Cost estimates in this appendix include external costs borne by parties other than Ecology or Health, which would not be funded through agency budget requests. Recommendations presented in the CAP identify estimates of agency implementation costs that could potentially be funded through additional budget allocations.

Our analyses compare potential actions to the current situation where no action is taken. This is the baseline, and it reflects legal requirements that exist regardless of whether proposed actions are taken (e.g., state dangerous waste regulations). The baseline can also include actions that are already planned or occurring (e.g., ongoing removal, disposal, and replacement of aqueous film forming foam (AFFF) at military facilities).

Because of developing knowledge about PFAS—from scientific research, to testing and identification, to understanding the extent of use and contamination—our ability to fully quantify implementation costs and resulting costs and benefits is limited. Where full quantification (total costs or benefits) was not possible, we have included what partial quantification was possible, such as unit costs, costs per event, or costs per firm. Where no quantification was possible, we have included qualitative discussion of impacts.

Recommended actions analyzed

- Action 1.1: Identify funding for PFAS drinking water mitigation.
- Action 1.2: Technical support for site characterization, source investigation, and mitigation at contaminated sites.
    - Ecology will continue to collaborate with and provide technical assistance to involved parties at PFAS contamination sites in the state. These efforts will help to better understand the sources, composition, and distribution of PFAS contamination in soil and water. This work will also inform evaluation of appropriate cleanup actions and their costs.
- Action 1.3: Support biomonitoring to support impacted residents and help answer important health questions.
- Action 2.2: Partner with local organizations in communities with contaminated water or contaminated sites.
- Action 2.3: Work to prevent PFAS releases from AFFF use and manufacturing processes.

[192] https://apps.leg.wa.gov/wac/default.aspx?cite=173-333

    - Ensure that industrial use of AFFF provides for containment procedures along with collection of AFFF and contaminated soil or sediment for proper designation and disposal. Costs to industrial users to collect and dispose of released PFAS-containing AFFF include plan development, employee training, methods for containment, and disposal of waste.
- Action 3.1: Reduce PFAS exposure from carpet and rugs, water and stain resistance treatments, and leather and textile furnishings.
    - Implement a purchasing preference policy for PFAS-free carpet. Work with vendors on the flooring contract to offer PFAS-free carpet on all state master contracts and all agency contracts.
- Action 3.3: Implement other reduction actions for PFAS in products.
    - Establish a purchasing preference policy for products free of intentionally added PFAS. Work with vendors to offer PFAS-free textiles, furniture, and paints. If possible, select products that do not have stain- or water-resistance, or use safer alternatives. Apply this policy to all state master contracts and all agency contracts.
- Action 4.2: Evaluate PFAS in landfill leachate.
    - For this action, Ecology would consider adding requirements for PFAS testing, monitoring, and reporting for landfill leachate emissions.

Additional options analyzed

In developing this CAP, Ecology considered additional actions that were ultimately not recommended. They include:

- Requiring municipal wastewater treatment plants (WWTPs) to test influent and effluent.
- Recommending that the Legislature require alternatives assessments for specific products.

10.1 Costs of recommended actions

Action 1.1 Identify funding for PFAS drinking water mitigation

When concentrations of PFAS above the health advisory are detected in a drinking water supply, mitigation is required to bring drinking water quality back into compliance. Mitigation activities incur unanticipated costs to water utilities in a variety of ways, including but not limited to:

- Emergency response to continue providing water services.
- Site-specific investigations to determine the location, extent, and source of PFAS contamination.
- Information campaigns to notify affected water users.
- Identification and development of appropriate technologies to reduce or remove contaminants in order to meet drinking water quality standards.
- Implementation and maintenance of such measures in the short and long term.
- Costs associated with disposal of waste streams containing PFAS resulting from drinking water treatment.

In the short term, clean water may need to be supplied by purchase of drinking water from a neighboring system or distribution of bottled water to customers. Longer term mitigation measures focus on finding and accessing more permanent clean water sources or installing additional equipment, such as an expensive filtration system to remove PFAS, to treat water to meet applicable standards (see Appendix 4: Fate and Transport, Section 4.4). Without funding to defray these costs, regulated water systems and their ratepayers must absorb the costs of response.

Total site specific or statewide costs for PFAS mitigation in drinking water will not be known until further water testing defines the scope of the problem in Washington state. At this time, a few illustrative examples of costs of drinking water mitigation are available. Some examples do not separate the investigation costs.

- The City of Issaquah spent $600,000 to install a treatment system on one PFAS-contaminated city well. Filter maintenance and monitoring also require ongoing expenditures of $56,000 per year (York, 2020).
- The Sammamish Plateau Water and Sewer District has incurred testing and modeling costs in excess of $510,000 (Krauss, 2020). The District is funding an $800,000 project to design a PFAS treatment plant in response to the proposed Health SALs. Ultimate construction of a PFAS removal treatment plant is estimated to be $6 to $7 million dollars. The District has also incurred additional costs to replace water supply from wells that were removed from production due to PFAS contaminant levels.
- The Department of Navy (DON) spent $9.8 million to add granular activated carbon (GAC) treatment to the Town of Coupeville's water system and connect impacted private well owners to the Town's water system near Naval Air Station Whidbey Island, Outlying Landing Field (OLF) Coupeville. As of January 2021, the DON has also spent over $14 million for PFAS investigation and other drinking water mitigation efforts (Ginn, 2021).
- In response to PFAAs detection in April 2017, the public water system of Airway Heights shut down their contaminated wells and used an emergency intertie with the City of Spokane water system to flush their system with clean water. Flushing included draining reservoirs and water towers. During the flushing, Fairchild AFB provided bottled water to water customers. Airway Heights has since added another connection to the City of Spokane to supply drinking water while they pursue treatment options for the contaminated wells. This water purchase could cost over $687,000 in the first year, for over 439 million gallons of drinking water, for which the Air Force has agreed to pay the city (Sokol, 2017).
- As of late 2020, the Lakewood Water District is designing and implementing GAC treatment systems for four well systems producing more than 5 million gallons per day, which serve both the District and neighboring drinking water purveyors who purchase water on a wholesale basis. The District reports that initial construction costs to implement the systems exceeds $21 million, including design, permitting, and construction management in addition to capital costs (Black, 2020). Following system installation, the District estimated it would incur operating costs and GAC replacement costs, respectively estimated at $340 million and $1.1 billion over the next 50 years.

- At Joint Base Lewis McChord, McChord Field System, treatment of water from three wells, using activated carbon filtration, is estimated to cost $10.3 million in initial capital costs, with ongoing operating and maintenance costs of $830,000 per year (Health, 2021).

These costs are in line with similar drinking water remediation activities in other states. For example, Moose Creek, Alaska, has already incurred $3.5 million for a granular activated carbon system to treat drinking water sourced from groundwater contaminated by AFFF releases at Eielson Air Force Base (Gardner, 2019). The Pentagon will pay $30 million to extend the municipal water system from a neighboring community to Moose Creek (Ellis, 2020; DeFazio & Tynan, 2019). Average capital costs of $2 per gallon of drinking water treated to remove PFAS have been reported based on water purveyor surveys conducted in collaboration with the North East Biosolids & Residuals Association, the Water Environment Federation, and the National Association of Clean Water Agencies (CDM Smith, 2020).

Action 1.2: Technical support for site characterization, source investigation, and mitigation at contaminated sites

Parties that released PFAS into the environment are responsible for cleaning it up and may also need to reimburse the water purveyor or Ecology for cleanup or exposure-mitigation activities. As part of the cleanup process, Ecology establishes cleanup levels, which are concentrations of hazardous substances in the environment that are considered sufficiently "protective of human health and the environment under specified exposure conditions."

Action 1.2 includes the recommendation that Ecology collaborate with and provide technical support to involved parties at PFAS contamination sites in the state. These efforts will help to better understand the sources, composition, and distribution of PFAS contamination in soil and water. Evaluation of appropriate cleanup actions and their costs will be informed by this work.

The costs of developing and evaluating methods for investigating and cleaning up PFAS contamination are currently difficult to estimate due to significant uncertainties in our understanding regarding:

- How most PFAS affect people, animals, and plants, and in what concentrations.
- How to best measure the types and amounts of PFAS in the environment.
- How PFAS move through the environment and change over time.
- How to best clean up environmental PFAS contamination, including consideration of protectiveness, feasibility, and cost.

Ongoing research continues to expand our knowledge base on these issues and may significantly alter the way that Ecology's Toxics Cleanup Program (TCP) approaches cleanup in the future. TCP is currently working with the City of Issaquah and the Eastside Fire District to identify possible sources of the PFAS contamination affecting the city's drinking water. As of the end of 2018, Ecology has contributed $330,000 to this investigation (Ecology, 2019a).

Environmental PFAS contamination in Washington and examples of cost of interim cleanup actions in Washington and elsewhere

Known sites

Known areas with PFAS contamination in drinking water in Washington include:

- Issaquah (Eastside Fire and Rescue).
- Joint Base Lewis-McChord.
- Naval Air Station Whidbey Island.
- Naval Base Kitsap-Bangor.
- Fairchild Air Force Base, including Airway Heights.
- Cities of Lakewood, DuPont, Tacoma, and Parkland.

In some of these areas, concentrations of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) in groundwater used for drinking exceed the Environmental Protection Agency (EPA) health advisory level (see Appendix 7: Health, Section 7.4, Known areas of PFAS contamination). The primary source of contamination at all of these areas is believed to be releases of legacy PFAS-based firefighting foam (AFFF).

Investigation and exposure reduction actions in and around the military bases are being conducted by the Department of Defense (DOD). The City of Issaquah has installed a filtration system to reduce PFAS concentration in its finished drinking water. As noted above, TCP is currently working with the City of Issaquah and the Eastside Fire District to identify possible sources of the PFAS groundwater contamination affecting the city's drinking water. Detections of PFOA and PFOS at levels above the EPA health advisory level resulted in removing wells from operation.

Potential sites

In addition to fire suppression, PFAS have many industrial uses (see Appendix 3: Sources and Uses). Future investigations may identify releases at or near these types of facilities:

- Tanneries.
- Shoe manufacturing facilities.
- Textile treatment facilities.
- Plastics manufacturing facilities.
- Metal plating facilities.

Also, AFFF may have been released at many locations to extinguish fires, particularly petroleum fires. If PFAS releases are suspected at these types of facilities, testing should be conducted to evaluate the presence of environmental contamination.

Remediation costs are difficult to estimate and are expected to depend on variables such as:

- Extent and attributes of contamination.
- Affected populations.
- Geographic location and site attributes.
- Amount of contamination in soil versus groundwater.

Example costs

Moreover, the total cost of remediation for PFAS-contaminated groundwater is not yet known. Ecology is not aware of any completed cleanups of PFAS contamination. Instead, we are including illustrative costs of interim actions and options to scale them to full cleanup cost. Costs already incurred to address contaminated drinking water in Washington (noted above) are illustrative of sites undergoing mitigation and investigation, but no site has yet completed remediation. The cost to remediate a site will depend on site-specific factors such as the number of sources of contamination contributing to a site, the specific contaminants present, and how the contamination migrates from the sites. In the case of complex manufacturing contaminated sites, costs have escalated rapidly, for example:

- It was reported that Hoosick Falls, New York budgeted $10 million for temporary municipal and private residential water filtration systems and investigation into an alternate drinking water source (Safer States, 2019). The capital, operation, and maintenance costs of alternatives to address the drinking water contamination on a long term basis ranged from $6 to $48 million dollars (ERM & CHA, 2019). However, full remediation of the complexity of contamination from multiple sources will exceed these preliminary costs (New York Department of Environmental Conservation 2020).
- Statewide, Minnesota has estimated PFAS cleanup costs resulting from PFAS manufacturing to exceed $1 billion (Bjorjus, 2020; Minnesota 3M PFC Settlement, 2020a, 2020b).

Potential total cost of a cleanup in Washington

The Model Toxics Control Act (MTCA) Biennial Report provides data on remediation costs by stage for addressing contaminated sites (Ecology, 2016, 2018b, 2019b). These are costs associated with characterizing the site, mitigating the impact if drinking water is affected, and cleaning up contaminated soil and groundwater. The table below summarizes how costs are typically distributed between site investigation and cleanup phases.

Table 83. Percentage of cost by remedial activity phase.

Remedial activity category	2013 – 15 biennium	2015 – 17 biennium	2017 – 19 biennium
Cleanup	67%	72%	70%
Investigations	26%	16%	28%
Other	7%	12%	2%

Scaling the cost examples (related primarily to investigation and pre-cleanup activities using the MTCA remediation ratios with highest weighted cleanup) could result in overall remediation costs (excluding interim mitigation costs) of between $5.3 million and $62.8 million. Additionally, spending on interim solutions such as filtering or alternative sources of drinking water could result in ten-year costs of $6.5 million to $10 million.

Cleanup or mitigation?

Additional complexity in estimating potential costs comes from the developing nature of PFAS drinking water cleanups. Additional unknowns resulting in uncertainty include:

- The degree of remedial and preventative soil cleanup needed to reduce ongoing and future groundwater contamination.
- The best remediation method(s) and their cost-effectiveness in balance with mitigation efforts. This includes comparisons between actions such as:
  - Only treating drinking water prior to consumption.
  - Pumping, treating, and returning water to the aquifer.
  - Treatment at a single point versus multiple wells.
  - Treatment limiting the scope or spread of existing contamination.
- Multiple types of PFAS might be contaminating groundwater but do not currently have viable test methods.
- Size of populations consuming contaminated groundwater.
- Liability to other property owners, water purveyors, or consumers.
- Developing knowledge in PFAS toxicity to humans and the environment.
- Ability of liable parties to cover cleanup costs.
  - Parties such as small firefighting districts, that provide crucial services, may not be able to fund remedial actions on the same time scale or size as larger entities. Extending timeframes could increase interim mitigation costs and potential scope of contamination.

Action 1.3 Support biomonitoring and other health studies to answer important health questions

This action could involve finding competitive grant funding sources to offer subsidized biomonitoring for residents in areas impacted by PFAS-contaminated drinking water. Biomonitoring would let people know their exposure level relative to national averages and relative to other populations with elevated PFAS exposure. This information could help residents connect to health information that becomes available in the future.

Testing costs vary by number of analytes and whether they include drawing blood (Wagner & Bagenstose, 2017):

- Tests for PFOA or PFOS that do not include blood draws cost about $300 per test.
- Tests for 13 PFAS analytes cost between $450 and $500.
- Tests including drawing blood or a blood sampling and mailing kit cost between $528 and $797.

Testing performed by a centralized company or agency may receive different rates (e.g., bulk rates) but incur additional administrative costs, resulting in different and variable average per-person testing costs (Bagenstose, 2018):

- Serum testing of over 69,000 people in the mid-Ohio Valley for PFAS, for $70 million, averaged approximately $1,000 per person tested.

- The state of New York tested 3,000 people in Hoosick, New York for $3 million, averaging $1,000 per person tested.
- The Centers for Disease Control and Prevention (CDC) and state of New Hampshire tested 1,600 people in Pease, New Hampshire for nearly $340,000, averaging $211 per person tested.
- Under a CDC grant to the state of Pennsylvania, the state tested 250 people for $175,000, averaging $700 per person tested.

Action 2.2: Partner with local organizations in community outreach and support community involvement

This action involves providing funding to local organizations to engage communities affected by PFAS contamination. This could involve example activities including (as demonstrated in other states' public involvement):

- Educational materials.
- Rapid response information.

Ecology's Public Participation Grant (PPG) program funds activities similar to what is included in this recommendation. The PPG program, however, applies to a broad set of activity types, and is already limited in funds it provides for such activities, meaning the program is not likely to have funding available for PFAS activities. Additional funding under this action would be directed specifically to PFAS-related impacts to communities, rather than competing with (and potentially displacing) existing PPG grantees.

A component of the PPG program that funds information for communities impacted by contaminated sites is the Contaminated Site Project category of grants. An example of this type of grant project is the multi-component Futurewise program. This program is for communities affected by contamination in Algona, stemming from past Boeing manufacturing activities (Ecology, 2013). The two-year, $120,000 grant covered a large scope of activities, but included $25,000 for educational materials specifically:

- Printed and electronic education and outreach materials.
- Display booth.
- Health fair.
- Translated materials.

This action is likely to cover the types of activities listed above, as well as potential engagement of disadvantaged populations in problem solving and collective action. Provision of these educational materials would be helpful for communities that are at elevated risk of PFAS exposure. The degree and types of activity covered would depend on the funds available, as well as the number and types of projects requesting funding.

Examples of larger types of community-based action

While not envisioned as part of this recommended action, we note there are additional types of action taken through community-based grant programs in other states in response to PFAS drinking water contamination and exposure.

- Population PFAS testing.
- Public meetings.
- Health guidance and information provision.
- Information fairs.
- Involvement and representation in public processes for PFAS regulation.

PFAS projects developed under funding from this action are envisioned to be significantly smaller in scope, primarily intending to avoid displacing projects already using the PPG program. The $120,000 grant agreement for the Futurewise project covered (between October 1, 2013 and June 30, 2015) the activities below. Depending on the types of community engagement that would occur, and based on circumstances and grant applications, this action could include similar additional components.

- Administration ($13,625)
  - Tracking of spending and objectives.
  - Evaluation and reporting.
  - Final project report.
- Public events and outreach ($81,230)
  - Immediate resident audience
    - One-to-one outreach.
    - House parties with invited speakers such as health consultants.
    - Healthy home visits.
    - Outreach specialist.
    - Translation to relevant languages.
  - Greater Algona audience
    - Attending annual community-wide public events.
    - Creating exhibits, games, and interactive activities for education.
    - Holding a health fair.
    - Fact sheets: contamination, cleanup, participation in the Ecology public process.
    - Community meeting with speakers and cleanup updates.
  - Business audience
    - One-to-one outreach identifying questions and concerns.
    - Business-specific outreach materials.
    - Two outreach events with speakers and updates.
  - Student audience
    - Outreach to teachers and other adult youth leaders about cleanup and groundwater science.
    - Engaging youth volunteers in youth education and involvement.
- Education tools ($25,145)

- Printed and electronic education and outreach materials:
    - PowerPoint presentations.
    - Factsheets.
    - Display materials for event tables.
    - Meeting agendas.
    - Evaluation tools.
- Display booth.
- Health fair.
- Translated materials.

Action 2.3: Work to prevent PFAS releases from firefighting foam use and manufacturing processes

One of the recommended actions is to ensure that industrial use of AFFF provides for containment procedures along with collection of AFFF and contaminated soil or sediment for proper designation and disposal. Costs to industrial users to collect and dispose of released PFAS-containing AFFF include plan development, employee training, methods for containment, and disposal of waste.

For this action, Ecology would need to inform users of AFFF of the requirements and provide guidance on how to comply with them. Then users of AFFF would need to collect, treat, and properly dispose of PFAS-containing waste from AFFF use.

To prevent discharge of AFFF to the environment (or minimize it), industry would need to:

- Develop a plan for compliance.
- Purchase and carry compliance equipment.
- Collect runoff containing PFAS.
- Treat and dispose of runoff.

Runoff collection plan

We assumed development of a runoff collection plan would require 80 hours of technical, administrative, and managerial staff time at AFFF-using facilities. Assuming third-party median environmental engineer hourly wages of $46.89, loaded with additional overhead costs to reflect higher consultant prices (if external consultants are used—using exclusively internal staff, if possible, could reduce costs), and updated for inflation, the loaded hourly wage for this work would be $89.77 (Ecology, 2018a; U.S. Bureau of Labor Statistics, 2017, 2019). The cost per facility for this task would be $7,182. Potential additional costs would be incurred if additional internal staff time is required, such as for ongoing interaction with consultants during plan development.

Training

We further assumed four personnel would need to be trained in the runoff collection plan facilities using AFFF. Using the median firefighting wage of $35.28 per hour, updated for inflation and overhead to $68.51 per hour, and an estimate of 320 hours (80 hours each for four trainees) this cost becomes approximately $22,000 per facility (Ecology, 2018a; U.S. Bureau of Labor Statistics, 2017, 2019).

Training costs are, of course, more nuanced. Training materials may need to be developed, as well as labels and signage reminding firefighters of best practices. These materials may be generated by one party, and then shared with, or sold to, other facilities. Highly location-specific training needs, as well as staff turnover, may result in additional materials, instruction, and hours of employee time.

Containment, collection, and disposal

Effectively containing, collecting, and disposing of AFFF-contaminated runoff would likely entail measures such as:

- Portable booms, berms, and drain blocks.
- Pumps, hoses, and tanks.
- Potential pre-disposal treatment.
- Disposal of untreated or treated runoff.
- Disposal of treatment byproducts such as filters, sorbents, or solidifiers.

While these measures could be taken individually, facilities are likely to hire a specialist in wastewater and runoff management to properly manage PFAS-containing runoff (Environmental Security Technology Certification Program [ESTCP], 2003). While volumes of existing product are identifiable to some extent, actual volumes of runoff captured, treated, and disposed of will vary by site and firefighting activities (e.g., how much water is used, site characteristics). We could not, therefore, estimate total costs. We have, however, identified unit costs associated with elements of capture, treatment, and disposal.

Portable booms, berms, and drain blocks

We evaluated response equipment costs based on Grainger (2019). Depending on the style and length of boom, the per-foot cost ranges between $10 and $45, with a median price of $26 per foot. At typical purchasing lengths of up to 100 feet, this cost would be $260 per boom, at the median.

Similarly, depending on the style and length of berm, the per-foot cost ranges between $22 and $81, with a median price of $34 per foot. At typical purchasing lengths of up to 12 feet, this cost would be up to $408 per berm, at the median.

Drain blocks and seals vary in size and quality, but range between $110 and $581, with a median price of $238.

These prices do not include additional labor required for set-up during AFFF use, which will vary by site and firefighting characteristics.

Pumps, hoses, and tanks

Depending on the size needed and location of use, purchasing a portable trailer pump and tank (rather than hiring a contractor) could cost tens of thousands of dollars. A smaller-volume (50 gallon) portable pump and tank could cost up to $5,000 (Edson, 2019; JME Ellsworth, 2019).

Treatment and disposal

The cost of on-site treatment of AFFF-contaminated runoff water varies significantly by technology and type of product disposed. A DOD study comparing multiple treatment technologies and disposal products at large facilities indicates the following—with costs updated to 2018 values (U.S. Bureau of Labor Statistics, 2019):

- Existing off-site treatment and disposal costs ranged between $0.14/pound (lb) and $0.44/lb, with an average cost of $0.25/lb, if waste is approximately the density of water.
- Rental generators to run treatment would cost $137/day with anticipated work days lasting eight hours to treat 24,000 – 48,000 thousand gallons of wastewater.
- A potential treatment technology could incur capital costs of $236,000 to $306,000, but result in 94% reductions in disposal costs by reducing water waste to sludge.

Existing stored product

The exact makeup of most AFFF products is confidential business information (CBI), making a detailed economic analysis of replacement products impossible. However, technical documents from the United Nations (UN) Stockholm Convention (2012) provide a general assessment on replacing AFFF that contain PFOS, which may translate to PFAS replacement activities. Using this assessment as a guide, costs would likely be incurred during PFAS AFFF replacement from:

- Destruction or storage of the retired chemicals.
- Cleanup of impacts areas.
- Replacement of or upgrades to existing equipment.
- Potential changes in operations.

In lieu of ongoing use of AFFF, facilities have options of either disposal or other removal of the product, and replacement with an alternative PFAS-free product. Washington state does not prohibit removal of AFFF product from the state, but does encourage proper disposal at a permitted treatment, storage, and disposal facility.

Large scale replacement costs have included $6.2 million for replacement of AFFF at 180 U.S. Air Force facilities. For context, we note that the U.S. Air Force budget is in the hundreds of billions of dollars. More remote facilities incur higher transportation costs to airlift in new AFFF (U.S. Air Force, 2017). A recent DOD contract opportunity offered $5 million for removal, destruction, and disposal of AFFF from three geographic regions of facilities, but without replacement (DOD, 2018). The existence of these ongoing replacement and disposal activities, however, indicates that some of the costs of this action are part of the baseline (happening regardless of recommendations).

As identified in Appendix 9: Regulations, Section 9.1.1 Washington state laws, AFFF qualifies as a state-designated dangerous waste in Washington, and its disposal must therefore be managed in compliance with WAC 173-303[193] Dangerous Waste Regulations. Small quantity generators may transport their own hazardous waste, whereas medium and large quantity

[193] https://apps.leg.wa.gov/wac/default.aspx?cite=173-303

generators must hire a hazardous waste contractor. Small quantity generators (generating less than 220 lbs of dangerous waste in any month) may take waste to a facility licensed to accept hazardous waste. These facilities vary by county and charge their own set of fees, ranging up to $100 per ton equivalent. Equipment used in deploying AFFF may need to be retrofitted or replaced. This largely depends on the change in viscosity of the replacement product.

Medium and large quantity generators must dispose of their AFFF at permitted Transfer, Storage, and Disposal facilities, via a licensed hazardous waste contractor. This can cost in the tens of thousands of dollars, depending on the quantities of product being disposed of, and hauling distance.

There may also be costs associated with changing existing operations due to differing requirements of new AFFF products. The Stockholm Convention alternatives documents suggested that some AFFF users reported no change in operational costs when retiring PFOS chemicals, while others incurred higher costs (United Nations Environmental Programme (UNEP), 2012).

Action 3.1: Reduce PFAS exposure from carpet and carpet care products

One of the recommended actions is to implement a state agency purchasing preference policy for PFAS-free carpet.

Recent and previous research has shown carpet to be a repository for pollutants and that indoor air quality declines when carpeted areas are disturbed (Becher et al, 2018). According to the Carpet and Rug Institute (CRI), carpet accounts for 48% of the U.S. flooring market (CRI, 2020). PFAS, largely used for stain repellent in carpet, were worth close to $1 billion worldwide in 2006 for this use (Renner, 2006). Two North American studies frequently detected PFAS particles in significant concentrations in vacuum cleaner bags. The studies found a significant correlation between the presence of PFAS and the age of the house and floor covering type (Fromme et al, 2008).

For this action, Ecology would develop a purchasing preference policy (for purchases by the State of Washington) for carpet. A purchasing preference policy would not ban state purchases of PFAS-containing carpet. Instead, the policy could give points to state contract bidders, when they declare (and provide supporting data) that their carpet does not contain PFAS. These points would be part of the bid scoring process. This would create incentive for bidders to provide PFAS-free carpet to state agencies and municipalities that use the state contracting process.

We estimated the difference in costs for state carpet purchases that contain PFAS versus PFAS-free. We were able to estimate annual quantities of carpet purchased under the state contract, based on 2018 invoiced costs per quarter from Washington State Department of Enterprise Services (DES) (Table 84). Multiple types of facilities purchase carpet under the state contract:

- State agencies
- Cities
- Counties

- Fire districts
- Higher education establishments
- Libraries
- Nonprofits
- Ports
- School districts

Total invoiced amounts were identified by quarter, and are summarized in Table 84. Only one year of data was available for this analysis, so it may not be representative of all other years.

Table 84. Carpet invoices by group and quarter, 2018 (DES, 2018a).

Group	Q1	Q2	Q3	Q4	Annual
State	$822,883	$2,545,349	$332,531	$403,054	$4,103,817
Cities	$267,691	$451,481	$334,562	$373,953	$1,427,687
Counties	$501,283	$338,855	$194,010	$415,423	$1,449,571
Fire Districts	$57,094	$101,975	$186,309	$60,371	$405,749
Higher Education	$113,484	$702,653	$733,069	$345,657	$1,894,863
Libraries	$33,325	$173	$34,605	$159,470	$227,573
Nonprofits	$1,944	$1,431	$0	$1,771	$5,146
Ports	$51,053	$10,178	$5,534	$6,483	$73,248
School Districts	$193,700	$543,974	$3,751,886	$942,441	$5,432,001
ALL GROUPS	**$2,042,457**	**$4,696,069**	**$5,572,506**	**$2,708,623**	**$15,019,655**

While these invoiced amounts tell us the total cost of carpet purchases, they do not tell us the types of carpet purchased, or the square yards (quantity) purchased. We therefore made various combinations of assumptions to develop a range of square yardage potentially reflected in these invoices.

Using the multiple carpet options available under the state contract—which includes PFAS-containing and PFAS-free options or options that use alternative technologies to "permanently or inherently" make their carpet stain-resistant—we identified a price difference between carpets with and without topically applied treatment (see Table 85). Approximately 35.7% of offered carpet products have topically applied stain resistance, whereas 64.3% have permanent or inherent stain resistance (DES, 2018b).

Table 85. Price per square yard of carpet.

Summary statistic	Topically applied stain resistance	Permanent or inherent stain resistance
Minimum	$6.74	$11.43
Median	$17.06	$21.96
Maximum	$37.04	$45.56
Average	$17.09	$23.51

Uncertainty arises from whether these various types of carpet—many of which contain proprietary chemicals or fibers—do, in fact, contain PFAS. Topical treatments may or may not

contain PFAS. Similarly, fiber stain-resistance technologies that are described as non-degrading and "permanent," even when subjected to heat and cleaning in addition to normal wear, may potentially contain PFAS. Without comprehensive reporting of testing or knowledge of upstream production processes and treatment chemical or technology contents, these distinctions are not possible to make with reasonable certainty.

However, because the average price of inherently stain-resistant carpet was significantly higher than the price of carpet with topically applied stain-resistance treatment, and for simplified estimation, we assumed in this estimation that carpet with topically applied treatment contained PFAS, while those with inherent stain-resistance did not. This resulted in carpet containing PFAS costing less than the PFAS-free alternatives. We have also included a worst-case cost scenario, in which all carpet currently being purchased contains PFAS, and would be incentivized under this alternative to be replaced with PFAS-free carpet, by scoring PFAS-free carpet contractors higher than those not offering documented PFAS-free carpet.

If current carpet purchases are in line with the proportions of products offered, and based on the average topically applied price of $17.09/square yard (sy), the total invoiced costs reflect 725,000 sy of carpet. In this case, 35.7% of purchases would be incentivized to change their purchasing under this action. The total cost increase would then be 35.7% of 725,000 sy, purchased at the difference between the average permanently stain-resistant price of $23.51 and the topically applied price of $17.09. This total cost increase statewide would be $1.7 million per year.

In a worst-case cost scenario, however, all current carpet purchases contain PFAS in some form or another, potentially because of least-cost purchasing preferences. In this case, based on the average topically applied price of $17.09/sy, the total invoiced costs reflect 879,000 sy of carpet. In this case, all buyers would be incentivized to change their purchasing under this action. The total cost increase would then be 879,000 sy purchased at the difference between the average permanently stain-resistant price of $23.51 and the topically applied price of $17.09. This total cost increase statewide would be $5.6 million per year.

The table below summarizes how the cost increases under the two scenarios above would be distributed across various types of buyers.

Table 86. Total cost increase by group and scope of change, annual.

Group	Cost increase if 35.7% switch	Cost increase if 100% switch
State	$454,012	$1,542,781
Cities	$157,947	$536,722
Counties	$160,368	$544,949
Fire districts	$44,889	$152,537
Higher education	$209,632	$712,351
Libraries	$25,177	$85,553
Nonprofits	$569	$1,935
Ports	$8,104	$27,537
School districts	$600,951	$2,042,096
ALL GROUPS	**$1,661,648**	**$5,646,461**

We note there are also types of carpet that are not included in existing state contract rates. The prices above reflect various types of backed nylon carpet, either in tiles or broadloom. They do not include polyester carpets that do not need stain resistance added. They also exclude potential emerging new technologies in stain-resistance using alternative fibers designed to be more hard-wearing, such as nylon carpet (see, for example, Dupont's "Sorona Fiber" and Invista's "non-fluorinated Duratech") (Antron, 2016; Dupont, 2020) . We could not identify the relative cost of these options.

These estimates also assume that the same quantities of carpet will be purchased. Facing higher unit prices, buyers may substitute away from carpet and choose other floor coverings that are PFAS-free instead of PFAS-free carpet. This could lower overall costs, though we note that a specific floor covering may be chosen for any number of purposes, including, but not limited to, aesthetics, safety, acoustics, or other qualities.

Action 3.3: Implement reduction actions for PFAS in priority consumer products

One of the recommended actions is that a state agency purchasing preference policy be established for other products free of intentionally added PFAS. As identified in Appendix 3: Sources and Uses, Section 3.3 Consumer Products, PFAS have been detected in numerous commercial products, including cleaning products, paint, and treated upholstery. For this action, Ecology would assist the DES Services to develop a purchasing preference policy (for purchases by the State of Washington) for:

- Cleaning products—dispersed when used and are often discharged down the drain.
- Paint—used for any surface and could release PFAS to the environment.
- Other potential products with likely PFAS treatment, such as furniture or textiles.

A purchasing preference policy would not ban state purchases of PFAS-containing products. Instead, the policy would give points to state contract bidders when they declare (and provide supporting data) that their product does not contain PFAS. These points would be part of the bid scoring process. This would create incentive for bidders to provide PFAS-free products to state agencies and municipalities that use the state contracting process.

Cleaning products

Due to the broad nature of cleaning products and floor finishes that potentially contain PFAS, as well as the ability of janitorial services under state contract to purchase their preferred cleaning products, we could not identify the extent of PFAS-containing or PFAS-free cleaning product use in Washington. We do note that, of the identifiable products available for direct purchase under the state green janitorial products contract, only one floor polish (sold in three sizes) is explicitly listed as being PFAS-free. Other cleaning products surveyed and identified in supplier product searches do not mention PFAS.

While there is moderate literature on the replacement of PFAS-containing cleaning products, prices and price differences specifically for PFAS are not mentioned. However, we can approximate the price difference by using the example of the price difference between green cleaning products in general, and non-green cleaning products. While this does not necessarily

show PFAS contents, it is the nearest available quantification of this potential price difference. We note also that prices will depend on green product availability and market share, as reflected in price differentials by country. These price differences for four countries are summarized below (McCabe, 2008).

Table 87. Price difference between green and non-green products.

Country	All-purpose and floor care products	Sanitary cleaning products	Window cleaners
Sweden	-74%	-82%	-9%
Germany	+36%	+148%	-36%
Spain	+131%	+92%	-94%
Czech Republic	+158%	+2%	N/A

In markets with long-standing incentives and regulation for certain green products, where green substitutes for toxic chemicals are more prevalent, we see that green products are generally less expensive than non-green products. Where regulation or incentives are more recent or nonexistent, green products have a more niche market, and can be significantly more expensive. Data was not reported for the U.S., but we may assume that since 1) nontoxic substitutes for PFAS are currently limited or unknown, and 2) there are observationally few mentions of PFAS-free products in marketing and labeling, initial prices for PFAS-free products (holding other product attributes constant) would be higher than current prices.

Paint

We based cost estimation for paints on historic bids for state waterborne road marking paint contracts (DES, 2018c). This use is more likely to prefer the qualities PFAS provides for products of reduced adherence and staining. The quantity of different types of paint varied, as summarized below. The total quantity and types of paint purchased are expected to vary annually by the needs of planned projects and locations.

Table 88. Paint quantities purchased, by type.

Paint type	Quantity (gallons)
Standard, white, sold by the truckload	216,750
Standard, yellow, sold by the truckload	137,750
Standard, white, sold by less than truckload	12,500
Standard, yellow, sold by less than truckload	8,500
Cold weather, white, sold by the truckload	18,000
Cold weather, yellow, sold by the truckload	18,000
Cold weather, white, sold by less than truckload	0
Cold weather, yellow, sold by less than truckload	0
High build, white, sold by truckload	0
High build, yellow, sold by the truckload	0
High build, white, sold by less than truckload	0
High build, yellow, sold by less than truckload	0

Paint type	Quantity (gallons)
TOTAL	**411,500**

Across all paint types and quantities, prices were generally consistent across brands. The table below provides summary statistics for waterborne road marking paint prices in the current state contract.

Table 89. Paint price per gallon.

Summary statistic	Price per gallon
Minimum	$8.50
Median	$10.99
Maximum	$19.79
Average	$11.93

Based on existing prices reflected in state contracts, and allowing for variance in the types of paint purchased, we estimate that purchasing the quantities of paint shown in Table 89 would currently cost between $3.5 million and $8.1 million per year.

At this time, it is not possible to identify which road paints do or do not contain PFAS. Acceptable road paint choices are based on a large set of usability, functionality, and wear criteria, some of which may be tied to PFAS or other surfactant contents, but use of PFAS is not identified in choice criteria. Comprehensive paint contents is proprietary, so it is similarly difficult to directly identify PFAS use in existing contracted paints by brand and type. It is therefore also difficult to ascertain, from the literature, the pricing of adequate alternatives, or whether such alternatives are sufficiently available. The limited studies explicitly addressing road paint show that water-based alternatives are available that meet the same functionality and durability criteria (without identifying price differences), but also indicate that further study of alternatives is needed (Kougoulis et al., 2012).

Action 4.2: Evaluate PFAS in landfill leachate

For this action, Ecology would consider adding long term requirements for PFAS testing, monitoring, and reporting for landfill leachate. This could require a rule revision.

Landfill leachate

Landfills in Washington are regulated by local health districts under rules authored by Ecology. Chapters 173-350[194] and 173-500[195] WAC allow health districts to include stipulations in permits that require landfills to sample for additional constituents (e.g. PFAS). If, for some reason, a health district does not want to make that stipulation, then a rule change would be necessary to ensure sampling for PFAS. The process to adopt landfill leachate regulations into rule would likely span over several rulemakings as the science and policy surrounding PFAS

[194] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350
[195] https://apps.leg.wa.gov/wac/default.aspx?cite=173-500

continues to evolve. Ecology would likely pursue a single, complex rulemaking to create the initial policy followed by a series of less complex rule updates to incorporate new science.

The request for landfill testing for PFAS in leachate would be generated by Ecology and local health districts. The cost to a landfill operator to test for PFAS would depend both on the frequency of monitoring, and on whether there are requirements to test monitoring wells. Current laboratory cost to analyze for PFAS ranges from $600 to $1,200 per sample. Depending on landfill leachate collection configuration, more than one sample may need to be collected. The landfill operator would need to add PFAS to their existing landfill monitoring plan.

There are 53 landfills identified as operating in the state which are likely to store waste containing PFAS (limited purpose and municipal solid waste). Assuming a single sample is taken, testing leachate from 53 landfills would cost $63,600. Limited purpose landfills, however, are not required to collect leachate. Some limited purpose landfills may collect it voluntarily.

Depending on the scope of additional regulation surrounding PFAS in leachate, additional costs to the industry could also include:

- The cost to update their existing landfill monitoring plan.
- The cost of monitoring well sampling if PFAS has migrated to groundwater from the landfill.

These costs are landfill specific and Ecology cannot estimate them at this time.

10.2 Costs of other options analyzed

In developing this CAP, Ecology considered additional actions that were ultimately not recommended. They include:

- Requiring municipal WWTPs to test influent and effluent. The costs of this option are unknown without the development of individual monitoring plans.
- Recommending that the Legislature require alternatives assessments for specific products (discussion of costs below).

10.2.1 Alternatives assessments

For this action, Ecology could have recommended that the Legislature:

- Allocate funding for Ecology to conduct alternatives assessments of the use of PFAS in products, OR
- Require manufacturers of PFAS-containing products (specific products or industries) to work with independent third-party contractors to conduct alternatives assessments of the use of PFAS in their products.

We identified 13 industries operating in Washington that are likely to use PFAS in their production processes (see Appendix 3: Sources and Uses, Section 3.1.2 Secondary Manufacturing).

Table 90. Industries likely to use PFAS.

Industry	North American Industry Classification System (NAICS) code
Plastics product manufacturing	326199
Automobile manufacturing (plating activity)	3361
Carpet rug mills	314110
Corrugated solid fiber box manufacturing	322211
Electroplating, plating, polishing, and anodizing	332813
Leather hide tanning finishing	316110
Other fabricated wire product manufacturing	331222
Paper mills (except newsprint)	322121
Paper bag coated treated paper manufacturing	322220
Paperboard mills	322130
Pulp mills	322110
Semiconductors and related devices manufacturing	334413
Textile fabric finishing mills	31320

Cost if Ecology assesses alternatives

Ecology assumes that an alternatives assessment costs $400,000 and takes up to two years. Costs and time would vary by:

- Stakeholder interest and involvement.
- Project scope.
- Robustness of analysis.

The most significant expenditure for a robust alternatives assessment comes from completing the hazardous chemical assessment, which Ecology typically contracts out to a third-party toxicology consultant.

For this analysis, Ecology anticipates completing an alternatives assessment for each of the most common applications of PFAS chemicals in secondary products. PFAS polymer treatments are widely used to provide stain, grease, or water resistance to materials such as carpets and apparel. PFAS are also added to formulated products such as paints and sealers both to improve surface characteristics and to promote even wetting and spreading (fluorosurfactants). Alternative assessments may be appropriate for any or all of these typical PFAS product categories:

- Paint.
- Textiles.
- Cosmetics.
- Cleaning products.
- Floor and car waxes.
- Waterproofing sprays (for leather, carpet, or textiles).
- Automotive fluids.

The process to complete an alternatives assessment for one product is estimated to be two years long and cost $400,000 for each contract. Actual costs would depend on product category breadth and complexity. Oversight of the contractor and review of the assessment would require one staff person (a full time employee, specifically using one-quarter of their time) per year for two years for each assessment. At a cost of $400,000 per assessment, the cost to complete assessments of all seven product categories would total $2.8 million. This estimate is in nominal terms, reflecting the total cost if all costs are incurred immediately (i.e., all seven alternatives assessments are done at once). If one alternatives assessment is done at a time, the cost estimate would be lower, at $1.6 million based on average rate of return on U.S. Treasury Department Bonds (U.S. Treasury Department, 2020).

Cost if industry assesses alternatives

If industry, as a group, contracts alternatives assessments to consultants, all assessments could be completed in the first two-year cycle. Assuming all assessments begin in the first year, and assessments were completed for the seven applications as assumed for Ecology alternatives analyses, this action would cost $2.8 million, but assessments would be completed significantly sooner than with the above option.

Price impacts to products

If the alternative chemicals identified and subsequently required are significantly more costly than PFAS, then the prices of products could increase. Since we cannot know the attributes of substitute chemicals before an alternatives assessment is completed, we cannot determine with certainty whether assessments will identify viable alternatives that are significantly more costly than currently used PFAS. This is the nature of recommended actions that involve research and investigation. For potential price differences for carpet, cleaning products, and paints, see discussion for Actions 3.1 and 3.2, above.

10.3 Benefits of recommended actions

10.3.1 Current state of economic and scientific knowledge about PFAS

Research is emerging on the human health and environmental impacts of PFAS exposure. Because of this, it is not possible to succinctly quantify health- or environmental-related economic benefits of reduced PFAS exposure. However, the literature on relationships between PFAS exposure and impacts to human health and the environment is robust enough to provide a high-level discussion of those impacts and potential costs resulting from those impacts.

There are several key reasons for the poor resolution in the literature on PFAS exposure and health and environmental costs. A significant amount of information pertaining to the exact compositions of PFAS is confidential business information, and is unavailable to independent researchers. Molecular composition can vary widely among different producers, even within particular uses of PFAS, and this information is not available to the public. Studies suggest that PFAS manufacturing data be made public as a method to reduce public health expenditures on toxicology research and to better understand the global effects of PFAS (Scheringer et al., 2014). Unlike substances focused on in Ecology's previous CAPs, little is known about the

prevalence, locations, exposure, and quantitative effects of PFAS—which is largely related to the lack of reporting and disclosure requirements.

10.3.2 Human health and wellbeing benefits

Poor human health and related healthcare expenditures are generally associated with lower macroeconomic growth. This relationship results from reductions in:

- Consumer spending on non-medical goods.
- Worker productivity.
- Capacity for public investment in areas outside of healthcare (World Health Organization, 2009).

An increase in human health and productivity would result in macroeconomic benefits.

Despite the emerging nature of PFAS health impact research, several trends in human health conditions associated with exposure to certain PFAS are identified within the literature. These include:

- Increased risk of thyroid disease and endocrine system disruptions.
- Increased risk of certain cancers.
- Higher cholesterol levels.
- Reduced antibody response to vaccinations.

Appendix 7: Health, Section 7.1.2 Primary health endpoints of concern, discusses these health impacts in detail. Each of these health issues are associated with direct and indirect costs. Some are terminal illnesses, while others, like high cholesterol and immune deficiencies, increase risk for other illnesses, and are associated more with their secondary costs.

The health conditions associated with PFAS exposure not only affect the lives of sick individuals and their families, but they also influence economy-wide productivity losses. Among all sicknesses and diseases, absenteeism and presenteeism impacts to business productivity can be twice as high as medical and pharmacy costs (Loeppke et al, 2009). Presenteeism occurs when workers are present at their job, but function at a reduced capacity because of a health issue; depression is often cited as an example of a condition that affects presenteeism. The Commonwealth Fund estimated a nationwide impact of $260 billion in 2003, 2.4% of gross domestic product at the time, for reduced worker productivity, sick days, and the loss of adults from the workforce due to chronic disease and disability (Davis, 2005).

Children who are sick often and miss school may see long-term economic impacts. Recent research established a negative relationship between a child's school absenteeism and their overall performance on tests (García & Weiss, 2018). Studies dating back over 40 years have found positive associations between a person's educational attainment and their earnings, and one recent study linked high school GPA (academic performance) with annual salary, particularly during young adulthood (French et al., 2015).

10.4 Costs from likely PFAS-related health conditions

Because PFAS exposure thresholds associated with these health issues have not been established, it is not possible to quantify healthcare costs associated with PFAS chemicals at this time. Ecology assumes that rates of PFAS exposure are positively correlated with rates of the previously identified health outcomes. A reduction in exposure to PFAS chemicals would logically reduce the risk of these associated health issues and related costs. However, due to limited knowledge regarding how and to what extent PFAS contribute to these health impacts, we could not identify the degree or significance of such reductions.

Therefore, this analysis does not intend to, nor does it, provide a detailed quantitative analysis of the healthcare costs related to PFAS exposure for any one individual or any group of individuals. Instead, we review potential population-wide economic impacts by assessing costs associated with conditions that are likely related to PFAS exposure. As the science linking PFAS exposure with particular health conditions gains resolution, more detailed analyses of individual and population-wide health costs, and associated broader economic impacts, will be possible. Until then, it is not possible to determine how much of a condition's economic effects are related to PFAS exposure. The following discussion does not assume particular correlations between health-related costs and PFAS exposure, but is meant to be a high-level identification of population-wide costs of potentially associated health outcomes.

All dollar values are reported in 2017 dollars in the analyses below.

10.4.1 Thyroid disease and endocrine disruption

Some studies have found significant associations between PFAS exposure and endocrine disruption (Ballesteros et al., 2017). Research generally shows a positive relationship between thyroid hormone levels and exposure to PFAS, but more research is needed to confirm the relationship and establish exposure thresholds. Both thyroid disease and its associated illnesses are responsible for significant costs to those impacted, and to society as a whole.

According to the Endocrine Society and the Agency for Healthcare Research and Quality, thyroid disease treatment costs for females over age 18 in the U.S. approached $4.3 billion, with a per person mean expenditure of $409 for ambulatory services and $116 for prescriptions (Endocrine Society, 2015; Soni, 2008). Thyroid disease and endocrine disruptions are significantly more common in females than males. From 1996 to 2006, the occurrence of thyroidectomies in the U.S. has increased for both inpatient and outpatient services, with the most significant increases among Medicare and Medicaid patients (Sun et al., 2013). At this time, we cannot estimate the proportion of thyroid disease specifically caused by PFAS exposure, or its interactive or complementary affects in combination with other chemicals or behaviors.

10.4.2 Cancer risk

Studies have linked exposure to PFAS and cancer with varying degrees of significance for over 20 years (Australian Department of Health, 2018). Several distinct populations may have elevated risk of testicular and/or kidney cancer, including:

- Workers directly exposed in chemical plants to PFOA.
- Communities where PFOA exposure is significantly elevated (typically due to water supply contamination or being close to an industrial facility releasing PFOA).
- Those with high rates of background exposure (International Agency for Research on Cancer, 2017).

At this time, it is not possible to estimate the percentage of testicular and kidney cancer cases associated with PFAS exposure.

Cancers are generally shown to have the highest associated medical and pharmaceutical costs among common illnesses (Loeppke et al., 2009; Mitchell & Bates, 2011). Annual charges for an individual with kidney or testicular cancer are estimated at $39,841 and $33,747, respectively (U.S. Department of Health and Human Services, 2012). National expenditures for kidney cancer care in 2017 were $4.7 billion, while those related to testicular cancer approached $22 million (Aberger et al., 2014; U.S. Department of Health and Human Services, 2012; values reported in 2017 dollars).

The average annual productivity loss per employee due to cancer is commonly estimated at more than $1,600. Accounting for medical costs and lost productivity, annual cancer impacts to an average-sized company (10,000 employees) can approach $2.5 million (Mitchell & Bates, 2011). In 2005, productivity losses in the U.S. from testicular cancer were about $500 million, while kidney cancer was responsible for $3.4 billion in losses based on productivity losses from both kidney and renal pelvis cancers (National Cancer Institute, 2018).

10.4.3 Higher cholesterol levels

Several studies show links between PFAS exposure and increased cholesterol levels, although the extent to which PFAS exposure is responsible for increased cholesterol is not known (CDC, 2019). Current science suggests that diet is the most significant influencer of high cholesterol (Mayo Clinic, 2017). Although research does not suggest that PFAS exposure plays a significant role in health outcomes related to increased or high cholesterol nationally, there may be economic benefits from even slight reductions in population-wide cholesterol levels, given the widespread occurrence of the condition in the U.S. It is not possible to estimate what percentage of this impact is related to PFAS exposure at this time.

Between 2011 and 2012, just under 40% of U.S. adults had cholesterol levels high enough to be considered at risk for heart disease or stroke, dangerous conditions that are associated with significant costs (CDC, 2018). The CDC estimates that more than 43 million U.S. adults took cholesterol-lowering medications between 2005 and 2012 (Mercado et al., 2015). The cost of these drugs, known as statins, vary significantly, ranging from $36 to more than $600 per month (Consumer Reports, 2014). According to the American Heart and Stroke Associations, costs associated with heart disease and stroke in the U.S. exceed $316 billion, including both

medical expenditures and lost productivity. Similar costs related to heart disease alone approached $200 billion in 2012 to 2013 (American Heart Association/American Stroke Association, 2017).

10.4.4 Secondary immunodeficiency disorders

A number of studies have found associations between PFOA and PFOS exposure and immunodeficiency conditions, including reduced antibody response to vaccinations and hypersensitivity (Chang et al., 2016; Knutsen et al., 2018; National Toxicology Program, 2016; Stein et al., 2016). The literature suggests that PFAS serum concentrations may have significant negative correlations with antibody concentrations in both children and adults, resulting in a reduced protection against pathogens treated by vaccines including tetanus, diphtheria, and rubella (Grandjean et al., 2012; Osuna et al., 2014; Stein et al., 2016).

These health conditions are very rare in the U.S. today, largely because of widespread immunization. A reduction in the effectiveness of these immunizations would increase the occurrence of the conditions and their associated societal costs. Although it is not possible to estimate potential costs related to PFAS exposure at this time, we assume that an increase in the effectiveness of vaccinations would have economic benefits.

Asthma is a familiar hypersensitivity-related health outcome (National Toxicology Program, 2016; Knutsen et al., 2018). Affecting more than 8% of people living in the U.S., asthma's economic impacts in this country are significant. It is not possible at this time to determine the proportion of asthma cases related to PFAS exposure. Because cost estimates of this relationship are not available, we review total health costs related to asthma in the U.S.

Between 2008 and 2013, the estimated average annual medical cost per person associated with asthma was $3,266, and the total national cost was $50.3 billion (Nurmagambetov et al., 2018). The same study suggested that asthma was responsible for 8.7 million and 5.2 million missed days of work and school, respectively, representing a total productivity loss of $3 billion from 2008 to 2013. In all, total economic loss associated with medical expense, productivity, and mortality was estimated to be $81.9 billion (Nurmagambetov et al., 2018).

10.5 Environmental benefits

Similar to health benefits, there are several themes evident in the literature regarding PFAS and environmental impacts. As identified in Appendix 6: PFAS Ecotoxicology, Section 6.2 Bioaccumulation, most prevalent among the literature is its persistence within the environment and resulting bioaccumulation in animals, both of which will affect the services ecosystems provide to the public. PFAS are known to be very persistent in the environment and some bioaccumulate over time. Given the documented negative environmental impacts of PFAS emissions and related diminished ecosystem services, Ecology assumes that a reduction in PFAS emissions to the environment would have both environmental and economic benefits.

Ecosystems provide critical functions to society, like purifying water, mitigating the spread of disease, and providing raw materials. These functions are often referred to as ecosystem services. An ecosystem's ability to continuously or predictably provide services is often related to the degree of disturbance experienced by the ecosystem (Farley, 2012). Anthropogenic and

natural disturbances to ecosystems often can have a more significant impact on an ecosystem's services than to the ecosystem's long-term resilience. The loss of services provided by ecosystems may threaten a society's economic well-being when the disrupted services cannot be readily substituted (Farley, 2012).

Anthropogenic disruptions to ecosystems can take a variety of forms. Most pertinent to the PFAS discussion is the emission and persistence of these chemicals in the environment and their lasting impacts. One key assumption in ecosystem services economics is that the rate of emissions to an ecosystem cannot not exceed that ecosystem's ability to process the emissions without causing disruption to the provision of ecosystem services (Daly, 1990). In the case of PFAS emissions, the persistence and bioaccumulation of the chemicals are shown to have negative impacts on the health of water ecosystems, and impacts to organisms in the environment, as discussed in Appendix 6: PFAS Ecotoxicology, Section 6.3 Toxicokinetics.

The degradation of habitat and health impacts to key members of the trophic pyramid may negatively affect Washington's economy. For example, the health of native salmon populations is significantly related to the success of other species like Southern Resident Killer Whales and the economic well-being of tribal, recreational, and commercial fisheries. Key species often have significant cultural and spiritual value, in addition to their ecological and economic significance.

10.6 Data Gaps and Recommendations

10.6.1 Data Gaps

As addressed throughout the CAP and its appendices, data continues to be collected regarding PFAS impacts, possible future regulation, and resulting direct and indirect costs of PFAS controls, remediation activities, and environmental and human impacts.

10.6.2 Recommendations

This appendix does not propose any specific recommendations. Information collected under each of the recommendations proposed in this CAP will allow future refinement of our economic analysis.

References

Aberger, M., Wilson, B., Holzbeierlein, J. M., Griebling, T. L., & Nangia, A. K. (2014). Testicular self-examination and testicular cancer: a cost-utility analysis. *Cancer Medicine*, *3*, 1629–1634. https://doi.org/10.1002/cam4.318

Ahrens, L., & Bundschuh, M. (2014). Fate and effects of poly- and perfluoroalkyl substances in the aquatic environment: A review. *Environmental Toxicology and Chemistry*, *33*, 1921–1929. https://doi.org/10.1002/etc.2663

American Heart Association/American Stroke Associations (AHA/ASA). (2017). *Heart Disease and Stroke Statistics 2017 At-a-Glance*. https://healthmetrics.heart.org/wp-content/uploads/2017/06/Heart-Disease-and-Stroke-Statistics-2017-ucm_491265.pdf

Antron. (2016). The Antron Brand Launches Fluorine-free Duratech Soil Resistance Formula.

Australian Department of Health. (2018). Expert Health Panel for Per- and Poly-Fluoroalkyl Substances (PFAS). Retrieved from https://www1.health.gov.au/internet/main/publishing.nsf/Content/C9734ED6BE238EC0CA2581BD00052C03/$File/expert-panel-report.pdf

Bagenstose, K. (2018, November 26). Study: High PFAS blood levels in Bucks, Montgomery County residents. *The Pennsylvania Intelligencer*. Retrieved from https://www.theintell.com/news/20181126/study-high-pfas-blood-levels-in-bucks-montgomery-county-residents

Ballesteros, V., Costa, O., Iñiguez, C., Fletcher, T., Ballester, F., & Lopez-Espinosa, M.-J. (2017). Exposure to perfluoroalkyl substances and thyroid function in pregnant women and children: A systematic review of epidemiologic studies. *Environment International*, *99*, 15–28. https://doi.org/10.1016/j.envint.2016.10.015

Becher, R., Øvrevik, J., Schwarze, P., Nilsen, S., Hongslo, J., & Bakke, J. (2018). Do Carpets Impair Indoor Air Quality and Cause Adverse Health Outcomes: A Review. *International Journal of Environmental Research and Public Health*, *15*, 184. https://doi.org/10.3390/ijerph15020184

Bjorhus, J. (2020, February 27). Cleanup of PFAS “forever chemicals” could cost up to $1.2 billion, exceed 3M settlement: State estimates cleanup could cost up to $1.2 billion. *Star Tribune*. Retrieved from https://www.startribune.com/minnesota-estimates-cost-of-projects-to-treat-drinking-water-under-3m-settlement/568226032/

Black, R. (2020). Lakewood Water District Comment on Washington State Department of Ecology Draft PFAS Chemical Action Plan. November 20, 2020. Retrieved from https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did200002/pid_200743/assets/merged/ih0rinm_document.pdf?v=9BE2WNV76

Carpet and Rug Institute (CRI). (2020). Research and Resources webpage. Retrieved from https://carpet-rug.org/resources/research-and-resources/

CDM Smith. (2020). Cost Analysis of the Impacts on Municipal Utilities and Biosolids Management to Address PFAS Contamination. October 2020. Retrieved from https://www.wef.org/globalassets/assets-wef/3---resources/topics/a-n/biosolids/technical-resources/cost-analysis-of-pfas-on-biosolids---final.pdf

Centers for Disease Control and Prevention (CDC). (2018). High Cholesterol Facts. Retrieved from https://www.cdc.gov/cholesterol/facts.htm

Centers for Disease Control and Prevention (CDC). (2019). An Overview of the Science and Guidance for Clinicians PFAS on Per- and Polyfluoroalkyl Substances (PFAS). Retrieved from https://www.atsdr.cdc.gov/pfas/docs/clinical-guidance-12-20-2019.pdf

Chang, E. T., Adami, H.-O., Boffetta, P., Wedner, H. J., & Mandel, J. S. (2016). A critical review of perfluorooctanoate and perfluorooctanesulfonate exposure and immunological health conditions in humans. *Critical Reviews in Toxicology*, *46*, 279–331. https://doi.org/10.3109/10408444.2015.1122573

Consumer Reports: Best Buy Drugs. (2014). Evaluating statin drugs to treat: high cholesterol and heart disease. *Consumer Reports*. Retrieved from https://article.images.consumerreports.org/prod/content/dam/cro/news_articles/health/PDFs/StatinsUpdate-FINAL.pdf

Daly, H. E. (1990). Toward some operational principles of sustainable development. *Ecological Economics*, *2*, 1–6. https://doi.org/10.1016/0921-8009(90)90010-R

Davis, K., Collins, S. R., Doty, M. M., Ho, A., & Holmgren, A. L. (2005). Health and Productivity Among U.S. Workers. *The Commonwealth Fund*. Retrieved from https://www.commonwealthfund.org/sites/default/files/documents/___media_files_publications_issue_brief_2005_aug_health_and_productivity_among_u_s__workers_856_davis_hlt_productivity_usworkers_pdf.pdf

DeFazio, D., & Tynan, T. (2019). Threats to Drinking Water and Public Health in Alaska: The Scope of the PFAS Problem, Consequences of Regulatory Inaction, and Recommendations. *Alaska Community Action on Toxics*. Retrieved from https://www.akaction.org/wp-content/uploads/Report-Threats-to-Drinking-Water-and-Public-Health-in-Alaska-FINAL-web-version-9-24-19.pdf

Dupont. (2020). Sorona Eco-Efficient Performance Fiber. Retrieved from http://sorona.com/?gclid=EAIaIQobChMIuJCN0p-26QIV5Al9Ch0cywuvEAAYASAAEgJdA_D_BwE

Edson. (2019). Edson Pumps. Retrieved from https://www.edsonpumps.com

Ellis, T. (2020, February 16). Pentagon is paying to extend North Pole's water system due to PFAS contamination in wells. *Alaska Public Media*. Retrieved from https://www.alaskapublic.org/2020/02/16/pentagon-is-paying-to-extend-north-poles-water-system-due-to-pfas-contamination-in-wells/

Endocrine Society. (2015). *Thyroid: Endocrine Facts and Figures*. https://www.endocrine.org/topics/thyroid-disorders-and-cancer/facts-and-figures

Environmental Resources Management (ERM), & CHA. (2019). Municipal Water Supply Study for the Village of Hoosick Falls. Retrieved from https://www.dec.ny.gov/docs/remediation_hudson_pdf/hoosickmuniwatersupprept.pdf

Environmental Security Technology Certification Program (ESTCP). (2003). ESTCP Cost and Performance Report: Oil/Water Emulsion and Aqueous Film Forming Foam (AFFF) Treatment Using Air-Sparged Hydrocyclone Technology. *US Department of Defense (DOD)*. Retrieved from https://www.serdp-estcp.org/content/download/5686/78447/file/SI-200005-CP.pdf

Farley, J. (2012). Ecosystem services: The economics debate. *Ecosystem Services*, *1*, 40–49. https://doi.org/10.1016/j.ecoser.2012.07.002

French, M. T., Homer, J. F., Popovici, I., & Robins, P. K. (2015). What You Do in High School Matters: High School GPA, Educational Attainment, and Labor Market Earnings as a Young Adult. *Eastern Economic Journal*, *41*, 370–386. https://doi.org/10.1057/eej.2014.22

Fromme, H., Tittlemier, S. A., Völkel, W., Wilhelm, M., & Twardella, D. (2009). Perfluorinated compounds – Exposure assessment for the general population in western countries. *International Journal of Hygiene and Environmental Health*, *212*, 239–270. https://doi.org/10.1016/j.ijheh.2008.04.007

Garcia, E., & Weiss, E. (2018). Student absenteeism: Who misses school and how missing school matters for performance. *Economic Policy Institute*. Retrieved from https://epi.org/152438

Gardner, P. (2019, March 21). PFAS pollution already costing Michigan communities millions of dollars. *MLive*.

Giesy, J. P., & Kannan, K. (2002). Peer Reviewed: Perfluorochemical Surfactants in the Environment. *Environmental Science & Technology*, *36*, 146A-152A. https://doi.org/10.1021/es022253t

Giesy, J. P., Kannan, K., & Jones, P. D. (2001). Global Biomonitoring of Perfluorinated Organics. *The Scientific World Journal*, *1*, 627–629. https://doi.org/10.1100/tsw.2001.342

Giesy, J. P., Naile, J. E., Khim, J. S., Jones, P. D., & Newsted, J. L. (2010). Aquatic Toxicology of Perfluorinated Chemicals. *Environmental Contamination and Toxicology*, *202*, 1–52. https://doi.org/10.1007/978-1-4419-1157-5_1

Ginn, D. (2021). Department of the Navy Comment on Washington Department of Ecology Draft PFAS Chemical Action Plan. January 20, 2021. Retrieved from https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did200002/pid_200743/assets/merged/hi0qih3_document.pdf?v=9BE2WNV76

Grainger Inc. (2019). Spill Control Supplies. Retrieved from https://www.grainger.com/category/safety/spill-control-supplies

Houde, M., De Silva, A. O., Muir, D. C. G., & Letcher, R. J. (2011). Monitoring of Perfluorinated Compounds in Aquatic Biota: An Updated Review. *Environmental Science & Technology*, *45*, 7962–7973. https://doi.org/10.1021/es104326w

International Agency for Research on Cancer (IARC). (2017). IARC Monographs: Some Chemicals used as solvents and in polymer manufacture. *World Health Organization*, *110*, 1–289. Retrieved from https://monographs.iarc.fr/wp-content/uploads/2018/06/mono110.pdf

JME Ellsworth. (2019). Edson Model 28202 Pump Out Caddy w/ 25 Gallon Waste Collection Cart. Retrieved from https://www.jmesales.com/edson-model-28202-pump-out-caddy-w-25-gallon-waste-collection-cart/

Knutsen, H. K., et al. (2018). Risk to human health related to the presence of perfluorooctane sulfonic acid and perfluorooctanoic acid in food. *EFSA Journal*, *16*. https://doi.org/10.2903/j.efsa.2018.5194

Kougoulis, J. S., Kaps, R., Walsh, B., Bojczuk, K., & Crichton, T. (2012). Revision of EU European Ecolabel and Development of EU Green Public Procurement Criteria for Indoor and Outdoor Paints and Varnishes: Ecolabel Background Report. Retrieved from https://ec.europa.eu/environment/ecolabel/documents/Paints Background Report.pdf

Krauss, J. (2020). Sammamish Plateau Water and Sewer District Comment on Washington Department of Ecology Draft PFAS Chemical Action Plan. December 15, 2020. Retrieved from https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did200002/pid_200743/assets/merged/y20dibs_document.pdf?v=ZNUEFDP4V

Loeppke, R., Taitel, M., Haufle, V., Parry, T., Kessler, R. C., & Jinnett, K. (2009). Health and Productivity as a Business Strategy: A Multiemployer Study. *Journal of Occupational and Environmental Medicine*, *51*, 411–428. https://doi.org/10.1097/JOM.0b013e3181a39180

Mayo Clinic. (2017). High Cholesterol webpage. Retrieved from https://www.mayoclinic.org/diseases-conditions/high-blood-cholesterol/symptoms-causes/syc-20350800

McCabe, S., Clement, S., & Ochoa, A. (2008). Sustainable Procurement Guidelines for Cleaning Products and Services: Background Report. *Local Governments for Sustainability (ICLEI) for the United Nations Environment Programme – Division of Technology, Industry and Economics (UNEP-DTIE)*. Retrieved from https://www.greeningtheblue.org/sites/default/files/Backgroundoncleaningproducts_0.pdf

Minnesota 3M PFC Settlement. (2020a). Conceptual Drinking Water Supply Plan. *Minnesota 3M PFC Settlement*. Retrieved from https://3msettlement.state.mn.us/DrinkingWaterSupply

Minnesota 3M PFC Settlement. (2020b). Conceptual Drinking Water Supply Plan: Chapter 7 (Draft). Retrieved from https://3msettlement.state.mn.us/sites/default/files/Draft_Chapter7.pdf

Mitchell, R. J., & Bates, P. (2011). Measuring Health-Related Productivity Loss. *Population Health Management*, *14*, 93–98. https://doi.org/10.1089/pop.2010.0014

National Cancer Institute (NCI). (2018). Cancer Statistics webpage. Retrieved from https://www.cancer.gov/about-cancer/understanding/statistics

National Toxicology Program (NTP). (2016). NTP Monograph on Immunotoxicity Associated with Exposure to Perfluorooctanoic Acid or Perfluorooctane Sulfonate. *US Department of Health and Human Services*. Retrieved from https://ntp.niehs.nih.gov/ntp/ohat/pfoa_pfos/pfoa_pfosmonograph_508.pdf

New York Department of Environmental Conservation (DEC). (2020). Hoosick Falls Area: Information for Communities Impacted by Per- and Poly-fluorinated Aklyl Substances (PFAS). Retrieved May 15, 2020 from https://www.dec.ny.gov/chemical/108791.html

Nurmagambetov, T., Kuwahara, R., & Garbe, P. (2018). The Economic Burden of Asthma in the United States, 2008–2013. *Annals of the American Thoracic Society*, *15*, 348–356. https://doi.org/10.1513/AnnalsATS.201703-259OC

Osuna, C. E., Grandjean, P., Weihe, P., & El-Fawal, H. A. N. (2014). Autoantibodies Associated with Prenatal and Childhood Exposure to Environmental Chemicals in Faroese Children. *Toxicological Sciences*, *142*, 158–166. https://doi.org/10.1093/toxsci/kfu163

Pancras, T., Schrauwen, G., Held, T., Baker, K., Ross, I., & Slenders, H. (2016). Environmental fate and effects of poly and perfluoroalkyl substances (PFAS). *Concawe Soil and Groundwater Taskforce*. Retrieved from https://www.concawe.eu/wp-content/uploads/2016/06/Rpt_16-8.pdf

Prevedouros, K., Cousins, I. T., Buck, R. C., & Korzeniowski, S. H. (2006). Sources, Fate and Transport of Perfluorocarboxylates. *Environmental Science & Technology*, *40*, 32–44. https://doi.org/10.1021/es0512475

Renner, R. (2006). The long and the short of perfluorinated replacements. *Environmental Science & Technology*, *40*, 12–13. https://doi.org/10.1021/es062612a

Safer States. (2019). Costs of PFAS Contamination – Safer States – February 2019. Retrieved from https://saferchemicals.org/wp-content/uploads/2019/02/safer_states_costs_of_pfas_contamination.pdf

Scheringer, M., Trier, X., Cousins, I. T., de Voogt, P., Fletcher, T., Wang, Z., & Webster, T. F. (2014). Helsingør Statement on poly- and perfluorinated alkyl substances (PFASs). *Chemosphere*, *114*, 337–339. https://doi.org/10.1016/j.chemosphere.2014.05.044

Sokol, C. (2017). Air Force to reimburse Airway heights for clean water after decades of chemical contamination. Updated: Wednesday, November 8, 2017. *The Spokesman Review*. Retrieved from https://www.spokesman.com/stories/2017/nov/08/air-force-to-reimburse-airway-heights-for-clean-wa/

Soni, A. (2011). Use and Expenditures Related to Thyroid Disease among Women Age 18 and Older, U.S. Noninstitutionalized Population, 2008. *Agency for Healthcare Research and Quality*. Retrieved from https://meps.ahrq.gov/data_files/publications/st348/stat348.pdf

Stein, C. R., Ge, Y., Wolff, M. S., Ye, X., Calafat, A. M., Kraus, T., & Moran, T. M. (2016). Perfluoroalkyl substance serum concentrations and immune response to FluMist vaccination among healthy adults. *Environmental Research*, *149*, 171–178. https://doi.org/10.1016/j.envres.2016.05.020

Sun, G. H., DeMonner, S., & Davis, M. M. (2013). Epidemiological and Economic Trends in Inpatient and Outpatient Thyroidectomy in the United States, 1996–2006. *Thyroid*, *23*, 727–733. https://doi.org/10.1089/thy.2012.0218

Torpie, S. (2019). Personal communication. Email to Barbara Morrissey, Washington State Department of Health, from Scott Torpie, Washington State Department of Health. Subject: ASDWA PFAS Workgroup – PFAS treatment Case Studies. March 18, 2019.

United Nations Environmental Programme (UNEP). (2012). Technical paper on the identification and assessment of alternatives to the use of perfluorooctane sulfonic acid in open applications. *Stockholm Convention on Persistent Organic Pollutants*. Retrieved from https://www.informea.org/sites/default/files/imported-documents/UNEP-POPS-POPRC12FU-SUBM-PFOA-Canada-48-20161209.En.pdf

United States Air Force (USAF). (2017). Frequently Asked Questions: Aqueous Film Forming Foam Replacement and containment. Retrieved from https://www.afcec.af.mil/Portals/17/documents/Environment/AFFF FAQ replacement and containment.pdf?ver=2017-04-14-154056-060

U.S. Bureau of Labor Statistics. (2019). Consumer Price Index for Urban Consumers. Retrieved from https://data.bls.gov/timeseries/CUUR0000SA0?output_view=pct_12mths

U.S. Bureau of Labor Statistics. (2017). May 2017 wages by area and occupation. Retrieved from https://www.bls.gov/oes/2017/may/oes_wa.htm

U.S. Department of Defense (DOD). (2018). Federal Contract Opportunity for Removal, destruction and disposal of Aqueous Film-Forming Foam (AFFF). Award SP450018R0008. Retrieved from https://govtribe.com/opportunity/federal-contract-opportunity/removal-destruction-and-disposal-of-aqueous-film-forming-foam-afff-dot-sp450018r0008

U.S. Department of Human and Health Services. (2012). Urologic Diseases in America. Retrieved from https://www.niddk.nih.gov/about-niddk/strategic-plans-reports/urologic-diseases-in-america

U.S. Environmental Protection Agency (EPA). (2009). Long-Chain Perfluorinated Chemicals (PFCs) Action Plan. Retrieved from https://www.epa.gov/sites/production/files/2016-01/documents/pfcs_action_plan1230_09.pdf

U.S. Treasury Department. (2020). Series I Savings Bonds Rates & Terms: Calculating Interest Rates. Retrieved from https://www.treasurydirect.gov/indiv/research/indepth/ibonds/res_ibonds_iratesandterms.htm

Wagner, J., & Bagenstose, K. (2017, February 3). Local, National Labs offer PFC Blood Tests. *The Pennsylvania Intelligencer*. Retrieved from https://www.theintell.com/news/20170203/local-national-labs-offer-pfc-blood-tests/1

Washington State Department of Ecology (Ecology). (2013). Public Participation Grant Agreement Between the State of Washington, Department of Ecology, and Futurewise. Effective date: October 1, 2013.

Washington State Department of Ecology (Ecology). (2015). Model Toxics Control Accounts: Biennial Report of Expenditures 2013 – 2015 Biennium. Retrieved from https://apps.ecology.wa.gov/publications/documents/1509340.pdf

Washington State Department of Ecology (Ecology). (2018a). Ecology 2019 Standard Costs [Internal memo].

Washington State Department of Ecology (Ecology). (2018b). Model Toxics Control Accounts: Biennial Report of Expenditures 2015 – 2017 Biennium. Retrieved from https://apps.ecology.wa.gov/publications/documents/1709055.pdf

Washington State Department of Ecology (Ecology). (2019a). Invoice and budget tracking, Lower Issaquah Valley PFAS Characterization Study. Complete and ongoing work. Total invoiced through 12/28/2018.

Washington State Department of Ecology (Ecology). (2019b). Model Toxics Control Accounts: Biennial Report of Expenditures 2017 – 2019 Biennium. Retrieved from https://apps.ecology.wa.gov/publications/documents/1909045.pdf

Washington State Department of Enterprise Services (DES). (2018a). 00710 Flooring Sales by Agency.

Washington State Department of Enterprise Services (DES). (2018b). State carpet contract prices for Interface, Mannington, Mohawk, Shaw, and Tandus brands. Retrieved from https://apps.des.wa.gov/DESContracts/Home/ContractSummary/03916

Washington State Department of Enterprise Services (DES). (2018c). Bid sheet for state contract for waterborne road marking paint. Retrieved from https://apps.des.wa.gov/DESContracts/Home/ContractSummary/02817

Washington State Office of Financial Management (OFM). (2019). General government salary schedule. Retrieved from https://ofm.wa.gov/sites/default/files/public/shr/CompensationAndJobClasses/Salary Schedules/2019Jan1_GWA/Represented/GS_2019Jan1_Represented.pdf

World Health Organization (WHO). (2009). WHO guide to identifying the economic consequences of disease and injury. Retrieved from https://www.who.int/choice/publications/d_economic_impact_guide.pdf

York, R. (2020). Personal communication. Email to Priscilla Tomlinson, City of Issaquah, from Robert York, City of Issaquah. Subject: GAC costs. May 29, 2020. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Yamashita, N., Kannan, K., Taniyasu, S., Horii, Y., Petrick, G., & Gamo, T. (2005). A global survey of perfluorinated acids in oceans. *Marine Pollution Bulletin*, *51*, 658–668. https://doi.org/10.1016/j.marpolbul.2005.04.026

List of acronyms

General acronyms

Table 91. Acronyms found in the economic analysis appendix.

Acronym	Definition
AFFF	Aqueous film forming foam
CAP	Chemical Action Plan
CDC	Centers for Disease Control and Prevention
DES	Washington State Department of Enterprise Services
DOD	United States Department of Defense
DON	Department of Navy
Ecology	Washington State Department of Ecology
EPA	United States Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
GAC	Granular activated carbon
Health	Washington State Department of Health
lb	Pound
MTCA	Model Toxics Control Act
NH	State of New Hampshire
OLF	Outlying Landing Field
PPG	Public Participation Grant
sy	Square yard
TCP	Ecology Toxics Cleanup Program
UNEP	United Nations Environmental Programme
WAC	Washington Administrative Code
WWTP	Wastewater treatment plant

Chemical names

Table 92. Chemical name acronyms found in the economic analysis appendix, excluding the general acronyms listed in the table above.

Acronym	Chemical Name
PFAS	Per- and polyfluoroalkyl substances
PFCA	Perfluoroalkyl carboxylic acid
PFHxS	Perfluorohexane sulfonate
PFOSA	Perfluorooctanesulfonamide
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFSA	Perfluoroalkyl sulfonic acid

Appendix 11: Response to Comments

11.0 Overview

11.0.1 Introduction

In accordance with Washington Administrative Code (WAC) 173-333-430(6),[196] The Washington State Department of Ecology (Ecology) and the Washington State Department of Health (Health) (jointly "we") issued the Draft Per- and Polyfluoroalkyl Substances (PFAS) Chemical Action Plan[197] (CAP) on October 7, 2020 for review by the public.

Public comment notification

We notified the public of the issuance of the Draft CAP for comment using the following methods:

- Publication in the Washington State Register (WSR) (WSR, 2020a)[198]
- Announcement on the project webpage
- Announcement on the Washington State Department of Ecology's (Ecology) public events page
- Notification sent to the Chemical Action Plan list serve
- Notifications sent to other Ecology list serves:
  - Safer Products for Washington program list serve
  - Public Participation Grants list serve
  - E-Cycle Program list serve
- News release distributed to media outlets[199]
- Social media announcements sharing the comment period opening
  - On Twitter[200] and Facebook[201]
- Social media announcement sharing the first comment period extension
  - On Twitter[202] and Facebook[203]

The availability of the Draft CAP for comment was also announced during presentations Ecology staff gave at various regional and national workshop events (see subsection Public Comment Meetings below).

---

[196] https://apps.leg.wa.gov/wac/default.aspx?cite=173-333-430
[197] https://apps.ecology.wa.gov/publications/summarypages/2004035.html
[198] lawfilesext.leg.wa.gov/law/wsr/2020/19/20-19-130.htm
[199] https://ecology.wa.gov/About-us/Get-to-know-us/News/2020/Oct-8-Public-invited-to-comment-on-PFAS-Chemical-A
[200] https://twitter.com/EcologyWA/status/1314257704110624768?s=20
[201] https://www.facebook.com/125197434170426/posts/3513097185380417/?d=n
[202] https://twitter.com/EcologyWA/status/1329137296453595144?s=20
[203] https://www.facebook.com/125197434170426/posts/3628605970496204/?d=n

Public comment submission process

Public comments could be submitted via an automated comment form available from the project webpage, by email, by fax, or by regular postal service. For those submitted via mail, they had to be postmarked by the last day of the comment period.

Public comment duration

WAC 173-333-430(6)[204] requires a minimum comment period of 60 days. The Draft CAP was originally open for comment through December 7, 2020. We extended the comment period twice at the request of local health departments, whose resources to respond were limited due to their active participation in responding to the Coronavirus disease 2019 (COVID-19) pandemic.

- A first extension was granted at the request of Seattle/King County Health Department, extending the comment through January 4, 2021 (O'Rourke, 2020; Makarow, 2020a; WSR, 2020b[205]).
- A second extension was granted at the request of Seattle/King County Health Department extending the comment through January 22, 2021 (Tan, 2020; Makarow, 2020b; WSR, 2021[206]).

We published each of these extensions in the WSR, made concurrent updates to the project webpage, and sent notifications to the project list serve. We also announced the first extension on Ecology's Twitter and Facebook pages.

We received a third request for extension included in the comment letter from the National Waste and Recycling Association (NWRA) (Smith, 2021). The NWRA requested that additional time be provided so that recently released draft Environmental Protection Agency (EPA) guidance on destruction and disposal of materials containing PFAS could be reviewed (EPA, 2020a). Ecology and Health chose to close the comment period as planned (Makarow, 2021), given that many additional federal PFAS actions would continue into the future.

Public comment meetings

WAC 173-333-430(6) requires two in-person public meetings in eastern and western Washington. However, issuance of the Draft CAP occurred during the COVID-19 situation, during which time meetings in public were not possible (Inslee, 2020; 2021). As a result, we conducted virtual public meetings as follows:

- November 12, 2020, 2 p.m.
- November 18, 2020, 6 p.m.
- November 19, 2020, 2 p.m.

Seven members of the public provided comments verbally during these meetings.

---

[204] https://apps.leg.wa.gov/wac/default.aspx?cite=173-333-430
[205] lawfilesext.leg.wa.gov/law/wsr/2020/23/20-23-092.htm
[206] lawfilesext.leg.wa.gov/law/wsr/2021/02/21-02-031.htm

11.0.2 Comments received

Ecology received a total of 949 letter submissions and verbal comments. We posted all comments—whether submitted via the automated form or other means—to the project eComments page[207] to make them accessible to the public. We also transcribed the public meetings and shared them on the eComments page.

Three form letters represented a large portion of the comments submitted:

- Form letter 1: 142 submissions
- Form letter 2: 586 submissions
- Form letter 3: 146 submissions

The content of these form letters is included in our comment review, where we identify issues each form letter raised. Ninety-five of the form letters included personalized messages, generally encouraging action on PFAS.

Table 93 summarizes the number of comments by the type of person or organization submitting them. Supplement 1 to this Appendix lists the persons and organizations who submitted a comment letter.

Table 93. Summary of comments, both written and verbal, on the Draft PFAS CAP.

Source of submission	Number of submissions
Individual	899
Local Government	12
Public Agencies (other than local government departments)	7
State Agency	1
Federal Government	1
Tribe or Tribal Organization	3
Organizations and associations	20
Business and industry	6
Total submissions	949

11.0.3 Comment response overview

WAC 173-333-430(6)[208] requires that Ecology provide a response to public comments. As noted above, we received many individual comment letters—more than for any previous CAP. In addition, each submission covered multiple topics addressed in the CAP – resulting in many instances of overlap between individual letter submissions.

Ecology staff reviewed the comments received and responded to the substantive concerns on an issue-by-issue basis. We identified the "issues" based on their correspondence with

[207] http://hwtr.ecology.commentinput.com/comment/extra?id=j4eJD
[208] https://apps.leg.wa.gov/wac/default.aspx?cite=173-333-430

information presented in the Draft CAP, or on material association with a specific section or appendix of the Draft CAP. Several submissions address the same issue from different perspectives.

Therefore, we subdivided each of the comment letters or verbal comments from one person into the "issues" addressed. We considered comments in combination with similar concerns raised by others. Overall, we identified 299 "issues," which are presented in Section 11.1 with accompanying responses.

We organized the issues and responses by the location of where the topic is addressed in the CAP, with the following exceptions:

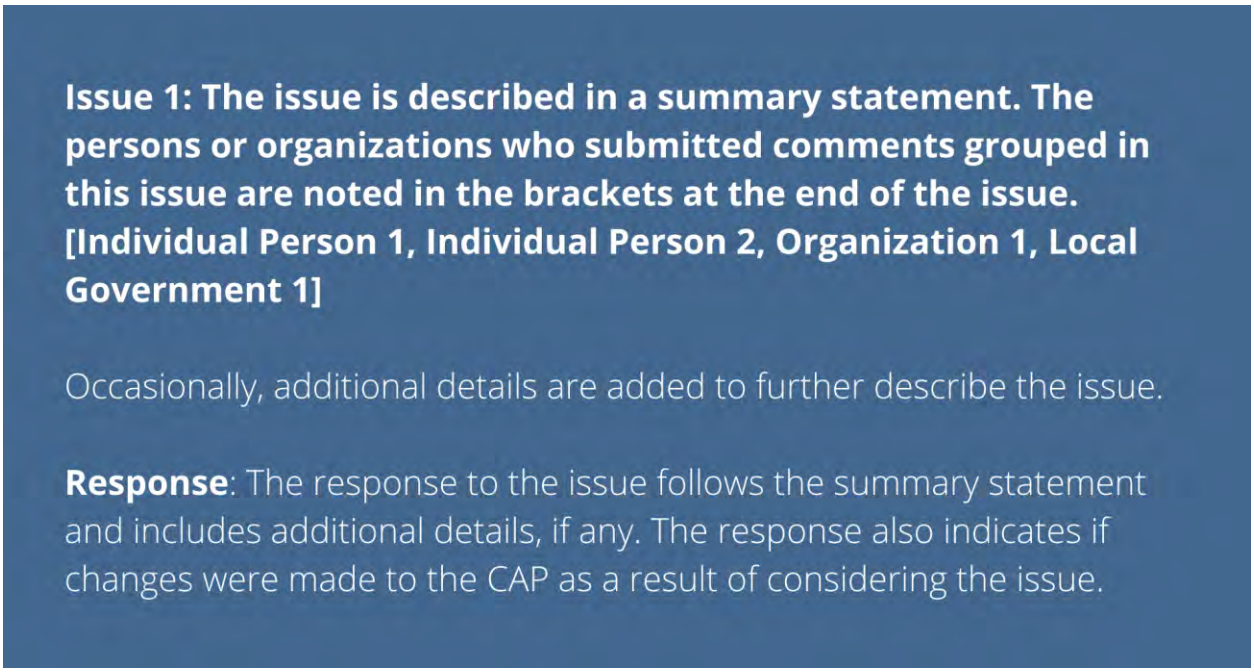
- Several issues were general or procedural—these are grouped and addressed as "general" issues.
- We grouped comments on the recommendations by each recommendation, regardless of whether the comment was specifically made on the version of recommendations appearing in the Draft CAP executive summary, in the main portion of the Draft CAP, or at the end of each appendix.

Each issue is presented in a consistent manner as follows:

- Each issue is numbered.
- The comments submitted on each issue are summarized in a summary statement.
- The persons or organizations who contributed comments on the issue are identified in brackets at the end of the summary statement.
- Occasionally, additional details about the issue are provided following the summary statement.
- The response to the issue starts following the bolded word "response."

Figure 49 provides an illustration of this issue and response organization.

Figure 49. Organization of comment responses including a summary of the issue, a list of individuals organizations who provided comments related to the issue, and the response.



11.1 Response to Comments

General issues

Issue 1: Comments received on the Draft CAP will be used as part of a rulemaking process. [Cascade Water Alliance, City of Vancouver, Avery, 3M, Form Letter 2, Form Letter 3, Toxic Free Future, The Lands Council, Public Health – Seattle & King County, 3M]

Comments were provided in the belief that the Draft CAP was part of a rulemaking process, or on topics addressed in a rulemaking related to PFAS in drinking water being conducted by the Washington State Board of Health (SBOH). These comments included, but were not limited to:

- Adoption of State Action Levels (SAL) for all PFAS.
- Overly protective standards currently being considered by the SBOH.
- Adoption of Maximum Contaminant Levels (MCL) and consideration of cumulative and aggregate exposures to PFAS mixtures and other chemicals.
- Lack of uniformity with federal government standards and guidelines.
- Supporting information regarding perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) emissions to be considered as part of a rulemaking process.

Response: Several comments submitted were related to the SBOH rulemaking for PFAS in drinking water. This rulemaking has a separate and dedicated process for public and stakeholder input. Information about how to participate is available on the Drinking Water

Rulemaking webpage.[209] Responding to comments on the draft drinking water rule is out of scope for the PFAS CAP. We did, however, share the comments with the Department of Health team who is developing the draft rule**.**

Several comments encouraged that any actions taken be uniform with federal government standards, guidelines, and policy developments. Ecology and Health are actively tracking and considering federal development of standards, guidelines, and policy surrounding PFAS (for example see Rice and Johnson, 2021). Washington state and many other states are moving ahead to put environmental and health protections in place due to the lack of current federal regulations.

Issue 2: Updating the CAP in the future. [City of Redmond, Yost]

Comments asked whether the CAP would be updated in the future, for example if cost estimates to implement recommendations addressing drinking water contamination exceed identified funding availability, or if new information regarding PFAS and their impacts becomes available.

Response: The agencies acknowledge that new information becomes available regarding chemicals studied in a CAP after a CAP is issued; we take this information into consideration in the CAP implementation phase. The CAP is a planning document. If a new plan is needed to address PFAS in Washington, we can consider that as our resources allow.

Issue 3: The CAP falls short in its recommendations, particularly with respect to using existing regulatory authority, setting timelines, and investing in solutions. The CAP should include an action timeline and enforcement steps. [Form letter 2, Olympic Environmental Council, Chow]

Response: Appendix 9, Regulations, updated in the CAP, summarizes the regulatory authorities for PFAS compounds applicable in Washington state. Ecology and Health are implementing multiple activities under these authorities as explained in the CAP at the Executive Summary, What else are we doing about PFAS?, Law implementation (also updated in the CAP). Ecology provides information about the timing of implementation steps at its webpages addressing activity under specific regulations. Both the Draft and this CAP have identified areas where additional rulemaking could be considered based on data collected as a result of implementing recommendations. In some cases, state authority is delegated or preempted by the federal government.

Following issuance of the CAP, Ecology and Health will begin implementing recommendations. As noted in the Draft and this CAP, some recommendations are already being implemented where funding for staff and other resources have been secured. Each agency will continue to prioritize and carry out its implementation activity based on available funding and staffing, and funding approved by the Legislature in support of the regulatory programs.

[209] https://www.doh.wa.gov/CommunityandEnvironment/DrinkingWater/RegulationandCompliance/RuleMaking

With respect to enforcement, Ecology is monitoring compliance with existing laws and regulations addressing PFAS and acting in areas where it believes regulated parties are not in compliance. For example:

- Packages containing metals and toxic chemicals (Chapter 70A.222 Revised Code of Washington [RCW]): The first report to the Legislature[210] identifying alternatives to PFAS in specific food packaging applications was submitted to the Legislature in February 2021; the ban addressing these specific applications will come into effect in 2023. Manufacturers of products complying with the law would be required to submit certificates of compliance in accordance with RCW 70A.222.040[211] starting in 2023.
- Firefighting agents and equipment (Chapter 70A.400[212] RCW): Ecology conducted outreach, and continues to do so, with regulated entities to inform them of regulatory requirements surrounding the manufacture, sale, and use of PFAS-containing firefighting foam. In July 2020, when the restriction on the sale and manufacture of PFAS-containing firefighting foam came into effect, Ecology was made aware of certain products containing such foam still being sold in the state (Valeriano, 2020). Ecology is taking action to contact the manufacturers and sellers of the products to notify them of the prohibition on the sale of these products (Sharp, 2021). RCW 70A.400.060 allows for the imposition of penalties in this situation.
- Children's Safe Products Act (Chapter 70A.430 RCW): Appendix 9, Section 9.1.2, Chapter 173-334[213] WAC, describes the procedures that manufacturers must follow to report the presence of PFOA and PFOS and its salts in children's products regulated under the Act. WAC 173-334-120 provides enforcement mechanisms allowing Ecology to collect children's products and analyze their components for the presence of chemicals of high concern to children (CHCC), and impose civil penalties if it finds a manufacturer has violated the provisions of the law. Ecology has used, and continues to use, this process to identify products violating the reporting requirements.

Issue 4: Numerous comments were submitted regarding concern over the potential adverse environmental and human health impacts resulting from PFAS emissions and use of products with PFAS. Comments supported existing and future action by Washington state, including source control, reducing or eliminating PFAS from products, working proactively with industry, manufacturers and businesses to eliminate releases to the environment, and funding by polluters to remove their contributions to the environment. [Fuerhelm, Murphy,

[210] https://apps.ecology.wa.gov/publications/summarypages/2104007.html
[211]https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.040
[212] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true
[213] https://apps.leg.wa.gov/wac/default.aspx?cite=173-334

Zimmerle, City of Vancouver, NWRA, Northwest Biosolids, King County Water Treatment Department, Public Health – Seattle & King County, Clark]

Response: Ecology and Health appreciate the interest the PFAS CAP has raised across numerous types of organizations and the public. As identified in the CAP at the Executive Summary, What else are we doing about PFAS?, both Ecology and Health are actively working to implement regulatory programs addressing PFAS in certain products, as well as obtaining funding from the Legislature to conduct studies recommended by the CAP. We recognize that source control is an important aspect of the CAP, as identified in numerous recommendations and as discussed in the response to Issue 82.

Issue 5: Document length may be a barrier to receiving public input. [Kuran]

Response: Thank you for your concern about public accessibility. Developing this CAP was a large and complex project partly because PFAS are a large class of chemicals, rather than a single contaminant. They also have many current uses that are unregulated, they occur in a number of waste streams (compost, landfills, sewer water, industrial discharge) and appear widely in environmental samples of water, sediments, soil, and biota. In addition, they are widely detected in human serum. As such, characterizing the extent of the PFAS problem in our state was challenging and involved extensive scientific review. The technical portions of the CAP will serve as a resource for professional staff and others as we implement the plan. We acknowledge that the PFAS CAP is a highly technical document. We are exploring new ways to develop CAPs that are more condensed and easily read by the public.

Issue 6: Additional stakeholders should be included in the CAP process. Comments requested that additional stakeholders be invited to future activities surrounding the CAP, including statewide organizations with interests in water, wastewater, biosolids, and waste handling sectors. [City of Vancouver, National Waste and Recycling Association]

Response: Ecology appreciates the interest conveyed by the waste management sector, public and private, regarding the issues of PFAS presence in a variety of waste streams. Sector concerns have been addressed throughout this response to comments, and changes made to the CAP to properly characterize landfilling practices. Preparation of the PFAS CAP stretched over multiple years, with new information being identified by regulatory agencies throughout this entire time. New stakeholders have emerged based on the development of guidelines and polices at various regulatory levels, in particular recent draft federal guidelines regarding disposal of materials containing PFAS (see Issue 227). The public comment process on the Draft CAP did allow participation of the waste sector in the CAP preparation process.

As indicated in responses to Issues 114 through 118, CAP recommendation 4.2 focuses on collecting more information before any decisions are made to require monitoring. Should Ecology decide that monitoring requirements are warranted in the future, the waste sector will have the opportunity to participate in comment processes associated with rulemaking.

Issue 7: Ecology and Health Should continue to collaborate when it comes to addressing PFAS in drinking water. [Sammamish Plateau Water and Sewer District, City of Redmond, Washington Association of Sewer and Water Districts]

Several comments supported and reinforced the importance of the alignment between Ecology and Health when addressing PFAS, especially in drinking water. Certain comments indicated such an alignment was necessary to provide clarity and effective PFAS administrative rules.

Response: Thank you for your support for agency coordination in addressing PFAS in drinking water. As you may know, Ecology and Health work together with stakeholders to prepare CAPs such as this one, as required by WAC 173-333-430.[214] Regarding drinking water impacts, we heard repeatedly from stakeholders that when PFAS impact drinking water supplies, local governments and water systems will need technical assistance with source identification, treatment options, clean-up standards that are coherent with drinking water standards, and a legal framework for working with responsible parties.

Issue 8: The CAP should include a table of definitions defining all relevant terms used throughout the document. Specifically, when using the term "contamination", does this refer to any level that exceeds an MCL? [Sammamish Plateau Water and Sewer District, City of Redmond].

Response: The authors attempted to ensure that terms being used are described in the text as necessary for proper context with respect to the issues being addressed. Because of the broad nature of the CAP, not only as a planning document, but also as an analysis of PFAS impacts across many environmental media, commercial sectors, and human health impacts it is not always possible to ascribe a single meaning to a term.

Regarding the word "contamination," the CAP uses it in its most general sense when applied to environmental concerns, as defined in Merriam-Webster as "a process of contaminating, or making unfit for use by the introduction of unwholesome or undesirable elements." When using the term, the CAP does not refer to any specific level exceeding any guidance value or regulatory standard.

Executive Summary

Why are we concerned about PFAS

Issue 9: Revisions were requested to text discussing bioaccumulation of long-chain PFAS in humans and animals and presence of perfluorinated alkyl acids (PFAA) in marine receptors. [TRC]

Response: Both of these revisions were incorporated into the subsection "Some PFAS are bioaccumulative."

Issue 10: The executive summary should identify ingestion of PFAS contaminated dust as an exposure route for humans. [Public Health - Seattle & King County]

Response: This mode of exposure was added to the subsection "Nearly everyone in Washington is likely exposed to PFAS." Children's exposure to household dust is already discussed in additional detail in Appendix 3, Section 3.3.2 PFAS in a typical home and Section 3.3.3 Consumer product priorities and Appendix 7, Section 7.3.3 Consumer products.

[214] https://app.leg.wa.gov/wac/default.aspx?cite=173-333-430

Issue 11: Statements in the executive summary regarding lack of understanding of (short-chain) PFAS replacement products may imply that short-chain PFAS are lower in toxicity. The CAP should emphasize that there is insufficient information about the toxicity of all PFAS, and that there is new data about hazardous effects of short-chain PFAS. [Abraham, Public Health - Seattle & King County]

A comment provides an additional reference regarding new toxicity data for short-chain PFAS (Nian et al., 2020). A comment requests that the CAP consider obtaining information from manufacturers to better understand how short-chain PFAS are being used in products and how they may impact the population.

Response: Several locations of the CAP identify that little is known about short-chain PFAS, including but not limited to Appendix 1: Chemistry, Section 1.3 Manufacturing, and Appendix 7: Health, Section 7.1.2 Primary health endpoints of concern, Sources of uncertainty in assessing hazard. Data gaps regarding PFAS are identified in most of the CAP appendices. We clarified replacement PFAS may not be safer and added Nian et al. (2020) to that discussion (see Appendix 7: Health, Section 7.1 Human health hazard assessment).

We also addressed in Appendix 9: Regulations, Section 9.2.2 Food and Drug Administration, that a voluntary phase-out of 6:2 fluorotelomer alcohol (6:2 FTOH) is being implemented because of toxicity data becoming available regarding this substitute. This action was taken based on new scientific data indicating these substances may be biopersistent in rodents.

Comments also suggested that action is being delayed because of our lack of knowledge about certain short-chain PFAS. This is not the case. In numerous sections of the CAP, we address short-chain PFAS because they are already in use to replace voluntarily discontinued long-chain PFAS, and we identify that it is important to avoid regrettable substitutions.

To obtain information regarding which PFAS are being used in manufacturing processes or appear in products sold in the state, the CAP identifies the following pathways:

- As part of working with industries and manufacturers to implement Recommendation 2.3, Ecology expects that we would identify specific PFAS being used at such locations so as to find successful reductions in use and emissions.
- As part of the assessment of priority products under the Safer Products for Washington program, Ecology has authority to request information regarding specific PFAS used in the products, the amount present, and their function (see RCW 70A.350.030(4)[215] and RCW 70A.430.060 (1)-(6)[216]).
- Finally, even though specific PFAS are not required to be identified, notifications provided under the Firefighting Agents and Equipment Law identify PFAS presence and the reason for their use in firefighting personal protective equipment (see RCW 70A.400.030[217]).

[215] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350.030
[216] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.430.060
[217] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400.030

Issue 12: The statement that "little is known" about specific PFAS substances used in products is a common misconception. The EPA has required manufacturers to generate considerable information for the relatively small number of PFAS substances in active commerce in the U.S. Significant information has already been collected regarding replacement products. [Alliance for Telomer Chemistry Stewardship]

The comment provides examples of how PFAS are used in the manufacture of a variety of products, and identifies that a robust body of scientific data has already been developed on some of the most common replacement products.

Response: The comment refers to the following statements: "For most products, little is known about the specific PFAS and amounts they contain, or the potential to expose humans or the environment during production, use, and disposal." Although some information on the types of uses of specific PFAS is available via EPA's review of substances under its Significant New Use Rules (SNURs) and New Chemical Review processes (see Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency, Toxic Substances Control Act), the publicly available information does not readily translate to:

- What PFAS are present in any specific product in commerce.
- In what concentration PFAS are found.
- The impacts of human exposure.
- How PFAS may be released into the environment.

Some of the uses allowed by SNURs are confidential. An informal survey of PFAS listed in EPA's Chemview database identified instances of permitted uses in substantive quantities with only generic descriptions of the application for which the use was permitted (EPA, 2015; 2021a). For example, a 2015 consent order allows the use of "perfluorobutanesulfonamide and polyoxyalkylene containing polyurethane (PROVISIONAL)" (Chemical Abstract Service [CAS] 241099) as a generic protective treatment potentially used as a consumer spray product, but protects specific uses identified in the consent order as confidential. As addressed in Issue 83, and in Appendix 3, Section 3.1.2 Secondary manufacturing, many efforts have compiled the myriad types of products that PFAS have been used in, and may still continue to be used in with some exceptions. See, for example, Glüge et al., 2020. Use of PFAS in secondary manufacturing is also not typically reported to regulatory agencies.

Replacement products, which often consist of short-chain PFAS, are not fully understood for the reasons explained. For example, the Food and Drug Administration's (FDA) recent voluntary phase-out of certain 6:2 FTOH substances was based on new data regarding the bio-persistence of these substances in rodents, and raising concerns that the substances "may also persist in humans following dietary exposure" (FDA, 2020). See:

- Issue 294
- Appendix 1: Chemistry, Section 1.3.5 trends in per-and polyfluoralkyl substance design.
- Appendix 6: Ecological Toxicology, Section 6.1.1 Short versus Long-chain PFAS and Section 6.2 Bioaccumulation.

- Appendix 7: Health, Section 7.1.2 Primary health endpoints of concern, Thyroid disease and thyroid hormone disruption.
- Appendix 9: Regulations, Section 9.2.2, Food and Drug Administration.

Issue 13: Clarify the statement regarding bioaccumulation of PFAS in animals even though they are distant from PFAS sources. [Alliance for Telomer Chemistry Stewardship]

Response: References to studies that have demonstrated long-range transport of certain PFAS and that wildlife do not need to be near emission sources to show bioaccumulation were included in Appendix 6, Section 6.2 Bioaccumulation. For example "…one study has shown elevated levels of PFAS in Scandinavian marine animals, although there is no production of PFAS in Scandinavia (Roos et al., 2013)."

Recommendations for action

We received comments on CAP recommendations relative to two main sections of the document: the recommendations listed in the Executive Summary, under the heading "Recommendations for Action," and then often repeated again in the main portion of the document under the heading "Draft CAP Recommendations."

Many comments raised the same issues relative to content in these separate sections. Occasionally, comments on the recommendations were also made in the appendices. To avoid repetition, our responses to comments raised regarding CAP recommendations are all grouped under the section "Draft CAP Recommendations" below.

What else are we doing about PFAS?

Issue 14: The CAP should provide more information on the status of Aqueous Film Forming Foam (AFFF) activities being conducted by Ecology (underway, complete), as well as relative to notification requirements regarding firefighting personal protective equipment. [Public Health – Seattle & King County]

Response: In the Executive Summary, What else are we doing about PFAS?, the Draft CAP provided an update regarding activities to implement the law. We updated this section to reflect which activities are ongoing or changes since issuance of the Draft CAP. Activity relative to Ecology's preparation of an Environmental Impact Statement (EIS)[218] to analyze the impacts of destruction of AFFF to be collected from local and state firefighting agencies was also added to this section.

Regarding notification requirements for firefighting personal protective equipment, the Draft CAP correctly described the activity that occurred upon law adoption—Ecology sent letters to protective equipment manufacturers in 2019 informing them of notification requirements and requesting certificates of compliance as permitted by RCW 70A.400.050(1) .[219] We requested that manufacturers confirm they provide notice to purchasers, or otherwise state that their products do not contain PFAS. Ecology tracked receipt of responses to this request. This activity

[218] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals/PFAS/Toxics-in-firefighting
[219] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.400.050

is complete, however Ecology may repeat the process in the future, pending availability of staff resources.

Issue 15: Comments asked that Ecology and Health develop a process to understand PFAS in children's products, that all PFAS be added to Children's Safe Products Act (CSPA) reporting requirements, and for CSPA to prevent imports of children's products containing PFOS and PFOA. The comments also request that a process be developed to understand PFAS in products, based on the work of Cousins et al., 2020. [Public Health - Seattle & King County, Toxic Free Future]

Response: Appendix 9, Sections 9.1.1, Washington state laws, and 9.1.2 Washington state rules, identify the reporting requirements for children's products that contain PFOS and PFOA. In order for all PFAS to be reported under CSPA, Ecology, in coordination with Health, would have to conduct a rule-making under WAC 173-334-060[220] to add these substances to the "reporting list of chemicals that the department has identified as high priority chemicals of high concern to children" (CHCC list). In order to be added to the list, chemicals must meet two criteria (WAC 173-334-070 (2)(a)[221]): toxicity, persistence or bioaccumulativity criteria specified in RCW 70A.430.010(9)[222]; and the exposure criteria specified in RCW 70A.430.030(1).[223]

We recommend that when the CHCC list is updated PFAS be considered; this has been added to Recommendation 3.3.

Children's exposure to PFAS also results from consumer products in the home, beyond children's products regulated under CSPA. Additional priority products can be identified as part of future work under Safer Products for Washington, as described under Recommendation 3.2.

Please see the response to Issue 91 regarding understanding PFAS in products based on the approach described in Cousins et al., 2020.

Issue 16: Additional information should be provided about development of fish consumption advisories. [TRC, Public Health - Seattle & King County, Port Gamble S'Klallam Tribe (Welch)]

Comments requested consideration of:

- Development of consumption advisories for marine or anadromous fish.
- Availability of marine and anadromous fish tissue PFAS data.
- Why fresh water species' tissue may be higher in PFOS than marine species'.
- Prioritization of data collection regarding bioaccumulation of PFAS in finfish and shellfish.

Response: Department of Health reviewed Ecology's data on freshwater fish from urban waters (see Appendix 5: Environmental Occurrence, Section 5.1.7 Freshwater fish). Some fish in urban waters exceeded health-based screening values for PFOS. Some of these water bodies already

[220] https://apps.leg.wa.gov/WAc/default.aspx?cite=173-334-060
[221] https://apps.leg.wa.gov/wac/default.aspx?cite=173-334-070
[222] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.430.010
[223] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.430.030

have fish consumption advisories for other contaminants. Sampling of several marine species by Washington Department of Fish and Wildlife and others indicates that PFAS are lower in marine species (see Appendix 5: Environmental Occurrence, Section 5.1.9 Marine Biota). Other recent studies also report only low detections of PFAS in marine fish and shellfish species (Ruffle et al., 2020). Differences between freshwater and marine species may reflect their exposure to local sources (Ali et al., 2021).

Health is currently conducting a study to fill key data gaps about the contribution of dietary fish to human exposures in Washington. The study will help us finalize our screening level for PFOS and will help us direct consumers to safer choices of fish if a PFOS advisory is issued. We expect to complete this study in 2021.

Issue 17: Ecology should fully implement the ban on PFAS in all paper food packaging. As of the issuance of the Draft PFAS CAP Ecology had fallen behind on the alternatives assessment schedule. Many PFAS-free alternatives have been identified by stakeholders. [Clean Production Action, Toxic Free Future]

Response: Ecology issued its PFAS alternatives assessment (AA) report to the Legislature[224] in February 2021. Throughout the PFAS AA process, Ecology informed the public and stakeholders as to reasons why the assessment took longer to complete than originally planned. This information is available via presentation materials and public updates posted on the PFAS AA project webpage.[225]

The commenters ask that Ecology "fully implement Washington state's ban on PFAS in paper food packaging." Ecology has done that in its first round of consideration of packaging types. As required by the law, Ecology considered chemical hazard, performance, cost and availability, and exposure data. Following its product evaluations, Ecology submitted its findings for external peer review. Ecology identified safer alternative products for certain applications, and submitted its report to the Legislature. Use of PFAS in these specific products will be banned starting in 2023. As required, we immediately began a second alternatives assessment to identify additional safer alternatives that meet criteria expressed in the law.

Issue 18: Address PFAS in Firefighter Personal Protective Equipment (PPE). The comment identifies manufacturers who have disclosed PFAS in firefighter turnout gear and requests the information be included in the CAP. [Clean Production Action, Toxic Free Future].

Response: Thank you for this information. The CAP Section entitled "What else are we doing about PFAS?" identifies the Firefighting Agents and Equipment Law and the requirements for firefighting PPE manufacturers to notify purchasers about the presence of PFAS. The law does not require that information about PFAS in turnout gear be made available publicly.

[224] https://apps.ecology.wa.gov/publications/summarypages/2104007.html
[225] https://www.ezview.wa.gov/site/alias__1962/37610/pfas_in_food_packaging_alternatives_assessment.aspx

PFAS Assessment Summary

Many of the comments provided on this section were also repeated, sometimes in more detail, in association with the text appearing in the CAP appendices. In such cases, our response to such comments is addressed below in Section 11.6, Appendices.

Chemistry (Appendix 1)

Issue 19: Sampling of resources containing PFAS that are utilized in the natural environment should be conducted (compost, biosolids, and reclaimed water) and appropriate limits/use restrictions set to prevent potential contamination from these sources. [City of Redmond]

Response: Please refer to the responses to issues as follows: Issue 102 about compost testing and regulations; Issue 119 about testing of biosolids; and Issue 108 about reclaimed water.

Issue 20: The CAP should identify a list of prioritized telomers. [Yost]

Response: It is not useful for the CAP to identify a list of prioritized telomers because the CAP reviews and addresses PFAS from different perspectives, for example:

- Certain long-chain PFAS receive (both historically and currently) significant attention due to their persistent, bioaccumulative, and toxic characteristics.
- Those PFAS that are pre-cursors to terminal degradation products found in the environment.
- PFAS which have been used to replace long-chain substances, such as short-chain PFAS and fluorotelomers, about which more information is needed regarding how they behave in the environment.

Issue 21: Revisions are proposed to two statements: degradability of PFAS under natural conditions as a result of their functionalization, and renaming "surfactants" to "fluorinated additives". [Alliance for Telomer Chemistry Stewardship]

Response: The statement regarding resistance to natural degradation was revised to indicate that **certain** PFAS are completely resistant to natural degradation. We retained the term surfactants.

Analytical methods (Appendix 2)

See issues addressed relative to Appendix 2: Analytical Methods below.

Sources and uses (Appendix 3)

Issue 22: Correct a typographical error, "fluorotelemer" to "fluorotelomer". [Alliance for Telomer Chemistry Stewardship]

Response: The typographical error was corrected.

Fate and Transport (Appendix 4)

Issue 23: Manufacturing processes emit PFAS through stack emissions. Comments request that PFAS air emissions from manufacturing processes be evaluated and steps taken to reduce PFAS aerial deposition from such processes. [City of Redmond]

Response: Recommendation 2.3, Work to prevent PFAS releases from firefighting foam use and manufacturing processes, addresses that Ecology needs to identify industries and manufacturing that have historically used, or continue to use, PFAS and identify their potential to emit PFAS into the environment. Investigations into environmental emissions would include air emissions, if such are produced by the industrial or manufacturing processes.

Issue 24: Revisions were proposed for the subsection entitled "PFAS assessment summary, Fate and Transport (Appendix 4). [TRC]

The comments requested the following revisions:

- Short-chain PFAS can also degrade into PFAAs, precursors are not a separate source of PFAS and all PFAA precursors are poly-fluorinated compounds.
- Revise the statement regarding PFAS solubility to align with similar statements in Appendix 4.
- Acknowledge EPA's November 2020 Interim Strategy for PFAS in Federally Issued National Pollutant Discharge Elimination System (NPDES) Permits.

Response: The statement regarding degradation of precursors to terminal substances has been revised to include both short- and long-chain PFAS.

General statements regarding PFAS solubility were revised throughout the CAP to identify that certain PFAS are highly soluble. Appendix 1, Chemistry, Section 1.2.4 Solubility in water, addresses in more detail that the solubility of PFAS is variable based on their make-up and the composition of the aqueous media.

EPA's interim strategy on PFAS in federally issued NPDES permits was included in Appendix 9, Section 9.2.1 Environmental Protection Agency.

Issue 25: The CAP should include a discussion of the PFAS cycle in layman terms, and should address how the cycle can be broken in addition to removing the source of PFAS from products. [Yost]

Response: A description of the PFAS cycle adapted to conditions in Washington state was added to the CAP introduction. The pathways of PFAS movement from products to the environment, and via waste streams are discussed throughout the CAP, and are specifically addressed in Appendix 4, Fate and Transport. The CAP recommendations identify actions that will serve to characterize various pathways so that the most significant can be identified and acted upon.

Environmental Occurrence (Appendix 5)

Issue 26: At Appendix 5, the CAP should address evaluation of PFAS in stormwater and catch basin sediments at facilities that manufacture, handle, store, or use products or materials containing PFAS, and require mitigation where appropriate. [City of Redmond]

Response: The Water Quality program's priority for PFAS is source identification. As sources are identified, Ecology will evaluate the best way to mitigate them. This may include the evaluation of PFAS in stormwater and catch basin sediments at facilities that manufacture, handle, store, or use products or materials containing PFAS.

Ecological Toxicology (Appendix 6)

Issue 27: References should be provided for the statement indicating that the high mobility and bioavailability of short-chain PFAS results in relatively high levels in fish tissues. [Alliance for Telomer Chemistry Stewardship]

Response: The reference to this statement is provided in Appendix 6 Ecological Toxicology, Section 6.1.1 Short versus long-chain PFAS, as Shi et al. (2018). As indicated in the introductory paragraph of the PFAS Assessment Summary, citations were not included to make the summary more accessible.

Biosolids (Appendix 8)

Issue 28: Regarding the statement that "the majority of perfluorinated compounds in Washington municipal wastewater originate from domestic sources," it should be noted that due to the PFAS transformations that can inadvertently take place within the wastewater treatment plant (WWTP) process, and the concentrating of PFAS within WWTP solids fraction, even a secondary or tertiary industry could potentially produce significant terminal PFAS in its biosolids stream. [TRC]

Response: There is no specific evidence of PFAS concentration in Washington biosolids attributable to transformation. There is every likelihood that the more water soluble congeners will leave in the effluent with longer chain versions ending up in the solids fraction. A mass balance evaluation would need to be conducted in order to determine the estimated total mass entering a WWTP compared with an estimate of the total amount of PFAS in biosolids in order to determine if there is some concentrating effect. No such evaluation has been conducted nor do we even have an accredited analysis method for biosolids in order to achieve precise and accurate results.

Issue 29: Comments question whether Washington policy of applying biosolids to cropland is more important to Ecology than protecting either the health of the people or the quality of agricultural soils where PFAS may accumulate. [Friends of Toppenish Creek]

Response: A comprehensive evaluation should review the scope of possible outcomes, not just focus exclusively on every potential negative consequence. The point being made in the CAP is that land application of Washington biosolids may pose a very low risk to human health and the environment (for the reasons enumerated) while very low contaminant thresholds may disrupt a vibrant organics industry that is intimately tied to large scale recycling programs in the state. Simply because there is recognition of potential consequences to the organics industry does not translate to Ecology prioritizing land application over human health and the environment. We don't have the data to support either position. It is important to note that the mere presence of a contaminant does not in itself demonstrate risk. Information on concentration and pathways of exposure is critical in determining risk to human health and the environment.

Regulations (Appendix 9)

Issue 30: The CAP should identify specialized uses of long-chain PFAS still allowed in the U.S. [TRC]

Response: Appendix 9, Section 9.2.1, Subsection "Toxic Substances Control Act" provides a summary of EPA's Significant New Use Rules and New Chemical Review regulatory processes by which certain specialized uses of certain PFAS are permitted. Two examples of limited uses were listed in Appendix 3, Section 3.1.2, Secondary Manufacturing.

Issue 31: The statement about FDA overseeing PFAS in food packaging should be altered to—FDA is "responsible" for this activity. [Public Health - Seattle & King County]

Response: This statement has been revised to state that FDA regulates this activity. The revision was made both in the PFAS Assessment Summary section of the CAP, as well as in Appendix 9, Section 9.2.2, Food and Drug Administration.

Draft CAP Recommendations

1.0 Ensure drinking water is safe

1.0: Ensure drinking water is safe

Issue 32: Expand testing to identify the full extent of drinking water systems contaminated by PFAS. [Form Letter 3, Toxic Free Future, The Lands Council, City of Vancouver, Mefford]

Response: Expanded testing of drinking water was recommended in the 2018 Interim CAP and is a central component of the draft drinking water rule being recommended to the SBOH by the Department of Health. The draft rule would require community Group A water systems (those serving more than 15 connections or 25 people) to test for PFAS using method 537.1 or 533. We agree that state-wide testing is necessary to more fully understand the scope of the PFAS issue in our state and to identify and reduce exposures of public health concern.

Issue 33: Recommendation 1 introductory statements indicate that less than 1% of Group A systems were tested; the CAP should identify when testing occurred and whether it was part of the third unregulated contaminant monitoring rule (UCMR3). The section should also reference Draft Recommended State Action Levels discussed in Appendix 7. [City of Vancouver]

Response: The text has been revised to include that the testing occurred as part of the EPA's UCMR3 in the period 2013 – 2015 and through subsequent voluntary testing conducted by the military and proactive public water systems (2016 – 2020). This revision was made both in the main portion of the document under Recommendation 1.0, Ensure drinking water is safe, as well as in Appendix 7, Section 7.6.2, Recommendations.

Regarding adding a reference to Appendix 7 at the discussion about the Interim CAP's recommendation to develop drinking water standards, we have avoided adding references and citations in this section to make this portion of the document more direct and accessible to the public. The text as written provides links to SBOH rulemaking documents where the information

can be found. As the commenter notes, the information is presented in Appendix 7, Section 7.5.2 Department of Health advice for PFAA's in drinking water.

Issue 34: Recommendation 1 statements, under "Interim CAP" should be clearer as to the reasons why DOH's planned statewide drinking water source testing plan could not be implemented, including whether water utilities were not willing to participate. [City of Vancouver]

Response: The text at this section indicated the reasons why the earlier recommendation was not implemented: "Health was unable to secure commercial laboratory services or sufficient funding for this initiative in 2018 – 2019."

1.1 Identify funding for PFAS drinking water mitigation

Issue 35: At Recommendation 1.1 the CAP should define "timely mitigation" and clarify why the word "may" is used. The CAP should recognize that "Do not Use" orders are subject to Health oversight. [Sammamish Plateau Water and Sewer District, City of Redmond, City of Vancouver].

Commenters are reacting to these 2 sentences:

- When PFAS concentrations in drinking water supplies exceed health advisory levels, timely mitigation may be needed to protect human health.
- Drinking Water State Revolving Fund can provide emergency loans in the event a water system is issued a "Do Not Use" order as a result of PFAS contamination.

Response: The intent of this paragraph was to describe some of the costs incurred by water systems in responding to PFAS detections in drinking water. It also pointed out how funding could help minimize disparities in the response. The details of how and when a utility should respond to PFAS detection in drinking water is a subject of discussion in the drinking water rule-making and is best answered in that process. The paragraph in the CAP was rewritten to focus on the types of costs potentially incurred by water systems.

Issue 36: The CAP should identify that finding an "alternative water source" to mitigate for PFAS contamination of drinking water may not be feasible in closed basins where issuance of new water rights may not be possible. [Sammamish Plateau Water and Sewer District, City of Redmond, Washington Association of Sewer and Water Districts].

Response: Several sections of the CAP described measures taken by water suppliers to address PFAS contamination, including the text associated with Recommendation 1.1, and Appendix 10, Section 10.1, Costs of recommended actions. These measures illustrated a variety of options generally available to address drinking water contamination. Ecology recognizes that some options may not be available to certain public water systems, leaving them with few options but to install water treatment systems. This is why Recommendation 1.1 emphasizes the importance of finding funding mechanisms so that appropriate mitigation measures are facilitated.

Issue 37: Mitigation programs should prioritize grant funding mechanisms over loans, and ensure such programs are robustly funded to avoid shifting remedial costs to ratepayers of

public drinking water systems. [Sammamish Plateau Water and Sewer District, City of Redmond, Washington Association of Sewer and Water Districts, PFAS Regulatory Coalition]

Response: Ecology and Health are not directly responsible for funding grant and loan programs—funding is appropriated by the state Legislature, or as payments from federal programs. The agencies do assist with identifying and disbursing funding if available to assist local water systems. The Washington State Department of Commerce maintains a summary of current funding sources (Department of Commerce, 2020). For each funding mechanism, the summary identifies the agency responsible for managing the disbursement of funds and the conditions under which the funds are dispersed.

The need for sufficient funding, however, is the main reason why the CAP includes Recommendation 1.1, which emphasizes that "State agencies, the Washington State Legislature, and water systems should work together to fund PFAS drinking water mitigation." We recognize that all levels of government need to work together to ensure that sufficient funding requests are made to state and federal legislators, and support such requests, so that the necessary funds are allocated to programs that can then disburse the funds to affected local governments and utilities. These funding requests can favor grant programs over loans.

Issue 38: Funding may be limited to sites with contamination by PFAS listed as hazardous substances; existing funding sources may not cover characterization and remediation of contamination. [Eastside Fire and Rescue]

The CAP should be clarified to:

- Identify when PFAS assistance is dependent on first receiving a hazardous substance listing for the individual chemical.
- Identify the needed funding mechanisms for investigation and remediation of PFAS sources in soil, groundwater, and surface water and how local agencies can work with Ecology to ensure ongoing investigations are completed to protect human health and the environment.

Response: Most Remedial Action Grants administered by Ecology's Toxic Cleanup Program (TCP) (e.g. Oversight Remedial Action Grants, Safe Drinking Water Action Grants and Area-wide Groundwater Investigation Grants) require that the compounds of concern be hazardous substances under the Model Toxics Control Act (MTCA). Safe Drinking Water Grants also specify that contaminant levels must exceed cleanup levels established by Ecology or may exceed the specified cleanup levels in the future. For more detailed information on project eligibility for these Remedial Action Grant types, see Ecology's most recent guidance.[226]

Ecology has concluded that PFAS compounds meet the definition of a hazardous substance under MTCA. The basis for this conclusion is discussed in more detail under Issue 60.

Issue 39: The CAP should address limitations on funding availability to private water companies, emergency funding, financial and legal assistance during litigation. Due to

[226] https://apps.ecology.wa.gov/publications/summarypages/2009055.html

potential cost impacts on water utility rate-payers, the Washington State Utilities and Transportation Commission (UTC) should be involved in discussions regarding testing mandates for water systems regulated by the Commission. [UTC].

Response: Recommendation 1.1 identifies that state agencies, the Legislature, and drinking water purveyors need to work together to ensure sufficient funding mechanisms are available and that they are properly funded. Given that the UTC regulates some water systems, we anticipate that the UTC would participate in these efforts.

Recommendation 1.1 has been revised to address the comments as follows:

- Acknowledge that funding sources available to private water companies are limited.
- Identify that costs will be incurred to maintain service while mitigation actions are implemented.
- Identify that legal fees can be significant.

Comments regarding the inclusion of UTC staff in discussions of testing mandates for investor owned systems are noted. However, they apply to specifics of SBOH rulemaking activities, which are beyond the scope of this CAP, as discussed in the response to Issue 1.

Issue 40: A commenter requests that we estimate the number of drinking water utilities likely to be impacted by PFAS and then provide an estimate of the total estimated cost to mitigate. They also urge us to conduct a state survey analogous to the Unregulated Contaminant Monitoring Rule (UCMR) to determine the number of utilities impacts before adopting any state drinking water standard. [City of Vancouver].

Response: We agree that the funding needed to address PFAS in drinking water will depend on the number of utilities impacted by PFAS. We do not have sufficient information about point sources of PFAS in our state to speculate about the likely number of utilities impacted by PFAS in their drinking water supplies. Some of the largest pollution sources in other states, fluoropolymer plants, have no known operations in Washington, so it is difficult to extrapolate from other state testing data.

Instead, the draft SALs would require a round of drinking water testing to determine how many utilities are impacted. The CAP acknowledges that financial assistance is needed to help water systems address PFAS. Ultimately, the cost of removing PFAS from drinking water should be borne as much as possible by responsible parties, including manufacturers.

Also, the fifth UCMR survey (UCMR5) is already planned for 2023 – 2025 and will require drinking water testing for 29 PFAS compounds.

Issue 41: Data and reports regarding characterization and investigation of sites should be easily accessible to local governments and the public. [Sammamish Plateau Water and Sewer District, City of Redmond, Public Health - Seattle & King County, Abraham]

Comments were provided to several CAP sections requesting that data collected about PFAS through response at affected sites be accessible:

- At Recommendation 1.1, in any case where state funding is being appropriated for investigation and mitigation, data and reports should be transparently shared with

interested or affected public water systems, without requirements for public record requests.

- At Recommendation 1.2 that a PFAS data base or data repository be created to allow utilities easy access to new and historical PFAS monitoring data and reports.
- At Recommendation 1.2 that communication structures be created to facilitate timely and effective communication to all PFAS affected parties, water utilities, and the community.
- At Recommendation 2.1 that information regarding cleanup efforts be provided to local impacted water systems.
- At Recommendation 2.1 that all data collected by methods used to test drinking water and other matrices should be made available to the public, beyond the five PFAS compounds for which SALs are being considered, or for which health advisories are currently in place.

Response: We agree that transparency will be beneficial to the many parties who will ultimately be involved in identifying, responding to, investigating, and cleaning up PFAS-contaminated areas. We will consider communication structures that promote that transparency. Health intends to make all drinking water data on PFAS collected under state rules accessible to the public. Ecology intends to include information on sites with PFAS contamination in our contaminated sites database. The timeline for completing this effort has not yet been determined.

Issue 42: Costs of response to drinking water mitigation are underestimated in the CAP. All direct and indirect costs should be accounted for. Additional information about actual costs is provided in the comments. The CAP also does not address how many utilities will be affected by implementation of proposed SBOH SALs. [Lakewood Water District, City of Vancouver, PFAS Regulatory Coalition]

Response: Appendix 10, Section 10.1, Costs of recommended actions, was updated to include the cost information provided by the Lakewood Water District. A summary of this updated information was included in Appendix 10, PFAS Assessment Summary, Economic Analysis. Text identifying legal fees to pursue liable parties was added to the introduction to Recommendation 1.1.

The CAP has identified that statewide costs for PFAS mitigation in drinking water will not be fully understood until further testing to characterize the occurrence in drinking water is complete (see PFAS Assessment Summary, Economic Analysis (Appendix 10); Appendix 10, Section 10.1, Costs of recommended actions, Action 1.1 Identify funding for PFAS drinking water mitigation).

Issue 43: Responsible party costs should be recovered as a State, such as what has occurred for tobacco products or opioids. The state could make long-term loans to water systems and then forgive such loans when settlements are awarded. [Whidbey Island Water Systems Association].

Response: We agree that costs of removing PFAS contamination from drinking water should be borne by responsible parties when possible. Thank you for your suggestion regarding the involvement of the Washington Attorney General. Advocating for a legal approach to cost recovery for water systems is beyond the scope of the CAP. However, you can provide this suggestion using the Attorney General's Office contact webpage.[227]

Issue 44: Mitigation response costs should be recovered from responsible parties, and not borne by local governments who were not responsible for the contamination. [Vilgalys, Ude, Public Health - Seattle & King County, Abraham]

Response: It is possible that actions by water purveyors to correct drinking water contamination need to be implemented prior to third parties being identified and held accountable under MTCA, or costs of mitigation or remediation having been reimbursed. As identified in Recommendations 1.1 and 2.1, classification of certain PFAS as hazardous substances by the federal government, or definition as hazardous substances under the state of Washington's statutes or rules, can allow that these substances be addressed under the MTCA framework, and provide an avenue for liable parties to be pursued for reimbursement of mitigation costs.

1.2 Provide technical support for site characterization, source investigation, and mitigation at contaminated sites

Issue 45: Recommendations 1.2 and 2.1 should include consideration of artificial changes to ground water flow that can occur from activities such as temporary construction dewatering, in characterizing and remediating a site. [Sammamish Plateau Water and Sewer District, City of Redmond].

Response: The CAP recommendations have been drafted at the planning level to indicate the major actions that should be taken to advance PFAS remediation measures statewide. Ecology acknowledges that many factors have to be considered when addressing remediation at a specific site, however it is beyond the scope of the CAP to incorporate this level of detail in the consideration of the steps needed to set cleanup standards.

Issue 46: Will mitigation and cleanup coordination be conducted through the Voluntary Cleanup Program (VCP). [Sammamish Plateau Water and Sewer District, City of Redmond].

Response: Ecology intends to use all of the available administrative process options to ensure that PFAS contamination is adequately addressed. In addition to the VCP, Ecology may also use Agreed Orders, Consent Decrees, Enforcement Orders, and if necessary, Ecology led cleanup actions.

Issue 47: The state should support the federal government's efforts to develop technical assistance and ensure that its recommendations conform and support those of the federal government. [PFAS Regulatory Coalition]

[227] https://www.atg.wa.gov/contact-us

Response: Ecology generally supports the Federal Government's efforts and often uses EPA guidance to help implement cleanup actions. However, MTCA contains requirements that differ from Federal provisions and as a result, Washington state does not always follow Federal recommendations.

Issue 48: If there is credible evidence of a problem, such as test results provided by citizens, Ecology and Health should conduct investigations with or without the support of local health departments, cities, or counties. [Abraham]

Response: As a result of regulatory authority, our agencies may not be those directly responsible for investigation of drinking water impacts or contaminated sites. However, the purpose of our recommendation is to specifically acknowledge that our agencies will continue to develop expertise and provide technical support in response to PFAS contamination. Our agencies will use our regulatory authorities to ensure drinking water contamination is appropriately addressed (see response to Issue 35), and that contaminated sites are addressed (see response to Issues 55 to 68).

Issue 49: Drinking water testing should identify PFAS at the lowest possible detection limits and should be made public. [Abraham]

Response: As the CAP discusses in Appendix 2: Analytical methods, Section 2.1.1 Drinking water methods, analytical methods for PFAS in drinking water have evolved significantly since the UCMR3 in 2013 – 2015. Current drinking water methods that have been validated by EPA can detect 29 PFAS with detection limits for most analytes in the low parts per trillion. Under the SBOH rulemaking, public drinking water systems would be required to test for PFAS under these current methods. The Department of Health intends to make the results of testing available to the public.

Issue 50: The proposal for Ecology to prioritize mitigation and clean up on the basis of the number of people impacted, the concentration of the PFAAs in the drinking water, and vulnerable populations is subjective. Objective criteria should be established while noting affected public water systems may have local standards for considering the need for PFAS mitigation. [Sammamish Plateau Water and Sewer District, City of Redmond]

Response: This portion of Recommendation 1.2 needs to be considered in the full context of how it was written. First, Ecology recognizes that certain public water systems must follow Health rules to provide drinking water that meets drinking standards. However this portion of the recommendation addresses cleanup and other groundwater mitigation activities under Ecology's jurisdiction—such as addressing the source of the drinking water contamination. Ecology believes it is important to identify and support mitigation and cleanup of the most critical contamination sources, i.e., "the number of people impacted and the concentration of PFAAs in the drinking water." However, prioritization of sites must also take into consideration vulnerable populations who may be present, and who may be disproportionately impacted. The focus of this recommendation is therefore to also identify populations who may be disproportionately impacted.

1.3 Support biomonitoring and other health studies to answer important health questions

Issue 51: Testing for the presence of PFAS in water supplies should take precedence over increasing opportunities for citizens to participate in studies to assess adverse health impacts. [Ude]

Response: Thank you for your input. We are prioritizing the testing of public drinking water. We continue to look for opportunities to participate in studies that answer important exposure and health questions.

Issue 52: Washington residents should have the opportunity to participate in biomonitoring and health studies, regardless of whether such studies are supported by local officials. [Abraham]

Response: Thank you for your input.

Issue 53: Scientific research studies recommended by the CAP should partner and coordinate with other agencies and organizations doing that research to increase efficiency and avoid duplication. [PFAS Regulatory Coalition].

Response: Thank you for your input.

Issue 54: Biomonitoring must be well designed, the limitations clearly explained, and presented in the context of quantitative risk assessment [PFAS Regulatory Coalition, Alliance for Telomer Chemistry Stewardship].

Response: Thank you for your input.

2.0 Manage Environmental Contamination

2.0 Manage environmental contamination

Issue 55: References to contamination in the City of Issaquah should further identify impacts to Sammamish Plateau Water and Sewer District from contamination of the Lower Issaquah Valley Aquifer. [Sammamish Plateau Water and Sewer District]

Comments identified the omission of the Sammamish Plateau Water and Sewer District from described impacts of PFAS in the Lower Issaquah Valley Aquifer.

Response: Thank you for your input. We added Sammamish Plateau Water and Sewer District to Appendix 7.

Issue 56: Identification of known locations of drinking water contamination by Class B firefighting foams based on UCMR3 data is insufficient. UCMR3 data is unreliable because of its reporting limits for PFAS substances. Sources of more prevalent, lower concentration PFAS contamination have yet to be determined. [City of Vancouver]

Response: Although this comment was raised relative to text associated with Recommendation 2.0, Appendix 7, Section 7.4 Known areas of PFAS contamination in drinking water aquifers in Washington state, provides a detailed description of all the data collected so far including UCMR3, military testing and additional voluntary testing by water systems. The key suspected source of contamination identified so far is release of Class B firefighting foam.

We agree that comprehensive water testing proposed in current rulemaking may expand the number of key sources of contamination in the state. For example, the Draft CAP identified that PFAS releases into the environment can be caused in many ways, resulting in varying presence of PFAS in all types of environmental media as well as drinking water sources. CAP Recommendations 1.2, 2.0, 2.1, 4.1, 4.2 and 4.3 all focus on better characterizing non-point releases to further our knowledge regarding potential impacts to drinking water contamination end environmental exposure to PFAS.

Issue 57: The cleanup of Issaquah's drinking water supply should be acknowledged in Recommendation 1.0, Ensure drinking water is safe. [King County Solid Waste].

Response: A comment was made relative to the introduction to Recommendation 2.0 Manage environmental PFAS contamination, where the Draft CAP discussed specific assistance provided by Ecology to the City of Issaquah to support PFAS groundwater contamination investigation. The Draft CAP (Recommendation 1.1, Identify funding for PFAS drinking water mitigation) did mention how the City of Issaquah received funding through the State Building Construction Account for groundwater investigation.

2.1 Establish PFAS cleanup levels for soil and groundwater

Numerous comments supported the CAP recommendation for Ecology to use its existing authority under MTCA to develop cleanup standards, including from Sammamish Plateau Water and Sewer District, City of Redmond, Washington State Association of Sewer and Water Districts, and in all three form letters we received.

Issues were raised regarding whether, and which, specific PFAS should be considered for such standards, and information that should be taken into consideration when establishing the standards. These issues are addressed below.

Issue 58: Recommendation 2.1 should be revised to show stronger intent for Ecology to establish cleanup standards, replacing "considering" with "requiring". [Sammamish Plateau Water and Sewer District, City of Redmond]

Response: Since the CAP is advisory in nature, using the word "required" would not be appropriate. However, the fourth bullet under this recommendation was changed to read: "Once sufficient supporting data are available, Ecology plans to develop cleanup levels for individual or mixtures of PFAS in soil, sediment, freshwater, and saltwater to protect ecological receptors."

Issue 59: With respect to Recommendations 2.1 and 2.3, Ecology should establish regulations which prohibit PFAS discharges in the environment where the known source exceeds the SBOH proposed State Action Levels or Ecology emission standards. [Sammamish Plateau Water and Sewer District, City of Redmond].

Response: As explained in Appendix 3, Section 3.4.2 Wastewater, there are no federal or state treatment requirements for PFAS in industrial or municipal wastewater discharges. There are also no validated analytical methods for detection of PFAS in wastewater. The planned SBOH SALs are applicable only to drinking water. Similarly, there are no state or federal air emission standards or validated test methods for PFAS in regulated air emissions.

It is premature to recommend regulatory action to establish such criteria for the following reasons:

- Lack of validated analytic methods to support monitoring of PFAS in regulated emission streams.
- Lack of federal standards for adoption by the state.
- Lack of data that informs the various exposure, toxicity, and other degradation criteria that need to be established in order to set emission standards in various types of media.

Ecology's priority is to address sources which may result in PFAS exposure for people and the environment, and this is reflected in the CAP recommendations. For example, Recommendations 4.1, 4.2, and 4.3 address collecting additional information about PFAS in certain waste streams that expose the environment to PFAS to better understand their relative contribution to releases to the environment. Recommendation 2.3 focuses on working with industries to reduce emissions to waste streams. Once this information is available, and validated analytical methods for specific media that could be regulated are established by EPA, Ecology can evaluate the best way to mitigate emissions that represent significant exposure pathways.

Issue 60: Ecology should designate PFAS as a class as hazardous substances, adopt cleanup standards in 2021, and address existing PFAS contamination as quickly as possible. [Form letter 1, Form letter 2, Form letter 3, Smith (Maddie), Zimmerle, Toxic Free Future, National Tribal Water Council, Olympic Environmental Council, Public Health - Seattle & King County, The Lands Council, Port Gamble S'Klallam Tribe (Welch, Carter)]

Response: Ecology has concluded that PFAS compounds meet the definition of a hazardous substance under MTCA. Chemicals that meet the definition of a hazardous substance under the Hazardous Waste Management statutes or the Dangerous Waste Regulations (Chapter 173-303[228] WAC) are also hazardous substances under MTCA.

The Hazardous Waste Management statute provides that wastes or other constituents exhibiting any of the characteristics or criteria of hazardous waste as set out in the dangerous waste regulations are considered to be hazardous substances. The dangerous waste regulations define hazardous substances as: "any liquid, solid, gas, or sludge, including any material, substance, product, commodity, or waste, regardless of quantity, that exhibits any of the physical, chemical, or biological properties described in WAC 173-303-090 or -100."

Halogenated organic compounds satisfy one of the criteria for exhibiting the chemical property of persistence under the dangerous waste regulations. PFAS compounds are by definition halogenated organic compounds because they have one or more fluorine atoms bonded directly to a carbon atom.

Regarding setting cleanup levels under MTCA, the absence of MCL's or Maximum Contaminant Level Goals (MCLG) on the Federal level, or MCL's established by the Washington State Board of Health will require Ecology to impose cleanup levels on a site specific basis. This will not allow

[228] https://apps.leg.wa.gov/wac/default.aspx?cite=173-303&full=true

for PFAS cleanup levels to be broadly established in 2021, but it may be possible to establish cleanup levels for individual sites. While Ecology supports addressing PFAS contamination as quickly as possible, limited staff resources and competing priorities will affect the overall timeline for many projects.

Issue 61: Ecology should not rely on drinking water standards or other proxies as a substitute for development of cleanup standards under MTCA; cleanup levels should be risk-based and compound specific. [Association of Washington Business, Alliance for Telomer Chemistry Stewardship].

Response: MTCA provides specific direction on how to determine cleanup levels. For groundwater, one of the provisions requires complying with the applicable state and federal laws, including:

- MCL's established under the Safe Drinking Water Act and published in 40 CFR 141.
- MCLG's for non-carcinogens established under the Safe Drinking Water Act and published in 40 CFR 141.
- MCL's established by the Washington State Board of Health and published in Chapter 246-290[229] WAC.

MTCA also provides several other options and Ecology intends to consider all available alternatives when establishing cleanup levels for groundwater. Initially, cleanup levels will be established on a compound-specific basis for the same five PFAS compounds that the State Board of Health promulgates SALs for.

Issue 62: The CAP should identify which compounds Ecology will develop cleanup standards for, and whether these are the same as those being considered by the SBOH for State Action Levels. Comments also called for designating all PFAS as hazardous substances [Public Health - Seattle & King County, City of Redmond]

Response: Ecology intends to initially develop cleanup levels for the same five PFAS compounds as the State Board of Health intends to promulgate SALs for, and the CAP has been revised to reflect this. See Issue 60 for a discussion on designating PFAS as a hazardous substance.

Issue 63: Ecology should defer to national cleanup standards developed by EPA. [PFAS Regulatory Coalition]

Response: It is very likely that Federal cleanup levels (e.g. MCLs) won't be promulgated for quite some time, and even then, their scope will be very limited. In the absence of Federal standards, MTCA provides specific direction for determining cleanup levels. Since the SBOH is moving forward to establish SALs for five PFAS compounds, Ecology intends to initially develop cleanup levels for these same five compounds.

Issue 64: Ecology should not designate PFAS as a hazardous substance under MTCA. [3M]

Response: See response to Issue 60.

[229] https://apps.leg.wa.gov/wac/default.aspx?cite=246-290

Issue 65: Cleanup levels should be established based on an understanding of fate and transport and supported by analytical methods. [City of Tacoma, Northwest Biosolids]

Response: See responses to Issues 61 and 67. Ecology intends to follow the provisions in MTCA for establishing cleanup levels. The default three-phase partitioning model specified by MTCA for establishing soil leaching cleanup levels that are protective of groundwater may not be an ideal model for PFAS, but at this time we don't know if there will be a more accurate model available. From a practical perspective, soil leaching cleanup levels for many PFAS are likely to fall below practical quantitation limits—in which case, it doesn't matter what the actual risk-based value is because the cleanup level will be based on the practical quantitation limit.

Issue 66: PFAS should be subject to the state hazardous substance tax. [Form Letter 3, Toxic Free Future, The Lands Council]

Response: In order to be subject to the hazardous substance tax, one of the provisions in RCW 82.21.020(1)[230] would need to be met, and PFAS currently do not meet any of the criteria.

In addition, even if PFAS met a criteria of RCW 82.21.020(1), it would not automatically subject consumer products containing PFAS to the Hazardous Substance Tax. RCW 82.21.010(1)[231] states, in relevant part: "It is the intent of this chapter to impose a tax only once for each hazardous substance possessed in this state…However, it is not intended to impose a tax on the first possession of small amounts of any hazardous substance (other than petroleum and pesticide products) that is first possessed by a retailer for the purpose of sale to ultimate consumers." That intent is further clarified under RCW 82.21.040(2)[232], which provides a tax exemption for possession of hazardous substances being used for personal or domestic purposes.

Issue 67: Establishment of cleanup standards should be delayed until: more science has been established; proven, affordable, and effective remediation technologies exist; and appropriate analytical methods have been established. [King County Solid Waste]

Response: Ecology believes that sufficient information is available for establishing cleanup levels, effective remediation techniques are currently being used, and sufficient analytical methods exist for performing the necessary analysis.

Issue 68: Additional funding, beyond Ecology's operating budget, should be allocated for Ecology to explore methods for investigation and cleanup of PFAS contamination; technologies that remove PFAS from waterways and the environment should be funded. [King County Solid Waste, Vilgalys]

Response: Up to now, funding for investigation and cleanup of PFAS contamination has been provided to Ecology by the Legislature and has been earmarked to complete specific tasks. Our technical staff routinely review information from the scientific literature. Ecology, the

[230] https://app.leg.wa.gov/rcw/default.aspx?cite=82.21.020
[231] https://app.leg.wa.gov/rcw/default.aspx?cite=82.21.010
[232] https://app.leg.wa.gov/rcw/default.aspx?cite=82.21.040

Governor, and the Legislature will need to review future funding priorities and decide if additional funding will be requested and appropriated for these efforts.

2.2 Partner with local organizations in communities with contaminated water or contaminated sites

Issue 69: Several commenters supported inclusion of equity impacts in recommendations addressing drinking water and requested additional support. [Public Health – Seattle & King County, City of Vancouver, PFAS Regulatory Coalition]

Specific areas of support were noted:

- Providing communication resources for local health jurisdictions to effectively communicate with private well owners and class B water systems.
- Supporting, in collaboration with local organizations, uniform standards and working with EPA and other organizations like the Environmental Council of States (ECOS) on risk communication tools currently under development.
- Dedicating funding for local health jurisdictions to engage with lower income and communities of color; funding to assist environmental justice (EJ), lower income and communities of color with sampling and cleaning up PFAS in the environment.
- Expanding research across the state to determine sources and communities most at risk of exposure to PFAS.

Response: Recommendation 2.2 addresses the needs to establish effective communications with communities affected by PFAS contamination of drinking water. As noted, resources for effective communication are being developed and implemented by Health. Since the development of this plan began in 2016, communication resources about PFAS have become available, for example the Association of State and Territorial Health Officials' (ASTHO)/ ECOS or Environmental Research Institute of the States (ERIS) Risk Communications Hub (ASTHO, 2021; ERIS, 2021) and the Interstate Technology & Regulatory Council's (ITRC) Risk Communication Toolkit (ITRC, 2021). Ecology and Health expect to draw from these and other publicly available communication resources.

Recommendation 1.1 addresses funding for PFAS drinking water mitigation. Ecology and Health recognize that multiple organizations need to work together to identify which types of community and governmental organizations will need funding to address PFAS, and identify ways to secure such funding.

Finally, recommendations 2.3, 4.1, 4.2, and 4.3 address Ecology data collection that is being proposed (and in some cases already being conducted) to identify PFAS emission pathways into the environment and evaluate their relative significance regarding environmental and human exposure. Once we confirm release pathways of significance, steps can be taken to reduce PFAS emissions, especially in consideration of communities most at risk from exposure from such releases.

Issue 70: In addition to considering whether certain communities are "overburdened" with PFAS-containing products, Ecology should also consider whether certain vulnerable or

underserved communities uniquely or disproportionately benefit from the unique properties and protections provided by PFAS chemistries. [Alliance for Telomer Chemistry Stewardship]

Response: Our consideration of "overburdened" communities in the CAP focuses on the meaning related to EJ concerns, reflected, for example, in the definition provided by the state Environmental Justice Task Force (Environmental Justice Task Force, 2021) and, most recently, the Legislature's passage of Engrossed Second Substitute Senate Bill (E2SSB) 5141[233], which the Governor signed into law on May 17, 2021:

- Environmental Justice Task Force: "Overburdened communities" are communities who experience disproportionate environmental harms and risks due to exposures, greater vulnerability to environmental hazards, or cumulative impacts from multiple stressors.
- E2SSB 5141: "Overburdened community" means a geographic area where vulnerable populations face combined, multiple environmental harms and health impacts, and includes, but is not limited to, highly impacted communities as defined in RCW 19.405.020.[234]

Recommendation 3.2 focuses on engaging with overburdened communities regarding products containing PFAS that may cause disproportionate exposures to such communities. Appendix 7: Health, Section 7.3 Sources and pathways for human exposure, addresses the primary pathways of human exposure we have identified to-date.

Issue 71: For the work on safer products, Ecology and Health should dedicate staff and funding to develop a specific engagement plan to identify recommendations on actions regarding products that contain PFAS. [Public Health – Seattle & King County]

Response: As explained in the subsection "Cost" for each of Recommendations 3.1 and 3.2 the Safer Products for Washington program is being conducted using funding appropriated specifically to implement the program's underlying legislation. Both Ecology and Health staff resources are already being paid for, including development and implementation of engagement and communication plans. The program publicizes its engagement activities via its website and develops outreach materials aimed at helping the public purchase safer products and protect themselves from toxic chemicals. The program also plans to host additional public workshops to engage community in the work and seek input in the future.

Issue 72: An EJ section should be developed for the CAP. Recommendations from the State Environmental Justice Task Force should be incorporated into the CAP at a specific section, highlighting how EJ activities can be taken for each of the actions proposed in the PFAS CAP. [Public Health – Seattle & King County]

Response: Additional discussion of EJ concerns was added to the CAP in two locations:

[233] http://lawfilesext.leg.wa.gov/biennium/2021-22/Pdf/Bills/Session%20Laws/Senate/5141-S2.SL.pdf?q=20210713132200
[234] https://app.leg.wa.gov/RCW/default.aspx?cite=19.405.020

- First, within the CAP, at the end of the Section entitled PFAS CAP Recommendations, the Section "How health equity and environmental justice goals informed the CAP recommendations" to summarize how health equity and EJ was incorporated throughout the CAP recommendations.
- Second, at Appendix 7: Health, we added Section 7.6, Health equity and environmental justice, where we describe our state of knowledge about population demographics and exposure to PFAS, and the types of information existing EJ analysis tools can provide to better inform our communication with EJ communities.

Agency work on PFAS concerns will continue to coordinate with potentially affected EJ and historically overburdened communities. These practices will be further developed through agency implementation of EJ Task Force recommendations and guidance developed by the new Environmental Justice Council.

Issue 73: Tribal and vulnerable populations should be prioritized when planning cleanup and mitigation activities. [Port Gamble S'Klallam Tribe (Carter, Welch)]

Response: As part of Recommendation 1.2 Ecology will take into consideration the presence of vulnerable populations when prioritizing mitigation and cleanup activities. Ecology will use EJ mapping tools to characterize demographics of the population served by impacted drinking water.

2.3 Work to prevent PFAS releases from firefighting foam use and manufacturing

Issue 74: in addition to preventing releases from AFFF use and industrial uses, the CAP should consider releases associated with wastewater treatment plant sludge, effluent and reclaimed water. [Sammamish Plateau Water and Sewer District, City of Redmond]

Response: The Draft CAP discusses PFAS in biosolids (i.e. wastewater treatment plant sludge) at Appendix 8: Biosolids, and PFAS in municipal WWTP effluents at Appendix 3: Sources and Uses, Section 3.4.2 Wastewater. Recommendations 4.1 and 4.3 address PFAS in WWTPs and biosolids respectively. Discussion of reclaimed water has been added to Appendix 3: Sources and Uses, Section 3.4.2 Wastewater.

Issue 75: As part of Recommendation 2.3 Ecology should consider establishing a registry of known sites where AFFF was used for fire suppression or training, and require fire department reporting. Costs for disposal of stockpiled AFFF should be borne by industries, manufacturers and agencies handling PFAS. [Sammamish Plateau Water and Sewer District, City of Redmond]

Response: Currently, the Washington's Toxics in Firefighting foam law (Chapter 70A.400[235] RCW) does not authorize Ecology to require fire departments to report when they use AFFF as it is intended. However, MTCA (RCW 70A.305.10[236]) requires fire departments to remediate soil

[235] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true
[236] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.305&full=true

or groundwater contaminated by releases of PFAS. In addition, under WAC 173-340-300,[237] the owner or operator (i.e., Fire Department) who has information that a hazardous substance (i.e., AFFF) has been released to the environment, shall report this information to the appropriate regional Spills office within 90 days. Under MTCA, parties responsible for releases of toxics chemicals into the environment are required to cover cleanup costs.

In addition, on January 13, 2020, the Department of Defense (DOD) issued a policy that took effect immediately for all DOD sites to begin reporting all AFFF usage or spills (not associated with use). This reporting is to include:

- The name of the installation and date of the AFFF use or spill.
- The amount (gallons) and type of AFFF used.
- The cause for the use or spill.
- A summary of the AFFF usage or spill.
- Notification to the DOD Component Environmental Department for on-base releases or to supported entity for mutual aid responses.

In 2018, the Legislature created the Product Replacement Program designed to identify and address some of the most problematic chemicals affecting our state. This program provides reimbursement funding, collection and disposal services, or other opportunities to help business owners transition to less toxic options. One of the funding projects is the collection, transport, and safe disposal of AFFF stockpiles at the state's municipal fire departments. Currently, more than 70 fire departments have identified roughly 30,000 gallons of AFFF they want to dispose.

Ecology is conducting an EIS review of the AFFF collection and disposal program[238]. The EIS will consider the collection and disposal program's impact upon the environment, public health, disadvantaged communities, wildlife including endangered species, and other resources still to be determined. The EIS will also investigate potential disposal methods. Those disposal methods are likely to include options such as landfill, deep-well injection, emerging technologies such as supercritical water oxidation, and incineration. No decision regarding the preferred destruction method has been made. Ecology expects a decision by the end of 2021 or early 2022.

Issue 76: At Recommendation 2.3, Ecology should expand its approach with industry, manufacturers and businesses to include any generator of PFAS products. [Sammamish Plateau Water and Sewer District, City of Redmond]

Response: As identified in Appendix 3: Sources and Uses, Section 3.1.1 Primary manufacturing, Ecology is not aware of any facilities that may have manufactured PFAS compounds in Washington state. Nevertheless, should future activities to implement Recommendation 2.3 identify sites where PFAS were manufactured, these would be appropriately addressed.

[237] https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-300
[238] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals/PFAS/Toxics-in-firefighting

Issue 77: When working with industries, manufacturers and businesses that have used or continue to use commercial quantities of PFAS Ecology should share this information with local governments so that these locations can be tracked. [City of Renton]

Response: Under section 7321 of the recently enacted National Defense Authorization Act (NDAA) for 2020, certain PFAS are immediately added to the list of chemicals covered by the Toxics Release Inventory (TRI). Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) provides a framework for additional PFAS to be added to TRI on an annual basis. According to the EPA, the TRI is a public resource for learning about toxic chemical releases and pollution prevention activities reported by industrial and federal facilities. TRI data support informed decision-making by communities, government agencies, companies, and others. EPCRA Section 313 created the TRI Program.

The first public reports on the initial 172 PFAS added to the TRI for reporting year 2020 were due July 1, 2021. Three additional PFAS chemicals are automatically added to the 2021 reporting year. See more information in EPA's list of PFAS chemicals added to the TRI.[239]

Issue 78: Paper mills can be a significant source of PFAS contamination. In addition to investigating industrial releases in wastewater, industries could be asked to report on historical and current use of PFAS, and then work to eliminate releases, as has been done using the NPDES process in Michigan. [Cellarius]

Response: The Draft CAP, Appendix 3: Sources and Uses, Section 3.1.2, Secondary Manufacturing, addressed manufacturing activity types that could have used, or could still be using, PFAS in the manufacturing process or their products, including the paper industry. Use of PFAS in manufacturing is not typically reported to Ecology.

Recommendation 2.3 focuses on identifying those manufacturing sectors, and then specific facilities, which may have used PFAS in Washington, and any releases that may have occurred, not just in wastewater. Ecology would then evaluate PFAS release potential from these sites, which could include collaboratively gathering information about their PFAS use practices. The last bullet of Recommendation 2.3 focuses on identifying ways for these facilities to reduce their emissions, as suggested in the comment.

Issue 79: The issues surrounding use of AFFF at Part 193 airports are unique, especially surrounding federal requirements for emergency response; anticipated dates for FAA to authorize fluorine-free AFFF and the DOD to modify its military specification should be taken into consideration when state laws are enacted and implemented. Ecology should continue to focus on containment of AFFF releases, until such time that PFAS-free Class B firefighting foams that have been qualified for military specification MIL-F-24385 become available, and Class B firefighting foam users have had the time to modify or switch suppression systems to use the PFAS-free foams. [Association of Washington Business, PFAS Regulatory Coalition, Port of Seattle]

[239] https://www.epa.gov/sites/production/files/2021-01/documents/tri_non-cbi_pfas_list_1_8_2021_final.pdf

Response: We acknowledge the myriad complexities of addressing AFFF at airports, and the effect the pandemic could have on timelines.

On October 5, 2018, the U.S. Congress passed the Federal Aviation Administration (FAA) Reauthorization Act. Within this act is a mandate directing the FAA to stop requiring the use of fluorinated foam no later than three years from the date of enactment of the reauthorization act (or October 4, 2021).

When the law was passed, the Legislature made special provisions in case of shortages of non-PFAS foams. RCW 70A.400.020(2)(b)[240] requires Ecology to publish in the WSR and to provide notice to appropriate legislative committees of any change in federal rules that would "allow the use of alternative firefighting chemicals that do not contain PFAS chemicals."

If the FAA rule requiring the use of fluorinated foam were to become unenforceable on October 4, then Ecology would publish a notice in the WSR and notify legislative committees to that effect. Two years thereafter, the sale of Class B foam to which PFAS has been added would be prohibited for uses previously required by the FAA rule. See the table below for the dates when particular state actions would commence.

Table 94. Timeline for Ecology publications and notifications, Part 139 Airport reporting and prohibitions for AFFF sale and use under Chapter 70A.400 RCW.

Date	Action	Impact
October 4, 2021	Ecology Notice of Finding is published in WSR	Ecology will publish a notice alerting state House and Senate committees' about a change in federal law that no longer requires the use of PFAS containing AFFF. The notice must identify the involved federal agency and, **if identified by the federal agency**, the alternative firefighting agent.
April 4, 2023	Airport Report Due	All Airports in Washington certified under 14 Code of Federal Regulations (CFR) Part 139 are required to report to Ecology on the status of obtaining alternative firefighting agents approved by the FAA and any necessary infrastructure.
October 4, 2023	Additional AFFF restrictions apply	The sale, manufacture, and distribution of class B firefighting foam that contains intentionally added PFAS for the uses specified in 14 CFR Part 139.317 is prohibited. **These restrictions will be delayed until October 4, 2024** if Ecology determines that any airport in Washington certified under 14 CFR Part 139 has not been able to secure alternative firefighting agents and any necessary infrastructure to apply the agent in order to meet certification requirements because of lack of commercial availability.

[240] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.400.020

Date	Action	Impact
October 4, 2023	Second Notice	Ecology must publish an additional notice delaying the restrictions on the sale, manufacture, and distribution of class B firefighting foam that contains intentionally added PFAS for the uses specified in 14 CFR Part 139.317 if the alternative firefighting agents or infrastructure are not commercially available.
October 4, 2024	Restrictions enacted	Restrictions as mentioned in the October 4, 2023 Ecology notice would apply.

Issue 80: The statement that landfills are a source of AFFF releases is questionable; landfills are receivers of PFAS containing waste, and do not generate or use such wastes. At Recommendation 2.3, additional recommendations should be made to keep AFFF out of landfills. [King County Solid Waste]

Response: The text regarding use of AFFF to respond to fires at landfills was removed. Ecology agrees that AFFF would not be disposed in a landfill because AFFF would designate as a persistent dangerous waste (halogenated organic compounds) under WAC 173-303-100.

Issue 81: We prefer incineration to landfilling of stockpiles of AFFF held by airports, manufacturing, and transportation sectors. A program should be launched to collect and destroy PFAS containing AFFF through incineration from all sources, not just the limited group listed in the CAP. [King County Solid Waste]

Response: Currently, the Washington Department of Ecology is preparing for an EIS review of the AFFF collection and disposal program. The EIS will consider the collection and disposal program's impact upon the environment, public health, disadvantaged communities, wildlife including endangered species, and other resources still to be determined. The EIS will also investigate potential disposal methods. Those disposal methods are likely to include options such as landfill, deep-well injection, emerging technologies such as supercritical water oxidation, and incineration. No decision regarding the preferred destruction method has been made. The EIS will be completed by the end of 2021 or early 2022.

3.0 Reduce PFAS in products

3.0 Reduce PFAS in products

Issue 82: Numerous comments were received supporting the reduction of PFAS at the source, i.e. in the products that are produced and used. A range of comments as to the extent of removal of PFAS from commerce was also received. Support for authority to eliminate PFAS in food packaging via House Bill 2658 was indicated. It was requested that the CAP discuss safer alternatives for products such as food packaging, carpeting, and personal care products. It was encouraged that Ecology restrict the use of PFAS in AFFF and remove it from storage for proper disposal where possible. It was also requested that Health and Ecology lay out a clearer plan for PFAS beyond the Safer Products for Washington program's mandate. [City of Tacoma, Baumgartner, Cowlitz County Public Works, NWRA, Northwest Biosolids; WASWD, Waste Connections, Public Health - Seattle & King County, City of Vancouver]

Response: Ecology and Health appreciate the positive support for activities aimed at removing PFAS from the source. Responses to issues under sections 3.0 through 3.3 below address the range of requests for removal of PFAS from products—from no restrictions of PFAS use beyond already applicable federal requirements, to consideration of essential uses only, to complete bans on all PFAS. The identification of safer alternatives for uses of PFAS in food packaging are already discussed in detail in the 2021 report to the Legislature.[241] The identification of safer alternatives for PFAS in priority products will be addressed in the future under the Safer Products for Washington program[242] (for carpeting, leather and textile furnishings, and aftermarket treatments). Ecology's work surrounding AFFF is being conducted under the requirements of Chapter 70A.400 RCW[243]—this is already discussed in more detail above and in the CAP at section "What else are we doing about PFAS? Law implementation." As discussed throughout the CAP recommendations, and responses to issues in this appendix, the CAP presents the activities that are proposed to address PFAS via recommended activities, as well as work which is being conducted under the various laws addressing PFAS in products in Washington.

Issue 83: The CAP should reference the recently published paper on consumer products with PFAS (Glüge et al, 2020). [Public Health - Seattle & King County]

Response: The paper referenced in the comment has been added to the CAP at Appendix 3: Sources and Uses, Section 3.1.2 Manufacturing, and Section 3.3.2 PFAS in a typical home.

Issue 84: Regulations should be enacted to require the disclosure of PFAS in consumer products and other applications. Consumers need to be made aware of these products through labelling and educational outreach. There is a need for a CAP that can act quickly to cleanup up PFAS contamination and prevent further use and spread of this toxic, persistent chemical. [Re Sources]

[241] https://apps.ecology.wa.gov/publications/summarypages/2104007.html
[242] http://ecology.wa.gov/Safer-Products-WA
[243] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400

Response: At this time, there are no state laws that give Ecology or Health the authority to adopt rules to require disclosure of PFAS present in all products and applications or labeling of such products. Several state laws are in place to provide notification of PFAS in certain products. As described in Appendix 9: Regulations, Section 9.1 Washington state laws and regulations:

- Notification of PFAS presence in firefighting protective equipment must be provided to purchasers of such equipment under Chapter 70A.400 RCW.
- The presence of PFOS and PFOA in children's products must be reported to a publically accessible database under Chapter 70A.430 RCW.

There are no federal laws requiring labelling of products that contain PFAS. Under the Safer Products for Washington program, Ecology will consider whether regulatory actions will be necessary for priority products containing PFAS.

The purpose of this CAP is to serve as a long-term planning document for actions to reduce human and environmental exposure to PFAS. The CAP does not direct or assist actions to clean up contamination related to a specific release event. The CAP includes various recommendations to assess and minimize releases of PFAS to the environment. Both Ecology and Health maintain websites to disseminate information regarding toxic chemicals, including PFAS, to the public (Ecology, 2021a,[244] Health, 2021a[245]).

3.1 Reduce PFAS Exposure from carpets, rugs, water and stain resistance treatments, and leather and textile furnishings

Issue 85: At Recommendation 3.1, consider a program to subsidize legacy carpet replacement in low income housing. [City of Tacoma, Northwest Biosolids]

Response: We expanded our recommendation to implement a product replacement program for carpet with PFAS to low-income housing in addition to community centers, libraries and daycares.

Issue 86: New studies (Glüge et al., 2020) have identified that textile related PFAS usage is small relative to other industries and product manufacturing. Eliminating all uses in textiles would not make a meaningful impact on monomeric PFAS pollution. Long-chain fluorinated polymers for use as a repellent for textiles should be restricted in the light that advancements in short-chain fluorinated polymers have been made for this use. Use of short-chain fluorinated polymers is important in select uses. [National Council of Textile Organizations]

Response: Our recommendations for reducing PFAS in products focus on reducing PFAS as a class based on the definition of PFAS in recent Washington legislation (Chapter 70A.350 RCW and RCW 70A.222.070[246]) and their environmental persistence, toxicity, data gaps, and potential for regrettable substitutions. Appendix 7: Health describes toxicity concerns around

[244] https://ecology.wa.gov/PFAS
[245]https://www.doh.wa.gov/CommunityandEnvironment/Contaminants/PFAS
[246] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222.070

both short- and long-chain PFAS. While there are less data available on short-chain PFAS, the data we have suggest that they may have similar toxicity concerns.

Under Recommendation 3.1, the Safer Products for Washington program will investigate whether safer alternatives are feasible and available and then make regulatory determinations. Each product category is considered individually. Identifying safer alternatives includes consideration of unique performance needs on a product category basis, such as medical PPE. We cannot make restrictions if safer alternatives are not feasible and available.

Thank you for recommending we consider Glüge et al. (2020). We added this citation to the CAP. While the uses of PFAS in textiles appear small in Figure 3 of Glüge et al. (2020), the contribution textiles make to PFAS in homes, schools, and workplaces is not miniscule. Table 3 of Glüge et al. (2020) is limited to information reported under TSCA that is not CBI.

Based on the data available and the uncertainties, the authors still conclude "Considerable quantities of PFAS, especially of side-chain fluorinated polymers, have been used as surface protectors in textile, apparel, leather, carpets, and paper. These are open and dispersive uses where many consumers come into contact with the PFAS-containing products. It has also been reported that there are high emissions to air, dust, and wastewater from a textile manufacturing plant in China. The side-chain fluorinated polymers contain PFAAs as impurities and they may act as important precursors to PFAAs."

Issue 87: Recommendation 3.1 states that regulatory actions could include requesting that manufacturers identify products that contain PFAS, disclose their use of priority chemicals in product ingredients, release information on exposure and chemical hazard, and describe the amount and function of PFAS in products. However, should Ecology choose to require such disclosure, the agency should carefully define the entities who are required to disclose the information so as to avoid compliance gaps by downstream users who may not have access to the information. [Association of Washington Business]

Response: Thank you for highlighting the challenges around supply chain transparency. Further action to require disclosure of products containing PFAS would be done under the authority for Chapter 70A.350 RCW. This law defines manufacturer as "any person, firm, association, partnership, corporation, governmental entity, organization, or joint venture that produces a product or is an importer or domestic distributor of a product sold or offered for sale in or into the state." Ecology implements the Safer Products for Washington program emphasizing transparency in our evaluations and approaches. We welcome and encourage industry and other stakeholders to participate in this process.

Issue 88: Recommendations should include researching a recycling process for legacy carpet to remove PFAS from the material, so that it can be made safe for reuse and avoid it being landfilled. Product stewardship programs for carpet, furniture, and other textiles could be of benefit. [King County Solid Waste]

Response: The industry surrounding recycling of carpet into re-usable goods, carpeting or otherwise, is not yet fully established (California Carpet Stewardship Program, 2020). Furthermore, recycling carpet back into carpet is not always feasible—in many cases the

constituent parts of carpet are recycled into products of lower value used for different purposes (Product Stewardship Institute, 2015).

It is reported that nationally, as of 2017, only about five percent of carpet waste is diverted for recycling (Healthy Building Network [HBN], 2017). California is the only state that requires a minimum amount of carpet to be recycled, with a mandated target of a 24 percent recycling rate for post-consumer carpet by January 1, 2020 (California Code, Public Resources Code - PRC § 42972[247]). An effort to adopt similar legislation in Washington in 2012 was not successful (Washington State Legislature, 2012).

The presence of toxic chemicals, including PFAS, in carpet components presents one of several challenges to recycle this product (HBN, 2017; Anthesis Consulting Group, 2018). When the production of recycled products free of those chemicals is a key objective, the carpet recycling industry tests incoming materials and screens out incoming carpet products that contain toxic chemicals from the recycling process.

The CAP acknowledges that legacy carpet in landfills may release PFAS to landfill leachate and such releases may be of concern where landfills are not lined. However, there is insufficient information to determine the relative contribution of legacy carpeting to leachates. The CAP identifies that it is important to characterize potential release pathways into the environment, and therefore includes Recommendation 4.1, Evaluate landfill PFAS emissions.

The Safer Products for Washington program has identified carpet as priority product containing PFAS, with a focus on removing this PFAS exposure pathway. The program will be seeking input from stakeholders as to whether and how it should be addressed from a regulatory perspective in upcoming stages of the implementation of Chapter 70A.350 RCW.

Issue 89: With respect to Recommendation 3.1, Ecology must clearly identify and announce in advance the specific PFAS compounds and product usages which are being targeted for substitution strategies. From a toxicological perspective, regulatory agencies must have adequate science for determining health-based values before promulgating standards, limits, and related regulations for individual compounds. Regulating PFAS in certain priority product categories should focus on particular applications under consideration, identifying unreasonable risk considering both hazard and exposure and finding safer alternatives at comparable cost and performance. [PFAS Regulatory Coalition, Alliance for Telomer Chemistry Stewardship]

Response: Any further actions that restrict the use of PFAS in products or require disclosure of PFAS in products would be implemented under the Safer Products for Washington program (Chapter 70A.350 RCW). The Safer Products for Washington program follows a hazard-based approach to identify priority products. This approach considers the hazards of the priority chemical and the potential for exposure.

247 https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=PRC&division=30.&title=&part=3.&chapter=20.&article=

PFAS were identified by the Legislature as a priority chemical class. The Safer Products for Washington program has identified carpets and rugs, furnishings, and aftermarket treatments as significant sources or uses of PFAS based on the potential for exposure to people and the environment, and is currently investigating safer alternatives. If safer alternatives are feasible and available, a restriction is possible. Regulatory determinations will be based on the specific direction in RCW 70A.350.040, not whether a particular product, use, or exposure is associated with an unreasonable risk. Further discussions about the scope, timeline and content of regulations will be conducted through the Safer Products for Washington program and any potential rulemaking that follows.

We have clarified that "PFAS-free" means free of intentionally added PFAS and that purchasers should select products that do not require stain or water resistance or are made using safer alternatives if possible.

3.2 Identify additional sources and uses of PFAS to consider in the second safer Products for Washington cycle

Issue 90: Ecology should avoid delays to act on other products containing PFAS, and should not wait until future cycles of the Safer Products for Washington. Ecology should take action to reduce the largest sources of PFAS by declaring all textiles, cleaning products, floor waxes and stone/wood sealers, non-stick cookware, and personal care products as priority products under the Safer Products for Washington law so that the search for safer alternatives begins now and bans can be put in place by 2025. [Form letter 1, Form Letter 3, Maddie Smith, Toxic Free Future, Whidbey Island Water Systems Association, Weafer, Clean Production Action, The Lands Council]

Response: The Safer Products for Washington law (Chapter 70A.350 RCW) gives Ecology the authority to restrict the use of PFAS in consumer products only when safer alternatives are available and feasible. While we understand concerns over the time it takes for us to identify safer alternatives and implement rules, this process is important because it helps us avoid situations where PFAS is replaced with a chemical equally or more toxic. In addition to working on restrictions, in the meantime, we're creating public outreach materials (like videos[248] and infographics[249] we translate into multiple languages) to help consumers purchase safer products and reduce exposure for them and their families.

Safer Products for WA sets in place four phases that repeat on a five-year cycle, with dedicated periods for public outreach and potential legislative action. We submitted our priority product report to the Legislature in July 2020. We identified carpets and rugs, furnishings, and aftermarket treatments as priority products because our research suggested these were among the biggest PFAS uses. We are now looking for safer alternatives to PFAS for these products.

However, we know PFAS are ubiquitous, and we know there are many important uses that we weren't able to include in this first cycle. Starting with carpet, furnishings, and aftermarket treatments gives us a good foundation identifying safer alternatives and reducing the use of

[248] https://www.youtube.com/watch?v=P6WfpWnIpLc
[249] https://apps.ecology.wa.gov/publications/SummaryPages/2004043.html

PFAS. We expect continued interest from our stakeholders in reducing PFAS in products during future cycles of Safer Products for Washington.

Issue 91: PFAS containing substances should be eliminated from commerce in Washington as soon as possible and be managed as a chemical class. The CAP should recommend a class based approach and focus on eliminating non-essential uses of PFAS. [National Tribal Water Council, ReSources, Public Health - Seattle & King County, Form letter 2]

Coordinating data collection based on the reporting of PFAS substances in the TRI is limited to the 172 compounds that will be reported. An approach to PFAS management in products is presented in Kwiatowski et al. (2020) and Cousins et al. (2020).

Response: The Draft CAP section on CAP Requirements explains:

- Purposes of a CAP.
- Why the CAP should examine the various groups of substances that make up this large group of chemicals of PFAS.
- The CAP's limitations—such as not imposing new requirements on uses or releases of PBTs, and not creating new authorities.

The CAP acknowledged that although WAC 173-333-310 only lists the PFOS chemical group, there were several reasons why it was pertinent to look at different types of PFAS to gain a full understanding of their potential for degradation into PBTs, availability of substitutes and safer alternatives. We also acknowledged that legislation recently adopted in Washington addressing PFAS has consistently viewed PFAS as "a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom" (Chapters 70A.222, 70A.400, and 70A.350 RCW).

As explained in the response to Issue 101, neither Ecology nor Health have the authority to eliminate all PFAS containing substances from commerce in Washington. Nevertheless, legislation enacted since 2018 has addressed PFAS present in AFFF, food contact packaging, and priority products, and has banned PFAS in certain products (see Appendix 9: Regulations, Section 9.1 Washington state laws and rules).

We acknowledge that the concept of focusing regulatory efforts on essential uses has emerged more recently. Aspects of PFAS-related legislation passed in Washington rely on similar considerations. For example:

- As part of the PFAS Alternatives Assessment in Food packaging, a performance evaluation is conducted to determine whether the prioritized alternatives "perform as well as or better than PFAS chemicals in a specific food packaging application" according to RCW 70A.222.070.[250] This reflects considerations as to whether the use of PFAS in a specific food paper packaging application is substitutable by a non-PFAS alternative.
- Not withstanding that PFAS are defined as a class under Chapter 70A.350 RCW, evaluation of priority products under the Safer Products for Washington program

[250] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222.070

seeks to identify safer alternatives (including safer chemicals or safer processes) and allows the consideration of whether "members of a class of priority chemicals are functionally necessary in the priority consumer product" (RCW 70A.350.030(4)(a)).

- The Firefighting Agents and Equipment Toxic Chemical Use law (Chapter 70A.400 RCW) acknowledges that certain uses of Class-B firefighting foams (in particular airports in Washington certificated under 14 C.F.R. Part 139) are necessary (i.e., essential) until such time that PFAS free substitutes authorized by federal regulation are made available.

Ecology recognizes that TRI reporting will be limited, however it will be an additional source of data that has not been available to-date, and will assist in identifying industries and manufacturers who are using these substances in Washington state.

Issue 92: While the issue of regulating PFAS as individual substances versus regulating them as a class is not explicitly discussed in the CAP, it is an important issue that other state agencies have considered PFAS should not be regulated as a class. Grouping PFAS substances to develop regulatory criteria or using a single criterion to regulate all PFAS compounds is not scientifically defensible. Ecology and Health should adopt a science based process to regulate PFAS on the characteristics of individual chemicals. PFAS, as a group, includes thousands of substances with unique physio-chemical properties, unique fate and transport properties, and unique toxicological profiles. [NCASI, National Council of Textile Organizations, Alliance for Telomer Chemistry Stewardship]

Response: The CAP neither regulates PFAS as a class, groups PFAS to develop regulatory criteria, nor uses a single criterion to regulate all PFAS compounds. The CAP provides information about various characteristics of PFAS as to their relationship with environmental releases and potential adverse effects to people and the environment. The CAP has identified when data are applicable to only certain chemicals from this wide-ranging group. The CAP has also explained why it is important to view various subgroups of PFAS chemicals from the perspective of degradation products, available substitutes, and whether alternatives are safer, as described in the Section PFAS CAP Requirements. It should be noted, however, that state legislation has defined PFAS as a class. See Appendix 9: Regulations, Section 9.1.1 Washington state laws and rules. Also see response to Issue 205.

Issue 93: Wastewater treatment plants and landfills are not "sources" of PFAS. They are the recipients of PFAS containing waste streams from homes and businesses. Source control is the strongest action that can be taken to control PFAS exposure for humans and the environment. Cradle to grave management of this chemical is essential. [King County Water Treatment Department, Public Health – Seattle & King County]

Response: Text has been edited throughout the CAP to reflect that WWTPs and landfills are not a "source" of PFAS, rather a waste stream pathway, including:

- Recommendations 2.3 and 4.0
- Appendix 3: Sources and Uses, Sections:
  - 3.4.2 Wastewater
  - 3.4.4 Landfilled Products

- 3.6 Data gaps
- Appendix 5: Environmental Occurrence, 5.0.1 Findings
- Associated summary statements in the Executive Summary and introductory sections of the CAP.

The CAP incorporates both source control and "cradle to grave" needs to address PFAS. Source control is achieved through ongoing work to minimize AFFF and manufacturing releases (Recommendation 2.3), as well as reducing PFAS presence in products (Recommendations 3.1 to 3.3). Recommendations 4.1 to 4.3 address important pathways through which PFAS travel through the environment. Appendix 4: Fate and Transport, Section 4.5 Long term PFAS management, acknowledges the current uncertainties and risks related to PFAS waste management in the long-term.

Issue 94: Focus CAP recommendations on actions that would eliminate long-chain PFAS found at elevated levels in the state and their sources, or in products imported into Washington. [Performance Fluoropolymer Partnership]

Response: Our recommendations for reducing PFAS in products focus on reducing PFAS as a class based on the definition of PFAS in recent Washington legislation (Chapter 70A.350[251] RCW and 70A.222[252] RCW) and on their environmental persistence, toxicity, data gaps, and potential for regrettable substitutions. Fluoropolymers are highly persistent in the environment. They can be synthesized using PFAAs and can contain PFAAs as residual monomers and impurities, which can be released throughout their life-cycle (Lohmann et al., 2020).

Issue 95: The Draft CAP identifies products already regulated by the FDA, including through the food contact notification (FCN) process. State actions should only address those specific PFAS compounds that are not otherwise already approved under federal statutory authority. [PFAS Regulatory Coalition]

Response: RCW 70A.222.070[253], which addresses the use of PFAS in packaging that comes into contact with food, restricts all PFAS that meet the class-based definition "fluorinated organic chemicals containing at least one fully fluorinated carbon atom." Ecology was not given the authority to choose the definition of which PFAS would be restricted.

Ecology was also given the authority to regulate priority chemicals including PFAS in consumer products under Chapter 70A.350 RCW as long as they are not "drug or biological products." To restrict or prohibit PFAS in any consumer product as part of the Safer Products for Washington program, Ecology must demonstrate the restriction will either reduce a significant source of or use of a priority chemical or is necessary to protect the health of sensitive populations or sensitive species. Because the FDA has approved certain PFAS for use in certain products that are not exempted by Chapter 70A.350[254] RCW, Ecology may focus on those PFAS and products.

[251] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.350&full=true
[252] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222&full=true
[253] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222.070
[254] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.350&full=true

Issue 96: The State should not presume which product categories will be included in the second Safer Products for Washington cycle. Reasons not to include the use of PFAS in products in the second Safer Products for Washington cycle include voluntary phase-outs and declining industry uses of PFAS. The State must also properly account for the fact that the body of scientific evidence does not show adverse health effects in humans from perfluoroalkyls. [3M]

Response: The CAP identified additional products that contain PFAS in Appendix 3: Sources and Uses. These sources and uses are highlighted in this recommendation for consideration for future cycles of Safer Products for Washington. This CAP does not identify these products as priority products. Prior to identifying the next round of priority products, there will be multiple opportunities for stakeholder involvement and input. This recommendation focuses on community engagement for identifying additional products for consideration under Safer Products for Washington.

The priority product report submitted to the Legislature in July 2020 discussed the availability and feasibility of safer alternatives, but did not make a determination. We are currently working on determining whether safer alternatives are feasible and available and will submit those findings to the Legislature in June 2022.

Issue 97: The CAP should address how Ecology will specifically utilize the Safer Products for Washington program to explore products containing PFAS given limitations on this law and competing substances of concern, as well as how Ecology and Health will understand the exposures to Washington residents and implement protections that remove these sources of exposure to humans and the environment. [Public Health - Seattle & King County]

Response: The information from the CAP may inform future cycles of the Safer Products for Washington program. However, the program has a defined five-year cycle with specific phases for public involvement and potential legislative action. While the program can incorporate the recommendations into the CAP, specific actions (such as identifying priority chemicals or products or restrictions) will need to be implemented through the Safer Products for Washington process.

Therefore, it is not possible to lay out a detailed approach for what the Safer Products for Washington program will do in future cycles in this CAP. However, the research and input used to identify consumer products that are sources or uses of PFAS could be included in future cycles of the program.

In addition to our work on Safer Products for Washington to reduce PFAS in consumer products, we're also working on outreach materials and environmentally preferable purchasing recommendations to help consumers choose safer products and reduce their exposure. The CAP includes recommendations for community engagement in identifying additional sources of PFAS exposure, biomonitoring, and continued research.

3.3 Implement other reduction actions for PFAS products

Issue 98: The Draft CAP uses an overly broad definition of PFAS that could unnecessarily capture fluoropolymers themselves. PFAS surfactants commonly used to produce certain fluoropolymers are the target of concern. Fluoropolymers made without the use of PFAS surfactants should not be restricted in any way. Certain fluoropolymers can be produced without the use of PFAS surfactants, and can provide certain environmental benefits through minimizing production volumes. [Arkema]

Response: Our recommendations for reducing PFAS in products focus on reducing PFAS as a class based on the definition of PFAS in recent WA legislation (Chapter 70A.350[255] RCW and RCW 70A.222.070[256]) and their environmental persistence, toxicity, data gaps and potential for regrettable substitutions. Fluoropolymers are highly persistent in the environment. They can contain PFAAs as residual monomers and impurities which can be released throughout their life-cycle. The CAP does not make restrictions.

Issue 99: Other regulatory actions to reduce PFAS exposure in consumer products should ensure that 1) safe alternatives are feasible and available prior to restricting any PFAS-containing product, to avoid regrettable substitutions; 2) any restriction or regulation clearly specifies the PFAS compound that is being restricted or regulated; and 3) any State restrictions or regulations do not contradict federal law. [PFAS Regulatory Coalition]

Response: Please refer to the response to Issues 89 and 95.

Issue 100: The sentence "Long-chain PFAAs include perfluorinated carboxylates (PFCAs) with eight or more fully fluorinated carbons (for example, PFOA)" should be corrected to indicate "seven or more fully fluorinated carbons…". [Alliance for Telomer Chemistry Stewardship]

Response: This correction has been made throughout the CAP.

Issue 101: Products with PFAS should be banned from import into and commerce in the state. New PFAS should not be approved. [Vega, Vilgalys, Olympic Environmental Council, Stephens, Clark, Ude, Port Gamble S'Klallam Tribe(Welch)]

Response: Ecology and Health do not have the authority to ban all products containing PFAS outright, nor to ban importation of products containing PFAS into the state. Although Recommendation 3.3 identifies the proposal of a ban on the importation and sale of products containing PFOS and PFOA, such action would have to be taken by the state Legislature.

Nevertheless, legislation enacted since 2018 has addressed PFAS present in AFFF, food contact packaging, and priority products, and has banned PFAS in certain products (see Appendix 9: Regulations, Section 9.1 Washington state laws and rules). Section "What else are we doing about PFAS?" has been updated to reflect ongoing work to restrict PFAS in certain products, including:

[255] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.350&full=true
[256] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222.070

- Compliance monitoring with respect to the ban on sale of AFFF containing PFAS starting July 2020.
- A ban on PFAS in certain food packaging products starting in 2023.
- Consideration of regulatory action on priority products containing PFAS under the Safer Products for Washington program.

Neither Ecology nor Health have the authority to approve production, uses, or imports of PFAS. As explained in Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency, the EPA has, and is using, authority under the federal Toxic Substances Control Act (TSCA) to review new uses of specific PFAS.

4.0 Understand and manage PFAS in waste

4.0 Understand and manage PFAS in waste

Issue 102: Compost should also be targeted for understanding PFAS in waste management. PFAS thresholds should be established for Table 220-B requirements in WAC 173-350-220 based on studies conducted to understand PFAS concentrations in feedstocks. Small-scale composters should be funded to help with any additional sampling parameters added to Table 220-B. [Public Health - Seattle & King County]

Response: Due to uncertainty associated with PFAS and its impacts to soil and food uptake, more focused studies of composts are needed. EPA has established the health threshold for PFAS in drinking water, but a health threshold has not yet been established for compost. Also, there is no standardized testing method that labs can use to test for PFAS in compost—making it difficult to get standardized results. Washington can do as other states have done and create its own threshold, use a threshold chosen by another state, or wait until EPA identifies a threshold. Washington would also have to specify which test will be used in order to make results comparable. To conclude, before a threshold can be added to WAC 173-350-220,[257] Table 220-A, a health threshold must be established and a standardized test specific to composts must be created.

Issue 103: The CAP should address the life cycle of PFAS containing waste; it should also evaluate landfilling as a final repository of wastes containing PFAS. [King County Solid Waste]

Response: Appendix 3: Sources and Uses, Section 3.4 Waste Management, addresses waste streams that can contain PFAS and describes how PFAS can transfer from one waste stream to another (e.g. landfill leachate being transferred to WWTPs for treatment). Appendix 4: Fate and Transport, Section 4.3.2, Release to Aqueous media, addresses how PFAS can leach from solid waste or compost. Appendix 4: Fate and Transport, Section 4.5 was revised to include discussion of EPA's draft interim guidance on the destruction and disposal of PFAS and materials containing PFAS, and the uncertainties related to disposal options (EPA, 2020a). Text addressing the sequestration of PFAS in landfills was added at Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products.

[257] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-350-220

Issue 104: The CAP should acknowledge and incorporate the findings of EPA's "Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances," dated December 18, 2020. [King County Solid Waste, PFAS Regulatory Coalition]

Response: Acknowledgement of EPA's interim guidance has been added to Appendix 4: Fate and Transport, Section 4.5.3 Ultimate disposal. As indicated in the guidance, it is expected that information regarding the disposal and destruction of PFAS compounds, and materials containing PFAS compounds, will continue to evolve and inform agency activity both at the state and federal levels.

Issue 105: If PFAS containing wastes are classified as a Dangerous Waste (DW), provisions should be made in Chapter 173-303 WAC Dangerous Waste Regulations to allow for their disposal at a municipal solid waste landfill. [King County Solid Waste].

Response: Any business that generates a solid waste must determine if that material is a DW under WAC 173-303.[258] PFAS solid waste materials containing 100 parts per million (ppm) or greater halogenated organic compounds (HOC) are regulated as a persistent criteria waste under WAC 173-303-100.[259] Solid waste materials containing 10,000 ppm or greater HOCs are considered an extremely hazardous waste (EHW). Although the CAP has now identified products that contain PFAS and industries that generate PFAS wastes, the requirement for all businesses to properly designate and manage their persistent wastes, including any "newly" identified waste streams, has been in the DW regulations for many years. Current DW regulations have exclusions and exemptions for disposal of persistent DW to a municipal solid waste landfill (MSWLF). These allowances include:

- The household hazardous waste exclusion.
- Small Quantity Generator (SQG) waste. SQGs may dispose of their non-liquid DW at a MSWLF.
- Special wastes, as defined at WAC 173-303-040[260] and per WAC 173-303-073[261] requirements. Solid waste that designates as a federal hazardous waste or state EHW does not qualify as special waste.

Ecology is not considering an additional exclusion for PFAS solid waste at this time. The public may submit a petition under WAC 173-303-910[262] for regulatory relief.

Issue 106: Comments support Washington state efforts to evaluate PFAS in wastewater, landfill leachate and biosolids. The CAP should include a plan for funding for the effort as well as understanding the specific compounds and processes that could be causing contamination. [PFAS Regulatory Coalition]

---

[258] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-303&full=true
[259] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-303&full=true#173-303-100
[260] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-303&full=true#173-303-040
[261] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-303&full=true#173-303-073
[262] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-303&full=true#173-303-910

Response: Following issuance of a CAP, Ecology and Health implement recommendations presented in the CAP based on availability of agency resources and successful requests for funding to the Legislature. Recommendations 4.1 through 4.3 focus on gathering information regarding PFAS present in WWTP effluents, landfill leachate and biosolids in order to better understand the prevalence of PFAS present in these waste streams, and how PFAS behave in waste management processes. Based on these data, Ecology can evaluate additional areas of investigation focused on specific PFAS in these waste streams.

Issue 107: PFAS monitoring requirements for waste streams such as wastewater treatment plant influent and effluent, landfill leachate, and biosolids are premature until validated test methods for those matrices are established. [PFAS Regulatory Coalition, 3M, City of Tacoma, Northwest Biosolids]

Response: If monitoring of PFAS in certain waste streams were required, Ecology expects that validated test methods would be used.

- Recommendation 4.1, concerning wastewater, already includes mention of a validated test method: "This should include consideration of whether EPA has developed approved analytical methods for PFAS suitable for WWTP effluent and a regulatory target (a nationally recommended water quality criterion for PFAS) for waters of the state." Ecology does not have, and is not working on any monitoring requirements for wastewater treatment plant influent, effluent, landfill leachate, or biosolids. Ecology agrees that we need a validated test method for these matrices before implementing monitoring requirements through our permitting programs.
- Recommendation 4.2, concerning landfill emissions: In January 2021, the EPA approved Other Test Method 45 (OTM-45) Measurement of Selected Per- and Polyfluorinated Alkyl Substances from Stationary Sources. OTM-45 is a draft method that is under evaluation and that will be updated as more data from stakeholders becomes available. In the meantime, the method allows for federal, state, and local entities to have a consistent standard to evaluate analytical results. This method may be considered as enforceable for permits when approved by EPA regional offices.
- Recommendation 4.3, concerning biosolids, states that a study should "Use EPA-validated analysis methods for biosolids and soils." These are currently under development by EPA.

4.1 Evaluate PFAS in wastewater treatment

Issue 108: Ecology should consider modifications to its WWTP sampling project. [City of Tacoma, Northwest Biosoilids, King County Wastewater Treatment Department, City of Redmond, City of Renton, Cascade Water Alliance]

Comments proposed the following considerations for WWTP sampling:

- Ecology should work with Industrial Pretreatment Programs to identify sources of PFAS in publicly owned treatment works (POTW) influent.
- The study should also include sampling of WWTPs with mostly residential sources to increase the understanding of residential versus industrial PFAS loadings.
- Consider POTWs that also receive landfill leachate.
- Reclaimed water should be sampled as an effluent.

Response: Ecology added a reclaimed water treatment plant to the WWTP sampling project and will be sampling the influent (which receives landfill leachate) and effluent.

Ecology is at the beginning of investigating PFAS in wastewater treatment plants. The funding and timeline for this project does not allow for a study addressing everything in this comment. Pending funding, Ecology will continue to investigate PFAS in wastewater and will consider all the suggestions laid out above.

Issue 109: Explain the meaning of "advance[d] solids removal. [City of Tacoma, Northwest Biosolids]

Response: Advanced solids removal is referring to membrane separation, for example membrane bioreactors. These bioreactors eliminate the need for a secondary clarifier and remove a higher percentage of solids than traditional settling.

Issue 110: The CAP should consider a recent report regarding the cost analysis of the impacts on municipal utilities and biosolids management to address PFAS contamination. [Northwest Biosolids]

Response: A citation to the report was added to our discussion of water treatment cost examples at Appendix 10: Economic Analysis, Section 10.1 Costs of recommended actions.

Issue 111: In evaluating the presence and sources of PFAS compounds in wastewater treatment facilities should leverage work already conducted by the EPA and utilize EPA's multi-laboratory validated wastewater analytical methods referenced in EPA's "Interim Strategy for Per- and Polyfluoroalkyl Substances in Federally Issued National Pollutant Discharge Elimination System Permits" (November 22, 2020). [Alliance for Telomer Chemistry Stewardship]

Response: Ecology will continue to consider resources and data made available by EPA as well as any other technical or regulatory associations. Ecology will continue to track the availability of validated analytical methods. The status of development of Clean Water Act Method 1600 is discussed in Appendix 2: Analytical Methods, Section 2.1.2 Non-drinking water sample methods.

Issue 112: Comments identified that the CAP does not address PFAS in reclaimed water. These comments were noted with respect to multiple locations throughout the CAP, including the Executive Summary, Recommendations, and Appendix 3, Sources and Uses. [Sammamish Plateau Water and Sewer District, City of Redmond, Cascade Water Alliance]

Response: The consideration of PFAS present in reclaimed water has been added to Appendix 3: Sources and Uses, Section 3.4.2 Wastewater. The CAP does not directly address PFAS in reclaimed water. However, Ecology is beginning to investigate PFAS in wastewater, which includes facilities producing reclaimed water from domestic wastewater.

As we gather more information about PFAS in wastewater, we will be able to address PFAS in reclaimed water.

Issue 113: Management of reclaimed water containing PFAS should be evaluated. [Cascade Water Alliance, City of Redmond, Sammamish Plateau Water and Sewer District]

Considerations should include:

- Identification of fate and transport of PFAS in reclaimed water.
- Monitoring and allowable PFAS limits for usage.
- Identification of current policies, data gaps, and recommendations.
- Risks from releases where PFAS levels exceed proposed SALs.
- Prohibition of use within Critical Aquifer Recharge Areas when PFAS levels exceed proposed SALs.
- Exploring who will be responsible for treating PFAS in landfill leachate, in consideration of impacts of this activity on where and how leachate is recycled.

Response: We are only beginning to investigate PFAS in wastewater and reclaimed water. We will review our policies and regulations for reclaimed water after the initial investigation. We will consider modifications to our reclaimed water policies and regulations pending those results and other agency findings.

4.2 Evaluate landfill PFAS emissions

Issue 114: Ecology should consider additional elements in its landfill leachate study. [King County Solid Waste, City of Redmond, Sammamish Plateau Water and Sewer District, Public Health - Seattle & King County]

Comments proposed the following additional considerations:

- Stating which landfills are chosen and the methodology/criteria by which they were selected.
- Identifying the sampling methods to be used.
- Researching treatments to remove PFAS from leachate.
- Collecting statistically significant data and conducting peer review before monitoring and other regulatory requirements are determined.
- Considering EPA's November 2020 "Interim Strategy for Per- and Polyfluoroalkyl Substances in Federally Issued National Pollutant Discharge Elimination System

Permits" and information it contains about validated chemical test methods for PFAS.

- Not overly relying on the Total Oxidizable Precursor (TOP) assay because of the likelihood the assay will overestimate PFAS presence and the resulting formation of PFAAs.
- Including groundwater modeling during the second phase of the study.
- Collecting landfill gaseous emissions at the same time as leachate to reduce sampling costs.

Response: In the fall of 2020, Ecology Solid Waste Management Program conducted Phase I of the Landfill Leachate PFAS Study. Phase I was designed to determine if landfill facilities might have a potential to contaminate environmental media. Ecology staff and facility staff sampled 17 landfills in Washington state. Since PFAS is contained in every day products that are disposed in landfills, Ecology wanted to evaluate leachate to determine if PFAS compounds were in the landfill leachate.

Ecology chose to key the survey on municipal solid waste landfills that generated leachate and had leachate collection systems. Ecology requested permission to collect samples from landfills that generated leachate and the participating landfills were selected based on their permission to allow the sampling.

Of the 17 landfills, 14 landfills were located in western Washington and four were located in eastern Washington. With two regional climates to study, Ecology will be looking at the role of climate in the potential natural degradation pathways, enhanced destruction methods, and migration of PFAS compounds.

Based on an analysis of the Phase I results, Ecology may finalize options to conduct Phase II of the leachate PFAS study to include groundwater, soil gas generation, plus stormwater and surface water analytical evaluations. The evaluation criteria would be further developed to determine potential vulnerable receptors, matrix and media interactions and pathways, and possible remedial actions.

Issue 115: Solid waste handling standards and criteria for Municipal Solid Waste Landfills should be updated specific to PFAS (Chapters 173-350 and 173-351 WAC respectively), including PFAS testing of leachate, landfill gas, groundwater, compost and air. [Public Health - Seattle & King County]

Response: The purpose of Recommendation 4.2 is to gain more knowledge regarding the presence of PFAS in landfill leachate, and later in gaseous emissions. Ecology has already conducted the first phase of landfill sampling in the fall of 2020; the results of this first sampling effort are still being analyzed and considered.

As indicated in the recommendation, additional sampling of landfills beyond Phase I may be considered. Ecology would then determine whether monitoring requirements for landfills to test leachate for PFAS are warranted, and if so, would initiate rulemaking to update Chapters 173-350 and 173-351 WAC.

It is speculative to require groundwater testing in the vicinity of landfills at this time, as Ecology does not know whether specific landfills were likely to have received wastes containing high levels of PFAS. As indicated in Recommendation 4.2, Ecology will continue to research makeup of PFAS waste entering and potentially currently stored in landfills, and expects to conduct groundwater sampling as part of Phase II of the study to collect information on this issue.

Please refer to Issue 102 regarding compost.

Issue 116: Ecology should advance knowledge around PFAS waste streams entering landfills, and give consideration to the PFAS Waste Source Testing Report for New England Waste Services of Vermont. Differences between climatic conditions on PFAS concentrations during leachate generation could be evaluated. Funding will be needed to identify data gaps and conduct sampling. [Public Health - Seattle & King County]

Response: As indicated in Recommendation 4.2, Ecology will continue to research makeup of PFAS waste entering and potentially currently stored in landfills. The Draft CAP referenced Lang et al. (2017), which identified the influence of climatic conditions on leachate generation and its potential effect on PFAS mobilization into leachate. Additional information was added to Appendix 3: Sources and Uses, Section 3.4.3, Landfilled products, to emphasize the effect of climate.

The Sanborn Head and Associates, Inc. study, PFAS Waste Source Testing Report, prepared for New England Waste Services of Vermont (Sanborn Head and Associates Inc., 2019), was added at Appendix 3: Sources and Uses, Section 3.4.3, Landfilled products.

Please refer to the response to Issue 114 regarding Phase I sampling of landfills in both western and eastern portions of the state. Phase I was not designed with a climate influence analysis in mind, however the data collected may allow us to determine whether a more focused look at climate influences should be part of Phase II of the study.

Issue 117: The Draft CAP is not very clear about the proposed course of action for gaining a better understanding of makeup of PFAS waste entering and currently stored in landfills in Washington. The CAP doesn't specify whether this information, and data from the landfill emissions study, would be used to prohibit certain wastes from future landfill disposal. [King County Solid Waste]

Response: Recommendation 4.2 is not proposing to prohibit certain wastes from future landfill disposal. This recommendation only proposes, if warranted, additional monitoring requirements for landfills to test for PFAS in leachate.

Possible ways to evaluate the waste stream makeup for PFAS content would be to conduct a waste stream assessment (WSA). There are several levels of a WSA. A low-level WSA would involve using borrowed data from other studies or facilities. A higher-level WSA would gather data from a generator survey or gather waste composition data from a floor waste sort. In all cases, pre-planning is paramount—the WSA scope and goal must be clearly stated and the limitations of the data collected must be clearly understood.

Issue 118: Ecology should not proceed on rulemaking to require monitoring of PFAS in leachate at this time until validated test methods are made available and better scientific

information is available about other wastewater streams that also contribute to WWTPs in addition to landfill leachate, including recycling and composting wastewater sources. [King County Solid Waste]

Response: Ecology is not intending to immediately proceed with rulemaking to require monitoring. The recommendation states that Ecology will consider whether monitoring requirements are warranted based on study results. If Ecology determines that monitoring requirements should be implemented, Ecology would consider the availability of validated test methods to meet such requirements. The Draft CAP acknowledges in Section 3.4.2, Wastewater, that many sources can contribute PFAS to WWTP influents.

4.3 Evaluate Washington biosolids management

Issue 119: Testing should be conducted on sludge and biosolids, as well as agricultural locations where biosolids have been applied. Ecology should develop a sludge (biosolids) standard for all PFAS, including products made from biosolids. Alternatives for disposal should be evaluated. [Form letter 1, Form letter 2, Smith (Maddie), Zimmerle, Toxic Free Future, Olympic Environmental Council, NWTC, The Lands Council, Zero Waste Washington (Heather Trim)]

Response: It is important to use the correct terminology when describing wastewater solids. As explained in Appendix 8: Biosolids, Section 8.2 Federal and state regulations, in the state of Washington "Sewage sludge" is mandated to be disposed of in a landfill. "Biosolids" is sewage sludge that has undergone specific process requirements, and meets the EPA established analytical thresholds for land application. Only biosolids are land applied.

In order to get scientifically reliable, accurate and precise results, testing needs to be performed using validated methods. Please refer to Appendix 8: Biosolids, Section 8.7.1 PFAS concentration data, regarding inconsistency in results. Also see Appendix 8: Biosolids, Section 8.9.2 Recommendations, regarding the need for an accredited analysis method. As described in Appendix 8: Biosolids, Section 8.4 PFAS analysis methods for biosolids, EPA is currently undertaking a multi-lab validation for PFAS analysis in biosolids and soil using a modified SW-846 method.

Such validation is critical to ensure that the developed methodology can be used by a variety of labs and obtain consistent results. Laboratories have different staff and analytical equipment. Such differences can lead to difficulties achieving consistent results across a spectrum of labs. When Washington embarks on research into concentration and mobility of PFAS on land application sites, we want a validated analysis method along with realistic site evaluations. If such evaluation involves modeling, it is important to use accurate estimates of environmental factors such as organic matter content.

Current research indicates that longer chain compounds are the ones likely to be found in biosolids. Long-chain PFAS are less likely to leach from soil due to reduced solubility. There is also significant dilution by soil when land applied, likely resulting in low soil concentrations. Low concentrations of PFAS in soil, combined with restricted pathways of exposure (due to current state biosolids regulations), suggest that risk to human health and the environment from current land application practices is low.

Issue 120: Data obtained on PFAS present in biosolids should be made publicly available. [National Tribal Water Council]

Response: There is no regulatory authority to test biosolids for PFAS. In order to get cooperation from operators to release data that is proprietary, we need to offer anonymity of results. It is also important that initial results are reviewed and validated prior to any public dissemination to ensure the data is indeed precise and accurate. Investigations of PFAS land application will include multiple replications and control samples.

Issue 121: While the details in Recommendation 4.3 regarding biosolids evaluation are supported, additional considerations are proposed. [Sammamish Plateau Water and Sewer District; City of Redmond, WASWD, King County Wastewater Treatment Department, Public Health - Seattle & King County, Whidbey Island Water Systems Association, City of Tacoma, Northwest Biosolids]

Comments proposed the additional considerations for biosolids evaluation:

- Require scientific modeling to assess potential PFAS transfer from biosolids to soil or groundwater.
- Use "realistic" exposure and model parameters, and consider science-based and peer-reviewed exposure pathways.
- Support efforts to improve analytical methods for extracting PFAS from biosolids matrices.
- With respect to investigation of land application sites and mimicking rates and practices permitted under current state rule:
    - Include non-biosolids amended control samples to quantify background PFAS soils concentrations.
    - Conduct field replications given difficulties with sample contamination.
- Investigate leachate and runoff from biosolids application.

Response: Replicate sampling and comparison to a control was intended. Our first steps in an investigation will include development of a set of protocols (Quality Assurance Progress Plan or QAPP), selection of representative sites—both biosolids and control sites, sample collection, analysis, and review of the data. Following this process, the data may be used as model inputs to ensure real world parameters.

Appendix 1: Chemistry

1.0 Overview

1.0.1 Findings

Issue 122: Several corrections are proposed to the "Findings" statements on page 77. [Alliance for Telomer Chemistry Stewardship, TRC]

Comments proposed the following revisions for this subsection:

- Use of PFAS is too broad and does not reflect the diversity of compounds and properties
- Provide references for the Organisation for Economic Co-operation and Development (OECD) and EPA citations
- Update the number of PFAS currently identified consistent with EPA's September 2020 Master List of Compounds
- Identify that the electrochemical fluorination (ECF) process produces branched and linear compounds
- Specify that shifts to short-chain manufacture occurred by year-end 2015
- Consider a recommendation to give notice to countries that are still manufacturing long chains
- Update EPA's Master List of Compounds identifying 9,252 PFAS compounds as of September 2020.

Response:

- The draft CAP relies on vocabulary from established scientific literature to describe this large group of chemicals. Using the term "PFAS" to describe the per-and polyfluoralkyl substances as a group has been established both by well-known researchers in the field (e.g. Buck et al., 2011) as well as through organizations such as the ITRC (e.g. documentation and fact sheets[263]). The CAP balances goals to provide information in a publicly accessible manner while remaining technically correct. In Appendix 1: Chemistry, and throughout the document the CAP emphasizes that only certain PFAS present specific physical chemistry or toxicological characteristics.
- The citations to statements regarding the number of PFAS identified by OECD and EPA are included in the draft CAP at Section 1.0.2, and the references for the citations are included in references section at the end of Appendix 1: Chemistry.
- The statement regarding ECF process was revised to acknowledge linear chains being produced.

[263] https://pfas-1.itrcweb.org/

- The statement regarding the transition to shorter-chain PFAS was revised to indicate this was conducted by the end of 2015.
- The reference to the number of PFAS compounds identified by EPA's Master List of Compounds was updated.

With respect to the recommendation to provide notice to countries that are still manufacturing long-chain PFAS, it is not clear what the purpose of such notice would serve without federally legislated action to prevent import of products containing such substances.

1.1 Subclasses of per- and polyfluoroalkyl substances (PFAS)

1.1.1 PFAS Terminology

Issue 123: In the cited Buck definition, correct the moiety to be CnF2n+1. [TRC]

Response: The correction was made.

1.1.3 Non-polymer PFAS

Issue 124: Fluoropolymers are neither toxic nor bioaccumulative, are not mobile and do not degrade to PFOS or PFOA. Inclusion of fluoropolymers in the CAP does little to achieve the goal of protecting human health and the environment. [Performance Fluoropolymer Partnership]

Response: The Draft CAP identified that in general "polymeric PFAS are currently believed to pose less immediate human health and ecological risk relative to some non-polymer PFAS". Discussion of these substances in the CAP remains pertinent because, as stated in the Draft CAP some polymeric PFAS incorporate one or more PFAS monomer(s) during their synthesis, and although these monomers may be present in small amounts in final products, their degradation could result in a release of PFAS to the environment.

Issue 125: Several corrections are proposed to the "Non-Polymer PFAS" statements in this section. [Alliance for Telomer Chemistry Stewardship, TRC]

Comments proposed the following revisions for this subsection:

- Regarding perfluoroalkyl substances, revise the moiety to state CnF2n+1 with n ≥2 (instead of n>2)
- Correct the second sentence, paragraph 2, to state "Perfluoroalkane sulfonamide substances…"
- Figure 6 represents the 8:2 fluorotelomer sulfonic acid, and is inconsistent with the figure caption and preceding text
- Multiple revisions were proposed for Tables 4 and 5 with respect to footnote usage, acronyms, functional group corrections and omission of certain subclasses.
- At Table 4 and throughout the document change "Polymer Processing Aid" to "Polymer Polymerization Aid"
- At Table 4, recognize that: for perfluorooctanoyl fluorides ("–COF/POF") this has not been a major raw material for either fluorosurfactants, or surface protection

products; and 6:2 fluorotelomer sulfonyl chloride (FTSCl) is indeed an intermediate but it is generally not regarded as an environmental transformation product
- At Table 5 recognize that all U.S. manufacturers have discontinued long chain usage

Response: Corrections were made as indicated in comments except for the following:

- In Table 5, footnotes a and b were not associated with the sub-class instead of the class to respect how the information was originally presented in Buck et al., 2011.
- In Table 5, and throughout the document we have retained the term "polymer processing aid" because that term was used in Buck et al., 2011.
- In Table 5 the line item "Sub-class: n:2 Fluorotelomer sulfonic acid chloride" was removed altogether.
- For Figure 6 in the Draft CAP (Figure 7 in this CAP), the caption and associated text were revised to discuss 8:2 fluorotemoler sulfonic acid.
- Regarding the uses for COF and POF, the use indicated in Table 4 was drawn directly from the Buck et al., 2011 reference used as a basis for this table.

1.1.4 Polymeric PFAS

Issue 126: Several corrections are proposed to the "Polymeric PFAS" statements in this section as well as Table 6. [TRC]

Comments proposed the following revisions for this subsection:

- Perfuloropolyethers should be described as: Carbon and oxygen polymer backbone with F atoms directly attached to backbone C atoms
- Side-chain fluorinated polymers are those ending in CnF2n+1.
- The uses for fluorinated acrylate and methacrylate polymers, fluorinated urethane polymers, and fluorinated oxetane polymers should be surface protection products and not surfactants.

Response: The typographical error in the side chain description nF2n+1 was corrected. The other recommended changes were not included because the text in the Draft CAP reflects the information presented in Buck et al. (2011).

1.2 Select physical and chemical properties of PFAS

1.2.3 Modifications for PFAS Chemical Function

Issue 127: Regarding the concept of "spacer", it should be identified that these have been used since the early 1970's, and are unrelated to short-chain introduction described by Renner. [Alliance for Telomer Chemistry Stewardship]

Response: We reviewed Renner and confirmed that the text in the CAP reflect the source, which states "Guo, DeSimone, and Paul Resnick, an ex-DuPont chemist, added extra hydrocarbon groups to prop up the chains, so that the C–F3 tips could get to the surface. The hydrocarbon groups also promote the formation of physical links between the chains, Guo says" and this is in response to concerns about bioaccumulation of long-chains.

Issue 128: Figure 8 should be clarified by identifying the hydrocarbon backbone, and noting that the fluorinated sidechain that the fluorinated part is black and the spacer is gray. [Alliance for Telomer Chemistry Stewardship]

Response: The figure (Figure 9 in this CAP) was revised.

1.3 Manufacturing

Issue 129: Correct typographical errors [TRC]

The following corrections were proposed:

- The title of Figure 10 should be corrected to state "A schematic of the ECF reaction that forms PFOS".
- At Section 1.3.4, 3rd paragraph, the reference to Figure 14 should be corrected to Figure 12.

Response: Both of these corrections have been made.

1.3.2 Telomerization

Issue 130: Corrections are proposed to the "Telomerization" statements in this section. [Alliance for Telomer Chemistry Stewardship]

Comments proposed the following revisions for this subsection:

- It should be clarified at page 95 that, although currently dominant, the telomerization process is not new, having been invented in the 1960's and fully commercialized in the early 1970's.
- At page 96, indicate that although fluorotelomer acrylates (FTAC) are made from fluorotelomer acrylate (FTOH) monomers but that is not the only currently used commercial process for making FTACs.

Response: A sentence was added at Section 1.3 identifying the time periods where ECF and telomerization were developed, 1940's and 1970's respectively. The sentence regarding dominance of the telomerization process was revised to indicate it is not the only dominant process.

Regarding the processes used to make FTACs, we have revised the text to include both ECF and telomerization.

1.3.5 Trends in per- and polyfluorinated substance design

Issue 131: Corrections are proposed to the statements in this section. [Alliance for Telomer Chemistry Stewardship]

Comments proposed the following revisions for this subsection:

- At page 98, the primary surfactant for polymer polymerization was the ammonium salt of PFOA, ammonium perflorooctanoate (APFO), not PFOA itself
- At page 99, correct the generally untrue statement that larger quantities of short-chain PFAS are used to attain similar performance of long-chain PFAS

Response: We have revised the text to indicate that APFO is the primary surfactant for polymer polymerization.

We have removed the statement that larger quantities of short-chain PFAS are used to attain similar performance of long-chain PFAS, as this may only apply to certain products (waxes and polishes) as reported by Poulsen et al. (2005).

1.4 Characteristic uses of PFAS

Issue 132: Corrections are proposed for entries in Table 7. [Alliance for Telomer Chemistry Stewardship]

Comments proposed the following revisions for this subsection:

- In the first row <C6 should be ≤C6
- The current use product Ammonium salt of PFOA is not correct; current use products are generally perfluoroalkyl ether carboxylates (PFECAs)

Response: The changes were made to Table 7.

1.4.2 Paper and paper packaging treatment

Issue 133: Correct the second item in the bulleted list on page 103: Acrylates and methacrylates are on the FCN list while the polyfluoroalkyl phosphate esters (PAP) are no longer permitted. [Alliance for Telomer Chemistry Stewardship]

Response: The sentence has been clarified.

1.4.3 Specialty Chemicals

Issue 134: Revise to indicate polymer polymerization aids are currently characterized by using PFECA's. [Alliance for Telomer Chemistry Stewardship]

Response: PFCA's were included in the revisions to Table 7 (see Issue 132).

1.4.4 Fire fighting chemicals

Issue 135: At page 104, correct the impression that current 6:2 fluorotelomer sulfonamindes are new – they have been in use since the 1970's; since 2006 formulations have moved to very high purity 6:2 fluorotelomer sulfonamides, the "modern" AFFF. [Alliance for Telomer Chemistry Stewardship]

Response: The text was revised to reflect that the formulations have been in use since the 1970's with higher purity products being in use today.

1.4.5 Polymer Processing Aids

Issue 136: Revise the title of this section to "Polymer Polymerization Aids". [Alliance for Telomer Chemistry Stewardship]

Response: Please refer to Issue 125.

1.5 Data gaps and recommendations

Issue 137: The data gaps and recommendations for this section are minimal. Emphasis should be placed on why the data gaps exist. [Public Health - Seattle & King County]

Response: Data gaps were identified throughout the Draft CAP appendices, and important data gaps were re-emphasized in the Data Gaps section of each appendix. With respect to the "Chemistry" of PFAS, we have identified that the primary data gap is lack of information regarding the applications, properties and fate of these substances.

1.5.1 Data Gaps

Issue 138: The data gap section overstates that thousands of PFAS are in commerce and in use, and should be revised. [Alliance for Telomer Chemistry Stewardship]

Response: The statement was revised to indicate that there are "hundreds" of compounds in use, consistent with the information presented in Appendix 3: Sources and Uses, Section 3.1.2 Secondary manufacturing. Information about the limited number of PFAS used commercially in the U.S. today was also added to Section 1.3.3 Other Processes. We have also cited the recently issued paper by Buck et al. (2021).

Appendix 1 – List of Acronyms

Issue 139: Corrections are proposed to acronym definitions. [TRC]

Comments proposed the following revisions for this subsection:

- At Table 8 correct the "ITRC" definition to "Interstate Technology & Regulatory Council"
- At Table 9 revise the definition for "PFSA" to Perfluoro-sulfonic acid.

Response: The corrections were made.

Appendix 2: Analytical Methods

2.0 Overview

2.0.1 Findings

Issue 140: The CAP should clarify if modified versions of EPA-validated methods can be used for regulatory purposes in Washington for non-drinking water matrices; this information should be included in Section 2.4.1 as well. [Public Health - Seattle & King County]

Response: With lack of standardization among laboratories performing modified EPA validated methods, we recommend as part of the PFAS CAP implementation that the laboratory selection process for non-drinking water matrices analyses, that the laboratory analytical procedure should be evaluated based on the following:

- DOD Quality Systems Manual (QSM) to ensure all parameters meet acceptance criteria for all analytical quality control (QC) elements.
- The QC elements should be evaluated to ensure that they are set at levels that meet the project's measurement quality objectives (MQOs).

- The laboratories are required to provide an initial demonstration of capability (IDC) consistent with the DOD QSM for Ecology bid evaluation.
- The QC criteria should not be less stringent than the criteria found in the DOD QSM, Version 5.1, Appendix B, Table B-15 (DOD, 2017) or later version.
- Assessment of laboratories performing validated modified methods by Ecology will be based on that laboratory standard operating procedure (SOP) for such modification, which are subjective and varies with laboratories. As such, there is no standard guidance document in evaluating a laboratory's ability to perform the modified methods. EPA does not accept the modification of validated methods except as defined in the methods.

Ecology will only accept modified versions of EPA-validated methods for regulatory purposes in Washington for non-drinking water matrices if all the above conditions are met until EPA publishes validated methods for non-drinking water matrices.

2.1 Published standard methods for PFAS analysis

Issue 141: Update the CAP to reflect anticipated issuance of Method 8328 and OTM Method in 2021. [City of Vancouver, TRC]

Response: The CAP was updated to reflect the release of the Draft Method 8328 and OTM Method 45 in 2021.

Issue 142: The CAP should recognize that recent analytical advances, utilized in association with UCRM5, will provide a consistent institutional framework to obtain PFAS levels with better accuracy. [City of Vancouver]

Response: Method 8329 was abandoned by EPA. Draft Method 8328 was to have been issued by EPA in 2020, now expected in 2021. EPA published Methods 537.1 and 533 will be utilized in UCMR5 consistent with the methods requirements and modification.

Issue 143: Opportunities should be made to generate data on PFAS other than the five proposed drinking water SALs when drinking water will be tested. A system to track and access this data should be set up for state and local agencies. [Public Health - Seattle & King County]

Response: EPA published Methods 537.1 and 533 can analyze 29 PFAS between them in drinking water. Method 537.1 revision 1 included flexibility to improve the method performance and enhance data integrity. Please refer to the response to Issue 41 regarding data being made publicly available.

Issue 144: Ecology should regularly update its analytical method guidance and recommend methods that will most accurately measure PFAS in different media. [Public Health - Seattle & King County]

Response: Ecology will attempt to update analytical methods as needed. Analytical methods for measuring PFAS in different media are limited with only a few EPA approved validated methods.

Issue 145: Ecology should develop testing and sampling standards for PFAS in WACs 173-201A, -308, -340, -350, -351 and -401. This will help to address major PFAS exposure pathways from air, biosolids, solid waste, soil, surface water, and groundwater. [Public Health - Seattle & King County]

Response: As indicated in response to Issue 144, EPA has few published validated analytical methods for measuring PFAS in different media. Ecology defaults to EPA sampling and testing standards for PFAS where applicable, based on specific project data quality objectives. Ecology also recommends the use of non-EPA standard analytical methods for PFAS analysis developed by other federal agencies for specific project applications. EPA maintains current listings of standard, research, and other federal analytical methods (EPA, 2020b; 2021b).

Ecology requires the use of standard validated methods to meet regulatory requirements. The federal clean water act (CWA) requires use of 40 CFR 136 methods for effluent monitoring. As described in the response to Issue 140, non-validated methods can be approved for use by Ecology under specific conditions.

2.1.1 Drinking water methods

Issue 146: Corrections are proposed to the statements in this section. [TRC]

Comments proposed the following revisions for this subsection:

- In the second paragraph of subsection Method 537.1, remove the duplicate listing of hexafluoropropylene oxide dimer acid in the parenthetical
- Add “acid” to the definitions of perfluorobutane sulfonic acid (PFBS), perfluorohexane sulfonic acid (PFHxS), and perfluoro(2-ethoxyethane) sulfonic acid (PFEESA)

Response: The duplicate hexafluoropropylene oxide dimer acid was deleted; it was meant to be 4, 8-Dioxa-3H-Perfluorononoic acid (ADONA), which was added. “Acid” was added to the definitions in Table 10.

2.1.2 Non-drinking water sample methods

Issue 147: It is important to note that SW-846 Methods 8327 and 8328 refer only to the instrumental aspects of the methods. SW-846 also typically includes sample preparation as separate methods (3000 for organics). For Method 8327, the only published sample preparation is Method 3512, which is filtration/dilution/acidification for aqueous samples. Because there is no concentration, detection limits are usually quite high. A more comprehensive description of sampling and analysis would be appropriate in this section of the CAP. [NCASI]

Response: Ecology agrees. Please see the response to Issue 145 regarding sampling and analytical testing for PFAS.

Issue 148: Corrections are proposed to the statements in this section. [TRC]

Comments proposed the following revisions for this subsection:

- At paragraph 3, the most recent version of the DOD QSM, Version 5.3 (2019) should be cited for PFAS quality standards.
- A recommendation should be included to not utilize EPA SW-846 Method 8327 as this is not an isotope dilution method and has shown to be less reliable for several PFAS analytes. Isotope dilution is the gold standard and should be used for any non-drinking water matrix where matrix interferences are more likely. In addition, the detection limits are higher using 8327 than those obtainable using isotope dilution techniques.
- Move perfluorotetradecanoic acid (PFTeDA) from Table 13 to Table 12 and remove Table 13; it should be with the other PFCAs.
- For consistency with the discussion on Method 8327, please include "SW-846" in the method title for EPA Method 8328; update the issuance date to 2021.
- Regarding ASTM D7968: Solids (soil), cite the most recent version of the DOD QSM, Version 5.3 (2019) for PFAS quality standards.

Response: The revisions were incorporated as follows:

- The most recent version of the DOD QSM, Version 5.3 (2019) was included for PFAS quality standards. Until EPA publishes validated methods for use Ecology will default to any later version of published DOD QSM.
- EPA SW-846 Method 8327 is a published validated method using external calibration. Although it is not an isotope dilution method, it went through a multi-laboratory validation process. The method includes a two-phase study for 24 PFAS analytes and 19 isotopically labeled PFAS surrogates. Ecology agrees that there are quality and confidence issues in PFAS results when using Method 8327. However, special care is needed in using this method for specific data quality objectives. Ecology will not include a recommendation not to use Method 8327 except if the method is withdrawn by EPA.
- Table 13 was an error in formatting and was deleted. PFTeDA was moved to table 12.
- Comment noted. EPA SW Method 8328 was used in the method title and draft method issue date was changed to 2021.
- The most recent version of the DOD QSM, Version 5.3 (2019) version was cited.

2.2.1 Non-standard analytical techniques for measuring PFAS

Issue 149: Page 127 of the Draft CAP indicates "The TOP assay has not been demonstrated on large molecular weight polymer compounds or newer ether-linked PFAS like GenX. It is unknown if the oxidative process would liberate PFAAs from these types of compounds." Hexafluoropropylene oxide dimer acid (GenX) is itself a product and does not appreciably degrade in the environment. A TOP assay (which uses persulfate but not ultraviolet [UV]/persulfate) is unlikely to convert GenX. As further indicated in the CAP (page 128, Section 2.3 Challenges of analytical method selection), citing the limitation that GenX and

ADONA (another replacement compound for PFOA) cannot be analyzed using TOP is not appropriate. These two compounds are not precursors, but rather PFAS products, and are already target analytes for environmental analysis. [NCASI]

Response: Regarding the comment on the statement at page 127 of the Draft CAP, the statement is correct as of the time of publication. The published paper by Zhang et al. (2019) on the fate of per- and polyfluoroalkyl ether acids (PFEAs), including fluorinated replacements such as GenX and Adona, and manufacturing byproducts, found that PFEAs containing the -O-CFH- moiety were readily oxidized in the TOP assay.

GenX, in their study, was among the ten perfluoroalkyl ether acids and one chlorinated polyfluoroalkyl ether acid (F-53B) that were stable of the 15 PFEAs in the TOP assay. Prior to the Zhang et al. (2019) paper, PFEAs were not in the TOP assay analyte list—their paper recommended that adding PFEAs will capture a higher percentage of the total PFAS concentration in environmental samples. The polyfluoroalkyl ether acids with a -O-CFH- moiety were mostly oxidized to products that could not be identified by targeted liquid chromatography and high-resolution mass spectrometry.

Although, GenX may not appreciably degrade in the environment, other PFEAs may degrade as described in Zhang et al. (2019). Appendix 2: Analytical methods, will be updated to reflect Zhang et al. (2019) and 30 other publications that referenced their paper.

As for the statement at page 128 of the Draft CAP, GenX and ADONA are target analytes for environmental analyses with EPA Methods 537.1 and 533 respectively. However, they were not on the analyte list for TOP assay before Zhang et al. (2019) was published. Zhang et al. (2019) and other publications that reference it have demonstrated that polyfluoroalkyl ether acids with a -O-CFH- moiety such ADONA are amenable to TOP assay. Application of TOP assay to PFEAs showed the presence of precursors that form perfluoroalkyl carboxylic acids.

2.4 Data gaps and recommendations

2.4.1 Data gaps

Issue 150: This section should identify a data gap in the consistency with how labs are dealing with particulates in aqueous samples (e.g., wastewater, surface water, groundwater). For example, some labs are centrifuging/decanting the water and separating out the particulates, some labs are doing separate extractions of the aqueous and particulate phases and combining the extracts for a true total number. Both methods can yield very different results due to the nature of PFAS (e.g., long-chain PFAS adhere to solids more). [TRC]

Response: Ecology agrees with your comment. However, extraction procedures dealing with different matrix samples such as aqueous samples are project specific based on the data quality objective of the project. Lab procedures for PFAS sample preparation are better discussed by the lab performing the PFAS analysis.

2.4.2 Recommendations

Issue 151: The lack of knowledge regarding the complete list of PFAS relevant to environmental and human exposure should continue to be emphasized. A recommendation should be added for state agencies to require for companies to disclose PFAS chemicals used in products and applications and what methods they recommend for detection of the compounds. [Public Health – Seattle & King County]

Response: The Draft CAP identified data gaps within each appendix, and re-emphasized important gaps in the Data Gaps section at the conclusion of each appendix. Except for available validated standard methods for PFAS analysis, manufacturers may have their own proprietary methods that are not approved or multi-lab validated. Such methods could not be used for regulatory purposes without meeting the requirements specified in the CAP. Ecology does not have the authority to require manufacturers to disclose their proprietary analysis methods. Issue 84 addresses comments requesting that PFAS in products be disclosed.

Issue 152: The CAP should include more information on laboratory accreditation for PFAS analytical methods, as well as how laboratories can seek Ecology accreditation for PFAS analytical methods. [Public Health - Seattle & King County]

Response: Information regarding procedures on applying for laboratory accreditation is available on Ecology's Environmental laboratory accreditation webpage.[264] Ecology has accredited laboratories for certain PFAS analytes – these can be found using the Lab Search database.[265]

Issue 153: Ecology should develop guidance for reducing PFAS contamination during sampling and analysis. Funding will be needed to support evaluation and developing this guidance. [Public Health - Seattle & King County]

Response: There is already guidance available, and if sampling is for regulatory purposes Ecology should be consulted to provide feedback or approve proposed methods. See response to Issues 140 and 145. Guidance for reducing PFAS contamination during sampling and analysis are included in the QAPP and the SOP relative to the specific project. See more in the EPA's resources for PFAS sampling and analysis.[266]

[264] https://ecology.wa.gov/Regulations-Permits/Permits-certifications/Laboratory-Accreditation
[265] https://apps.ecology.wa.gov/laboratorysearch/Default.aspx
[266] https://www.epa.gov/water-research/pfas-analytical-methods-development-and-sampling-research#:~:text=EPA%20method%20that%20measures%20PFAS,for%2050%20specific%20PFAS%20compounds

Appendix 2 – List of Acronyms

Issue 154: Corrections are proposed to acronym definitions. [TRC]

Comments proposed the following revisions for this subsection:

- At Table 16: Correct the definitions of ITRC, particle-induced gamma ray emission (PIGE), and TOP.
- At Table 17: Correct the definitions for fluorotelomer sulfonate (FTS), PFEESA, perfluoroheptane sulfonic acid (PFHpS) and PFHxS.

Response: The corrections were made. (Tables 16 and 17 of the Draft CAP are now Tables 15 and 16 in this CAP.)

Appendix 3: Sources and Uses

3.0 Overview

3.0.1 Findings

Issue 155: Findings in the fourth paragraph related to waste management should be clarified as to whether they address only industrial pathways, and it should be made clear that groundwater, surface water and municipal wastewater are not "sources" of PFAS, but receptors. Cookware should be removed from the fifth paragraph, as elsewhere it is stated that PFAS fluoropolymers used in this application are stable. [City of Vancouver]

Response: The text in the fourth paragraph has been clarified to address the origin of the waste streams, and that they can represent pathways of release of PFAS to the environment as a result of PFAS being present in the waste.

Regarding the statement about nonstick cookware in the fifth paragraph, we added a clarifying sentence at Appendix 3: Sources and Uses, Section 3.3.2 PFAS in a typical home. We don't expect the estimated amount of PFAS in the home from individual products and people's exposure from those products to be the same—we interact with products in unique ways, and PFAS in different applications can be more or less stable.

While some PFAS (such as PTFE), may be heat stable, they can still chip off or be incinerated when the cookware is being used, leading to potential exposure. So although they are more stable in this application, exposure is still possible, and cookware should not be ignored as a source.

3.2 Aqueous film forming foam

Issue 156: Contamination of groundwater by PFAS at the Ridge Run site in Pennsylvania resulted from the use of Class B firefighting foams to control a tire fire. Have any similar occurrences been identified in Washington state. [Mefford]

Response: Incidences of drinking water contamination resulting from the use of AFFF to extinguish tire fires were added to Appendix 3: Sources and Uses, Section 3.2, Aqueous film forming foam. At this time, no areas of drinking water contamination have been identified as resulting from similar events in Washington state. Tire fires occurred at the Everett landfill site in Everett, WA, in 1983 and 1984 (Ecology, 2021b). It is not known whether AFFF was used during fire response at this site.

The City of Everett's drinking water system, supplied from surface water, participated in UCMR3 and reported "non detect" for all six PFAS tested (EPA, 2017). No public water systems appear to be down gradient from the Everett landfill (Ecology, 2021b; Health, 2021b). The site has undergone cleanup and now meets the cleanup standards under the Model Toxics Control Act for petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), bis(2-ethylhexyl) phthalate, and metals. AFFF is no longer recommended for extinguishing tire fires but can be recommended to prevent run-off oil from igniting (U.S. Fire Administration, 1998).

3.2.3 Defense installations

Issue 157: Text in this section should be corrected to reflect that Federal law requires that the Secretary of Defense prohibit the use of fluorinated aqueous film forming foam for training exercises at military installations by October 2024; a citation should also be revised to "Naval Air Station Whidbey Island." [U.S. Department of the Navy (DON)]

Response: The proposed revisions were incorporated.

3.2.4 Petroleum storage and transport

Issue 158: The map legend of Figure 23 covers about ¼ of the state and likely blocks locations of depicted locations of oil facilities. [City of Vancouver]

Response: The figure (Figure 24 in this CAP) was reformatted so that no portion of the state is obscured by the legend.

3.2.5 Transportation (called "Tunnels" in the Draft CAP)

Issue 159: Please describe how fixed foam firefighting systems used in tunnels in the Seattle area are managed by Washington State Department of Transportation (WSDOT); what happens during training and is the foam replenished when it expires. [Public Health - Seattle & King County]

Response: As indicated in Appendix 3: Sources and Uses, Section 3.2.5, Transportation (called "Tunnels" in the Draft CAP), AFFF is the active ingredient used in fire suppression systems in three WSDOT-operated tunnels:

- Interstate (I)-90– Mercer Island
- I-90 - Mt. Baker
- I-5 Washington State Convention Center

WSDOT regularly samples and tests the foam in these systems to ensure it meets fire suppression performance standards (Fanning, 2021). The foam is not replaced on a regular schedule. The foam was last replaced under a construction project (2016 – 2018 timeframe) as part of the retrofit of the I-90 tunnels to accommodate light rail.

WSDOT does not use the foam for either training or overall system operation testing at these locations. WSDOT continues to seek AFFF alternatives to replace the foam in these existing systems, provided the alternatives must meet DOT regulatory requirements. WSDOT is considering fire suppression systems that don't use AFFF for new projects, for example State Route 520.

Issue 160: The CAP should describe marine transportation related uses (e.g. ferries) of AFFF. [Public Health - Seattle & King County, Whidbey Island Water System Association]

Response: AFFF used for emergency fire protection on ferries has been added to Appendix 3: Sources and Uses, Section 3.2.5, now called "Transportation." According to WSDOT staff, training regarding use of the systems is not performed aboard ferries, but in WSDOT's fire training center in North Bend, Washington—training is performed using a soap and water mix (Cory, 2021a, b). Testing of the systems aboard the ferries does not involve any release of Class B firefighting foam. If foam is released as a result of an emergency response activity, the vessel Captain provides the vessel position where the release occurred and the approximate volume discharged.

3.2.6 Summary of AFFF quantities

Issue 161: At Table 25, the entry for "Other Petroleum Facilities" should be updated to 387,999 for consistency with Table 22. [TRC]

Response: The entry in the table (Table 24 in this CAP) was corrected.

3.3 Consumer Products

Issue 162: Without resources available to tribal governments, tribes can be overloaded with the extensive need to identify PFAS-contamination that exists in tribal offices, drinking water systems, schools, homes, and landfills. [National Tribal Water Council]

Response: Ecology and Health recognize that EPA is the lead on drinking water protection and hazardous material releases on Indian Lands. Nevertheless, actions taken by the state to reduce PFAS emissions into the environment and reduce people's exposures will benefit all residents within the state. As part of the Draft PFAS CAP comment process, Ecology communicated with regional and national Tribal organizations to explain the goals and recommendations of this CAP. Ecology will continue to inform these organizations regarding CAP implementation activities. Ecology and Health also work closely with EPA when contamination issues have the potential to involve state and federal jurisdictions.

Issue 163: All efforts should be made to understand PFAS use in products and subsequent exposure of humans and the environment. [Public Health - Seattle & King County]

Response: CAP recommendations will collect information that furthers our knowledge regarding human and environmental exposure to PFAS. Activities already being conducted under the Safer Products for Washington and PFAS in Food Packaging Alternatives Assessment programs are also providing new information as products containing PFAS are considered for additional regulation (see Executive Summary, What else are we doing about PFAS?).

3.3.1 PFAS in children's products

Issue 164: The data in Table 27 is informative and reflects the likely shift to short-chain PFAS. This section should discuss what is known regarding PFAS in children's products and whether additional PFAS should be considered for inclusion under CSPA. [Public Health - Seattle & King County]

Response: Ecology has not assessed the reasons for yearly variations in reports of PFOS and PFOA submitted under CSPA requirements, and therefore cannot confirm whether it is due to voluntary production phase-outs of PFOS and PFOA in the U.S. or other reasons. As described throughout Appendix 3: Sources and Uses, Section 3.3. Consumer Products, exposure to PFAS is ubiquitous, and children can be exposed to PFAS not only through children's products, but also through exposure to products used widely in homes and through dietary intakes as described in Appendix 7: Health, Section 7.2.1, Trends and demographics of PFAA exposure. Refer to the response to Issue 15 regarding the expansion of CSPA regulations to other PFAS.

3.3.2 PFAS in a typical home

Issue 165: Update the information in this section with new information from the paper by Glüge et al. (2020). Update Tables 41 and 42 with any missing products. [Public Health - Seattle & King County]

Response: We have added a reference to the Glüge et al. (2020) paper in Appendix 3: Sources and Uses, Section 3.1.2 Manufacturing, and 3.3.2 PFAS in a typical home. These tables are not intended to be all encompassing, but to provide a summary of types of products containing PFAS that might be present in a home. We populated the tables with information where concentrations of specific PFAS in products were available. Although Glüge et al. (2020) may identify additional items that may be present in the home, it does not provide concentrations of PFAS in those products.

Issue 166: Customers have established high performance, quantifiable specifications to maximize the useful life, and reduced maintenance costs when it comes to fabrics such as military fabrics, upholstery, certain apparel items, awnings and other longer-life textiles which have been treated for oil and water repellency using fluorinated products. Data was collected indicating that reduced product life for these types of fabrics, i.e. if products were not treated with fluorinated repellents, results in quantifiable negative environmental impacts resulting from early product replacement. Although recycling of treated upholstery is still in its infancy, it has demonstrated that the presence of fluorinated repellents does not prevent the thermo-mechanical recycling of polyester. Consumers have the freedom of choice to make informed decisions on which fabrics are best-suited for their end-use. [National Council of Textile Organizations]

Response: By adopting Chapter 70A.350[267] RCW, the Legislature identified the class of PFAS as a "priority chemical" and directed Ecology and Health to identify priority products where action could be taken to reduce exposure to PFAS. As discussed in Recommendation 3.1, Ecology identified carpets, water and stain resistance treatments, and leather and textile furnishings as significant sources of PFAS and selected these as priority products. Under the law, Ecology may restrict or prohibit a priority chemical or members of a class of priority chemicals in a priority consumer product when it determines (RCW 70A.350.040[268] (3)) "(a) Safer alternatives are feasible and available; and (b)(i) The restriction will reduce a significant source of or use of a priority chemical; or (ii) The restriction is necessary to protect the health of sensitive populations or sensitive species."

The law does not include consideration of environmental impact or recyclability as part of the criteria as to whether regulatory actions should be proposed.

Issue 167: In an October 2020 report to the European Union (Whiting et al., 2020) , home textiles and consumer products have been reported as dominant sectors for the use of PFAS in textiles, upholstery, leather apparel and carpet. The dominant life cycle stage for PFAS

[267] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.350&full=true
[268] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.350.040

emissions into the environment is from PFAS released to sewer water from washing of these textiles. [Clean Production Action]

Response: This reference was added to text in Appendix 4: Fate and Transport, Section 4.3.2 Water, relative to the discussion of PFAS entering wastewater from the use of products.

Issue 168: Recent research (Ma et al., 2020) has shown that pets are also exposed to PFAS, likely from the same sources as people. [Toxic Free Future]

Response: This reference was added to Appendix 3: Sources and Uses, Section 3.3.2 PFAS in a typical home.

Issue 169: Tables 28 and 29 should be updated with more recent data to reflect current products in commerce versus all historical legacy products. [Alliance for Telomer Chemistry Stewardship]

Response: These tables (27 and 28 in this CAP) were intended to provide a summary of types of products containing PFAS that might be present in a home. We populated the tables with information where concentrations of specific PFAS in products were available. The comment did not provide information on newer references with similar information that could be used to update the table.

We do recognize that as market forces change, certain products may now be produced with substitute PFAS, or may be fluoro-free. That said, certain products in the home are not replaced on a regular basis, and legacy products with the PFAS shown may still be present in homes, even though newer fluoro-free products are being sold today.

3.3.3 Consumer Product Priorities

Issue 170: Table 30 should recognize that carpet cleaning wastewater may be discharged to a sewage treatment plant. [City of Vancouver]

Response: We updated this table (Table 29 in this CAP) to recognize that carpet cleaning waste water may be discharged to a sewage treatment plant.

Issue 171: Section 3.3.3 and Table 30 mischaracterize landfill disposal of waste with PFAS as a "contribution to environmental disposal." Solid waste landfills receive societal waste and typically do not manage concentrations of PFAS similar to those that are found at heavy-user sources. While some landfill types could result in releases to the environment, there is no data available on releases to the environment of PFAS from waste management facilities in Washington state. When properly disposed of in modern, lined, environmentally-engineered landfills with leachate collection systems, especially where the leachate is managed onsite, PFAS will remain isolated from potential environmental and human receptors that could present any meaningful environmental risk. Ecology should revise this and other CAP sections this section based on further information on the role of the landfill sector in controlling releases of PFAS waste into the environment. [Waste Management of Washington]

Response: The entries in the table were revised to indicate that this could be an environmental exposure pathway if leachate is not properly controlled or collected. Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products, recognizes that landfills receive wastes representative

of items manufactured or in commerce in the state. The purpose of Recommendation 4.2 is to collect data regarding potential landfill emissions in Washington. See our response to Issue 93 regarding revisions throughout the CAP to reflect that landfills are not a "source" of PFAS. Please refer to the response to Issue 179 regarding exposure of people to PFAS present in landfilled materials or discharged via leachate. Refer to the response to Issue 182 regarding modern landfill requirements to collect and manage leachate.

3.3.4 Service and retail settings

Issue 172: The CAP should include ski manufacturing, ski waxing, and recycling of products that may contain PFAS in the list of activities. [Public Health - Seattle & King County]

Response: Appendix 3: Sources and Uses, Section 3.3.4 Service and retail settings, was updated to include workers in the ski industry and workers in the waste collection and recycling industry. It should be noted that data available in certain outdoor recreation industry categories is not narrowed down to only the ski industry—therefore certain occupational numbers added to Appendix 3: Sources and Uses, Section 3.3.4 under potential ski industry exposures overestimate exposed workers because they include all sports. Similarly, data for employment in a "ski facility" includes all types of occupations, some of which are not involved in applying ski waxes.

3.4 Waste management

3.4.2 Wastewater

Issue 173: Discussion about wastewater throughout the CAP should be more clear as to whether "industrial" or "municipal" wastewater is being addressed. [City of Vancouver]

Comments were made regarding:

- Clarity throughout the document as to whether wastewater meant "industrial" or "municipal", and whether the title of Section 3.4.2 should be adjusted.
- Distinction between direct and indirect industrial discharges (to POTWs).
- Inaccuracy regarding qualifiers about "large volumes of water" being treated in publicly owned WWTPs.
- Solids such as influent screening and grit which are recuperated during treatment and are treated as solid waste.
- Sludge being processed into biosolids rather than "transformed."
- Identifying the periodic removal of solids from on-site wastewater systems and delivery of these solids to WWTPs or commercial processing facilities.

Response: The following changes were made to Section 3.4.2 of the CAP to address the comments:

- The title of Section 3.4.2 was shortened to "Wastewater" and we have reviewed our use of "WWTP" throughout the document and clarified the distinction between industrial and publicly owned facilities when necessary.

- The text was clarified to indicate that industrial wastewater can be discharged to receiving (surface) water or to publicly owned WWTPs (with pretreatment).
- The qualifier regarding "large volumes of waste" has been removed.
- Influent screening and grit removal was acknowledged.
- "Processing" of biosolids was incorporated.
- Discussion of periodic removal of solids from on-site wastewater systems was included.

Issue 174: Include a discussion regarding EPA's recent interim strategy on wastewater permits. [TRC]

Response: EPA's interim strategy for wastewater permits was not added to Appendix 3: Sources and Uses, Section 3.4.2 because it does not apply to WWTPs in Washington. We did, however, discuss the strategy at Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency.

3.4.3 Landfilled products

Issue 175: The CAP mischaracterizes landfills as sources of PFAS. Landfill operations neither manufacture nor use PFAS; they receive wastes containing numerous and undefined PFAS compounds and PFAS quantities from the sources they provide services to. PFAS cannot be eliminated from landfills or significantly reduced in landfill leachate if they continue to circulate in the economy in myriad products, by products and goods. Work should continue to discontinue and phase-out PFAS production and use at manufacturing facilities and find safer alternatives for heavy-use areas such as firefighting training sites. [Cowlitz County Public Works, NWRA, Washington Refuse and Recycling Association, Waste Connections, King County Solid Waste, Waste Management of Washington]

Response: Please refer to the response to Issue 93. Updates throughout the CAP reflect that landfills are not a "source" of PFAS, rather a waste stream pathway by which PFAS can enter the environment. Issue 93 also describes that Recommendations 2.3, 3.1, 3.2 and 3.3 aim to limit certain PFAS emissions at their source.

Issue 176: PFOS and PFOA concentrations in leachate may be declining as a result of phase out-outs of these compounds in the market place. This is supported by unpublished data which was gathered and submitted to the State of Minnesota. With the phase out of PFOS and PFOA, average levels of these compounds in human blood levels have declined from 1999 to 2014. The state should continue seeking means of assisting PFAS manufacturers and users to transition away from their use and avoid importation of PFAS containing consumer products into Washington. [Cowlitz County Public Works, NWRA, Waste Connections]

Response: Ecology does not have access to unpublished data that was submitted to the State of Minnesota suggesting that PFOA and PFOS concentrations in leachate appear to be declining as a result of phase-outs of these compounds in the marketplace.

Recommendation 2.3 aims specifically to provide assistance to manufacturers and industries who may be using PFAS—including reaching out to these industries to discuss their use of PFAS, identifying opportunities to switch to safer alternatives, implementing best practices, and ensuring proper waste management.

Appendix 7: Health, Section 7.2.1 Trends and demographics of PFAA exposure, discusses trends of median serum levels for certain PFAS and how these have dropped subsequent to voluntary phase-outs by U.S. industries.

Issue 177: When landfill leachate is sent to WWTP for treatment, it can represent a relatively small fraction of total PFAS contributions to the WWTP influent. Studies in Michigan and North Carolina concluded that non-leachate sources are the most significant mass contributors to PFOA and PFAS at POTWs, with landfill leachate representing a minor contribution. [Cowlitz County Public Works, NWRA]

Response: The studies completed by the Michigan Waste and Recycling Association and the National Waste and Recycling Association – Carolina Chapters, were included in Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products.

Issue 178: The operation of landfills and POTWs is interdependent. Landfills rely on POTWs to accept landfill leachate for treatment, and POTWs rely on landfills to accept certain biosolids. If either of these interdependent waste stream transfers is precluded based on PFAS being present, these waste streams would be stranded, resulting in either increased operation costs or inability to continue operating. [Cowlitz County Public Works, NWRA, Waste Connections, Waste Management of Washington]

Response: Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products, identifies that "Under current State requirements, landfill leachates that are collected are sent either to WWTPs or evaporation ponds," underlining the interdependency of WWTPs and landfills. Recommendation 4.2, Evaluate landfill PFAS emissions, does not preclude landfill leachate from being sent to WWTPs on the basis of PFAS being present in the leachate. Recommendation 4.1, Evaluate PFAS in wastewater treatment, does not preclude WWTPs from receiving landfill leachate. Both of these recommendations propose collecting additional information regarding PFAS in these waste streams and, if warranted, considering additional monitoring for PFAS.

Issue 179: The CAP overstates the significance of landfills for overall PFAS exposures. It is important to place landfills in proper context when examining potential PFAS exposure routes for the general public. While it is true that landfills receive materials that contain PFAS, this does not equate to any significant public exposure. Stringent regulation of landfill leachate is unlikely to translate into materials reductions in public exposure, given the low mass involved as compared to continued household exposures. [Cowlitz County Public Works, Washington Refuse and Recycling Association, Waste Connections]

Response: The Draft CAP does not indicate that the public is directly exposed to PFAS in landfills or present in landfill leachate. Appendix 7: Health, Section 7.3 Sources and pathways for human exposure, identifies primary pathways for human exposure, none of which include direct contact with materials in landfills or landfill leachate. The CAP identifies landfill leachate as a potential pathway of release of PFAS into the environment, which could in turn contaminate drinking water or expose fish or wildlife to the substances. Recommendation 4.2 is not proposing stringent regulation of PFAS in landfill leachate—it proposes a study to gather more information regarding the presence of PFAS in landfill leachate in Washington, and if warranted, monitoring of PFAS in leachate.

Issue 180: State policy making should understand that PFAS cannot be completely eliminated from landfills. Landfills cannot avoid receipt of PFAS containing wastes as long as PFAS is present in commercial and other products. The CAP should include a comprehensive examination of the life cycle of PFAS containing wastes and PFAS waste management. Data collection regarding PFAS in landfills and leachate is just beginning; regulatory requirements should not be enacted prematurely. [Cowlitz County Public Works, NWRA, Washington Refuse and Recycling Association, Waste Connections, King County Solid Waste]

Response: The Draft CAP recognized that many types of solid waste, including household waste, can contain products with PFAS, and that "Landfills store wastes containing PFAS representative of items manufactured or in commerce in the state." The CAP does not recommend that landfills should be precluded from receiving non-hazardous wastes that might contain PFAS. The CAP comprehensively addresses the PFAS life-cycle:

- How PFAS are used (Appendix 3: Sources and Uses, Sections 3.1 Manufacturing, 3.2 Aqueous film forming foam and 3.3 Consumer products).
- How they enter waste streams when products are used or discarded (Appendix 3: Sources and Uses, Section 3.4 Waste Management).
- How they enter the environment as a result of direct emission, product use or waste stream management (Appendix 4: Fate and Transport, Appendix 5: Environmental Occurrence, and Appendix 8: Biosolids).

Recommendations 4.1 and 4.2 addressing WWTPs effluents and landfill leachate respectively, are both based on collecting data prior to making any decisions to require additional monitoring of effluents.

Issue 181: The CAP should address that recyclers and composters are also unable to avoid receiving PFAS containing wastes in food packaging, biodegradable products, carpeting, textiles and other recyclable materials. Policies affecting "receivers" such as landfills, recyclers, and composters should balance the impact of managing PFAS contaminated wastes with their environmental value and their necessity. [King County Solid Waste]

Response: The CAP is not proposing any policies or recommendations that would limit receipt of solid waste intended for recycling or composting operations.

PFAS in compost was addressed in the Draft CAP at Appendix 3: Sources and Uses, Section 3.4.5 Compost. Refer to the response to Issue 195 and Issue 197 regarding how presence of PFAS in paper/food packaging may be affecting receipt of compostable materials at composting facilities. Refer to the response to Issue 88 regarding carpet recycling.

Issue 182: The CAP should better differentiate among different types of landfills and the risks they may present with respect to PFAS releases in landfill leachate. Factors such as the type of landfill (e.g., unlined landfills, construction and demolition waste landfills, municipal solid waste (MSW) landfills, etc.), the climatic setting, leachate management (on-site or offsite), and if the facility produces landfill gas and how it is managed are all important factors in determining a particular facility's ability to manage these wastes in a protective manner. Banning PFAS in certain consumer products will require assessing appropriate solid waste –

and potentially dangerous waste – disposal alternatives. Ecology should consult with the public and private operators of waste management facilities prior to further development and implementation of the CAP. [Cowlitz County Public Works, NWRA, Washington Refuse and Recycling Association, Waste Management of Washington]

Response: The Draft CAP identified the different types of landfills present in the state and those that are required to have leachate collection systems based on applicable regulations. We updated Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products, to emphasize the many factors that can affect the mobilization of PFAS in a landfill.

When bans of certain products are enacted in the state, Ecology works with regulated persons affected by the ban to educate them about waste designation and resulting disposal requirements potentially affecting the products. For example, when the SBOH and the FDA enacted regulations to ban certain vaping and e-cigarette products, Ecology provided guidance to persons managing waste as a result of the ban (Ecology, 2020). At this time, there are only two types of products that have a ban in place, or will have a ban in place in the future.

- Sale of AFFF is banned in the state as of July 2020. As described in Section "What else are we doing about PFAS?," Ecology is conducting an environmental review to identify appropriate disposal alternatives for AFFF stocks held by public firefighting agencies. Since the legislation went into effect, Ecology has coordinated extensively with affected parties (see Executive Summary).
- The sale, manufacture, and distribution of certain types of food packaging materials containing PFAS will be banned starting in February 2023.[269] The ban does not prevent the use of the packaging that businesses may have purchased for direct use prior to the ban on sale and distribution. Disposal of used or new products in Washington that cannot be sold or distributed after the ban would continue according to how the packaging designates (as a solid waste), as it did prior to the ban.

Issue 183: The CAP should not base PFAS disposal volume estimates on unrealistically high PFAS concentration data for carpets. By suggesting that carpeting could contain PFAS concentrations greater than 0.01%, the CAP suggests that used carpeting destined for recycling or disposal may be classified as a "dangerous waste" under Washington's Dangerous Waste Regulations. [Cowlitz County Public Works, NWRA, AWB, Waste Management of Washington]

Response: We urge the readers to keep in mind that the volume estimates in the CAP are just that—estimates. Because analytical testing is only available for a subset of PFAS, it's difficult to confirm whether the KEMI estimation of 15% or the industry estimation of 0.1% is more accurate. It's also possible the two estimations refer to different PFAS technologies. Regardless, we moved the description of the industry estimation earlier in the document so the reader

[269] https://apps.ecology.wa.gov/publications/summarypages/2104007.html

could see both estimations together and understand the potential uncertainty and variability around our estimation.

Appendix 4: Fate and Transport, Section 3.4.3 Landfilled products, is not suggesting that all carpet is regulated as a persistent criteria waste under Chapter 173-303[270] WAC. As indicated above, the purpose of this section is to provide an estimate of how much PFAS could have ended up in state landfills based on available estimates of PFAS concentrations in carpet. The response to Issue 105 further addresses the responsibilities of a waste generator to determine whether a waste they produce designates as state dangerous waste.

Issue 184: The CAP should acknowledge that PFAS profiles in leachate and groundwater can vary by landfill age, as reported in a study conducted for the Vermont Department of Environmental Conservation. [Public Health - Seattle & King County]

Response: We updated Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products, to emphasize that the age of a landfill can affect the mobilization of PFAS in a landfill into landfill leachate. The study conducted on the New England Waste Services of Vermont, Inc. Landfill in Coventry, Vermont, was also added to this section (Sanborn, Head & Associates, Inc., 2019).

Issue 185: The CAP should acknowledge studies conducted in Michigan and North Carolina that show landfill leachate is a small contribution of PFAS to WWTP influents. The CAP gives the misleading impression that landfills are major sources of the wastewater being managed through WWTPs and therefore are potentially large sources of PFAS to the WWTPs. [Waste Management of Washington]

Response: We updated Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products, to identify these studies. The Draft CAP did not attribute any significance level to the contribution of PFAS to WWTPs. Recommendation 4.2 aims to better characterize PFAS presence in landfill leachate in the state.

Issue 186: The CAP should provide additional discussion on the proper disposal of wastes containing PFAS that exceed the threshold for dangerous waste classification. The reported PFAS concentrations in certain commercially available products (such as cleaning agents, commercial carpet care liquids, treated floor waxes and stone/wood sealants, impregnating sprays, and waterproofing agents) would designate as dangerous waste once the materials are no longer in service and become wastes. This may be especially important relative to non-exempt large commercial sectors that have to manage certain materials containing PFAS as dangerous wastes. [Waste Management of Washington]

Response: The commenter is correct that businesses have been and will be required to follow Chapter 173-303[271] WAC designation and disposal requirements for PFAS containing waste streams. Although the CAP has now identified products that contain PFAS and industries that generate PFAS wastes, the requirement for all businesses to properly designate and manage

[270] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-303&full=true
[271] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-303&full=true

their persistent wastes has been in the DW regulations for many years. Ecology resources are available for businesses to help them understand their responsibilities under the DW rules via our DW management website,[272] guidance publications,[273] and technical assistance program.

Issue 187: Ecology should support and fund academic science to determine what the leachability and transformations these compounds exhibit in landfills versus simply identifying them once they are disposed. The landfill leachate study as proposed will not provide reliable information on the leachability of PFAS compounds. [Waste Management of Washington]

Response: The leachability of PFAS was not within the scope of the landfill leachate study. The goal of Phase I of the study was to determine which, if any, landfills had the potential to contaminate the environmental media around the landfills.

Phase I of the study did detect PFAS in landfill leachate from around the state. Ecology will look at that data and determine whether to expand the study to include PFAS potential impacts to groundwater, soil, soil vapor, surface water, and air.

Throughout any expanded follow-up PFAS planning process, Ecology would seek comments and other input from public agencies, jurisdictional health departments, academia, private and municipal solid waste disposal facility operators, neighboring state solid waste programs, community groups, and regional and state solid waste associations to help determine the scope and duration of any additional studies.

Issue 188: The CAP overemphasizes landfills as a potential source of uncontrolled leachate discharging PFAS into the environment, and under emphasizes that most active landfills in the state have leachate collection systems. [Waste Management of Washington]

Response: The Draft CAP identified that uncontrolled landfill leachate and transfer of landfill leachate to WWTPs can each result in pathways for PFAS to enter the environment. The Draft CAP did not rank or attribute a level of significance as to the importance of these pathways relative to other pathways of PFAS entering the environment.

Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products, has been revised to identify requirements for leachate collection prior to discussing leachate releases or impacts from PFAS resulting from such releases. Studies conducted elsewhere, and cited to in the CAP, have identified that historical landfill sites without leachate collection systems, or with improperly functioning systems, can be sources of environmental PFAS releases and drinking water contamination, especially when such locations were used to store commercial and manufacturing wastes containing PFAS.

Issue 189: Waste Management of Washington and 16 other landfills have previously provided PFAS landfill leachate data to Ecology. This data should be included in the CAP and compared

---

[272] https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Dangerous-waste-guidance

[273] https://apps.ecology.wa.gov/publications/UIPages/PublicationList.aspx?IndexTypeName=Program&NameValue=Hazardous+Waste+%26+Toxics+Reduction&DocumentTypeName=Publication

to other leachate data collected nationally. It is premature to generalize about how Washington landfills are a source of PFAS into the environment without consideration of actual leachate data and the potential toxicological risks that these levels present to the environment. [Waste Management of Washington].

Response: Ecology just received this data and is reviewing it.

Issue 190: Ecology should direct efforts towards source control by determining PFAS levels in products and wastes and how those levels are changing over time, and their impact on PFAS in incoming waste streams. Ecology should coordinate with EPA's existing efforts to understand the concentrations of PFAS in incoming waste streams and their toxicological effects before undertaking more data-gathering on landfill leachate. [Waste Management of Washington].

Response: Recommendation 4.2 proposes the following activities to better understand the relationship of waste-makeup on concentrations of PFAS in leachate:

- Identifying specific types of wastes that are likely to generate PFAS releases in leachate.
- Determining the specific types of waste streams that lead to higher PFAS values.
- Continuing to research the makeup of PFAS waste entering and potentially currently stored in landfills.

As part of this research, Ecology will consider data collected in other states as well as data generated by researchers and EPA—for example data collected via EPA awards to research potential environmental impacts of PFAS[274] in waste streams.

Issue 191: The CAP should revisit its unsupported statement that PFAS can contaminate landfill leachate from the use of AFFF in fighting fires at landfills. [Waste Management of Washington]

Response: We removed the information regarding use of AFFF (Class-B firefighting foams) to respond at fires at landfills.

Issue 192: The CAP should place drinking water contamination from improperly managed landfill leachate in context with other known sources of PFAS contamination that have had greater impacts on drinking water sources. [Waste Management of Washington]

Response: As described in Appendix 7: Health, Section 7.4 Known areas of PFAS contamination in drinking water aquifers in Washington state, the primary source suspected in these areas is firefighting foam that contained PFAS. The CAP considers information regarding other pathways of PFAS release to the environment, such as PFAS mobilized in landfill leachate, based on documented scientific information available from other regions of the U.S.

However, the CAP also recognizes data gaps in Washington state regarding potential emissions into the environment, for example landfilling of manufacturing waste that may contain PFAS.

[274] https://www.epa.gov/newsreleases/epa-awards-6-million-research-potential-environmental-impacts-pfas-substances-waste-0

Recommendation 2.3, for example, identified that additional information needs to be gathered to determine whether such situations may occur in the state.

Issue 193: Fluoropolymers are not used in carpet treatments and the text at page 171 regarding their use in carpet treatments should be corrected. [Performance Fluoropolymer Partnership]

Response: The correction was made.

Issue 194: Corrections are proposed to Section 3.4.3. [TRC]

Comments proposed the following revisions for this subsection:

- Under Waste characterization studies, clarify if the data is for PFOS, or PFAS:
  - The first bullet under Carpet.
  - Both bullets under Furniture.
- At Food Packaging, second paragraph, correct "FPAS."
- In the summary, clarify if values are for PFAS or PFOS based on comments above, and define the asterisk for the low estimate for carpet.

Response: PFOS was correctly quoted with regards to "carpet" and "furniture" under Waste Characterization studies. The typographical error "FPAS" was corrected.

Tale 34 summarizes the information from preceding paragraphs. At Table 34, the heading columns read "PFAS" because data for different substances is presented based on the material type. For carpet and furniture, PFOS is reported. For textiles, the number is a sum of tonnages for PFCAs and PFAS. For compostable paper packaging, the data is for FTOH and PFCAs. We clarified the table by adding the specific substances with the estimated tonnages. The asterisk was a typographical error and was removed.

3.4.5 Compost

Issue 195: Composters are unable to avoid receiving PFAS contained in food, packaging and some biodegradable service ware. Policies affecting composters should balance minimal impact of PFAS at their operations with the environmental value they provide. [Brookhart, Cowiltz County Public Works, NWRA, Republic Services]

Response: Compost facilities still have the option to identify the feed stocks they choose to accept. The CAP is not proposing any policies or recommendations that would limit receipt of solid waste intended for composting operations. PFAS in compost was addressed in the Draft CAP at Appendix 3: Sources and Uses, Section 3.4.5 Compost. Refer to the response to Issue 197 regarding how PFAS present in paper food packaging may be affecting receipt of compostable materials at composting facilities.

Issue 196: Provide clarification regarding the statement that reducing the use of PFAS chemicals has resulted in a reduction in PFAS in human blood serum. [Public Health - Seattle & King County]

Response: This statement has been removed because the presence of PFAS in human serum is already discussed in Appendix 7: Health, Section 7.2.1 Trends and demographics of PFAA exposure.

Issue 197: The CAP should discuss several sources of information relative to PFAS in composting information. [Public Health - Seattle & King County]

The following information should be considered:

- Work done by the Minnesota Pollution Control Agency to characterize PFAS in contact water at compost facilities.[275]
- Report by Purdue University, Perfluoroalkyl Acid Characterization in U.S. Municipal Organic Solid Waste Composts.[276]
- How short- and long-chain PFAS behave in composting.
- Summary sheet, January 2018, by Lee and Trim, Evaluating Perfluoroalkyl Acids in Compost with Compostable Food Serviceware Products in the Feedstocks.[277]
- New requirements that composting facilities are setting for acceptance of only PFAS-free packaging in Washington state.

Response: Thank you for the additional information. We updated Appendix 3: Sources and Uses, Section 3.4.5 Compost, to include the work conducted by the Minnesota Pollution Control Agency regarding PFAS identified in contact water from composting operations. The Draft CAP already referenced the work conducted by Choi et al. (2019), which reported on the Purdue University and Zero Waste Washington studies.

Ecology will continue to make every effort to stay informed about PFAS testing in compost—including around issues regarding specific PFAS behaviors in compost operations and feedstock limitations being considered by the composting industry. When testing for PFAS in compost becomes more standardized and standards specific to compost are established, Ecology will evaluate adding threshold criteria to WAC 173-350-220[278], Table 220-A.

[275] https://cdn.ymaws.com/www.compostingcouncil.org/resource/resmgr/documents/advocacy/pfas/pfas_report_minnesota.pdf

[276] https://cdn.ymaws.com/www.compostingcouncil.org/resource/resmgr/documents/advocacy/pfas/lee-purdue-study.pdf

[277] https://cdn.ymaws.com/www.compostingcouncil.org/resource/resmgr/documents/advocacy/pfas/lee-trim.pdf

[278] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-350-220

3.5 Global estimate: Washington proportion

3.5.3 Estimate of PHxSF and PFDS emissions

Issue 198: Clarify why perfluorodecane sulfonate is listed twice in the first sentence with two different acronyms. [TRC]

Response: This was a typographical error and it was corrected.

3.5.4 Summary of historical emissions

Issue 199: Review the inconsistency between the average annual Washington direct perfluorooctane sulfonic acid (POSF) emissions stated in text (29.4 metric tons) versus what is shown in table 40 (20.41 metric tons). [TRC]

Response: The in-text value (29.4) was a typographical error, and was corrected to 20.4, matching with the value in the table.

3.5.5 Current emissions

Issue 200: In the phrase "following voluntary phase-outs of PFOA and fluoropolymer manufacturing," and should be replaced by in. [Performance Fluoropolymer Partnership]

Response: The correction was made.

Issue 201: Correct the acronym in the last sentence to PFHxS. [TRC]

Response: The acronym was corrected.

3.6 Data gaps and recommendations

3.6.1 Data Gaps

Issue 202: Under the WWTPs section, suggest adding the following sentence: "In addition, the information should inform state and local agencies for upstream strategies to reduce receipt of PFAS in influent, such as pretreatment technologies at industrial sources, consumer and commercial source control efforts, and consumer educational materials."[City of Vancouver]

Response: Section 3.6.1 Data gaps, subsection WWTPs, was revised to include that WWTP influent data can be used to identify upstream PFAS dischargers and allow further consideration of pretreatment strategies or source control strategies. Recommendation 2.3 was also revised to specify that Ecology will consider data collected during activities conducted under other recommendations to identify industries that may be discharging PFAS.

Issue 203: The CAP should identify PFAS concentrations in compost as a data gap. Ecology should identify upcoming studies and resources for sampling PFAS in compost. Funding should be provided for small-scale composters. Feedstocks with higher PFAS concentrations should be sampled to acquire additional information. Best management practices at compost facilities to reduce PFAS impacts on the environment should be identified. [Public Health - Seattle & King County]

Response: Testing for PFAS in compost is still in developmental stages. Ecology staff are tracking national compost testing efforts and protocols used. Before Ecology can conduct or recommend that compost facilities test for PFAS in finished compost, a standard test for

compost (with a clear list of feedstocks used to make the compost) needs to be identified and all testing must use the same test and/or lab to ensure consistency. As indicated in Issue 197, information was provided that certain composting industry associations are collecting information about the potential for PFAS to be present in feedstocks, and starting January 2021, excluding feedstocks with greater than 100 ppm total fluorine from their member's operations. (Compost Manufacturing Alliance, 2020, 2021). Ecology will continue to track composting industry practices related to PFAS. We have added data gaps related to compost to Appendix 3: Sources and Uses, Section 3.6.1 Data gaps.

3.6.2 Recommendations

Issue 204: At Recommendation 3.3, review the statement that "Purchasing PFAS-free products could increase state costs." Regulatory action, or research and development, could incentivize the market to produce PFAS-free products at lower cost. [Public Health - Seattle & King County]

Response: The statement regarding increased costs of PFAS-free products was removed from the recommendation.

Issue 205: Revisions were proposed for Recommendation 4.1, Evaluate PFAS in wastewater treatment. [City of Vancouver, Public Health - Seattle & King County]

The following revisions were proposed:

- First bullet: The description of the three types of treatment plants is confusing. For example, what is meant by "advanced solids removal"?
- Ecology should consider process points in different types of treatment plants to understand the fate of PFAS and degradation products in secondary activated sludge processes; membrane processes; filtration processes; chlorine disinfection; and uv disinfection.
- The recommendation should make a nexus to Appendix 8: Biosolids, because these are generated at WWTPs.
- The numbering of Recommendations 4.1 and 4.2 should be changed for consistency with their relationship to Appendix 3: Sources and Uses
- Second bullet: The study design should be amended to also sample WWTPs with mostly residential sources in order to increase understanding of residential versus industrial loading of PFAS to wastewater influent. This would inform any decision by Ecology about future requirements for monitoring or compliance in domestic WWTPs. This would require additional funding.

Response: Recommendations regarding WWTP effluent (4.1) and biosolids (4.3) were kept separate because different Ecology programs will be implementing them. Regardless, the interrelationship of WWTPs and the biosolids they produce was described in the CAP.

Recommendation numbering was established at the Interim CAP stage—before the appendices were numbered and sequenced as they appeared in the Draft CAP. The numbering reflects that the recommendations fall into four broad categories:

1. Protecting drinking water.
2. Managing environmental contamination.
3. Reducing PFAS in products.
4. PFAS in waste streams.

With respect to the suggestions for changes to the WWTP study:

- Ecology received funding for this project in 2020 and it is underway
- Ecology had a limited scope for this project due to funding but did incorporate some of the comments and suggestions above:
  - The study is sampling at different process points in different types of treatment plants.
  - The study included wastewater treatment plants with different secondary treatment technologies.
- Ecology is at the beginning of investigating PFAS in wastewater treatment plants. The funding and timeline for this project does not allow for a study addressing everything in this comment. Pending funding, Ecology will continue to investigate PFAS in wastewater and will consider all the suggestions laid out above.
- This study alone will not inform future requirements for monitoring for PFAS in domestic wastewater. Ecology agrees that more information regarding residential versus industrial loading of PFAS to WWTP is needed.

Appendix 3 – List of Acronyms

Issue 206: Corrections are proposed to acronym definitions. [TRC]

Comments proposed the following revisions for this subsection:

- At Table 43, correct the definition of ITRC and revise the definition of Social Science Environmental Health Research Institute (SSEHRI).
- At Table 44, revise the definition of FTS, clarify whether the definition of "PDSF" is the same as perfluorodecane sulfonate (PFDS), and revise the definition of PFAA.

Response: The requested corrections were made.

Appendix 4: Fate and Transport

4.0 Overview

4.0.1 Findings

Issue 207: Several bullets in this section should be revised. [TRC, Alliance for Telomer Chemistry Stewardship]

The following revisions are proposed:

- Transformation, Bullet 1: The statement should be revised because (1) PFAS monomers include many other groups of perfluoroalkyl compounds, such as perfluoroalkyl ether sulfonic acids (PFESA), PFECAs, perfluoroalkane sulfonyl fluorides (PASF), perfluoroalkanoyl fluorides (PAF), perfluoroalkyl iodides (PFAI), and perfluoroalkyl aldehydes and aldehyde hydrates (PFAL); and (2) all PFAA precursors are poly-fluorinated compounds, and it is more straightforward to refer to them as such.
- Transformation, Bullet 1: Monomer is a broad term and can have many meanings. Please define here so that the reader clearly understands what the CAP document means. It is not usually used in the context shown here in the document.
- Transformation, Bullet 3: It should be noted that there is both published work as well as work presented at scientific conferences that do indicate the half-life for precursor transformation to vary from hours/days to months to hundreds of years to thousands of years.
- Transformation Bullet 2: This statement should be revised because perfluoroalkyl substances are not PFAA precursors; only polyfluoroalkyl substances are.
- Fate: Bullet 5: Please revise this statement to reflect that short-chain PFAS are less bioaccumulative in animals, but this has not been found for plants.

Response: Under the bulleted subsection Transformation:

- The first bullet was revised to state polyfluorinated PFAS.
- The second bullet was revised.
- Regarding bullet 3, timeframes for transformation were discussed in Appendix 4: Fate and Transport, Sections 4.1 Non-polymer PFAS and 4.2 Polymeric PFAS.
- Under the bulleted subsection Fate, we revised the fifth bullet to indicate short-chain PFAS are less bioaccumulative in animals.

4.1 Non-polymer PFAS

Issue 208: At Figure 26, the structure for 8:2 fluorotelomer alcohol (8:2 FTOH) is incorrect, as it shows a ketonic structure. [Alliance for Telomer Chemistry Stewardship]

Response: This figure (Figure 27 in this CAP) was revised.

4.1.2 Biotic aerobic transformation

Issue 209: A statement should be added to emphasize that these transformations were shown to occur under controlled and sometimes highly oxidizing laboratory conditions, and so would not necessarily translate to natural environmental conditions. [TRC]

Response: The studies were performed under conditions attempting to replicate WWTPs, which is explained in the text.

4.1.4 Consequences of chemical transformation

Issue 210: It should be added that many of the precursors are still unknown. This section could also refer back to EPA's continually growing list of master compounds, mentioned in Section 1.0.1. [TRC]

Response: Additional information is unnecessary. No specific precursors are mentioned, and the CAP already explains that non PFAAs are precursors.

4.2 Polymeric PFAS

Issue 211: in the third paragraph the following statement should be revised "If side-chain fluorinated polymers—which are often used as oil—and water-resistant treatment for consumer products degrade, then they could be a potential source of PFAS emissions for decades or centuries if not properly disposed and contained in landfills." The phrase "in landfills" should be removed, because these polymers could still reach the environment through leachate disposal to POTWs or liner leaks to groundwater. [TRC]

Response: We removed "in landfills" from the text at Appendix 4: Fate and Transport, Section 4.2 Polymeric PFAS.

Issue 212: Review the reference citing 15,000 years as a half-life for biodegradation; what is often cited is 1,200 – 1,400 years in the Russell et al. publications. [Alliance for Telomer Chemistry Stewardship]

Response: The text was changed to 1,200 – 1,700 years, as described in the abstract.

4.3 Emission Sources

4.3.2 Water

Issue 213: In the subsection "Release to aqueous media" the CAP should mention the recent announcement by EPA on PFAS-required sampling for EPA-issued NPDES permits. [TRC]

Response: The cited article says that the EPA is "recommending" to permittees to "consider" "phased-in monitoring," so we believe revisions to this section are not necessary. The guidance only applies to EPA-issued permits. EPA's announcement regarding NPDES permits was added to Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency.

Issue 214: The CAP should identify that surface water is also potentially affected, including surface water that discharges to Puget Sound. [Stuart, Salo]

Response: Surface water is already mentioned several times. An update was made to emphasize that historical AFFF releases can contribute PFAS via runoff to surface water.

Issue 215: Surface water and stormwater characterization should be pursued; the current use of injection wells for stormwater disposal could act as a conduit for PFAS entering drinking water sources. [WASWD]

Response: A sentence was added to acknowledge stormwater discharge into injection wells.

Issue 216: In the subsection "Release to aqueous media," fourth paragraph referring to domestic waste water effluents, correct the text to: "…domestic wastewater effluents released from domestic onsite wastewater systems…" [City of Vancouver]

Response: We revised the information and mentioned septic systems for additional clarification.

Issue 217: In the subsection "Release to aqueous media," eighth paragraph referring to releases of AFFF, it may be helpful to the reader to qualify what is meant by "large source" as AFFF use is very localized and is currently only used to fight high hazard Class B fires. In addition, almost all testing and training with AFFF has been discontinued in the U.S. and elsewhere. [Alliance for Telomer Chemistry and Stewardship]

Response: The section was revised to say, "has historically."

Issue 218: In the subsection "soil interactions" in the text discussing PFAS adsorption to organic carbon in soil, we suggest adding a statement that some PFAS adsorb more readily at low pH and therefore are more mobile at high pH. [TRC]

Response: Information was added to this subsection mentioning pH.

4.3.3 Solids

Issue 219: In the third paragraph, the statement "Biosolids have been identified as a significant source of PFAS emissions" does not include data or context to qualify "significant." The referenced report is also not freely available to the public. The word "significant" should be removed. [City of Vancouver]

Response: The word "significant" was removed.

4.5 Long term PFAS management

4.5.1 Removal of PFAS from water

Issue 220: Revisions were proposed for this section. [TRC]

- Text regarding ineffectiveness of conventional water treatment systems should be revised to indicate that these approaches have not been demonstrated to be effective to date, to reflect that water treatment research continues to emerge.
- "GAC" is typically the acronym for "granular activated carbon."
- Water streams may have to be pre-treated for organics and contaminants prior to PFAS removal by GAC; GAC also needs to regenerated or be disposed of.
- Consider mentioning foam fractionation technology.

Response: The statement regarding the ineffectiveness of conventional treatment systems was revised to add the words "to-date"—the CAP recognizes that research is ongoing at the end of the subsection. The term GAC was revised to refer to "granular activated carbon." The Draft CAP addressed GAC regeneration; information was added to reflect the potential for influent pre-treatment and GAC disposal at the end of its useful life, and that this adds additional ongoing cots for treatment system operation.

Responses to Issue 296 and Issue 298 also address costs of disposal of spent treatment media. Foam fractionation was mentioned as a developing treatment technology.

Issue 221: Least cost alternative(s) should be promoted in the selection of treatment methods used to meet established water (quality) standards [UTC]

Response: The CAP is not proposing any recommendations for regulations surrounding treatment of drinking water, groundwater or any specific mitigation or remediation activity. Information was added to the introduction of Section 4.5 to further emphasize this.

Appendix 4: Fate and Transport, Section 4.5.1 Removal of PFAS from drinking water, is meant only to acknowledge the range of alternatives currently available, or being developed, to remove PFAS from water. Individual water systems needing to mitigate PFAS contamination would determine appropriate actions based on site-specific conditions and least cost considerations if applicable.

Issue 222: The CAP should consider the use of pyrolysis to destroy the PFAS and derivatives being filtered out of the water stream using GAC. [Mothersbaugh]

Response: Information was added regarding EPA's PFAS Innovative Treatment Team (PITT), established in 2020 for a six-month period to assess whether existing destruction technologies could be applied to PFAS-contaminated media and waste (EPA, 2021c). The PITT published a report regarding the feasibility of pyrolysis and gasification (EPA, 2021d)

Issue 223: Carbon Treatments, Ion Exchange Treatments, and High-pressure Membranes have shown the most promise at removing PFAS from drinking water. However, these methods transfer PFAS from one media to another—the waste media is not being accepted by businesses involved in disposal. [Vega, Yost]

Response: Appendix 4: Fate and Transport, Section 4.5.1 Removal of PFAS from drinking water, and Section 4.5.3 Ultimate disposal or destruction, provide an overview of the technologies available, and in development, for removal of PFAS from drinking water, as well as the complexities surrounding disposal of spent treatment media.

Issue 224: The state should consider costs when contemplating PFAS regulation. Any requirement to treat wastewater with GAC or other methods could have much greater monetary and environmental costs than the state anticipates. [3M]

Response: The CAP is not proposing recommendations to treat wastewater. The purpose of Appendix 4: Fate and Transport, Section 4.5 Long term PFAS management, is to provide a brief overview of technologies available, or being developed, to address environmental contamination in the long term.

Recommendation 4.1. Evaluate PFAS in wastewater treatment, focuses on characterizing levels of PFAS in WWTP effluent, and if warranted, considering monitoring such levels. The title of Section 4.5.1 was revised to specify the section addresses removal of PFAS from drinking water. Information was added to the introduction of Section 4.5 to emphasize no recommendations are being provided as to any specific mitigation or remediation method.

4.5.2 Stabilization of PFAS in soils

Issue 225: Regarding sorption and stabilization of PFAS in the unsaturated soil zone using amendments, the CAP should specify that this is highly dependent on geochemical conditions, which are subject to change in situ with changing environmental conditions. [TRC]

Response: We added information to this section to identify that these techniques are dependent on geotechnical conditions, which may be variable.

4.5.3 Ultimate Disposal

Issue 226: Comments request that Washington state continue to evaluate the potential risks of PFAS incineration or even prohibit the burning of PFAS solid and hazardous wastes and pursue safer storage or disposal options. [NWRA, Form letter 3]

Response: The Spokane waste to energy facility is only permitted to handle municipal solid waste (Spokane Regional Clean Air Agency, 2013). The facility is not permitted to handle state designated dangerous or hazardous waste. As identified in Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency, PFAS are not currently regulated under the federal Clean Air Act (CAA). The state CAA also does not regulate PFAS air emissions. Ecology therefore does not have the authority to prohibit the incineration of municipal solid waste on the basis of PFAS being present in items collected as municipal waste.

EPA has identified that many uncertainties exist regarding how PFAS present in municipal solid waste behave in municipal waste combustors (MWCs) (EPA, 2020a). EPA has identified that there are limited characterizations of both potential PFAS emissions from MWC's, and of how PFAS contaminants partition between air emissions and solid residuals generated by such facilities. Emission measurement methods also need to be developed. Research and testing of PFAS destruction performance within MWC's is very limited, and is not always representative of the incineration processes of specific MWC's.

As discussed in Appendix 9: Regulations, Section 9.1.2 Washington state rules, Chapter 173-303[279] WAC, DW regulations require all solid wastes to be designated for state toxic or persistence criteria, unless the source is from households. If a waste is designated as dangerous waste, it must be handled and disposed of as required by the regulations. The CAP has identified that certain items discarded into the municipal waste stream may contain PFAS. Much of this PFAS containing material is from households and small quantity generators, and is allowed to be disposed in the municipal waste stream.

Generally speaking, solid waste that was legally disposed to a municipal solid waste landfill is not required to be re-designated under the DW regulations. Industries using PFAS in manufacturing processes are the most likely sources of wastes, which could designate as state persistent DW. Recommendation 2.3 proposes to work with such manufacturers and industries to identify opportunities to switch to safer alternatives, implement best practices, and ensure proper waste management.

As discussed in the response to Issue 81, Ecology is preparing for an EIS review of the AFFF collection and disposal program.

Issue 227: The CAP should consider EPA's recently issued interim guidance regarding methods to dispose or destroy wastes containing PFAS. The guidance indicates, and data collected in Vermont supports, that modern landfills can sequester a large proportion of PFAS entering the landfill long-term, thereby limiting exposure of the public from these compounds. [NWRA, Waste Management of Washington, Cowlitz County Public Works, Washington Refuse and Recycling Association, Waste Connections]

Response: EPA's draft interim guidance on destruction and disposal of PFAS and materials containing PFAS was added to the text at Appendix 4: Fate and Transport, Section 4.5.3 Ultimate disposal. We included EPA's guidance on which options were associated with less uncertainty—i.e., interim storage, permitted hazardous waste landfills (Resource Conservation and Recovery Act [RCRA] subtitle C), and solid waste landfills (RCRA subtitle D) that have composite liners and leachate collection treatment systems. Data collected in Vermont was incorporated at Appendix 3: Sources and Uses, Section 3.4.3 Landfilled products. Refer to Issue 184 for more information.

Issue 228: For completeness, a statement about leachate management and reference the biosolids section of the document could be included in this section of the CAP. [TRC]

Response: References to these two CAP sections were already included in several locations of this appendix.

[279] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-303&full=true

Appendix 5: Environmental Occurrence

5.0 Overview

5.0.1 Findings

Issue 229: The presence of PFAAs in marine fish, addressed in this section, should also be included in previous sections of the document, including the executive summary. [TRC]

Response: Information regarding marine fish was added at the following sections: Executive Summary, and Why are we concerned about PFAS?.

Issue 230: In the fourth paragraph of this section, replace "WWTP sources" with "WWTP effluent discharges." WWTPs are not sources of PFAS. They are "pass through" facilities. [City of Vancouver]

Response: We have revised the text in Section 5.0.1 to clarify WWTP effluent discharges.

5.1 PFAS in Washington's Environment

5.1.4 Surface Water

Issue 231: The EPA issued a municipal separate stormwater sewer system (MS4) NPDES permit to Navy Air Station Whidbey Island without taking into account the potential presence of PFAS in stormwater. [Newkirk, G.; Newkirk, B.]

Response: The EPA develops and administers MS4 permits for federal facilities, which includes the Naval Air Station on Whidbey Island. Ecology did issue a 401 certification[280] with conditions in June 2019 for the Whidbey Island Naval Air Site, which is required when a federal agency will discharge a pollutant in state waters. However, without state or federal water quality standards for PFAS, Ecology was unable to include a condition for PFAS.

The EPA issued the permit in November 2020 with specific requirement for PFAS based on feedback they received during the public comment period. For more information about PFAS and EPA's MS4 permit, please refer to the EPA website[281] for this permit. It is Ecology's understanding that the EPA made changes to the draft permit regarding PFAS based on the public comments they received. More information is available in the EPA's response to public comment document[282] and the permit fact sheet.[283]

Issue 232: Ecology didn't conduct surface water sampling for PFAS in Yakima County. [Friends of Toppenish Creek]

---

[280] https://apps.ecology.wa.gov/publications/documents/2110013.pdf
[281] https://www.epa.gov/npdes-permits/npdes-stormwater-permit-naval-air-station-whidbey-island-ms4-washington
[282] https://www.epa.gov/sites/production/files/2020-12/documents/r10-npdes-naval-air-station-whidbey-ms4-was026611-rtc-2020.pdf
[283] https://www.epa.gov/sites/production/files/2020-08/documents/r10-npdes-naval-air-station-whidbey-ms4-was026611-fact-sheet-2020.pdf

Response: We recognize that Ecology's 2008 and 2016 statewide surveys of PFAS were limited in the number of waterbodies sampled and that land-application of biosolids was not included in our study location selection criteria. Sites were selected in the 2008 and 2016 surveys to reflect varying degrees of PFAS contamination potential from stormwater, AFFF releases, WWTP effluent discharges, and atmospheric deposition.

We appreciate the information, and will consider the Lower Yakima Valley in future PFAS surveys. For more information on work being done by Ecology and our partners in the Lower Yakima Valley, please visit Ecology's Lower Yakima Valley groundwater webpage.[284]

5.1.7 Freshwater fish

Issue 233: Please clarify in the CAP whether cleanup levels for human health risks from freshwater fish ingestion will be calculated using data from whole body samples, fish livers, or filets, or a combination, taking onto consideration the portion of the fish commonly consumed. [TRC]

Response: Ecology plans to initially develop cleanup levels for groundwater and soil using criteria set out in the Model Toxics Control Act (MTCA). Additional evaluation and assessment will be necessary for determining the appropriate input parameters for surface water and sediment cleanup levels. See our responses to Issues 60 through 65 for more information on cleanup levels.

Health typically assesses contaminant concentrations present in fillet tissue when conducting a human health evaluation of fish consumption. The fillet tissue concentration is used to derive an estimate of potential exposure to humans. For more information on Health's approach to PFAS in edible fish tissue, see comment responses to Issue 273 and Issue 274.

5.1.8 Osprey

Issue 234: Consider revising Figure 34 to include sample location names on the X-axis or defining what locations the codes represent.

Response: We have revised Figure 35 in this CAP (Section 5.1.8) to include a note identifying what the sample location codes represent.

5.1.9 Marine Biota

Issue 235: Impacts of PFAS to Puget Sound. [Stuart, Salo]

Comments were submitted asking questions about the releases of PFAS to Puget Sound and their potential effects in the marine environment:

- Presence of PFAS in surface water.
- Sources of PFAS contributing to Puget Sound.
- Behavior of PFAS in the aquatic environment.
- Toxicity of PFAS to environmental biota.

[284] https://ecology.wa.gov/Water-Shorelines/Water-quality/Groundwater/Protecting-aquifers/Lower-Yakima-Valley-groundwater

- Impacts to Puget Sound marine biota.
- Bioaccumulation effects.
- Using Navy records to answer questions in the comment letter submission.

Response: We addressed the issues raised in the comments in the CAP as follows:

- Presence of PFAS in surface water: See Appendix 5: Environmental Occurrence, Section 5.1.4 Surface Water
- Sources of PFAS contributing to Puget Sound: See Appendix 4: Fate and Transport, Section 4.3 Emission Sources, as well as Appendix 3: Sources and Uses. The same types of sources affect marine environments.
- Behavior of PFAS in the aquatic environment: See Appendix 4: Fate and Transport, Section 4.3.2 Water.
- Toxicity of PFAS to environmental biota: See Appendix 6: Ecological Toxicology, Section 6.3 Toxicokinetics and Section 6.4 Toxicological Effects.
- Impacts to Puget Sound marine biota: See Appendix 5: Environmental Occurrence, Section 5.1.9 Marine biota.
- Bioaccumulation effects: See Appendix 6: Ecological Toxicology, Section 6.2 Bioaccumulation.
- With respect to using DON records to answer questions in the submission, that effort is beyond the scope of the CAP, which serves as a planning document.

Issue 236: Based on lack of bioaccumulation of PFAA in mussels and overall lower PFAA concentration in marine fill tissue, will PFAS cleanup levels in marine water bodies be greater than those in freshwater bodies based on this significant difference? [TRC]

Response: Ecology has not determined variables to be considered when establishing freshwater versus marine cleanup levels.

5.3 Data Gaps and Recommendations

5.3.1 Data gaps

Issue 237: The CAP should list likely and potential sources for PFAA contamination of fresh water lakes, such as Lake Washington. [TRC]

Response: Appendix 3: Sources and Uses, provides a detailed description of likely and potential sources of PFAS to the environment. In Section 5.3.1, we list sources suggested by previous research specific to elevated PFAS concentrations in urban lakes. These include automobile and railway transportation (Kim & Kannan, 2007; Zushi & Masunaga, 2009) and the transfer of indoor air PFAS loads to the outdoor environment (Gewurtz et al., 2009).

5.4 Washington environmental concentrations data

Issue 238: Tables 52 and 53 should include notes as to whether PFOA wasn't tested, given that PFOA is included in SBOH proposed State Action Levels. [City of Redmond]

Response: We reordered these tables (Tables 46 through 56 in this CAP) to show PFOA testing results together.

Issue 239: The PFAS CAP team should coordinate with the Toxics in Fish Vital Sign project to evaluate PFAS in marine biota, especially salmon and their predators, giving consideration to using culled pinnipeds as a proxy for orcas. [Whidbey Island Association of Water Systems]

Response: Thank you for your comment. Available PFAS data for marine biota was summarized in Section 5.1.9. We are not aware of current plans to sample pinnipeds for PFAS concentrations. Ecology and Washington State Department of Fish and Wildlife (WDFW) staff will continue to coordinate with the Toxics in Fish Vital Sign.

Appendix 6: Ecological Toxicology

6.1 PFAS chain length and representative PFAS

6.1.1 Short versus long-chain PFAS

Issue 240: The statement in the third paragraph beginning "Although short-chain PFAS are not bioaccumulative…" should be corrected to reflect that short-chain PFAS are more bioaccumulative in plants than long-chain PFAS especially the perfluoroalkyl carboxylic acids (PFCAs). [TRC]

Response: Our statement, "Although short-chain PFAS are not bioaccumulative, according to regulatory criteria (Conder et al., 2008)," reflects text in Conder et al. (2008) who state, "it is clear that PFCAs with seven fluorinated carbons or less (including PFO) are not bioaccumulative according to regulatory criteria." Discussion of PFAS bioaccumulation in plants occurs in Section 6.2, Bioaccumulation, where we highlight bioaccumulation of short-chain PFAS in leaves, fruits, and roots, with levels correlating with water content of the plant (Blaine et al., 2013; Scher et al., 2018).

Issue 241: Tables 60 and 61 should be updated to reflect more current literature sources, including the most recent ITRC April 2020 Table 5-1, which notes several studies with bioaccumulation factors (BAF) up to 214 for PFHpA. [TRC]

Response: Comment noted, although Ecology will not update Tables 60 and 61 (which present data from Conder et al., 2008). Conder et al. (2008) state that bioaccumulation potential is considered likely on a regulatory basis for compounds with BAF/Bioconcentration factor (BCF) greater than 1,000 – 5,000 L/kg (well above BAF of 214 L/kg, identified by the commenter).

This regulatory criterion has been added to Section 6.1.1. Furthermore, Ecology points out that the current and rapid proliferation of ecotoxicology studies on PFAS (including bioaccumulation) diminishes the usefulness of continual updating. Rather, our appendix on PFAS ecotoxicology represents a snapshot in time. More importantly, this type of update would not influence Ecology's recommendation (Section 6.5.2).

6.4 Toxicological effects

6.4.2 Terrestrial biota

Issue 242: Table 65 should be clarified with respect to the following: lack of entries for PFHxS, PFBS, or perfluorooctane sulfonamide (PFOSA) even though studies for each of these PFSAs have been recently summarized in Strategic Environmental Research and Development Program (SERDP) Project ER18-1614 (Conder et al., 2020) and SERDP Project ER18-1653 (Divine et al., 2020); and inconsistency in no observed adverse effects level (NOAEL) and lowest observed adverse effects level (LOAEL) reporting units when these are typically reported as a dose in milligram (mg)/kilogram(kg)-day. [TRC]

Response: Comment noted, although Ecology will not update Table 65 (which present data from a review by Stahl et al., 2011). Data presented in Stahl et al. (2011) represent a sample of PFAS literature on reproductive and developmental effects in surrogate animal species. It was not Ecology's objective to present a comprehensive review of all PFAS chemicals with effects data in birds and mammals. Rather, our intent was to present a subset of representative studies. We revised the information to clarify this.

Importantly, this limitation does not influence Ecology's recommendation (Section 6.5.2). However, the SERDP report by Divine et al. (2020), referenced by the commenter, has been added to Section 6.5.1 to acknowledge this important review (along with another recent SERDP report by Conder et al., 2020). Finally, although NOAELs and LOAELs are often expressed as a dose (mg/kg body weight/day (BW/d)), these metrics can also be expressed as a concentration (mg/kg), as in EPA's ecological soil screening levels (EcoSSL) for soil.

6.5 Data gaps and recommendations

6.5.2 Recommendations

Issue 243: Ecology should consider recent risk-based screening levels for numerous PFAS compounds in different environmental media as reported by SERDP Project ER18-1653 (Divine et al., 2020) when developing its cleanup levels for PFAS as part of Recommendation 2.1. [TRC]

Response: Ecology is currently preparing soil, surface water, and sediment cleanup levels for several PFAS chemicals for ecological receptors. Although Ecology will follow prescribed methods to derive these protective concentrations (e.g., Ecology's wildlife exposure model), the suggested SERDP report by Divine et al. (2020) will be helpful. As a result, this reference has been added to Section 6.5.1, Data gaps.

Appendix 7: Health

Issue 244: Regulating carcinogens at a risk level of one in a million is not rational given the occurrence of natural carcinogens in our diet. [Myrick]

Response: Only a few PFAS have been tested for their potential carcinogenicity. Most PFAS risk evaluations focus on non-cancer effects such as organ toxicity and reproductive or developmental effects.

Issue 245: Commenters raised concern that potential immune suppression by PFAS would make people more vulnerable to COVID-19 or make coronavirus vaccines less effective [Form letter 3, Vega, Olympic Environmental Council, Abraham, Public Health - Seattle & King County]

Response: We agree that the pandemic highlights concern about PFAS and their potential to alter immune responses in people. One study reported that among a Danish population with confirmed COVID-19 infection, detectable levels of PFBA in blood plasma was associated with more severe COVID-19 disease (Grandjean et al., 2020). No other PFAS measured in this study showed a similar association. We consider this report preliminary. The U.S. Centers for Disease Control and Prevention (CDC) is currently investigating whether there is an association between levels of PFAS in the blood and the risk of coronavirus infection in first responders.

7.0 Overview

7.0.1. Findings

Issue 246: The CAP should reflect the updated 2020 PFBS state action level of 860 parts per trillion (ppt). [DON]

Response: Thank you. The CAP will list the most current recommended values.

Issue 247: The CAP should consider that human exposure varies by locale. [Alliance for Telomer Chemistry Stewardship]

Response: Human exposure could differ by locale depending on the local industries and localized environmental sources of PFAS (such as release sites and contaminated sites). In a study of Red Cross Blood Donors from six regional centers, there was not great variation between regions—except for higher PFAA levels in residents from an area of North Carolina with a history of textile manufacturing (Olsen et al., 2017). We added "local environmental contamination or industrial sources" as a source of human exposure.

7.1. Human health hazard assessment

Issue 248: An industry commenter asserts that scientific evidence does not show that PFAS – either individually or as a group – cause adverse health effects in humans. They also cite Australian government expert panel that concluded that the evidence does not support any specific health or disease screening or other health interventions. [3M]

Response: Appendix 7: Health does not claim that a causal relationship has been demonstrated between PFAS exposure in humans and adverse health conditions and disease. Section 7.1 Human health hazard assessment and Supplement 1 Summary of Primary Health Concerns by

PFAA, describe that certain PFAS have demonstrated toxicity in laboratory animals including in rats, mice, and monkeys. In addition, various PFAS exposures have been associated with an increased risk of some adverse effects for human health.

Our statements are in line with:

- Current conclusions by EPA[285]: "There is evidence that exposure to PFAS can lead to adverse health outcomes in humans."
- Agency for Toxic Substances and Disease Registry (ATSDR)[286]: "Research involving humans suggests that high levels of certain PFAS may lead to the following: Increased cholesterol levels, decreased vaccine response in children, changes in liver enzymes, increased risk of high blood pressure or pre-eclampsia in pregnant women, small decreases in infant birth weights, and increased risk of kidney or testicular cancer."
- Others, including the American Association for the Advancement of Science (AAAS) (AAAS, 2021).

Inherent limitations of epidemiological studies make it challenging to clear the high evidentiary bar of demonstrated causality—especially when we still have a limited understanding of underlying biological mechanisms of PFAS in both laboratory animals and in humans. This does not mean that we should delay action when the weight-of-evidence points to a human health hazard.

Several authoritative bodies have evaluated the evidence streams from toxicological and epidemiological studies and concluded that the available evidence supports a hazard to humans:

- The C8 Science Panel concluded that six adverse health conditions/diseases (pregnancy-induced hypertension and preeclampsia, kidney cancer, testicular cancer, thyroid disease, ulcerative colitis, and high cholesterol) were "more probably than not based on the weight of the available scientific evidence" related to PFOA exposure.
- The National Toxicology Program classified PFOS and PFOA as presumed immune hazards to humans. In addition, many state and federal governments (including the Australian Government) have concluded that there is sufficient toxicological and epidemiological data to recommend protective limits on human exposure to a number of PFAS (See Table 73).
- The C8 Medical Panel suggested certain health screenings[287] for the C8 study population, including blood tests for cholesterol, uric acid, thyroid hormones, and liver function.

[285] https://www.epa.gov/pfas/basic-information-pfas
[286] https://www.atsdr.cdc.gov/pfas/health-effects/index.html
[287] http://www.c-8medicalmonitoringprogram.com/

- ATSDR developed interim clinical guidance, and conducted outreach to health care providers who serve patients with environmental and occupational exposure to PFAS. This guidance recommends standard medical screening for asymptomatic patients and established standards of care for symptomatic patients. This guidance is currently being reviewed by the National Academies of Science.

7.1.2 Primary health endpoints of concern

Issue 249: In Section 7.1.2 PFHxS is listed twice in the first sentence. [TRC]

Response: The extra listing was deleted.

7.1.1 Epidemiology

Issue 250: The description of C8 Science Panel findings should be accompanied by a review article, published by the C8 Science Panel members and their collaborators (Steenland et al., 2020). Excerpts from this review indicate that a number of C8 Panel findings are no longer supported or less supported by the evidence. [3M]

Response: The C8 study was a landmark scientific investigation into health effects associated with PFOA exposure in a large exposed community. We have added the following short description of the 2020 study to the C8 study summary.

"The C8 Science Panel and collaborators published updated scientific evidence in 2020. Compared to their 2012 findings, they acknowledged strengthening evidence for kidney cancer, impaired immune function (reduced response to vaccines), and altered liver enzymes. The authors acknowledged a modest weakening of evidence for thyroid disease and ulcerative colitis."

We noted that the review by Steenland et al. (2020) "did not revisit the probable link decisions but re-states them." The authors summarized their conclusions differently than the commenter: "Evidence supports an association between PFOA and kidney and testicular cancer… There is consistent evidence of a positive association between PFOA and cholesterol, but no evidence of an association with heart disease. There is evidence for an association with ulcerative colitis, but not for other auto-immune diseases. There is good evidence that PFOA is associated with immune response, but uneven evidence for an association with infectious disease. The evidence for an association between PFOA and thyroid and kidney disease is suggestive but uneven. There is evidence of an association with liver enzymes, but not with liver disease. Suggested reductions in birthweight may be due to reverse causality and/or confounding."

7.1.2 Primary health endpoints of concern

Issue 251: The scientific assessments of PFAS conducted by ATSDR, EPA, and a number of U.S. states included in the CAP are flawed and don't represent the best available scientific evidence on these compounds. Additional information was provided to correct or supplement the assessments conducted by others. [3M]

Response: We believe we have presented a balanced but brief overview of the literature on PFAS and specific outcomes, including some of the uncertainties and limitations of this evidence. Although we did not cite every study or every point in the comment, we are familiar with these studies and do not think the additional detail would change our overall summary.

It is beyond the scope of the PFAS CAP to respond to technical comments submitted to other federal and state governments regarding their scientific evaluations of PFAS. These agencies have responded to these comments before finalizing their assessments. ATSDR recently finalized their 2018 PFAS Assessment. EPA has finalized assessments of PFOA, PFOS, and PFBS. The European Food Safety Authority (EFSA) had adopted their assessment of PFOS, PFOA, PFHxS, and perfluorononanoic acid (PFNA). The CAP health summary follows our normal practice of relying on better resourced science teams at federal and state agencies to help us summarize the hazards of PFAS.

Issue 252: A commenter agreed with our discussion of uncertainties of extrapolating from animal research when assessing PFAS hazard to humans. [Alliance for Telomer Chemistry Stewardship]

Response: Thank you for your comment.

7.2 PFAS Exposure in people

7.2.1 Trends and demographics of PFAA exposure

Issue 253: A paper by Waterfield et al. (2020) should be added to the Reproductive toxicity summary. [Public Health – Seattle & King County]

Response: We described the evidence for reduced birth weight under developmental toxicity rather than reproductive toxicity. Rather than review every individual study, we chose to summarize the literature on this outcome by highlighting meta-analyses. Waterfield et al. (2020) supports evidence already discussed regarding slightly lower birth weights.

Issue 254: The reference to "thousands of individual PFAS" is incorrect; the number of PFAS in commerce is likely to be in the hundreds. A typographical error was reported in PFOA half-life. [Alliance for Telomer Chemistry Stewardship]

Response: The reference to thousands of individual PFAS includes commercial PFAS, and the PFAS that form from them in the environment. This includes intermediate and final degradation products (see Appendix 1: Chemistry).

We corrected the typographical error in the PFOA half-life. It should have read 2.3 – 3.9 years.

Issue 255: Impacts to indigenous populations should be considered in the CAP. The CAP should include guidance appropriate to tribes and rural small communities on whether PFAS

monitoring of their drinking water systems or private wells is warranted. Washington should develop and implement risk communication strategies specifically for informing tribal communities of potential health risks from all types of PFAS contamination or PFAS-containing media in household goods and natural resources. [National Tribal Water Council]

Response: Thank you for your input. Health will reach out to tribes through our government to government consultation process before issuing any fish consumption advice.

The CAP is not issuing recommendations about who should test their drinking water for PFAS. Most Group A water systems would be required to test for PFAS under a rule being considered by the State Board of Health. If that occurs, and PFAS are detected in a water supply, Health will work with nearby tribes and local government to notify others who may have impacted drinking water supplies. This would include smaller systems and private wells.

Health has invited Tribes (through EPA Region 10) to be included in subsidized PFAS water testing in advance of the rule adoption. As we receive testing data associated with PFAS contamination in our state, we will be working with the tribes to inform them of potential risks and, upon their request, provide further assistance and guidance.

Issue 256: Information on air, water, food and land concentrations of PFAS and other chemicals in various locales in the state should be provided. The main sources of PFAS should be identified. [Bein]

Response: We have summarized the data we have on environmental occurrence of PFAS in Appendix 5: Environmental Occurrence and the data on PFAS in drinking water in Figure 46 in this CAP. PFAS may be encountered in food, water, land, or air (See Section 7.3 for more details). We have summarized what we know of the sources of PFAS in Appendix 3: Sources and Uses.

Issue 257: Various grammatical errors and typos were identified in section 7.2.1 through 7.2.2. [TRC]

- At Section 7.2.1, the date of domestic production of PFAS (2000) should be corrected.
- At Section 7.2.1, there is a duplicate reference to Figure 40.
- The first sentence of Section 7.2.1 should include perfluorodecanoic acid (PFDA) in the list of the top PFAA measured in human serum.
- An extra parenthesis and a typographical error were identified in Section 7.2.2.

Response: Thank you for these edits. Revisions were made as noted by the comments.

Issue 258: The state should consider declining serum levels of phased out PFAS before determining whether and how to move forward. Washington must present a full and accurate picture of the state of the science, use, and exposure potential for each PFAS it considers regulating. [3M]

Response: The decline in U.S. serum levels of four PFAS are shown following manufacturing phase-outs in Figure 41 in this CAP. We agree that phase-outs were effective in reducing non-specific exposures to these PFAS in the general U.S. population.

Unfortunately, historic use of these compounds persists in the Washington environment and appears to be the source of drinking water contamination in at least five areas of our state. At one site in Spokane County, residents of the City of Airway Heights who participated in an Exposure Assessment study[288] continue to show much higher serum levels of PFOS and PFHxS compared to the general population, even two years after the drinking water exposure ceased. Legacy contamination persists, and will continue to require state attention long after PFAS are phased out from use.

7.2.2 Populations with elevated PFAS exposure

Issue 259: Educational outreach about PFAS health risks and PFAS serum testing for forest and rangeland firefighters are recommended. [Friends of Toppenish Creek]

Response: Thank you for your suggestion. It is our understanding that PFAS firefighting foams are not typically employed to fight forest and rangeland fires. Rather, PFAS are used in specialty Class B foams, used to extinguish flammable liquids like gasoline. PFAS may be in firefighter turnout gear, where it serves a protective function. Our Legislature passed a law in 2018 (Chapter 70A.400[289] RCW) that requires vendors of firefighting gear to tell purchasers about the presence of PFAS in their equipment and any function it serves.

Issue 260: PFAS use in apparel is a source of occupational exposure for firefighters, apparel workers, military personnel, and healthcare workers. The comment identifies studies considering occupational exposures to PFAS. [Clean Production Action, Toxic Free Future]

Response: Thank you for this information. Some of this information is already discussed in the Draft CAP under 7.2.2. Occupational exposures, Manufacturing workers and those working with PFAS products. We incorporated new references.

Issue 261: All three communities (Pease Tradeport, NH and Airway Heights, WA) should be shown in Figure 44 and discussed in the text. [TRC]

Response: This inconsistency was corrected.

7.3. Sources and pathways for human exposure

Issue 262: There is an extra "at" in the first bullet at Section 7.3. [TRC]

Response: The text was corrected.

[288] https://www.atsdr.cdc.gov/pfas/communities/factsheet/Spokane-County-Community-Level-Results-Factsheet.html
[289] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.400&full=true

7.3.1 Drinking Water

Issue 263: The CAP should include guidance appropriate to tribes and rural small communities on whether PFAS monitoring of their drinking water systems or private wells is warranted. [NWTC]

Response: If we detect PFAS contamination of drinking water supplies, we will inform and provide guidance to nearby water systems, local governments, and any tribal nations.

7.3.3 Consumer Products

Issue 264: PFAS-treated apparel is a source of exposure for adults and children. [Clean Production Action, Toxic Free Future]

The comment provides information regarding exposure of babies and children to PFAS as a result of mouthing PFAS-treated apparel, or eating food that has come into contact with bibs that may contain PFAS. Children can also be exposed when coming into contact with apparel to which aftermarket treatments have been applied, or by handling bottles that contain the treatment solutions.

Response: We added a short section on apparel to Appendix 7: Health, Section 7.3.3, Apparel, describing consumer products and their potential for exposure. This is also covered in Appendix 3: Sources and uses, Section 3.3 Consumer products.

7.4 Known areas of PFAS contamination in drinking water

Issue 265: Several commenters were confused by Figure 45 and the narrative describing it. Changes regarding Naval facilities were requested to the figure. [City of Vancouver, DON]

Response: This map represents what is known currently from several limited sampling efforts. We agree that it does not present a picture of true PFAS prevalence in Washington state drinking water. Comprehensive water testing will be needed to understand the scope of contamination in Washington. The figure (Figure 46 in this CAP) and the narrative describing the figure were revised for clarity and accuracy.

Issue 266: Information about PFAS sampling at the Yakima Firing Center was not included in the CAP. [Friends of Toppenish Creek]

Response: This facility is operated by Joint Base Lewis McChord. The Draft CAP mentioned that drinking water at the Yakima Training Center was tested for PFAS in 2016, and there were no detections (see Appendix 7: Health, Section 7.4.4 Joint Base Lewis-McChord). There is new information from Joint Base Lewis McChord on their site investigation at the Yakima Training Center.

PFAS were detected in perched groundwater near fire training areas at this site. More sampling is planned to determine whether it is in drinking water off base. We added this information to the map, and made it clear that PFAS has so far only been detected in groundwater monitoring wells, not drinking water wells.

7.4.1 City of Issaquah, 2015 – 2016

Issue 267: The CAP should identify the Lower Issaquah Valley aquifer and recognize the interests of Sammamish Plateau Water and Sewer District. [Sammamish Plateau Water and Sewer District, City of Redmond].

The District's test results do not exceed EPA's lifetime health advisory limit, but they do exceed Health's proposed SAL. Table 69 should incorporate information about Sammamish Plateau Water and Sewer District UCMR3 data follow-up and contamination in District wells located in the Lower Issaquah Valley Aquifer.

Response: Thank you for this updated information. We have clarified the description of PFAS contamination in the Lower Issaquah Valley Aquifer in Section 7.4 and added Sammamish data to Table 69.

7.4.2 NAS Whidbey Island, 2016 – 2019

Issue 268: Corrections and updates were provided to text on pages 324 and 326. [DON]

Response: Thank you for these corrections, updates, and clarifications. They have been made in the CAP.

7.4.10 Washington state testing site summary

Issue 269: A footnote in Table 69 has repeated text. [TRC]

Response: The repeated text was removed.

Issue 270: Corrections were proposed for Table 69. [DON]

Response: These updates and corrections were made.

7.5 Public health advice

7.5.1 EPA health advice for PFOS and PFOA in drinking water

Issue 271: The CAP should note that the clearance of some PFAS in humans may be faster at higher exposures because a receptor-mediated re-absorption in the kidney may be saturable at high levels of exposure. A proper estimate of human clearance is necessary to correctly extrapolate Human Equivalent Dose (HED) and resulting toxicity values for humans from animal studies. [NCASI]

Response: Thank you for your comment. It is possible that faster elimination of certain PFAS occur following high occupational exposures. There are many other factors that appear to influence elimination rates including (ATSDR, 2021):

- Length of follow-up monitoring.
- Sex of studied population.
- The isomers profile of PFAS studied.

Elimination rates derived in studies of populations with low exposures may also be biased (overestimates of elimination half-life) by ongoing background exposures to PFAS (Bartell, 2012; Russell et al., 2015). Where possible, we have used clearance values derived from studies

of similar populations with similar environmental exposures. This issue is discussed in detail in ATSDR's 2021 PFAS Tox Profile.[290]

7.5.2 Washington Department of Health advice for PFAAs in drinking water

Issue 272: The CAP should elaborate on how Health selected the five PFAS for SAL development. [TRC]

Response: Thank you for this suggestion. We have added the following sentence to that section: "Health also reviewed the evidence available to support health-based values for the most commonly reported PFAS in state drinking water supplies."

7.5.4 Washington state assessment and advice for PFAS contaminants in fish

Issue 273: Fish advisories have not yet been developed. [Cellarius]

Response: Health is collecting additional data in 2021 to help us finalize our health-based screening value and to investigate PFAS levels in alternate sources of dietary fish. Our advice to consumers should not discourage people from eating fish in general, and typically directs consumers to wiser choices of fish.

Issue 274: Concern was expressed about higher exposure to PFAS in indigenous populations from their higher consumption of wild foods, shellfish, and finfish. Request for further sampling of traditionally harvested foods. [National Tribal Water Council, Port Gamble S'Klallam Tribe]

Response: Washington State Department of Fish and Wildlife reported on reconnaissance PFAS testing of Puget Sound in fish and shellfish in Puget Sound (see Appendix 5: Environmental Occurrence, Section 5.1.9 Marine Biota). We will consider your recommendation for further sampling, including in traditionally harvested areas and seafood species of particular concern for Tribal communities. Health fish advisories do consider the higher rates of seafood consumption by Tribal communities.

7.5.5 International health guidance values

Issue 275: PFOS is erroneously listed twice in Section 7.5.6 (sic). [TRC]

Response: Thank you. This has been corrected.

[290] https://www.atsdr.cdc.gov/ToxProfiles/tp200-c3.pdf

7.6 Data gaps and recommendations

7.6.1 Data gaps

Issue 276: Specific data gaps for the PFAS should be called out in the following sentence, especially for PFHxA. "Further toxicity testing on other PFAS that occur in drinking water and human serum (especially perfluoroheptanoic acid [PFHpA], perfluorohexanoic acid [PFHxA], perfluorobutanoic acid [PFBA], 6:2 fluorotelomer sulfonate [6:2 FTS], and PFDA)." [Alliance for Telomer Chemistry Stewardship]

Response: PFHxA has a considerable toxicology data set, but has data gaps in immune and thyroid endpoints. Also, few human observational studies have included PFHxA in investigations of potential health effects in people. Although PFHxA is not frequently detected in serum of the U.S. population in CDC surveys, it has been measured in other human tissues like lung tissue (Perez et al., 2013) and in breastmilk (Lee et al., 2018; Zheng et al., 2021) Accumulation of PFHxA in humans should be further investigated.

We did not have the space for this level of detail for each compound. We shortened this data gap to be more general: "Further toxicity testing on other PFAS that are detected in drinking water and in human biomonitoring."

Supplement 1: Summary of Primary Health Concerns by PFAA

Issue 277: A typographical error was identified in Supplement 1, PFHxA summary. [Alliance for Telomer Chemistry Stewardhip]

Response: We corrected one typographical error and added Anderson et al. (2019) to the summary of PFHxA in Supplement 1. The health-based value for chronic oral intake developed by the Michigan Science Advisory Workgroup (MI SAW) is correctly written as 83,000 nanogram per kilogram per day (ng/kg-day). The drinking water limit derived from this acceptable oral intake was 400,000 ppt, and is the basis of Michigan's MCL for this compound.

Appendix 8: Biosolids

Issue 278: The CAP should address commercial products containing sewage-laden biosolids marketed for use in residential and commercial gardening and landscaping applications. This type of use exposes families and pets. Biosolids used in farms, forests and to amend other soils expose grazing wildlife through absorption into edible crops. [Olympic Environmental Council]

Response: It is inaccurate to state that composted material in Washington is "sewage-laden" or that "sewage wastes" are applied to farm, forest, and other soils. Biosolids are not "sewage laden." Appendix 8: Biosolids clearly explains how biosolids, produced under controlled municipal wastewater treatment processes, are regulated at the state and federal level to permit safe agronomic application. There is no evidence in the scientific literature that land application rates in Washington have resulted in absorption into edible plant parts and uptake by grazing animals.

8.2 Federal and state regulations

Issue 279: In the second paragraph, the CAP should note that sewage sludge can be disposed via incineration, in addition to landfill. [City of Vancouver]

Response: Incineration of biosolids is energy intensive because biosolids are mostly water. Although allowable, only a small fraction of state biosolids can be incinerated due to facility limitations. The ash from incinerators is disposed of in a landfill. Appendix 8: Biosolids, Section 8.2 Federal and state regulations cites 2017 data indicating that 85 – 90% of biosolids generated in Washington are land applied, the remainder going to landfill.

8.3 Biosolids risk assessment: Rule development, national surveys, and National Research Council

Issue 280: The CAP should revisit its statement "that the increasing body of evidence demonstrates that the majority of compounds studied do not place human health at risk when biosolids are land applied on farmland (Clarke & Smith, 2011). [Friends of Toppenish Creek]

The paper Abstract states: "In particular, a number of 'emerging' organic contaminants (PFOS, PFOA, and polychlorinated alkane [PCA]) were identified for priority attention that are environmentally persistent and potentially toxic with unique chemical properties, or are present in large concentrations in sludge, that make it theoretically possible for them to enter human and ecological foodchains from biosolids-amended soil."

Response: The Clarke/Smith paper also states that the study cautions "continued vigilance in assessing 'emerging' organic contaminants in sludge is necessary to support and ensure the long-term sustainability and security of the beneficial agricultural route for biosolids management."

The purpose of this Chemical Action Plan is to do just that. We have proposed collecting data on biosolids and field sites to make a real-world assessment of PFAS in our biosolids along with land application effects on soils in Washington. The point being made here is that claims about emerging contaminants have arisen numerous times before, and it's important to take an objective view. Risk is based on toxicity, concentration, and pathways of exposure, not the mere presence of a contaminant.

8.4 PFAS analysis methods for biosolids

Issue 281: The statement "This method uses a chemical oxidation pretreatment" should be revised to include "in order to drive precursors to their terminal end points and provide an estimate of the total PFAS mass present." [TRC]

Response: The **objective** of the oxidative pretreatment is to drive all the precursors to their terminal endpoints. Our reading of the literature indicates that oxidative treatments vary and may have differing effectiveness in oxidizing all the precursors.

8.5 PFAS concentration and trends in biosolids

Issue 282: The CAP should present data from testing of biosolids from the Metropolitan King County, Renton facility included in the "National inventory of perfluoroalkyl substances in archived U.S. biosolids from the 2001 EPA National Sewage Sludge Survey" (Venkatesan & Halden, 2013), referenced in this section. The state could make the military pay for testing of sewage residuals at military bases such as Whidbey Island where the concerned citizen group in Coupeville reports that wastewater and biosolids are applied near Penn Cove oyster beds. [Cellarius]

Response: Regarding samples collected at the Wyandotte plant in Renton, it actually appears to be a WWTP in Michigan. The treatment plant in Wyandotte is called the Downriver Wastewater Treatment Facility. King County Natural Resource Division was contacted about this topic, and they have no PFAS data on King County biosolids.

While states and federal agencies can cooperatively work on obtaining data, the state of Washington cannot dictate that the federal government pay for analyses.

8.6 Literature review of biosolids land application effects

Issue 283: Provide the source for the data estimating Washington application of PFAS to cropland at 6.95 Megagram per hectare (Mg/ha). [Friends of Toppenish Creek]

Response: As stated in the text, the 6.95 Mg/ha is the mean rate of biosolids application in Washington state, not the rate of PFAS application via biosolids. The CAP identifies that this number was calculated based on "809 regulatory approvals for land application of biosolids for Alfalfa or grass hay, barley, canola, corn, hops, sunflowers, triticale, and wheat over the years 2010 – 2017, for which data are available."

This average value is actually higher than what we typically approve, because there are a few lagoon cleanouts included. These lagoon biosolids had a significant amount of sand and silt (essentially inert material) with very low nutrient content. As such, these biosolids were applied at rates significantly higher than average, skewing the overall average application rate.

8.7 Factors influencing risk assessment of PFAS in Washington biosolids

8.7.1 PFAS Concentration data

Issue 284: At the end of the third paragraph, correct the typographical error referring to the "Northeast Biosolids Association". [City of Vancouver]

Response: Ted Beecher coordinates research for The Northeast Biosolids and Residuals Association (NEBRA). The typographical error was corrected.

8.7.2 Modeling data

Issue 285: A review of models that could potentially be chosen to derive criteria for PFAS in land applied residuals has been prepared. It considers the strengths and weakness of these models relevant to the unique properties of PFAS in the environment and discusses the impact of decision making for input selection on the functionality of selected models. This review can be cited to in Section 8.7.2 as well as in the recommendations Section 8.9.2. [TRC, NCASI]

Response: The first steps to be taken are to fill in the data gaps as described in 8.9.1. This data is important in providing inputs to any selected model used to estimate fate and transport.

8.9 Data gaps and recommendations

8.9.2 Recommendations

Issue 286: The CAP should consider a moratorium on application of biosolids to farmland until more research is conclusive. Biosolid purveyors should inform farmers who receive biosolids of the risks for PFAS accumulation in their soils. [Friends of Toppenish Creek]

Response: We disagree that all biosolids land application activities should be halted until such time that research is 'conclusive.' We refer the commenter to Section 8.9.2 Recommendations. An objective investigation evaluating Washington's biosolids management should be made to obtain data upon which to make decisions regarding biosolids practices in Washington.

Issue 287: The CAP does not recommend a change to current biosolids regulation or management citing information gaps in the risks that PFAS in biosolids pose to human health and the environment. Applying biosolids at an agronomic rate as suggested in the CAP may limit the exposure of people to PFAS but it does not prevent it. [RE Sources]

Response: Given the fact that we know PFAS is used in a variety of consumer products to which people are exposed on a regular basis (carpeting and upholstery for example), and that even house dust contains measurable amounts of these chemicals, we do not agree that the statement "even small exposures can have dire health consequences" can be substantiated at this time.

The ubiquity of PFAS in breastmilk worldwide indicate that most of us are exposed to PFAS in low concentrations from a variety of media. These exposures have been going on for decades since these chemicals were initially manufactured in the 1940's. In order to accurately assess risk from Washington's program for managing biosolids, we need to evaluate biosolids produced in the state along with actual land application site evaluations.

As noted in the CAP, studies involving very high rates of application or spiked soil studies can produce results not seen when evaluating actual application rates and concentrations. It is important to reiterate that risk is based on toxicity, concentration, and pathways of exposure. There must be pathways of exposure for there to be risk to human health. There is no data that documents the concentrations of PFAS in Washington biosolids along with actual application rates that have resulted in the uptake of PFAS into edible plant parts.

Until we have such data, statements to the contrary are premature. This is not to suggest there is no uptake, but that we currently have no data to conclude one way or another. One of the purposes of the CAP is to set a path forward in obtaining accurate and representative data upon which to base management decisions.

Issue 288: We would like to see more testing at wastewater treatment plants to assess the amount of PFAS in the influent and effluent so that we have an idea of how much PFAS is in the biosolids. New permits should not be issued to biosolid facilities until there is empirical evidence that biosolids are not a source of PFAS or other toxic contamination. [RE Sources]

Response: Testing influent and effluent can be part of the picture, but appropriate sampling and analysis of biosolids using validated methods is the key to determining actual PFAS concentrations in biosolids. We can use data from influent and effluent to help inform mass balance calculations, but direct sampling and analysis of biosolids is needed to provide the specific data necessary to assess actual amounts of PFAS applied to the land. Such data is also what we need to use models that are accurately predictive of fate and transport.

The General Permit for Biosolids Management is due to be renewed in 2021. There will be a public comment period of 30 days when Ecology will be accepting input on the draft General Permit. There will be outreach to advertise the comment period.

Appendix 9: Regulations

9.1 Washington state laws and regulations

Issue 289: At Table 80, for laws and regulations where both Ecology and Health are identified, the CAP should clarify which agency has primacy in the event of conflicting requirements. [TRC]

Response: The listings of responsible agencies in Table 80 have been clarified to identify that Ecology is the lead agency implementing the law or regulation, and Health is consulted. The more detailed law and regulation descriptions in Sections 9.1.1 and 9.1.2 of the CAP have also been edited to delineate the responsibility of each agency. For the most part, Ecology is the department that implements the laws, and consults with Health on specific issues identified in the laws or regulations. In practice, Ecology and Health work cooperatively to conduct activities under the laws and regulations, such as the preparation of this CAP.

9.1.2 Washington state rules

Issue 290: Ecology's Publication 97-407 should be updated with references to EPA and Ecology methods under development for analyzing PFAS compounds in different media. The CAP should identify resources needed for such an update as well as to train local health jurisdiction staff on testing methods. [Public Health - Seattle & King County]

Response: The CAP cites Chapter 173-303[291] WAC for designating PFAS wastes under the 100 ppm thresholds for HOCs. Ecology Chemical Test Methods for Designating Dangerous Waste (Publication 97-407), WAC 173-303-090[292] and 173-303-100[293], addresses Test Methods for Determining Halogenated Organic Compounds, and PFAS as HOCs are included in the test methods for determining and designating persistent compounds in waste.

Ecology will explore ways to secure the resources necessary to train local health jurisdiction staff on testing methods.

9.2 Federal

9.2.1 Environmental Protection Agency

Issue 291: How would the CAP adapt to a federal designation of the family of PFAS as "hazardous substances" rather than the five PFAS identified for proposed State Action Levels and would this require expanded monitoring. [City of Redmond]

Response: To clarify, the Draft CAP identified SBOH activity to designate SALs for five PFAS under Section 9.1.2, subsection Chapter 246-290 WAC, and then described the potential for EPA to consider designating PFOS and PFOA as hazardous substances under its 2019 PFAS Action Plan (Section 9.2.1). The Draft CAP also identified that "In January 2020, the House of Representatives passed the PFAS Action Act (H.R. 535, S. 638), omnibus PFAS legislation." The Senate has not yet taken up companion legislation. The PFAS Action Act would require EPA to designate PFAS chemicals as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) within one year of enactment of the legislation." The PFAS Action Act of 2021 was also introduced and passed by the House of Representatives in July 2021 (H.R. 2467[294]). This legislation would similarly require EPA to designate PFAS chemicals as hazardous substances under CERCLA within one year of enactment of the legislation.

As discussed in the response to Issue 2, the CAP will not be revised after it has been issued. The SBOH consideration of SALs for drinking water is not related to or dependent on federal designation of PFAS (individually or as a group) as hazardous substances under CERCLA. Any such federal designation would not require additional monitoring under SBOH rules as currently proposed.

[291] https://apps.leg.wa.gov/wAc/default.aspx?cite=173-303
[292] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-303-090
[293] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-303-100
[294] https://www.congress.gov/bill/117th-congress/house-bill/2467

Issue 292: Additional information was provided regarding EPAs revision of its regulations in June 2020 subsequent to the addition of 172 PFAS substances to TRI reporting by virtue of the 2020 NDAA. [Alliance for Telomer Chemistry Stewardship]

The comment also identified an advance notice of proposed rulemaking issued in December 2019 (84 Federal Register (Fed. Reg.) 66369).

Response: The text at Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency, regarding TRI reporting was updated to reflect the June 2020 EPA regulation revision. The December 2019 advanced notice of rulemaking (84 Fed Reg 6639) was withdrawn in March 2020 (EPA, 2020c).

Issue 293: Comments provided on SBOH's proposed SALs identified the voluntary phase-out of PFOA and PFOS starting in 2000 and largely complete by 2002. Since then EPA only allows the manufacture or import of PFOS and PFOS precursors under a few limited, highly technical uses where no alternatives are available. EPA has published data indicating that production and import of PFOA and PFOS have halted or dropped below Chemical Data Reporting Program reporting thresholds (85 Fed. Reg. at 14115). PFOS has not been reported to EPA as manufactured or imported into the United States since at least 2006. Many countries have also signed on to the Stockholm convention which now requires the elimination of PFOS in essentially all consumer and other goods originating in member countries. [3M]

Response: The comment addresses information submitted to SBOH as part of a rulemaking proceeding separate from the CAP. Appendix 9: Regulations, Section 9.2.1 Environmental Protection Agency, describes EPA actions relative to voluntary phase-outs of PFOS and PFOA and subsequent review of other PFAS compounds under EPA's SNURs. Appendix 1: Chemistry, Section 1.3.5 Trends in per-and polyfluorinated substance design, also acknowledges that production-related PFCA emissions were substantively eliminated in Japan, Western Europe and the U.S. by 2002.

Appendix 3: Sources and Uses, Section 3.3.1 PFAS in children's products, reports data provided to Ecology under CSPA, indicating that regardless of U.S. phase-outs, PFOS and PFOA have been reported in products still being sold in Washington, though with decreasing reports over-time for this product category.

9.2.2 Food and Drug Administration

Issue 294: On July 31, 2020, FDA announced a voluntary agreement with manufacturers to phase out the distribution in commerce of several short-chain PFAS compounds for use in food packaging by the end of 2023. [Alliance for Telomer Chemistry Stewardship]

Response: Appendix 9: Regulations, Section 9.2.2 Food and Drug Administration, was updated with this new information.

9.5 Data gaps and recommendations

9.5.2 Recommendations

Issue 295: Recommendation 4.2 should be revised to require PFAS testing of landfill leachate during landfill monitoring for limited purpose landfills (WAC 173-350-400[295]) and inert waste landfills (WAC 173-350-410[296]) in addition to Municipal Solid Waste Landfills (WAC 173-351[297]). [Public Health - Seattle & King County]

Response: Ecology will look at the data from the landfill leachate study and other state and national studies and upon review will make whatever recommendations necessary for updates to the scope and applicability of the appropriate regulations. In the meantime, jurisdictional health departments already have the authority to require additional constituents be evaluated as circumstances and conditions warrant.

Appendix 10: Economic Analysis

10.1 Costs of recommended actions

Issue 296: Updated costs of activities to address PFAS contamination of drinking water were provided by the Sammamish Plateau Water and Sewer District and the U.S. Navy, to update subsection "Action 1.1 Identify funding for PFAS drinking water mitigation". [Sammamish Plateau Water and Sewer District, City of Redmond, DON]

Response: The updated cost information provided by both the DON and the Sammamish Plateau Water and Sewer District was added to the CAP at Section 10.1, Costs of recommended actions, as well as in the PFAS Assessment Summary, Economic Analysis (Appendix 10). See also Issue 42.

Issue 297: At subsection "Action 1.2 Technical Support for site characterization, source investigation, and mitigation at contamination sites", the budget cited for investigation and remediation seems low. Several additional considerations are proposed. [Public Health - Seattle & King County]

The comments request the following considerations:

- More research should be pulled from other states that have more experience with groundwater remediation.
- Ecology should utilize best estimates, accounting for uncertainties in the data, to determine a value for the overall market share of PFAS, when performing the economic analysis to understand impacts of regulation and cleanup. This could help incentivize industry to provide more specific and reliable data for Ecology's consideration of potential impacts.

[295] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-400
[296] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-410
[297] https://apps.leg.wa.gov/wac/default.aspx?cite=173-351&full=true

- The economic evaluations should weight the costs of health and cultural impacts (accounting for uncertainties in data) more heavily than financial impacts on producers.

Response: The focus of the information in this section of the CAP is to identify the range of costs that could be incurred to respond to PFAS contamination. The section provides some examples of responses at more severely impacted sites with complex release histories (e.g., the City of Hoosick Falls, and statewide response in Minnesota) as well as sites impacted by AFFF releases. The conclusion drawn on this, and other cost data presented in the preceding section Action 1.1 Identify funding for PFAS drinking water mitigation, is that costs to respond to PFAS contamination of drinking water can be extensive and variable based on site-specific characteristics. Conducting additional research to document costs incurred in other states would not change this conclusion, nor Recommendations 1.1 and 1.2.

With respect to the cost of groundwater remediation, Washington has extensive experience in such activities, and our cost estimates are based on historical data from our state. We have identified that there are numerous uncertainties that can influence (i.e., increase upwards) remediation costs when it comes to PFAS. Although there is a lot of work to identify remediation methods (see new text added at Section 4.5, Long term PFAS management, and the response to Issue 222), we have not identified any sites in other states where remediation has been completed and where the total cost of remediation is available.

We agree that having more comprehensive data on the use of PFAS in products and processes would improve the accuracy of economic analyses. As we discuss, this information is not transparent or known. We believe as we work with industry to identify their uses of PFAS and potential safer alternatives, our understanding of this data will improve.

The costs of health impacts are addressed in Section 10.4, Costs from likely PFAS-related health conditions. While the CAP discusses identifiable costs where possible, it is not intended to be a benefit-cost analysis or other efficiency analysis. We did include discussion of benefits, as it gives readers more context for the types of harm resulting from PFAS, but no comparison or weighting is included in the CAP. Health and EJ impacts are part of formulating and implementing recommendations, regardless of whether comparison of quantitative or qualitative costs and benefits is required.

Issue 298: Several sources of costs from treatment activity have not been addressed in the CAP. These potential costs should be included when considering remediation activity under the CAP to more accurately assess the potential economic impact of this activity. [NCASI]

Comments identified the following areas where costs should be identified:

- Influent and effluent testing at POTWs.
- Treating municipal or industrial wastewaters to remove PFAS.
- Destroying or otherwise ultimately disposing of separated and concentrated PFAS waste streams generated as a result of drinking water treatment for PFAS.
- Pretreatment, which may be required for wastewaters in order for previously discussed treatment technologies that target PFAS (such as GAC, ion exchange, and

membrane processes) to be effective, and destruction of PFAS sorbed to treatment media after it has been separated from drinking water, which would also contribute to the overall cost of treating wastewater contaminated with PFAS.
- Managing landfill leachates to address PFAS contamination, including a cost study prepared for the New England Waste Services of Vermont Landfill.

Response:

- Recommendation 4.1 could result in Ecology considering whether monitoring of PFAS in influents and effluents of some or all WWTPs is needed. We have added this as an action for which a cost estimate was considered (see Appendix 10: Economic Analysis, Section 10.1 Costs of recommended actions, Action 4.1). However, as indicated in the added information, a monitoring program would depend on the type of WWTP. We are therefore unable to estimate the cost that might be incurred based on WWTP, mode of operation, and frequency of monitoring.
- The commenter is correct that Section 10.1 did not address treatment costs because Recommendation 4.1, Evaluate PFAS in wastewater treatment, may only require that WWTP dischargers monitor their effluent based on the results of a sampling effort that Ecology would complete. The recommendation does not address any actions related to treatment of effluent from domestic or industrial WWTPs. The commenter agrees that at Section 10.1, Action 1.1 the Draft CAP did not provide total or statewide costs for drinking water mitigation on the basis of various elements of uncertainty, and that the CAP didn't consider costs of destroying or otherwise ultimately disposing of separated and concentrated PFAS waste streams. We have edited this section to reflect that disposal of concentrated PFAS waste streams introduced a cost element into a drinking water mitigation action.
- The commenter identified that at Section 10.1, the Draft CAP did not discuss costs associated with destruction of PFAS sorbed to treatment media after it has been separated from wastewater. Section 10.1 did not address these costs because Recommendation 4.1, Evaluate PFAS in wastewater treatment, may only require that WWTP dischargers monitor their effluent based on the results of a sampling effort that Ecology would complete. The recommendation does not address any actions related to treatment of effluent from domestic or industrial WWTPs. Therefore, an analysis of costs to treat effluent to remove PFAS, and subsequent treatment of media to which PFAS is sorbed, is not warranted.
- Finally, the commenter raises the issue that at Section 10.1, Action 4.2, the Draft CAP did not evaluate the cost of treating landfill leachate. This is because Recommendation 4.2 only focuses on "Considering additional monitoring requirements for landfills to test leachate" or "Potentially updating the rules

(Chapters 173-350[298] and 173-351[299] WAC) to require PFAS testing of leachate during landfill monitoring." The recommendation does not seek for landfill operators to treat landfill leachate in order to remove PFAS. An assessment of the cost to implement landfill leachate treatment is therefore not needed at this time.

Note that while the recommendations are high-level, any implementation through regulatory change would be required to perform economic analyses around requirements that do not exist under the baseline. As the requirements and covered parties would be explicitly specified, these analyses would likely include more in-depth and specific analysis of the types of costs identified by the commenter.

Issue 299: When assessing the economic impact of replacing PFAS-containing carpeting with non-PFAS carpeting, Ecology should consider the increased durability provided by PFAS treatments. [Alliance for Telomer Chemistry Stewardship]

Response: The focus of the action (i.e. Recommendation 3.1) referred to in this comment is to reduce human exposure to PFAS in carpet and to PFAS in dust resulting from carpet wear. The economic analysis focuses specifically on the portion of the recommendation, which would implement a state agency purchasing preference policy for PFAS-free carpet, and estimates the difference in cost that might be incurred by the state.

Costs over time are a function of unit prices as well as frequency of purchases, so if PFAS treatment increases the durability of carpet, in that it does not need to be replaced as frequently, then PFAS-free alternatives would also put upward pressure on costs. As of April 2021, the Washington Department of Enterprise Services does not have a current flooring contract in place—a new flooring contract is expected to be issued for bid in mid-summer 2021. Information from Ecology staff involved in discussions surrounding specifications for the contract has confirmed that the contract would specify durability specifications consistent with industry standards (Simcich, 2021).

[298] https://apps.leg.wa.gov/wac/default.aspx?cite=173-350
[299] https://apps.leg.wa.gov/wac/default.aspx?cite=173-351

Supplement 1. List of Commenters

Agencies

- Cascade Water Alliance
- City of Redmond
- City of Renton
- City of Tacoma
- City of Vancouver
- Cowlitz County - Dept. of Public Works
- DON
- Eastside Fire and Rescue
- King County Environmental Health Services Division
- King County Solid Waste Division
- King County Wastewater Treatment Division
- Lakewood Water District
- Port of Seattle
- Public Health - Seattle & King County
- Sammamish Plateau Water
- Utilities and Transportation Commission
- Whidbey Island Water Systems Association

Organizations

- 3M
- Alliance for Telomer Chemistry Stewardship
- Arkema Inc.
- Association of Washington Business
- Clean Production Action
- Friends of Toppenish Creek
- Hazardous Waste Management Program
- National Council of Textile Organizations
- National Waste & Recycling Association
- NCASI
- Northwest Biosolids
- Olympic Environmental Council
- Performance Fluoropolymer Partnership
- PFAS Regulatory Coalition
- RE Sources
- Republic Services
- The Lands Council

- Toxic-Free Future on behalf of multiple organizations
- TRC
- Washington Association of Sewer & Water Districts
- Washington Refuse and Recycling Association
- Waste Connections
- Waste Management of Washington Inc.

Tribes and tribal organizations

- National Tribal Water Council
- Port Gamble S'Klallam Tribe

Individuals

- Abigail Houghton
- Adrienne Blackburn
- Aisha Farhoud
- Alexis Macdonald
- Alfred Ferraris
- Alissa Andersson
- Allison Ciancibelli
- Allison Fradkin
- Alyce Fritch
- Amanda Dickinson
- Amy Hitchens
- Amy Kiba
- Amy Mower
- Amy Platt
- Amy Scott
- Anand Naik
- Andrea Gruszecki
- Andrea Speed
- Andrew Rosenthal
- Angela Kelly
- Angeline Johnson
- Angie Dixon
- Anita Shelton
- Ann Dawson
- Ann Smith
- Anna Booth
- Anna Dyer
- Anna Johnson
- Annapoorne Colangelo
- Anne Hawkins
- Anne Hepfer
- Anne Morgan
- Anthony Buch
- April Love-King
- Arlene Levy
- Arnold Strang
- Art Hanson
- Asphodel Denning
- Audrey Adams
- B.A. McClintock
- Barb Drake
- Barbara Anderson
- Barbara Blackwood
- Barbara Davidson
- Barbara Gregory
- Barbara Ierulli
- Barbara Rosenkotter
- Barbara Sim
- Barbara Wight
- Barbara Wills
- Barret Carpenter
- Behnoosh Armani
- Ben Moore
- Ben Rall
- Beth Brunton
- Beth Call
- Beth Russo
- Bethany Temple
- Betsy Grimes
- Betsy Teays
- Betty Terrell
- Bill Benjamin
- Bill Sampson
- Blanche Hill
- Bob Kutter
- Bob Rodgers
- Bonnie Newkirk
- Brandie Deal
- Brian Ferguson
- Brian Reid
- Brie Gyncild
- Brock Smith
- Bronwen Evans
- Brooke Lucy
- Bruce McGlenn
- Candace LaPorte
- Carla Montante
- Carol Ellis
- Carol Fillman
- Carol Meyer
- Carol Price
- Carole Burger

- Carole H
- Caroline Bowdish
- Carolyn Akinbami
- Carolyn Treadway
- Carolyn Yabui
- Carrie Heron
- Catherine Lee
- Catherine Ruha
- Cathleen Burns
- Cathleen Lindsay
- Cathy Erntson
- Celeste Maris
- Chad Evans
- Chandra Capobianco
- Charlene Bender
- Charles R Myrick
- Charlotte Wells
- Chelsea Norvell
- Cherie Holman
- Cheryl Biale
- Chris Covert Bowlds
- Chris Guillory
- Chris Hellstern
- Chris Landback
- Chris Stay
- Christie Hedman
- Christina Manetti
- Christopher Rossi
- Cigdem Capan
- Claudio Parazzoli
- Clayton Hamill
- Clayton Jones
- Coleman Byrnes
- Colleen Curtis
- Connie Harder
- Cornelia Teed
- Craig Swanson
- Cynthia Lachance
- Cynthia Zimmermann
- D Anderson
- D Smith
- D Valdez
- Dan Schneider
- Dan Snyder
- Daniel Henling
- Darla Austerman
- Darlene Hernandez
- Darlene St Martin
- Dave Baine
- Dave Pierot
- David Arntson
- David Cosman
- David Neevel
- David Newman
- David Nowlis
- David Stetler
- David Winiecki
- Debbi Pratt
- Debbie Mahder
- Debbie Ramos
- Debbie Spear
- Debbie Thorn
- Debby Felnagle
- Deborah Bancroft
- Deborah Bisenius
- Deborah Cruz
- Deborah Kaye
- Deborah Parker
- Deirdre Gabbay
- Delorse Lovelady
- Den Mark Wichar
- Den Wichar
- Dena Fantle
- Denee Scribner
- Denise Bunge
- Denise Lytle
- Denise McGregor
- Denni Carcelli
- Dennis Bahr
- Dennis Mace
- Derek Benedict
- Derek Gendvil
- Desiree Nagyfy
- Diana Johnson
- Diane Bisset
- Diane Horn
- Diane Marks
- Dinah Dubble
- Dolly Sutherland
- Dolores Pino
- Don Gargas
- Don Williams
- Don Worley
- Donald Barrie
- Donald Graham
- Donald Greenberg
- Donald Wilson
- Donna Glaser
- Donna Scott
- Doris Cellarius
- Dorothy Hall
- Dorothy Jordan
- Dorothy Wendler
- Dr Demian
- Dre Say
- Duane Johnson
- E Ellis
- Earl McCarter
- Edie Jorgensen
- Edith Kusnidc
- Edward Kaeufer
- Eizabeth Guss
- Elaine Hickman
- Elena Rumiantseva

- Elisabeth Heath
- Elizabeth Burton
- Elizabeth Ellis
- Elizabeth Hansen
- Elizabeth Johnson
- Elizabeth Nedeff
- Elizabeth Watson
- Ellen Kritzman
- Ellen Madsen
- Emily Happy
- Emily Van Alyne
- Enid Cox
- Eric Dolph
- Eric Zimdars
- Erik LaRue
- Esther Kronenberg
- Eugenia Sostrich
- Eva Coombs
- Eva Demetro
- Eve McClure
- Evelyn Bittner
- Evelyn Lemoine
- Evita Krislok
- F T
- Fanette Stewart
- Fay Payton
- Felicity Devlin
- Felipe Morales
- Felix Lee
- Florie Rothenberg
- Forest Shomer
- France Morrow
- Frances Blair
- Francesca Favorini-Csorba
- Francie Rutherford
- Fred Karlson
- Fred Thaller
- Gail Atkins
- Garett Newkirk
- Gary Brill
- Gayla Shoemake
- Gayle Austin
- Gelsey Lluberes
- Gena DiLabio
- Geoffrey Richards
- George Keefe
- George Waldref
- Geri Eekhoff
- Giles Sydnor
- Gill Fahrenwald
- Glen Anderson
- Glenn Franko
- Gloria McClintoch
- Gloria Skouge
- Goldie Silverman
- Grace Huang
- Graham Lang
- Greg Espe
- Greg Goodwin
- Gregory Penchoen
- Gretchen Lee
- Gretchen Metz
- Heather Davidson
- Heather Grube
- Heather Kreeck
- Heather Murawski
- Heidi Colkitt
- Heidi Sanborn
- Heidi Stephens
- Helen Sargeant
- Henry Bernard
- Holly Hallman
- Howard Harrison
- Ingrid Mager
- J Christensen
- J H
- J Kelly
- J S
- Jackie Easley
- Jacob Schmidt
- Jae Geller
- James Bates
- James Cavallaro
- James Chumbley
- James Cook
- James Feit
- James Hipp
- JAMES MOTHERSBAUGH
- James Mulcare
- James Rogers
- James Tandoo
- James Wallrabenstein
- James Wiley
- James Williams
- Jamie Kitson
- Jamie Peltier
- Jan De Roos
- Jan Dove
- Jana Wiley
- Jane Ely
- Jane Spini
- Janelle Church
- Janet Farness
- Janet Hedgepath
- Janet Riordan
- Janet Wright
- Janet Wynne
- Janice Schuch
- Janice Tufte
- Janna Rolland
- Jared Howe
- Jasmine Ligenza-posante
- Javier Ortiz

- Jayme Jonas
- Jayson Luu
- Jean Johnson
- Jean M. Avery
- Jean Pauley
- Jean Schwinberg
- Jeanie Bein
- Jeff Berner
- Jeff Green
- Jeffrey Kozma
- Jeffrey White
- Jen Bentzel
- Jen McGill
- Jen Mullen
- Jennifer Brodie
- Jennifer Calvert
- Jennifer Corrigan
- Jennifer Ernst
- Jennifer Ibach
- Jennifer Strauss
- Jennifer Westra
- Jenny Hayes
- Jeri Harris
- Jesse Gillman
- Jesse Mallory
- Jessica D'Amour
- Jessica Taylor
- Jill Feuerhelm
- Jill Meier
- Jim Cronin
- Jim Gayden
- Jim Minick
- Jim Mynar
- Jim Roberts
- Ji-Young Kim
- Jo Harvey
- Jo Payne
- Joan Nelson
- Joan Temple
- Joanna Stiehl
- Joanne Watchie
- Joe Mayo
- Joe Nichols
- Joel Flank
- John Birnel
- John Burrows
- John Dunn
- John Guros
- John Lambert
- John McGill
- John Mefford
- John Murphy
- John S
- John Thompson
- John Woll
- Jonah Griffith
- Jonathan Loeffler
- Jonathan Neufeld
- Jonathan Pasley
- Jordan Harshbarger
- Joy Vartanian
- Joyce Grajczyk
- Joyce Wilkerson
- Judi Robbins
- Judith Beaver
- Judith Desmarais
- Judith Hance
- Judith Nappe
- Judith Starbuck
- Judith Thierry
- Judy Avery
- Judy Tralnes
- Julia Hensley
- Julia Larsen
- Julia McLaughlin
- Julianne Martinson
- Julie Glover
- Julie Hungar
- Julie O'Donnell
- Julieann Palumbo
- Justas Vilgalys
- Justine Hickerson
- Kalama Reuter
- Karen Curry
- Karen Dahmer
- Karen Edwards
- Karen Flood
- Karen Fortier
- Karen Laughlin
- Karen Loeser
- Karen Stone
- Karen Weis
- Karla Taylor
- Karol Long
- Katherine Reed
- Kathleen Grimbly
- Kathleen Lee
- Kathleen Lowney
- Kathleen Steele
- Kathryn Lambros
- Kathryn Ryan
- Kathy Golic
- Kathy Kuyper
- Kathy Partida
- Kathy Schaeffer
- Kathy Wilmering
- Keith Cowan
- Kelley Coleman-Slack
- Kelli Turner
- Kerry Dearborn
- Kevin Clark
- Kevin Gallagher
- Kevin Hughes
- Kim Brandt
- Kim Lombardozzi
- Kim Mack

- Kim Peterson
- Kim Rice
- Kimberly Seater
- Kimberly Sims
- Kimberly Teraberry
- Kindy Kemp
- Kirk Heim
- Klaudia Englund
- Kristen Meston
- Kristi Weir
- Kristin deLancey
- Kristin Sykes-David
- Kristine Weafer
- Kym Harris
- Lakota Crystal
- Lanie Cox
- Lanny Shuman
- Lara Backman
- Lara Lorenz
- Larissa Ruiz
- Larry Fox
- Laura Clarson
- Laura Finkelstein
- Laura Paise
- Laura Ramon
- Laura Robinson
- Laura Zerr
- Lauren Mendez
- Lauren Sewell
- Laurie Cooper
- Laurie Dils
- Laurie Gogic
- Lawrence Magliola
- LeeAnne Beres
- Lemoine Radford
- Lendri Purcell
- Leon Robert
- Leonard Obert
- Lesley Morgan
- Lesley Wright
- Leslie Lowe
- Leslie Marshall
- Leta Rosetree
- Lin Provost
- Linda Carroll
- Linda Chapman
- Linda Curry
- Linda Gaines
- Linda Johnson
- Linda Lindsay
- Linda Wasserman
- Linda Wright
- Lisa Ceazan
- Lisa Ehle
- Lisa Kavas
- Lisa Messinger
- Lisa Winters
- Liza Martin
- Lloyd Hedger
- Lord-Wood Dominica
- Lori Gudmundson
- Lorie Haywood
- Lorraine Hartmann
- Lorraine Johnson
- Lucas Peiser
- Lucinda Brouwer
- Lucinda Wingard
- Lucy Ostrander
- Lynn Brevig
- Lynn Rabenstein
- Lynne Bannerman
- M Fritchie
- M Johnson
- Madelyn Hart
- Maja Persson
- Mana Iluna
- Manuel Vega
- Marcy Golde
- Margaret Eames
- Margaret Iuro
- Margaret Thomas
- Margaret Woll
- Margie Maddux
- Marguerite Winkel
- Mari Ellingsen
- Maria Gaspar
- Mariah Mitchell
- Marian Gillis
- Marian Karpoff
- Marian Wineman
- Mariana Castillo
- Marie Weis
- Marilyn Cornwell
- Marilyn Mills
- Marilynn Bernahl
- Marina Kuran
- Mark Arntson
- Mark Bradley
- Mark McIntire
- Mark Proa
- Mark Weiss
- Marla McCune
- Marquam Krantz
- Marsha Shaiman
- Marty Crowley
- Mary Bicknell
- Mary Cunningham
- Mary Cutrera
- Mary Ellen Smith
- Mary Emmons
- Mary Ferm
- Mary Garttmeier
- Mary Gear
- Mary Gibson
- Mary Hanson
- Mary Lou Dickerson

- Mary Michael
- Mary N
- Mary Onufer
- Mary Patrick
- Marylin Mayers
- Matt Brookhart
- Matthew Boguske
- Maureen Lang
- Maxwell Feldman
- Megan Hoerler
- Melanie Kenoyer
- Melinda Mehring
- Melissa Lound
- Melissa Rees
- Melissa Roberts
- Melodie Martin
- Menno Sennesael
- Meredith Shank
- Mia Heavyrunner
- Michael Betz
- Michael Czuczak
- Michael Jones
- Michael Leff
- Michael Pinc
- Michael Saunders
- Michael Symonds
- Michelle McRae
- Michelle Pavcovich
- Michelle Stepp
- Michelle Tirhi
- Michelle Trosper
- Mike Giese
- Mike Johnson
- Mike Stuart
- Mildred Templeton
- Millie Magner
- Miranda Marti
- Miranda Scalzo
- M'lou Christ
- Moira Landis
- Molly Jones
- Monica Maxa
- Monica Vasquez
- Morris Williams
- Mr Egtvedt
- Mrs Risser
- Mustafa Guroglu
- Nancy Ellingham
- Nancy Farrell
- Nancy Gleim
- Nancy Hh
- Nancy Lewis
- Nancy Phelps
- Nancy Snyder
- Nancy Uding
- Nancy Vandenberg
- Nancy White
- Nata Y
- Nathaniel Jungbluth
- Neil Rader
- Neil Umphred
- Nicholas Heyer
- Nick Engelfried
- Nina Mettler
- Noah Ehler
- Noel Allen
- Nora Nickum
- Norm Conrad
- Norm Frampton
- Norman Baker
- Oneida Arnold
- P. Elle
- P. P.
- Paige Kenney
- Pamela Clough
- Pamela Engler
- Pat Lagerway
- Pat Nordby
- Patrice Roberts
- Patricia Bryant
- Patricia Coffey
- Patricia Doran
- Patricia Page
- Patricia Safrin
- Patricia Wilson
- Patrick Barredo
- Patrick Conn
- Patrick Hickey
- Patrick McCormick
- Patti Brent
- Paul Bakke
- Paul Balle
- Paula Connelley
- Pauline Osborne
- Peggy Butler
- Peggy Leviton
- Peggy Willis
- Penelope Johansen
- Perry Bryant
- Pete Compton
- Pete Stoppani
- Peter Crowley
- Peter Ferre
- Peter Giono
- Peter Reagel
- Peto Gerth
- Phebe Schwartz
- Philip Chanen
- Philip Fischer
- Phillip Wood
- Phyllis Dolph
- Phyllis Farrell
- Polly Taylor
- Priscilla Martinez
- R McClain
- R Wood

- Rachel Haxtema
- Rachel Wilson
- Raemie Bruno
- Ralph Becker
- Ralph Myer
- Randall Potts
- Randy Guthrie
- Ranell Nystrom
- Rebecca Durr
- Rebecca Glass
- Rebecca McDonough
- Rebecca Nimmons
- Rebecca Szper
- Regina Ball
- Rein Attemann
- Rene Dubay
- Rene Ray
- Reuben Gelblum
- Richard Abraham
- Richard Frye
- Richard Johnson
- Richard Ress
- Richard Rutz
- Richard Schoonover
- Rick Eggerth
- Rick Hughes
- Rita Hogan
- Robert Brown
- Robert Corpus
- Robert Jensen
- Robert Meyer
- Robert Stephenson
- Robert Young
- Ron Baer
- Ron DiGiacomo
- Ron Kaufman
- Ronald Reagan
- Roni Patterson
- Ronlyn Schwartz
- Rose Rohrer
- Rosemary Blakemore
- Rosemary Sikes
- Ruth Falcon
- Ruth Mulligan
- Ruth Weedman
- Ryan Bollman
- Ryan Swanson
- Sally Burke
- Sally Schreder
- Sally Stroud
- Sandra Brouillette-Jobe
- Sandra Ciske
- Sandra Grace
- Sandra Thomas
- Sandy Covich
- Sara Bhakti
- Sara Burgess
- Sara Davis
- Sarah Bauman
- Sarah Brouwer
- Sarah Samnick
- Sarah Schmidt
- Scott Bishop
- Scott Fortman
- Selim Uzuner
- SF Brown
- Shannon Markley
- Shannon Svensson
- Sharon Anderson
- Sharon Cox
- Sharon Kenyon
- Shary B
- Shauna Boyd
- Shelley Simcox
- Shelly Ackerman
- Shemayim Elohim
- Sierra Sanchez
- Sigrid Salo
- Silvia DeLosSantos
- Stacee Anderson
- Stacia Haley
- Stacie Hartman
- Stephanie Chlebowski
- Stephanie Colony
- Stephanie Lecovin
- Stephanie Peace
- Stephanie Stohler
- Stephanie Trasoff
- Stephen Bailey
- Stephen Swanson
- Steve Hansen
- Steve Uyenishi
- Steve V
- Steve Wilson
- Steven Hansen
- Steven Reeves
- Steven Thomason
- Steven Woolpert
- Sue Jarrard
- Sue Stoeckel
- Supportive Services
- Susan and Peter Risser
- Susan Betourne
- Susan Hampel
- Susan Hass
- Susan Kane
- Susan MacDonald
- Susan MacGregor
- Susan Ramsauer
- Susan Ratner
- Susan Shouse

- Susan Vogt
- Susan Vossler
- Susan Waters
- Susan Wilson
- Susanne Weil
- Suzanne Nevins
- T Thompson
- Tamara Saarinen
- Tanya Lasuk
- Ted Brookes
- Teresa Allen
- Teri Wright
- Terri Dundas
- Terri Stromberg
- Terry Nightingale
- Terry Teigen
- Theresa Espana
- Theresa Skager
- Therese Cushing
- Thomas Brady
- Thomas Libbey
- Tiffany Dodge
- Tika Bordelon
- Tina Bartlett
- Toby Smith
- Tom Borst
- Tom Craighead
- Tom Devine
- Toniann Reading
- Tosha Mayo
- Tracy Wang
- Tracy Weldon
- Trudy Cordes
- Tyler Otto
- Vana Spear
- Vanassa Lundheim
- Vanessa Jamison
- Vicki Elledge
- Vickie Woo
- Victoria Poling
- Victoria Urias
- Vincent Duffy
- Virgene Link-New
- Virginia Davis
- Vivian Bartlett
- Vivienne Bembridge
- Wally Bubelis
- Walther Soeldner
- Wanda Unger
- Wayne Ude
- Wendy Kraus
- Whitney Fish
- Will Silva
- William Brogan
- William Brooks
- William Golding
- William Hoffer
- William Sneiderwine
- William Treacy
- Yonit Yogev

References

Ali, A.M., Langberg, H.A. Hale, S.E., Kallenborn, R., Hartz, W.F., Mortensen, Å, K., Ciesielski, T.M., McDonough, C.A., Jenssen, B.M., & Breedveld, G.D. (2021). *Environmental Science: Processes & Impacts, 23*, 588-604. https://doi.org/10.1039/D0EM00510J

American Association for the Advancement of Science (AAAS). (2021). Center for Scientific Evidence in Public Issues. Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water: Guides for Local and State Leaders. January 2021. Retrieved from https://www.aaas.org/sites/default/files/2021-01/AAAS%20EPI%20Center%20PFAS%20Guides.pdf

Anderson, J.K., Luz, A.L., Goodrum, P., & Durda, J. (2019). Perfluorohexanoic acid toxicity, part II: Application of human health toxicity value for risk characterization. *Regulatory Toxicology and Pharmacology, 103,* 10-20. https://doi.org/10.1016/j.yrtph.2019.01.020.

Anthesis Consulting Group. (2018). Toxics in Carpets in the European Union. March 2018. Retrieved from https://circulareconomy.europa.eu/platform/sites/default/files/knowledge_-_toxics_in_carpets_eu_review_anthesis_final_study.pdf

Association of State and Territorial Health Officials (ASTHO). (2021). PFAS Risk Communications Hub. Retrieved April 30, 2021 from https://astho.org/PFAS/

Bartell, S. (2012). Bias in half-life estimates using log concentration regression in the presence of background exposures, and potential solutions. *Journal of Exposure Science and Environmental Epidemiology,* 22**,** 299–303. https://doi.org/10.1038/jes.2012.2

Blaine, A. C., Rich, C. D., Hundal, L. S., Lau, C., Mills, M. A., Harris, K. M., & Higgins, C. P. (2013). Uptake of Perfluoroalkyl Acids into Edible Crops via Land Applied Biosolids: Field and Greenhouse Studies. *Environmental Science & Technology*, *47*, 14062–14069. https://doi.org/10.1021/es403094q

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., de Voogt, P., Jensen, A. A., Kannan, K., Mabury, S. A., & van Leeuwen, S. P. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environmental Assessment and Management*, *7*, 513–541. https://doi.org/10.1002/ieam.258

Buck, R. C., Korzeniowski, S.H., Laganis, E., & Adamsky, F. (2021). Identification and Classification of Commercially Relevant Per-and Poly-fluoroalkyl Substances (PFAS). Manuscript Final. *Integrated Environmental Assessment and Management*. https://doi.org/10.1002/ieam.4450

California Carpet Stewardship Program. (2020). Recycled Carpet-Derived Products. December 2020. Retrieved from https://carpetrecovery.org/wp-content/uploads/2020/12/CARE_MrkDev_PCC_Dec2020_fnl.pdf

Chapter 19.405 RCW: Washington Clean Energy Transformation Act

Chapter 70A.222 RCW: Packages Containing Metals and Toxic Chemicals

Chapter 70A.350 RCW: Pollution Prevention for Healthy People and Puget Sound Act

Chapter 70A.400 RCW: Firefighting Agents and Equipment—Toxic Chemical Use

Chapter 70A.430 RCW: Children's Safe Products

Chapter 82.21 RCW: Hazardous Substance Tax – Model Toxics Control Act

Chapter 173-303 WAC: Dangerous Waste Regulations

Chapter 173-333 WAC: Persistent Bioaccumulative Toxins.

Chapter 173-334 WAC: Children's Safe Products Reporting Rule

Chapter 173-350 WAC: Solid Waste Handling Standards

Chapter 173-351 WAC: Criteria for Municipal Solid Waste Landfills

Chapter 246-290 WAC: Group A Public Water Supplies Rule

Choi, Y. J., Kim Lazcano, R., Yousefi, P., Trim, H., & Lee, L. S. (2019). Perfluoroalkyl Acid Characterization in U.S. Municipal Organic Solid Waste Composts. *Environmental Science & Technology Letters*, *6*, 372–377. https://doi.org/10.1021/acs.estlett.9b00280

Clarke, B. O., & Smith, S. R. (2011). Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids. Environment International, 37, 226–247. https://doi.org/10.1016/j.envint.2010.06.004

Compost Manufacturing Alliance. (2020). Compost Manufacturing Alliance-(PSA 1)- Profile submittal addendum related to fluorinated chemicals. Retrieved from https://compostmanufacturingalliance.com/wp-content/uploads/2020/06/fluorinated-chemicals-2020.pdf

Compost Manufacturing Alliance. (2021). Testing your Products. What is Field Testing?. Retrieved May 20, 2021 from https://compostmanufacturingalliance.com/cma-field-testing/

Conder, J. M., Arblaster, J., Larson, E., Brown, J., & Higgins, C. (2020). Guidance for Assessing the Ecological Risks of PFASs to Threatened and Endangered Species at Aqueous Film Forming Foam-Impacted Sites. SERDP Project ER18-1614. *Strategic Environmental Research and Development Program (SERDP)*. Retrieved from https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/ER18-1614

Conder, J. M., Hoke, R. A., Wolf, W. de, Russell, M. H., & Buck, R. C. (2008). Are PFCAs Bioaccumulative? A Critical Review and Comparison with Regulatory Criteria and Persistent Lipophilic Compounds. *Environmental Science & Technology*, *42*, 995–1003. https://doi.org/10.1021/es070895g

Cory. D. (2021a). Email from Devon Cory, WSDOT, to Irina Makarow, Ecology. Re: Class-B firefighting foam? May 11, 2021. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Cory. D. (2021b). Email from Devon Cory, WSDOT, to Irina Makarow, Ecology. Re: Class-B firefighting foam? May 17, 2021. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Cousins, I.T., DeWitt, J.C., Glüge, J., Goldenman, G., Herzke, D., Lohmann, R., Ng, C.A., Scheringer, M., & Wang, Z. (2020). The high persistence of PFAS is sufficient for their management as a chemical class. *Environmental Science: Processes & Impacts, 12*, 2307-2312. https://doi.org/10.1039/D0EM00355G

Department of Defense (DOD). (2017). DOD Quality Systems Manual Version 5.1 DOE Quality Systems for Analytical Services Version 3.1. Retrieved from https://cswab.org/wp-content/uploads/2018/03/DOD-DOE-Quality-Systems-Manual-5.1-includes-PFAS-Testing-Jan-2017.pdf

Divine, C., Zodrow, J., Frenchmeyer, M., Dally, K., Osborn, E., & Anderson, P. (2020). Approach for Assessing PFAS Risk to Threatened and Endangered Species. SERDP Project ER18-1653. *Strategic Environmental Research and Development Program (SERDP)*. Retrieved from https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/ER18-1653

Environmental Research Institute of the States. (2021). PFAS Risk Communications Hub. Retrieved April 30, 2021 from https://www.eristates.org/projects/pfas-risk-communications-hub/

Environmental Justice Task Force. (2020). Report to the Washington State Governor and Legislature. Recommendations for Prioritizing EJ in Washington State Government. Fall 2020. Retrieved from https://healthequity.wa.gov/Portals/9/Doc/Publications/Reports/EJTF%20Report_FINAL(1).pdf

Fanning. L. (2021). Email from Lee Fanning, WSDOT, to Irina Makarow, Ecology. Re: WSDOT use of AFFF foam/substitute for training /testing in tunnels. April 27, 2021. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Gewurtz, S. B., Bhavsar, S. P., Crozier, P. W., Diamond, M. L., Helm, P. A., Marvin, C. H., & Reiner, E. J. (2009). Perfluoroalkyl Contaminants in Window Film: Indoor/Outdoor, Urban/Rural, and Winter/Summer Contamination and Assessment of Carpet as a Possible Source. *Environmental Science & Technology*, *43*, 7317–7323. https://doi.org/10.1021/es9002718

Glüge, J., Scheringer, M., Cousins, I.T., Dewitt, J. C., Goldenman, G., Herzke, D., Lohmann, R., Ng, C.A., Trier, X., and Wang, Z. (2020). An overview of the uses of per- and polyflioralkyl substances (PFAS). *Environmental Science: Processes and Impacts*, 22, 2345-2373. https://doi.org/10.1039/D0EM00291G

Grandjean, P., Timmermann, C., Kruse, M., Nielsen, F., Vinholt, P. J., Boding, L., Heilmann, C., & Mølbak, K. (2020). Severity of COVID-19 at elevated exposure to perfluorinated alkylates. *PloS one*, *15*(12), e0244815. https://doi.org/10.1371/journal.pone.0244815

Healthy Building Network. (2017). Eliminating Toxics in Carpet: Lessons for the future of recycling. October 2017. Retrieved from https://s3.amazonaws.com/hbnweb.prod/uploads/files/eliminating-toxics-in-carpet-lessons-for-the-future-of-recycling.pdf

Inslee, J. (2020). Proclamation by the Governor Amending Proclamation 20-25. 20-28. Open Public Meeting Act and Public Records Act. March 24, 2020. Retrieved from https://www.governor.wa.gov/sites/default/files/proclamations/20-28%20-%20COVID-19%20Open%20Govt%20Laws%20Waivers%20%28tmp%291.pdf

Inslee, J. (2021). Proclamation by the Governor Amending and Extending Proclamations 20-05 and 20-28, et seq. 20-28.15 Open Public Meetings Act and Public Records Act Proclamations. January 19, 2021. Retrieved from https://www.governor.wa.gov/sites/default/files/proclamations/proc_20-28.15.pdf

Interstate Technology & Regulatory Council. (2021). Risk Communication Toolkit. Retrieved April 30, 2021 from https://rct-1.itrcweb.org/

Kim, S.-K., & Kannan, K. (2007). Perfluorinated Acids in Air, Rain, Snow, Surface Runoff, and Lakes: Relative Importance of Pathways to Contamination of Urban Lakes. *Environmental Science & Technology*, *41*, 8328–8334. https://doi.org/10.1021/es072107t

Kwiatkowski, C.F., Andrews, D.Q., Birnbaum, L.S., Bruton, T.A., DeWitt, J.C., Knappe, D.R.U., Maffini, M.V., Miller, M.F., Pelch, K.E., Reade, A., Soehl, A., Trier, X., Venier, M., Wagner, C.C., Wang, Z., & Blum, A. (2020). Scientific basis for managing PFAS as a chemical class. *Environmental Science & Technology Letters, 7, (8),* 532-543. DOI: 10.1021/acs.estlett.0c00255

Lee, S., Kim, S., Park, J., Kim, H. J., Choi, G., Choi, S., Kim, S., Kim, S. Y., Kim, S., Choi, K., & Moon, H. B. (2018). Perfluoroalkyl substances (PFASs) in breast milk from Korea: Time-course trends, influencing factors, and infant exposure. *The Science of the total environment*, *612*, 286–292. https://doi.org/10.1016/j.scitotenv.2017.08.094

Lohmann, R., Cousins, I.T., DeWitt, J.C., Glüge, J., Goldenmann, G., Herzke, D., Lindstrom, A.B., Miller, M.F., Ng, C.A., Patton, S., Scheringer, M., Trier, X., & Wang, Z. (2020). Are Fluoropolymers Really of Low Concern for Human and Environmental Health and Separate from Other PFAS? *Environmental Science & Technology Letters, 54, 20*, 12820–12828. https://doi.org/10.1021/acs.est.0c03244

Ma., J., Zhu, H, & Kannan, K. (2020) Fecal excretion of perfluorolkyo and polyfluroroalkyl substances in pets from New York State, United States. *Environmental Science & Technology Letters* 2020, 7, 135-142. https://doi.org/10.1021/acs.estlett.9b00786

Makarow, I. (2020a). Email from Irina Makarow, Ecology, to Rory O'Rourke, King County. Re: PFAS CAP Comment Period Extension Request for King County Comments. November 16, 2020. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Makarow, I. (2020b). Email from Irina Makarow, Ecology, to Shirlee Tan, King County. Re: PFAS CAP. December 28, 2020. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Makarow, I. (2021). Letter to Darrel K. Smith, National Waste & Recycling Association. January 25, 2021. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Nian, M., Luo, K., Luo, F., Aimuzi, R., Huo, X., Chen, Q., Tian, Y., & Zhang, J. (2020). Association between Prenatal Exposure to PFAS and Fetal Sex Hormones: Are the Short-Chain PFAS Safer? *Environmental Science & Technology, 54*, 8291−8299. https://doi.org/10.1021/acs.est.0c02444

Olsen, G. W., Mair, D. C., Lange, C. C., Harrington, L. M., Church, T. R., Goldberg, C. L., Herron, R. M., Hanna, H., Nobiletti, J. B., Rios, J. A., Reagen, W. K., & Ley, C. A. (2017). Per- and polyfluoroalkyl substances (PFAS) in American Red Cross adult blood donors, 2000–2015. *Environmental Research*, *157*, 87–95. https://doi.org/10.1016/j.envres.2017.05.013

O'Rourke, R. (2020). Email from Rory O'Rourke, King County, to Irina Makarow, Ecology. PFAS CAP Comment Period Extension Request for King County Comments. November 9, 2020. Retrieved from https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did200002/pid_200743/assets/merged/510miek_document.pdf?v=FUEWCV7Z4

Pérez, F., Nadal, M., Navarro-Ortega, A., Fàbrega, F., Domingo, J. L., Barceló, D., & Farré, M. (2013). Accumulation of perfluoroalkyl substances in human tissues. *Environment International*, *59*, 354–362. https://doi.org/10.1016/j.envint.2013.06.004

Poulsen, P. B., Jensen, A. A., & Wallström, E. (2005). More environmentally friendly alternatives to PFOS-compounds and PFOA. In *The Danish Environmental Protection Agency*. http://www2.mst.dk/udgiv/publications/2005/87-7614-668-5/pdf/87-7614-669-3.pdf

Product Stewardship Institute. (2015). Advancing Carpet Stewardship: A How-To Guide. October 2015. Retrieved from: https://cdn.ymaws.com/www.productstewardship.us/resource/resmgr/PSI_Reports/2015.10.14_PSI_Carpet_Report.pdf

Rice, D. & Johnson, L. (2020). Re: Docket ID No EPA-HQ-OLEM-2020-052 - Comments on *Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substa*nces, 85 Fed. Reg. 83554. December 22, 2020. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Roos, A., Berger, U., Järnberg, U., van Dijk, J., & Bignert, A. (2013). Increasing Concentrations of Perfluoroalkyl Acids in Scandinavian Otters (Lutra lutra) between 1972 and 2011: A New Threat to the Otter Population? *Environmental Science & Technology, 47*, 11757–11765. https://doi.org/10.1021/es401485t

Ruffle, B., Vedagiri, U., Bogdan, D., Maier, M., Schwach, C., & Murphy-Hagan, C. (2020). Perfluoroalkyl Substances in U.S. market basket fish and shellfish, *Environmental Research, 190,* 109932, https://doi.org/10.1016/j.envres.2020.109932.

Russell, M. H., Waterland, R. L., & Wong, F. (2015). Calculation of chemical elimination half-life from blood with an ongoing exposure source: the example of perfluorooctanoic acid (PFOA). *Chemosphere*, *129*, 210–216. https://doi.org/10.1016/j.chemosphere.2014.07.061

Sanborn, Head & Associates, Inc. (2019). PFAS Waste Source Testing Report. New England Waste Services of Vermont Inc. October 2019. Coventry, Vermont. Solid Waste ID No. OL510. Retrieved from https://anrweb.vt.gov/PubDocs/DEC/SolidWaste/OL510/OL510%202019.10.15%20NEWSVT%20PFAS%20Source%20Testing%20Rpt%20-%20Final.pdf

Scher, D. P., Kelly, J. E., Huset, C. A., Barry, K. M., Hoffbeck, R. W., Yingling, V. L., & Messing, R. B. (2018). Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. *Chemosphere*, *196*, 548–555. https://doi.org/10.1016/j.chemosphere.2017.12.179

Sharp, M. (2021). Personal communication between Irina Makarow, Ecology, and Marietta Sharp, Ecology, regarding action taken in response to allegations of possible violations of 2018 Washington state PFAS firefighting law. April 2, 2021. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Shi, Y., Vestergren, R., Nost, T. H., Zhou, Z., & Cai, Y. (2018). Probing the Differential Tissue Distribution and Bioaccumulation Behavior of Per- and Polyfluoroalkyl Substances of Varying Chain-Lengths, Isomeric Structures and Functional Groups in Crucian Carp. *Environmental Science & Technology*, *52*, 4592–4600. https://doi.org/10.1021/acs.est.7b06128

Simcich, T. (2021). Email from Tina Simcich, Ecology, to Irina Makarow, Ecology. Re: DES Carpet contract question. April 1, 2021. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Smith, D.K. (2021). Letter to Irina Makarow, Ecology. RE: Draft PFAS Chemical Action Plan. Retrieved from https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did200002/pid_200743/assets/merged/ct0rie8_document.pdf?v=T2EZ7PDG3

Spokane Regional Clean Air Agency. (2013). Statement of Basis for: Spokane Regional Solid Waste System Waste-to-Energy Facility Chapter 401 Air Operating Permit AOP-3 Renewal #2. February 11, 2013. Retrieved from https://spokanecleanair.org/documents/AOP_Permits/WTE%20Renewal%202%20Statement%20of%20Basis.pdf

Stahl, T., Mattern, D., & Brunn, H. (2011). Toxicology of perfluorinated compounds. *Environmental Sciences Europe*, *23*, 38. https://doi.org/10.1186/2190-4715-23-38

Steenland, K., Fletcher, T., Stein, C.R., M. Bartell, S.M., Darrow, L., Lopez-Espinosa, M.J., Ryan, P.B., & Savitz, D.A. (2020). Review: Evolution of evidence on PFOA and health following the assessments of the C8 Science Panel, *Environment International*, *145*, 106125. https://doi.org/10.1016/j.envint.2020.106125

Tan, S. (2020). Email from Shirlee Tan, King County, to Irina Makarow, Ecology. PFAS CAP. December 21, 2020. Retrieved from https://scs-public.s3-us-gov-west-1.amazonaws.com/env_production/oid100/did200002/pid_200743/assets/merged/490piqz_document.pdf?v=FUEWCV7Z4

U.S. Environmental Protection Agency (EPA). (2015). Pre-manufacture Notice Number P-15-502 Consent Order and Determinations Supporting Consent Order. November 6, 2015. Retrieved from https://chemview.epa.gov/

U.S. Environmental Protection Agency (EPA). (2017). UCMR3 (2013-2015) Occurrence data by state, 2017. Retrieved June 25, 2021 from https://www.epa.gov/sites/production/files/2017-02/ucmr-3-occurrence-data-by-state.zip

U.S. Environmental Protection Agency (EPA). (2020a). Draft Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances, December 18, 2020. Retrieved from https://beta.regulations.gov/docket/EPA-HQ-OLEM-2020-0527/document

U.S. Environmental Protection Agency (EPA). (2020b). Technical Brief. Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS. Methods and guidance for sampling and analyzing water and other environmental media. EPA/600/F-17/022h. Updated January 2020. Retrieved from https://www.epa.gov/sites/production/files/2020-01/documents/pfas_methods-sampling_tech_brief_7jan2020-update.pdf

U.S. Environmental Protection Agency (EPA). (2020c). Rulemaking Docket EPA-HQ-TRI-2019-0375. March 5, 2020. Retrieved March 22, 2021 from https://www.regulations.gov/docket/EPA-HQ-TRI-2019-0375/unified-agenda

U.S. Environmental Protection Agency (EPA). (2021a). Perfluorobutanesulfonamide and polyoxyalkylene containing polyurethane (PROVISIONAL). TSCA Section 5 Order. Retrieved from https://chemview.epa.gov/chemview/?tf=0&ch=241099&su=2-5-6-7-37574985&as=3-10-13-9-8&ac=1-14-15-16-6378999&ma=4-11-17-1981377&gs=&tds=0&tdl=10&tas1=1&tas2=asc&tas3=undefined&tss=&modal=template&modalId=15640453&modalSrc=16&modalDetailId=37150935&modalVaeChild=null

U.S. Environmental Protection Agency (EPA). (2021b). PFAS Analytical Methods Development and Sampling Research. Retrieved from https://www.epa.gov/water-research/pfas-analytical-methods-development-and-sampling-research#:~:text=EPA%20method%20that%20measures%20PFAS,for%2050%20specific%20PFAS%20compounds

U.S. Environmental Protection Agency (EPA). (2021c). PFAS Innovative Treatment Team (PITT). Retrieved April 8, 2021 from https://www.epa.gov/chemical-research/pfas-innovative-treatment-team-pitt

U.S. Environmental Protection Agency (EPA). (2021d). Research Brief. Innovative Research for a Sustainable Future Potential PFAS Destruction Technology: Pyrolysis and Gasification. January 2021. Retrieved from https://www.epa.gov/sites/production/files/2021-01/documents/pitt_research_brief_pyrolysis_final_jan_27_2021_508.pdf

U.S. Fire Administration. (1998). U.S. Fire Administration/Technical Report Series. Special Report: Scrap and Shredded Tire Fires USFA-TR-093/December 1998. Retrieved from https://www.usfa.fema.gov/downloads/pdf/publications/tr-093.pdf

U.S. Food and Drug Administration (FDA). (2020). FDA Announces the Voluntary Phase-Out by Industry of Certain PFAS Used in Food Packaging. Constituent Update. July 31, 2020. Retrieved March 31, 2021 from https://www.fda.gov/food/cfsan-constituent-updates/fda-announces-voluntary-phase-out-industry-certain-pfas-used-food-packaging

Valeriano, L. (2020). Letter from Laurie Valeriano, Toxic Free Future, to Darin Rice, Ecology. Regarding enforcement of the 2018 Washington state PFAS firefighting foam law. July 21, 2020. Available at https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFAS_CAP_PersonalCommunication_References.pdf

Venkatesan, A. K., & Halden, R. U. (2013). National inventory of perfluoroalkyl substances in archived U.S. biosolids from the 2001 EPA National Sewage Sludge Survey. Journal of Hazardous Materials, 252–253, 413–418. https://doi.org/10.1016/j.jhazmat.2013.03.016

Waterfield, G., Rogers, M., Grandjean, P., Auffhammer, M., & Sunding, D. (2020). Reducing exposure to high levels of perfluorinated compounds in drinking water improves reproductive outcomes: evidence from an intervention in Minnesota. *Environmental Health, 19*, 42. https://doi.org/10.1186/s12940-020-00591-0

Washington State Department of Commerce. (2020). Funding Programs for Drinking Water abd Wastewater Projects. Updated October 2, 2020. Retrieved from https://deptofcommerce.app.box.com/v/sciwaterfundingsummary

Washington State Department of Ecology (Ecology). (2020). Shoptalk, Dangerous Waste and Pollution Prevention newsletter, Spring 2020. Retrieved from https://apps.ecology.wa.gov/publications/documents/2004002.pdf

Washington State Department of Ecology (Ecology). (2021a). Per- and polyfluoroalkyl substances (PFAS). Retrieved on July 13, 2021 from https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals/PFAS

Washington State Department of Ecology (Ecology). (2021b). Everett landfill Tire Fire. Site Information. Retrieved from https://apps.ecology.wa.gov/gsp/Sitepage.aspx?csid=3862

Washington State Department of Health (Health). (2021a). PFAS. Retrieved on July 13, 2021 from https://www.doh.wa.gov/CommunityandEnvironment/Contaminants/PFAS

Washington State Department of Health (Health). (2021b). Washington State Department of health, Office of Drinking Water, Source Water Assessment Program (SWAP) Mapping Application. Accessed June 25, 2021. https://fortress.wa.gov/doh/swap/index.html

Washington State Legislature. (2012). Substitute Senate Bill 6341. February 3, 2012. Retrieved from https://apps.leg.wa.gov/documents/billdocs/2011-12/Pdf/Bills/Senate%20Bills/6341-S.pdf

Washington State Register (WSR). (2020a). WSR 20-19-130. Department of Ecology. Filed September 22, 2020, 10:59 a.m. Announcing the Draft Per- and Polyfluoroalkyl Substances (PFAS) Chemical Action Plan (CAP)—Complete and Published for Public Comment. Retrieved from lawfilesext.leg.wa.gov/law/wsr/2020/19/20-19-130.htm

Washington State Register (WSR). (2020b). WSR 20-23-092. Department of Ecology. Filed November 17, 2020, 2:35 p.m. Extending the Public Comment Period on the Draft Per- and Polyfluoroalkyl Substances (PFAS) Chemical Action Plan (CAP) Through January 4, 2021. Retrieved from lawfilesext.leg.wa.gov/law/wsr/2020/23/20-23-092.htm

Washington State Register (WSR). (2021). WSR 21-02-031. Department of Ecology. Filed December 29, 2020, 7:39 a.m. Extending the Public Comment Period on the Draft Per- and Polyfluoroalkyl Substances (PFAS) Chemical Action Plan (CAP) Through January 22, 2021. Retrieved from lawfilesext.leg.wa.gov/law/wsr/2021/02/21-02-031.htm

Whiting, I., Nicol, L., Keyte, I., KriBig, J., Crookes, M., Gebbink, W., Potrykus, A., &Schopel, M. (2020). The use of PFAS and fluorine-free alternatives in textiiles, upholstery, carpets, leather and apparel: Final report under framework contract ENV.A3/FRA/2015/0010. In V3 ed. October 10, 2020. Retrieved from https://echa.europa.eu/documents/10162/13641/pfas_in_textiles_final_report_en.pdf/0a3b1c60-3427-5327-4a19-4d98ee06f041

Zhang, C., Hopkins, Z.R., McCord, J., Strynar, M.J., & Knappe, D.R.U. (2019). Fate of Per- and Polyfluoroalkyl Ether Acids in the Total Oxidizable Precursor Assay and Implications for the Analysis of Impacted Water. *Environmental Sciences and Technology Letters, 6(11)*, 662–668. doi: 10.1021/acs.estlett.9b00525.

Zheng, G., Schreder, E., Dempsey, J.C., Uding, N., Chy, V., Andres, G., Sathyanarayana. S., & Salamova, A. (2021). Per- and Polyfluoroalkyl Substances (PFAS) in Breast Milk: Concerning Trends for Current-Use PFAS. *Environmental Science and Technology, 55,* 11, 7510–7520. https://doi.org/10.1021/acs.est.0c06978

Zushi, Y., & Masunaga, S. (2009). Identifying the nonpoint source of perfluorinated compounds using a geographic information system based approach. *Environmental Toxicology and Chemistry*, *28*, 691. https://doi.org/10.1897/08-194.1

List of acronyms

General acronyms

Table 95. Acronyms found in the response to comments appendix.

Acronym	Definition
AAAS	American Association for the Advancement of Science
AFFF	Aqueous film forming foam
ASTHO	Association of State and Territorial Health Officials
ATSDR	Agency for Toxic Substances and Disease Registry
BAF	Bioaccumulation factor
BCF	Bioconcentration factor
BW	Body weight
CAA	Clean Air Act
CAP	Chemical Action Plan
CAS	Chemical Abstract Service
CDC	U.S. Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHCC	Chemicals of high concern to children
COVID-19	Coronavirus disease 2019
CSPA	Children's Safe Products Act
CWA	Clean Water Act
D	Day
DOD	United States Department of Defense
DON	United States Department of the Navy
E2SSB	Engrossed Second Substitute Senate Bill
DW	Dangerous Waste
ECF	Electrochemical fluorination
ECOS	Environmental Council of States
ECOssl	Ecological soil screening levels
EFSA	European Food Safety Authority
EHW	Extremely hazardous waste
EIS	Environmental impact statement
EJ	Environmental justice
EPA	United States Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ERIS	Environmental Research Institute of the States
FAA	Federal Aviation Administration
FCN	Food contact notification
FDA	United States Food and Drug Administration

Acronym	Definition
Fed. Reg.	Federal Register
GAC	Granular activated carbon
Health	Washington State Department of Health
HED	Human equivalent
HOC	Halogenated organic compound
I	Interstate
IDC	Initial demonstration of capability
ITRC	Interstate Technology & Regulatory Council
Kg	Kilogram
LOAEL	Lowest observed adverse effects level
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
mg	Milligram
Mg/ha	Megagram per hectare
MI SAW	Michigan Science Advisory Workgroup
MQO	Measurement quality objectives
MSWLF	Municipal solid waste landfill
MS4	Municipal separate stormwater sewer system
MTCA	Model Toxics Control Act
MWC	Municpal waste combustor
NEBRA	Northeast Biosolids and Residuals Association
ng/kg-day	Nanogram per kilogram per day
NOAEL	No observed adverse effects level
NDAA	National Defense Authorization Act
NPDES	National pollutant discharge elimination system
NWRA	National Waste and Recycling Association
OC	Organic contaminant
OECD	Organisation for Economic Co-operation and Development
OTM	Other test method
PIGE	Particle-induced gamma ray emission
ppm	Part per million
ppt	Part per trillion
POTW	Publicly owned treatment works
QAPP	Quality assurance progress plan
QC	Quality control
QSM	Quality systems manual
RCRA	Resource Conservation and Recovery Act
RCW	Revised Code of Washington
SAL	State action level
SBOH	Washington State Board of Health
SERDP	Strategic Environmental Research and Development Program

Acronym	Definition
SNUR	Signficant New Use Rule
SOP	Standard operating procedure
SQG	Small quantity generator
SSHERI	Social Science Environmental Health Research Institute
TCP	Toxic Cleanup Program
TOP	Total oxidizable precursor
TRI	Toxics release inventory
TSCA	Toxic Substances Control Act
UCMR	Unregulated contaminant monitoring rule
UCMR3	Third unregulated contaminant monitoring rule
UCMR5	Fifth unregulated contaminant monitoring rule
U.S.	United States
UTC	Washington State Utilities and Transportation Commission
VCP	Voluntary cleanup program
WAC	Washington Administrative Code
WDFW	Washington State Department of Fish and Wildlife
WSA	Waste stream assessment
WSDOT	Washington State Department of Transportation
WSR	Washington State Register
WWTP	Wastewater treatment plant

Chemical names

Table 96. Chemical name acronyms found in the response to comments appendix, excluding general acronyms listed only in the table above.

Acronym	Chemical name
6:2 FTOH	6:2 fluorotelomer alcohol
8:2 FTOH	8:2 fluorotelomer alcohol
6:2 FTS	6:2 fluorotelomer sulfonate
ADONA	4, 8-Dioxa-3H-Perfluorononoic acid
APFO	Ammonium perfluorooctanoate
C	Carbon
F	Fluorine
FTAC	Fluorotelomer acrylate
FTOH	Fluorotelomer alcohol
FTS	Fluorotelomer sulfonate
FTSCl	Fluorotelomer sulfonyl chloride
H	Hydrogen
HFPO-DA (GenX)	Hexafluoropropylene oxide dimer acid

Acronym	Chemical name
PAF	Perfluoroalkanoyl fluoride
PAP	Per- or polyfluoroalkyl phosphate ester
PASF	Perfluoroalkane sulfonyl fluoride
PCA	Polychlorinated alkane
PFAA	Perfluorinated alkyl acid
PFAI	Perfluoroalkyl iodides
PFAL	Perfluoroalkyl aldehydes and aldehyde hydrates
PFAS	Per- and poly-fluorinated alkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonic acid
PFCA	Perfluoro-carboxylic acid
PFDA	Perfluorodecanoic acid
PFDS	Perfluorodecane sulfonate
PFEA	Perfluoroalkyl ether acids
PFECA	Perfluoroalkyl ether carboxylic acid
PFEESA	Perfluoro(2-ethoxyethane)sulfonic acid
PFESA	Perfluoroalkyl ether sulfonic acid
PFHpA	Perfluoroheptanoic acid
PFHpS	Perfluoroheptane sulfonic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOSA	Perfluorooctane sulfonamide
PFSA	Perfluoro- sulfonic acid
PFTeDA	Perfluorotetradecanoic acid
POSF	Perfluorooctane sulfonyl fluoride
UV	Ultraviolet

EXHIBIT F

Focus on: PFAS Cleanup Levels

Photo credit: jplenio on Pixabay

Purpose and background

This focus sheet provides the Washington State Department of Ecology's (Ecology's) recommended soil and groundwater cleanup levels for part of a group of harmful compounds known as per- and polyfluoroalkyl substances, or PFAS. These compounds include:

1. PFOA, or perfluorooctanonic acid,
2. PFOS, or perfluorooctane sulfonic acid,
3. PFNSA, or perfluorononanoic acid,
4. PFHxS, or perfluorohexane sulfonic acid,
5. PFBS, or perfluorobutane sulfonic acid, and
6. HFPO-DA (GenX), or hexafluoropropylene oxide dimer acid.

The Washington State Department of Health (DOH) issued a final rule that included groundwater State Action Levels (SALs) for the first five PFAS compounds listed above, which became effective on January 1, 2022. The Department of Health calculated the SALs using peer-reviewed non-cancer reference doses (RfDs) that represent the best available science. They used RfDs to establish the SALs because there are limited data available to support a quantitative assessment of cancer risk for PFAS compounds.

At a future date, we will release our recommended cleanup levels for terrestrial ecological, surface water, sediments, and air quality.

Recommended groundwater cleanup levels

For PFAS with SALs, Ecology recommends using the SALs as the appropriate groundwater cleanup levels. For chemicals without SALs, Ecology recommends using RfDs developed by EPA to calculate the appropriate cleanup level. The recommended groundwater cleanup levels for the first five compounds in Table 1 are the DOH SALs.

We calculated the recommended groundwater cleanup level for HFPO-DA using Model Toxics Control Act (MTCA) Equation 720-1[1] and EPA reference doses (RfDs).

For comparison purposes, we've also included the Environmental Protection Agency's (EPA) Health Advisory Levels for PFOA, PFOS, PFBS, and HFPO-DA. EPA is still evaluating the RfDs they used to develop the interim Health Advisory Levels for PFOA and PFOS, and it's possible these levels could be revised in the future. EPA is also developing RfDs for several other PFAS compounds, which may lead to additional groundwater health advisories.

Table 1: Recommended groundwater cleanup levels

PFAS Compound	Recommended Groundwater Cleanup Level	EPA Health Advisory Level
PFOA	10 ng/L	0.004 ng/L
PFOS	15 ng/L	0.02 ng/L
PFNA	9 ng/L	None
PFHxS	65 ng/L	None
PFBS	345 ng/L	2,000 ng/L
HFPO-DA (GenX)	24 ng/L	10 ng/L

Note: On June 15, 2022, EPA issued "interim" Health Advisories for PFOS and PFOA, and final Health Advisories for PFBS and HFPO-DA. Ecology is not using the EPA Health Advisory Levels as recommended cleanup levels because: 1) the levels for PFOA and PFOS are interim and subject to change, 2) the PFBS level exceeds the DOH SAL, and 3) the approach used to determine the level for HFPO-DA is not consistent with the process set out in MTCA.

Recommended soil cleanup levels protective of groundwater

Table 2 provides recommended soil concentrations for both the vadose zone and the saturated zone that are protective of groundwater. We calculated these levels using MTCA Equation 747-1,[2] the groundwater cleanup levels in Table 1, and the default soil characteristics listed in the MTCA Cleanup Rule. We used organic carbon-water partitioning coefficients (Koc) and Henry's Law constants (Hcc) from the Oak Ridge National Labs database.[3] We calculated soil water distribution coefficient (Kd) values from Koc values using MTCA Equation 747-2.

Table 2: Recommended soil cleanup levels protective of groundwater

PFAS Compounds	Vadose Zone	Saturated Zone
PFOA	6.3E-05 mg/kg	4.0E-06 mg/kg
PFOS	1.7E-04 mg/kg	9.9E-06 mg/kg
PFNA	8.0E-05 mg/kg	4.8E-06 mg/kg
PFHxS	4.1E-04 mg/kg	2.6E-05 mg/kg
PFBS	1.8E-03 mg/kg	1.2E-04 mg/kg
HFPO-DA (GenX)	1.0E-04 mg/kg	7.2E-06 mg/kg

Soil direct contact cleanup levels

The soil direct contact levels in Table 3 are protective of human health based on exposure through incidental soil ingestion. We calculated recommended cleanup levels using Equation 740-1[4] (Method B—unrestricted use) and Equation 745-1[5] (Method C—sites meeting the definition of an industrial property under the MTCA Cleanup Rule). We used the RfDs that were adopted by the Department of Health for establishing the State Action Levels, along with the associated default exposure assumptions provided in the MTCA Cleanup Rule. For HFPO-DA, we used the RfD developed by EPA.

Table 3: Recommended soil direct contact cleanup levels

PFAS Compounds	Method B	Method C
PFOA	0.24 mg/kg	11 mg/kg
PFOS	0.24 mg/kg	11 mg/kg
PFNA	0.2 mg/kg	8.8 mg/kg
PFHxS	0.78 mg/kg	34 mg/kg
PFBS	24 mg/kg	1,100 mg/kg
HFPO-DA (GenX)	0.24 mg/kg	11 mg/kg

Compliance with state and federal laws

Cleanup levels must comply with applicable local, state, and federal laws, along with requirements Ecology has determined to be relevant and appropriate in the MTCA Cleanup Rule (WAC 173-340-710(4)).[6] Together these requirements are referred to as ARARs. As of June 2022, there are no legally applicable state or federal laws, such as Maximum Contaminant Levels, to apply when developing PFAS cleanup levels. However, each cleanup site can be reviewed to determine if there are relevant and appropriate requirements that, while not legally required, should be applied depending on circumstances at the site. To make this determination, Ecology needs to evaluate criteria in WAC 173-340-710(4) to establish that the recommended levels are relevant and appropriate.

Until Ecology makes a site-specific determination, you can consider the soil and groundwater cleanup levels set forth in this focus sheet to be preliminary cleanup levels. This will provide a common understanding of the potential severity of the PFAS contamination found as part of a site investigation.

Related information

- PFAS and cleanups[7]
- Learn more about PFAS and health[8]
- MTCA Cleanup Rule (Chapter 173-340 WAC)[9]

Mark Gordon, P.E
mark.gordon@ecy.wa.gov
360-529-7727

To request an ADA accommodation, contact Ecology by phone at 360-407-7170 or email at first.last@ecy.wa.gov, or visit https://ecology.wa.gov/accessibility.
For Relay Service or TTY call 711 or 877-833-6341.

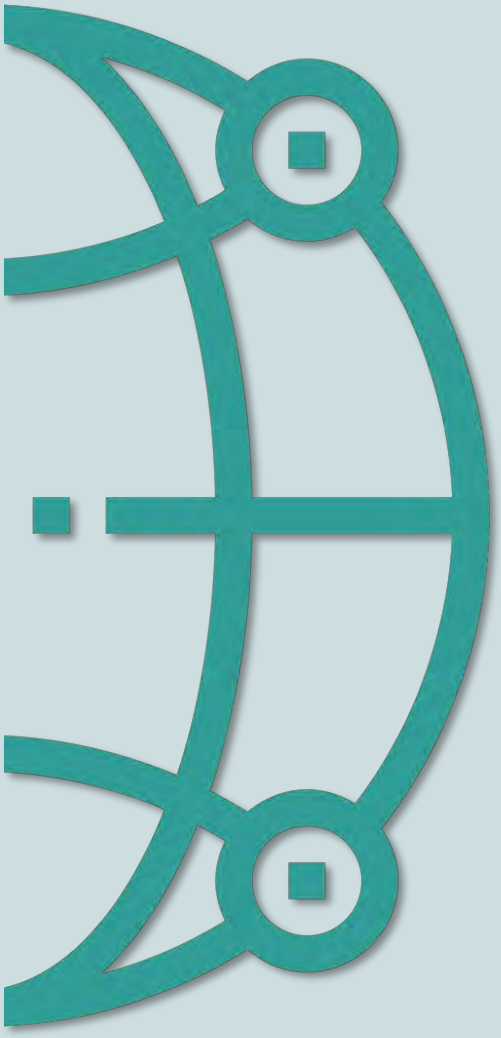
[1] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-720
[2] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-747
[3] https://rais.ornl.gov/
[4] https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-740
[5] https://apps.leg.wa.gov/wac/default.aspx?cite=173-340-745
[6] https://app.leg.wa.gov/wac/default.aspx?cite=173-340-710
[7] https://ecology.wa.gov/PFAScleanup
[8] https://ecology.wa.gov/PFAS
[9] https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340

EXHIBIT G

Fish Advisory Evaluation:

PFOS in Fish from Lakes Meridian, Sammamish, and Washington

2022



Washington State Department of Health

DECEMBER 2022

To request this document in another format, call 1-800-525-0127. Deaf or hard of hearing customers, please call 711 (Washington Relay) or email civil.rights@doh.wa.gov.

Publication Number

334-470

For more information or additional copies of this report:

Division of Environmental Public Health

Office of Environmental Public Health Sciences

P.O. Box 47846

Olympia, Washington 98504-7846

Toll free 1-877-485-7316

doheheha@doh.wa.gov

Report Authors

Emerson Christie
Toxicologist

Umair Shah, MD, MPH
Secretary of Health

Contents

Executive Summary

In 2018, the Washington State Department of Ecology (Ecology) collected freshwater fish from Lakes Meridian, Sammamish, and Washington and analyzed for 15 per and poly fluoroalkyl substances (PFAS). The Washington State Department of Health (DOH) has evaluated the fish tissue data to determine possible health implications and whether contaminant concentrations warrant changes to and/or issuance of fish advisories on Lakes Meridian, Sammamish, and Washington. Based on perfluorooctane sulfonate (PFOS) fish tissue concentrations and an average-sized adult (70 kg or 154 lbs) eating an eight-ounce meal, DOH provides the following recommendations:

Location/Species	Calculated Meals Per Month	Recommended Meals Per Month	Basis
Lake Meridian			
Brown bullhead	12	No Advisory	This evaluation
Kokanee	2	2	This evaluation
Largemouth bass	1	1	This evaluation
Northern pikeminnow	0	Do Not Eat	Statewide advisory
Smallmouth bass	0	Do Not Eat	This evaluation
Yellow perch	1	1	This evaluation
Lake Sammamish			
Brown bullhead	13	No Advisory	This evaluation
Largemouth bass	0	Do Not Eat	This evaluation
Northern pikeminnow	0	Do Not Eat	Statewide advisory
Smallmouth bass	2	2	Statewide advisory
Yellow perch	1	1	This evaluation
Lake Washington			
Brown bullhead	5	4	This evaluation
Common carp	0	Do Not Eat	Prior Lake WA advisory
Cut-throat trout	0	Do Not Eat	This evaluation
Largemouth bass	0	Do Not Eat	This evaluation
Northern pikeminnow	0	Do Not Eat	Prior Lake WA advisory
Pumpkinseed	19	No advisory	Prior Lake WA advisory
Rainbow trout	19	No advisory	Prior Lake WA advisory
Smallmouth bass	0	Do Not Eat	This evaluation
Sockeye salmon	20	No advisory	Prior Lake WA advisory
Yellow perch	1	1	This evaluation

Background

The Washington State Department of Health (DOH) works to protect and improve the health of people in Washington State. Part of this mission is to reduce or eliminate exposures to health hazards in the environment, including contaminants found in fish. Starting in 2008, the Washington State Department of Ecology (Ecology) has sampled freshwater and fish tissue in order to survey levels of per and poly fluoroalkyl substances (PFAS) in rivers and lakes across the state. A 2008 survey analyzed 15 composite fish samples of 11 different species collected from seven freshwater bodies throughout the state. Only four PFAS were detected and quantified. Perfluorooctane sulfonate (PFOS) was detected in 40% of fillet samples (6 out of 15). In 2008, Ecology collected fish from throughout the state as part of a screening survey for PFAS in Washington rivers and lakes (Ecology, 2010). PFOS was the primary compound observed and the highest concentrations were in samples from urban waters. In 2016, Ecology measured PFAS in various species of freshwater fish from 11 water bodies in Washington (Ecology, 2017) as part of the follow-up study to the 2008 survey. PFOS was still the dominant compound in all fillet samples, making up 62 – 100% of the total concentration of PFAS detected. The levels were highest in fish collected from urban waterbodies. This is consistent with global environmental surveys indicating PFAS concentrations are highest in urban watersheds due to increased anthropogenic inputs (Kurwadkar et. al. 2021).

To characterize PFAS levels in fish for DOH fish advisories, Ecology collected additional fish in 2018 from Lake Meridian, Lake Sammamish, and Lake Washington (Ecology 2022). Specifically, five fish species: brown bullhead (*Ameiurus nebulosus*), yellow perch (*Perca flavescens*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), and kokanee (*Oncorhynchus nerka*) from Lake Meridian; three fish species: brown bullhead, yellow perch, largemouth bass from Lake Sammamish; and five fish species: brown bullhead, yellow perch, largemouth bass, smallmouth bass, and cutthroat trout (*Oncorhynchus clarkii*) from Lake Washington. DOH evaluated the fish tissue data provided by Ecology to determine possible health implications and whether PFAS concentrations warrant changes to existing fish advisories and/or the issuance of new fish advisories on Lakes Meridian, Sammamish, and Washington.

Assessment Methodology

The assessment is based on a comparison of reported mean chemical concentrations with a corresponding screening level (SL). SLs are used as threshold values against which tissue residue levels of a contaminant in seafood can be compared. SLs were calculated based on non-carcinogenic effects of the chemical contaminant for both the general (SL = 1.8 µg/kg) and high (SL = 0.6 µg/kg) fish consumer groups. The method we use is discussed in detail in Volume 1 of EPA's Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories (EPA 2000a). The general equation to derive a screening level is as follows.

Non-carcinogens:

$$Screening\ Level\ (SL_{nc}) = \frac{RfD\ x\ BW\ x\ UCF}{CR} \times RSC$$

Where: SL_{nc} = chemical specific non-cancer screening concentration (mg/kg)

BW = average body weight of adult (70 kg) or childbearing age woman (60 kg)

UCF = unit conversion factor ($1x10^3$ g/kg)

RfD = chemical specific oral reference dose (mg/kg-day)

CR = consumption rate (g/day)

RSC = relative source contribution (unitless)

Consumption Rate

For this evaluation, DOH calculated SLs based on consumption rates of 8 and 23 meals per month, one meal is defined as one 8-oz. serving (6-oz. cooked). This is equivalent to 59.7 and 175 grams of fish per day, respectively. The eight meal per month consumption rate corresponds to advice from the Dietary Guidelines for Americans, recommending that people consume 8 to 12-oz of fish per week due to the health benefits from consuming seafood (Dietary Guidelines 2020). It is also the rate at which or below that DOH may issue an advisory. Twenty-three meals per month consumption rate corresponds to a value that Ecology proposed in setting Federal Clean Water Act (CWA) Standards, it is used by the state of Oregon for compliance with the CWA, and is further supported by the Columbia River Inter-Tribal Fish Commission (CRITFC). Twenty-three meals a month is approximately the 95th percentile consumption rate of its tribal members (CRITFC 1994). While DOH does not give meal restrictions on fish consumption rates greater than two meals per week (eight meals per month), DOH provides calculated meal recommendations for all available contaminant concentrations measured in a given species for individuals who exceed this general population consumption rate and have additional questions or concerns.

PFOS Reference Dose

Noncancer health effects associated with exposure to PFOS include a variety of adverse health effects observed in animal and human studies. Among the most sensitive of these health effects is immune suppression (Dong et al. 2009, Dong et al. 2011, Peden-Adams et al. 2008, Xheng et al. 2009, Guruge et al. 2009). A systematic review by the National Toxicology Program (NTP) for evidence of immune toxicity from epidemiological studies and studies in experimental animals concluded that PFOS met the criteria of a "presumed immune hazard" in humans (NTP 2016). This was based on high confidence that PFOS is immunotoxic in rodents and moderate evidence of immunotoxicity in humans. Therefore, DOH has chosen to use the RfD of 3 x 10^{-6} mg/kg-day, from the current State Action Level in drinking water based on Dong et. al. 2011, as the noncancer toxicity value for use in the derivation of the risk-based fish consumption guidelines for PFOS.

Relative Source Contribution

Relative Source Contribution (RSC) used in establishing fish advisories is meant to account for non-fish sources of exposure to non-carcinogens. Multiple exposure pathways exist for PFOS including drinking water, other foods, occupational exposures, and consumer products. In establishing drinking water criteria for PFOS, DOH has adopted a drinking water RSC of 0.2 (DOH 2021) and apportioned 80% (0.8) to all other potential sources of exposure to PFOS. Fish and shellfish consumption is considered to be the primary PFOS dietary exposure route (EFSA 2020). Here DOH chose to assign an RSC of 50% (0.5) to use when apportioning PFOS exposure from fish consumption, and the remaining 30% (0.3) from other unknown potential dietary and environmental sources.

Calculating Meal Limits for Individual Chemical Exposures

When concentrations in fish tissue exceed screening levels considered to be protective, meal limits are calculated to inform consumers. In calculating screening levels, advice is targeted to the most sensitive population (e.g. women of childbearing age and young children). Calculating safe consumption rates based on the sensitive population would then also protect all other populations if the advice is followed.

In this assessment, DOH uses mean tissue concentrations to calculate meal recommendations. While median values are important for evaluating contaminant concentrations, the median value is insensitive to outliers, particularly at the high end. Non-detected values were assigned a value equal to one-half the corresponding detection limit. When evaluating contaminant data for use in deriving a fish advisory, DOH does not evaluate data with a detection frequency of less than ten percent.

Allowable meal limits are calculated based on non-cancer criteria, average body weight of an individual, and the known contaminant concentration in seafood. The equation used to calculate a safe consumption rate is shown below, with exposure parameters as defined in Table 1 (EPA 2000b).

Non-cancer meal equation:

$$Meal\ per\ month\ = \frac{RfD\ x\ BW\ x\ CF1\ x\ CF2}{MS\ x\ C}$$

Table 1. Exposure Parameters for Calculating PFOS Fish Meal Limits

Parameter	Value	Units	Comments
Reference Dose (RfD)	3×10^{-6}	mg/kg-day	PFOS
Body Weight (BW)	70	kg	70 kg adult
Conversion Factor (CF1)	30.44	days/month	
Conversion Factor (CF2)	1000	g/kg	
Meal Size (MS)	227	g	8 oz. meal
Concentration in fish (C)	Mean	mg/kg	Species specific

Single contaminant meal calculations are assessed using the most restrictive health criteria. Calculated meal limits are rounded up or down to fit one of the six meal rate categories used by DOH (no consumption, one, two, four, eight meals per month, or no advisory) to address ease of messaging (Table 2).

Table 2. PFOS meal limit categories based on fish tissue concentration ranges.

$[C]_{fish}$ (µg/kg)	# Meals
< 1.8	No Advisory
1.8 – 2.3	8 meals/month
2.4 – 4.7	4 meals/month
4.8 – 9.4	2 meals/month
9.5 – 28.2	1 meal/month
> 28.2	Do Not Eat

Calculating meal limits is the quantitative phase of developing a fish advisory. Other qualitative considerations include, but are not limited to, chemical background concentrations, the ability to reduce chemical concentrations through cleaning and cooking techniques (Great Lakes 1993), chemical concentrations in other food, known benefits of fish consumption, and ease of messaging.

Results

Ecology analyzed a total of 76 composite fillet samples (each composite consisting of 3-5 individual fish) collected from Lakes Meridian, Sammamish, and Washington. Laboratory results for PFOS are summarized below (Table 3). Data sets available through Ecology's Environmental Information Management database https://apps.ecology.wa.gov/eim/search/default.aspx.

PFOS was detected in and was the dominant PFAS compound in all samples analyzed, making up 70+% of the total PFAS concentration in all fish species except brown bullhead. PFOS remained the dominant compound in brown bullhead but with a lower percent contribution (<70%) of the total. The remaining PFAS detected were long-chain perfluoroalkyl carboxylates (PFCAs) and were present in much lower amounts than PFOS across the species. At the present time DOH is developing fish consumption guidance based upon PFOS concentrations, although this may change in the future as additional information comes available.

A summary of average PFOS concentrations for fish species at each location are in Table 3. PFOS levels were comparable among species across locations with the exception of brown bullhead

which were slightly higher at Lake Washington compared to Lakes Meridian and Sammamish. PFOS levels were highest in smallmouth bass followed by largemouth bass and cut-throat trout. Cut-throat trout in Lake Washington and smallmouth bass and yellow perch in Lake Meridian had smaller sample sizes, however, PFOS concentrations were high enough to necessitate some guidance; especially with supporting concentrations observed in nearby lakes.

Table 3. Average PFOS concentrations per fish species per location.

Location/Species	Composite Sample Size	% Detected	Mean $[C]_{fish}$ (µg/kg)
Lake Meridian			
Brown bullhead	5	100%	1.2
Kokanee	3	100%	7.3
Largemouth bass	4	100%	24.2
Smallmouth bass	2	100%	62.1
Yellow perch	2	100%	10.8
Lake Sammamish			
Brown bullhead	5	100%	1.1
Largemouth bass	5	100%	37.8
Yellow perch	5	100%	15.4
Lake Washington			
Brown bullhead	15	100%	2.6
Cut-throat trout	2	100%	34.0
Largemouth bass	13	100%	31.4
Smallmouth bass	3	100%	93.8
Yellow perch	12	100%	13.2

Recommendations

General Fish Consumption Advice

Eat fish, fish are good for you. DOH encourages all Washingtonians to eat at least eight to twelve ounces of fish per week in accordance with The Dietary Guidelines for Americans (2020). The purpose of a fish advisory is not to discourage or restrict fish consumption but to inform people about risks associated with consumption of fish species at specific locations. Our advice helps people avoid fish high in contaminants in favor of fish lower in contaminants. People may eat more than eight ounces of fish weekly; however frequent consumers should consider taking steps to reduce exposure to contaminants in the fish that they eat. Some general guidance is as follows:

- Eat a variety of fish that are low in contaminants according to guidance provided by DOH (http://www.doh.wa.gov/fish/) and local health agencies.
- Consume younger, smaller fish (within legal limits). These fish typically contain lower levels of accumulative contaminants than older, larger fish.
- When cleaning fish, remove the skin, fat, and internal organs before cooking; this will help to reduce the amount of some contaminants.
- Grill, bake, or broil fish so that fat drips off while cooking.
- Young children and small adults should eat proportionally smaller meal sizes (Table 4).

Table 4. Adjustment of fish meal size based on the body weight of the consumer.

Weight (lbs)	Mass (kg)	Meal Size (oz)	Meal Size (g)
19	9	1	28
39	18	2	57
58	26	3	85
77	35	4	113
96	44	5	142
116	53	6	170
135	61	7	199
154	70	8	227
173	79	9	255
193	88	10	284
212	96	11	312
231	105	12	340
250	113	13	369
270	123	14	397
289	131	15	425
308	140	16	454

Waterbody Specific Guidance

DOH provides the following recommendations within table 5. Included are meal recommendations for PFOS, calculated utilizing the non-cancer meal equation described above, as well as pre-existing guidance for each waterbody from two prior fish advisories: a statewide advisory for mercury and a Lake Washinton advisory for polychlorinated biphenyls in fish tissue.

Table 5. Lake Meridian, Lake Sammamish, and Lake Washington recommended meals per month per species.

Location/Species	Calculated Meals Per Month	Recommended Meals Per Month	Basis
Lake Meridian			
Brown bullhead	12	No Advisory	This evaluation
Kokanee	2	2	This evaluation
Largemouth bass	1	1	This evaluation
Northern pikeminnow	0	Do Not Eat	Statewide advisory
Smallmouth bass	0	Do Not Eat	This evaluation
Yellow perch	1	1	This evaluation
Lake Sammamish			
Brown bullhead	13	No Advisory	This evaluation
Largemouth bass	0	Do Not Eat	This evaluation
Northern pikeminnow	0	Do Not Eat	Statewide advisory
Smallmouth bass	2	2	Statewide advisory
Yellow perch	1	1	This evaluation
Lake Washington			
Brown bullhead	5	4	This evaluation
Common carp	0	Do Not Eat	Prior Lake WA advisory
Cut-throat trout	0	Do Not Eat	This evaluation
Largemouth bass	0	Do Not Eat	This evaluation
Northern pikeminnow	0	Do Not Eat	Prior Lake WA advisory
Pumpkinseed	19	No advisory	Prior Lake WA advisory
Rainbow trout	19	No advisory	Prior Lake WA advisory
Smallmouth bass	0	Do Not Eat	This evaluation
Sockeye salmon	20	No advisory	Prior Lake WA advisory
Yellow perch	1	1	This evaluation

Benefits of fish consumption

Fish is considered a healthy food, known to be high in protein, low in saturated fats and rich in other nutrients such as vitamin D, iodine, and selenium. Health benefits of eating fish are well documented and linked to the reduction of cardiovascular disease, osteoporosis, and partial reduction of certain types of cancer. These major chronic diseases afflict much of the U.S. population. Advisories can be protective yet acknowledge benefits of eating fish, by recommending decreased consumption of fish known to have high concentrations of contaminants in favor of fish that are lower in contaminants.

Fish is the primary dietary source of two long chain n-3 polyunsaturated fatty acids (n-3 PUFAs), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). N-3 PUFAs are essential components of membranes in all cells of the body are vitally important for normal development of the brain and retinal tissues and for maintenance of normal neurotransmission and connectivity (Wenstrom 2014). Much of the research examining the possible adverse health effects of diets deficient in n-3PUFAs has focused on cardiovascular risks among older adults or developmental outcomes associated with perinatal exposure. An example of these benefits from fish consumption includes an associated with improvement of blood lipid profiles, decreased risk of heart disease, and lowered blood pressure (IOM 2006, Mozaffarian and Rimm 2006) and enhanced eye and brain development in early life (Fleith and Clandinin 2005). Other evidence of the beneficial health effects has shown improvement in rheumatoid arthritis (Kremer 2000), prevention of macular degeneration (SanGiovanni et al. 2007), lower risk of colitis (Hudert et al. 2006) and type 2 diabetes (Barre 2007), and improvements in neurologic and psychological disorders such as depression, schizophrenia, and Parkinson disease (Calon and Cole 2007).

Fish oil enriched with n-3 PUFAs has therapeutic value in treating a wide variety of inflammation-associated disorders. Infants whose mothers were supplemented with EPA and DHA during pregnancy were shown to have a decreased risk of food allergies and IgE-associated eczema (Furuhjelm et al. 2009) and decreased incidence of asthma (Olsen et al. 2008). Fish oil is associated with modulation of the immune function (Yagoob 2010), reductions subclinical inflammation (Souza et al. 2020) and has been associated with a boost of humoral (B cell) response to antigens, the lessening of and prevention of immune mediated inflammatory processes, and the development of immune functions in early infancy (Shaikh el al. 2012, Whelan et al. 2016, Calder 2017). Fish oil or more specifically, a metabolite of DHA administered to mice that were then subsequently challenged with influenza antigen vaccination showed an increase in both IgM and IgG antibody production as well as greater resistance to infection (Ramon 2014). Marine fatty acids (EPA and DHA) give rise to anti-inflammatory and inflammation resolving mediators called resolvins, protectins, and maresins and inhibition of activation pro-inflammatory transcription factors (Calder 2015).

Non consumptive benefits of fish

Fish is not only an important source of nutrition, the act of catching, preparing, and eating fish are important cultural and family practices that contribute to health and well-being. Fish is an important cultural food in Washington State that defines a recreational as well as a spiritual way of life in the Pacific Northwest. In Native American tribal communities, fish and other seafood are important to food security, community cohesion, ceremonies, and cultural practices that promote individual and community health and well-being (Donatuto et. al. 2011). Recreational fishing may also contribute to health and well-being in numerous ways such as spending time in nature (White et. al. 2019), experiencing mental relaxation that combats stress and anxiety (Craig

et. al. 2020), spending quality time with family and friends and practicing long-held traditions (Brown et. al. 2012).

Further, removal of fish from the diet of subsistence consumers may have serious health, social and economic consequences. Such populations are encouraged to consume a variety of fish species, to fish from locations with low contamination, and to follow recommended preparation and cooking methods.

Consideration of risk vs benefits

The health benefits of eating fish are not able to be assigned a value quantitatively for use in calculating a fish consumption advisory but they can be used qualitatively in advisory decisions. DOH has considered the health benefits of fish consumption in the selection of the RfD used for evaluating PFOS risk in fish tissue. Epidemiologic studies have indicated immunotoxicity (i.e. reduced vaccine antibodies in children) at very low levels of PFOS exposure and an interim reference dose (RfD) from the EPA reflects these lower levels (EPA 2022). However, the interim RfD would produce screening values that are lower than current methodological detection limits for fish tissue. Additionally, as described above fish consumption provides a number of health and immune benefits that cannot be included in a theoretical risk calculation. Therefore, DOH chose to use the RfD of 3×10^{-6} mg/kg-day from the current State Action Level in drinking water based on Dong et. al. 2011.

References

Barre DE. 2007. The role of consumption of alpha-linolenic, eicosapentaenoic and docosahexaenoic acids in human metabolic syndrome and type 2 diabetes – a mini-review. J Oleo Sci 56:319-325.

Brown, A., Djohari, N., and Stolk, P. 2012. Final Report of the Social and Community Benefits of Angling Project Section 2: Angling and Health and Well-Being.

Calder PC 2015. Marine omega-3 fatty acids and inflammatory processes: Effects, mechanisms, and clinical relevance. Biochim Biophus Acta. 1851(4):469-84.

Calder PC. 2017. Omega-3 fatty acids and inflammatory processes: from molecules to man. Biochem Soc Trans. 45(5):1105-1115.

Calon F, Cole G. 2007. Neuroprotective action of omega-3 polyunsaturated fatty acids against neurodegenerative diseases. Evidence from animal studies. Prostaglandins Leukot Essent Fatty Acids 77:287-293.

Craig, P.J., Alger, D.M., Bennett, J.L. and Martin, T.P., 2020. The transformative nature of fly-fishing for veterans and military personnel with posttraumatic stress disorder. Therapeutic Recreation Journal, 54(2), pp.150-172.

CRITFC 1994. Columbia River Inter-Tribal Fish Commission. A Fish Consumption Survey of the Umatilla, Nez Perce, Yakima, and Warm Springs Tribes of the Columbia River Basin. Technical Report 94-3. http://www.critfc.org/wp-content/uploads/2015/06/94-3report.pdf?x78172

Dietary Guidelines Advisory Committee. 2020. Scientific Report of the 2020 Dietary

Guidelines Advisory Committee: Advisory Report to the Secretary of Agriculture and the Secretary of Health and Human Services. U.S. Department of Agriculture, Agricultural Research Service, Washington, DC.

DOH 2021. Recommended State Action Levels for Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water: Approach, Methods, and Supporting Information. December 2021. Washington State Department of Health, Office of Environmental Public Health Sciences.

Donatuto, J.L., Satterfield, T.A., and Gregory, R. 2011. Poisoning the body to nourish the soul: Prioritising health risks and impacts in a Native American community. Health, Risk & Society Vol. 13, No. 2, 103–127.

Dong GH, et al. 2009. Chronic effects of perfluoroocatane sulfonate exposure on immunotoxicity in adult male C57BL/6J mice. Arch Toxicol, 83:805-15.

Dong GH, Liu MM, Wang D, Zheng L, Liang ZF, Jin YH. 2011. Sub-chronic effects of perfluorooctanesulfonate (PFOS) on the balance of type 1 and type 2 cytokine in adult C57BL6 mice. Archives of toxicology, 85(10), 1235-1244.

Ecology 2010. Perfluorinated Compounds in Washington Rivers and Lakes. August 2010 Publication No. 10-03-034. https://apps.ecology.wa.gov/publications/SummaryPages/1003034.html

Ecology 2017. Survey of Per- and Poly-fluoroalkyl Substances (PFASs) in Rivers and Lakes, 2016. September 2017. Publication No. 17-03-021. https://apps.ecology.wa.gov/publications/SummaryPages/1703021.html

Ecology 2022. Mathieu, C. Per- and Polyfluoroalkyl Substances in Freshwater Fish, 2018: Lake Meridian, Lake Sammamish, and Lake Washington. Publication 22-03-007. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/2203007.html

EFSA Panel on Contaminants in the Food Chain (EFSA CONTAM Panel), Schrenk, D., Bignami, M., Bodin, L., Chipman, J.K., del Mazo, J., Grasl-Kraupp, B., Hogstrand, C., Hoogenboom, L., Leblanc, J.C. and Nebbia, C.S., 2020. Risk to human health related to the presence of perfluoroalkyl substances in food. EFSA Journal, 18(9), p.e06223.

EPA 2000a. U.S. Department of Environmental Protection Agency. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Vol. 1, Fish Sampling and Analysis, Third Edition.

EPA 2000b. U.S. Department of Environmental Protection Agency. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Vol. 2, Risk Assessment and Fish Consumption Limits, Third Edition.

EPA 2022. INTERIM Drinking Water Health Advisory: Perfluorooctane Sulfonic Acid (PFOS) CASRN 1763-23-1.

Fleith M, Clandinin MT. 2005. Dietary PUFA for preterm and term infants: review of clinical studies. Crit Rev Food Sci Nutr 45:205-229.

Furuhjelm C, Warstedt K, Larsson J, Fredriksson M, Bottcher MR, Falth-Magnusson K, Duchen K. 2009. Fish oil supplementation in pregnancy and lactation may decrease the risk of infant allergy. Acta Paediatr. 98:1461-7.

Great Lakes 1993. Great Lakes Sport Fish Advisory Task Force. 1993. Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory. September.

Guruge K. et al., 2009. Effect of perfluorooctane sulfonate (PFOS) on influenza A virus-induced mortality in female B6C3F1 mice. J Toxicol Sci, 3:687-91.

Hudert CA Weylandt KH, Lu Y, Wang J, Hong S, Dignass A et al. 2006. Transgenic mice rich in endogenous omega-3 fatty acids are protected from colitis. Proc Natl Acad Sci USA 103:11276-11281.

IOM (Institute of Medicine) 2006. Seafood Choices: Balancing Benefits and Risks. Washington, DC: National Academy Press.

Kremer JM. 2000. N-3 Fatty Acid supplements in rheumatoid arthritis. Am J Clin Nutr 71(suppl 1):349S-351S.

Kurwadkar, S., Dane, J., Kanel, S. R., Nadagouda, M. N., Cawdrey, R. W., Ambade, B., ... & Wilkin, R. (2021). Per-and polyfluoroalkyl substances in water and wastewater: A critical review of their global occurrence and distribution. Science of The Total Environment, 151003.

Mozaffarian D, Rimm E. 2006. Fish intake, contaminants, and human health. Evaluating the risks and benefits. JAMA 296:1885-1899.

National Toxicology Program (NTP), Systemic Review of Immunotoxicity Associated withExposure to Perfluorooctanoic Acid (PFOA) or Perfluoroactance Sulfonate (PFOS). 2016, National Toxicology Program, U.S. Department of Health and Human Services.

Olsen SF, Osterdal ML, Salvig JD, Mortensen LM, Rytter D, Secher NJ, Henrikesen TB. 2008. Fish oil intake compared with olive oil intake in late pregnancy and asthma in the offspring: 16 y of registry-based follow-up from a randomized controlled trial. Am J Clin Nutr. 88:167-75.

Peden-Adams M, et al. 2008. Suppression of humoral immunity in mice following exposure to perflurooctane sulfonate. Toxicol Sci, 104:144-154.

Ramon S. Baker SF, Sahler JM, KIM N, et al., 2014. The specialized proresolving mediator 17-HDHA enhances the antibody-meditated immune response against influenza virus: a new class of adjuvant? I Immunol. 193(12):6031-40.

SanGiovanni JP, Chew EY, Clemons TE, Davis MD, Ferris FL, Gensler GR et al. 2007. The relationship of dietary lipid intake and age-related macular degeneration in a case-control study: AREDS report no. 20. Arch Ophthamlmol 125:671-679.

Shaikh SR, Jooy CA, Chapkin RS. 2012. N-3 Polyunsaturated fatty acids exert immunomodulatory effects on lymphocytes by targeting plasma membrane molecular organization. Mol Aspects Med. 33(1):46-54.

Souza DR, Pieri BLDS, Comim VH, Marques SO, Luciano TF, Rodrigues MS, De Souza CT. 2020. Fish oil reduces subclinical inflammation, insulin resistance, and atherogenic factors in overweight/obese type 2 diabetes mellitus patients: A pre-post pilot study. J Diabetes Complications28107553 (ahead of print).

Wenstrom KD, 2014. The FDA's new advice on fish: it's complicated. Am K Obstet Gynecol. 211(5):475-78.

Whelan J, Gowdy KM, Shaikh SR. 2016. N-3 polyunsaturated fatty acids modulate B cell activity in preclinical models: Implications for the immune response to infections. Eur J Pharmacol. 785:10-17.

White, M.P., Alcock, I., Grellier, J. et al. 2012. Spending at least 120 minutes a week in nature is associated with good health and wellbeing. Sci Rep 9, 7730 (2019). https://doi.org/10.1038/s41598-019-44097-3

Xheng L. et al. 2009. Immunotoxic changes associated with a 7-day oral exposure to perfluorooctane sulfonate (PFOS) in adult male C47BL/6 mice. Arch Toxicol 83:679-89.

Yagoob P, 2010. Mechanisms underlying the immunomodulatory effects of n-3 PUFA. Proc Nutr Soc. 69(3):311-15.


Washington State Department of
Health

EXHIBIT H

EPA
United States
Environmental Protection
Agency

PFAS Strategic Roadmap: EPA's Commitments to Action 2021–2024







A Note from EPA Administrator Michael S. Regan

For far too long, communities across the United States have been suffering from exposure to PFAS pollution. As the science has continued to develop, we know more now than ever about how PFAS build up in our bodies over long periods of time, and how they can cause adverse health effects that can devastate families. As Secretary of the North Carolina Department of Environmental Quality, I saw this devastation firsthand. For years, the Cape Fear River had been contaminated by these persistent "forever" chemicals. As I spoke with families and concerned citizens, I could feel their suffering and frustration with inaction. I knew my job was going to be trying and complex. But we were able to begin to address this pervasive problem by following the science, following the law, and bringing all stakeholders to the table.

As one of my earliest actions as EPA Administrator, I established the EPA Council on PFAS and charged it with developing an ambitious plan of action to further the science and research, to restrict these dangerous chemicals from getting into the environment, and to immediately move to remediate the problem in communities across the country. EPA's PFAS strategic roadmap is our plan to deliver tangible public health benefits to all people who are impacted by these chemicals—regardless of their zip code or the color of their skin.

Since I've been EPA Administrator, I have become acutely aware of the invaluable and central role EPA has in protecting public health in America. For more than 50 years, EPA has implemented and enforced laws that protect people from dangerous pollution in the air they breathe, the water they drink, and the land that forms the foundation of their communities. At the same time, my experience in North Carolina reinforced that EPA cannot solve these challenges alone. We can only make progress if we work in close collaboration with Tribes, states, localities, and stakeholders to enact solutions that follow the science and stand the test of time. To affect meaningful change, engagement, transparency, and accountability will be critical as we move forward.

This roadmap will not solve our PFAS challenges overnight. But it will turn the tide by harnessing the collective resources and authority across federal, Tribal, state, and local governments to empower meaningful action now.

I want to thank the co-chairs of the EPA Council on PFAS—Radhika Fox, Assistant Administrator for Water, and Deb Szaro, Acting Regional Administrator in Region 1—for their leadership in guiding the development of this strategy.

Let's get to work.

Administrator Michael S. Regan

PFAS Council Members

The following policy and technical leaders serve as members of the EPA Council on PFAS. They have been instrumental in working with their respective offices to develop the Agency's strategy. The Council will continue to coordinate across all EPA offices and Regions to accelerate progress on PFAS.

Co-Chairs

Radhika Fox, Assistant Administrator for Water

Deb Szaro, Acting Regional Administrator, Region 1

Office of the Administrator

John Lucey, Special Assistant to the Administrator

Andrea Drinkard, Senior Advisor to the Deputy Administrator

Office of Air and Radiation

John Shoaff, Director, Air Policy and Program Support

Office of Chemical Safety and Pollution Prevention

Jeffrey Dawson, Science Advisor

Tala Henry, Deputy Director, Pollution Prevention and Toxics

Office of Enforcement and Compliance Assurance

Cyndy Mackey, Director, Site Remediation Enforcement

Karin Leff, Director, Federal Facilities Enforcement

Office of General Counsel

Dawn Messier, Deputy Associate General Counsel, Water

Jen Lewis, Deputy Associate General Counsel, Solid Waste and Emergency Response

Office of Land and Emergency Management

Dana Stalcup, Deputy Director, Superfund Remediation and Technology Innovation

Dawn Banks, Director, Policy Analysis and Regulatory Management

Office of Research and Development

Tim Watkins, Acting Director, Center for Public Health and Environmental Assessment

Susan Burden, PFAS Executive Lead

Office of Water

Jennifer McLain, Director, Ground Water and Drinking Water

Deborah Nagle, Director, Science and Technology

Zachary Schafer, Senior Advisor to the Assistant Administrator

EPA Regions

John Blevins, Acting Regional Administrator, Region 4

Tera Fong, Water Division Director, Region 5

Contents

Introduction

Harmful per- and poly-fluoroalkyl substances (PFAS) are an urgent public health and environmental issue facing communities across the United States. PFAS have been manufactured and used in a variety of industries in the United States and around the globe since the 1940s, and they are still being used today. Because of the duration and breadth of use, PFAS can be found in surface water, groundwater, soil, and air—from remote rural areas to densely-populated urban centers. A growing body of scientific evidence shows that exposure at certain levels to specific PFAS can adversely impact human health and other living things. Despite these concerns, PFAS are still used in a wide range of consumer products and industrial applications.

Every level of government—federal, Tribal, state, and local—needs to exercise increased and sustained leadership to accelerate progress to clean up PFAS contamination, prevent new contamination, and make game-changing breakthroughs in the scientific understanding of PFAS. The EPA Council on PFAS developed this strategic roadmap to lay out EPA's whole-of-agency approach to addressing PFAS. To deliver needed protections for the American people, the roadmap sets timelines by which the Agency plans to take specific actions during the first term of the Biden-Harris Administration. The strategic roadmap builds on and accelerates implementation of policy actions identified in the Agency's 2019 action plan and commits to bolder new policies to safeguard public health, protect the environment, and hold polluters accountable.

The risks posed by PFAS demand that the Agency attack the problem on multiple fronts at the same time. EPA must leverage the full range of statutory authorities to confront the human health and ecological risks of PFAS. The actions described in this document each represent important and meaningful steps to safeguard communities from PFAS contamination. Cumulatively, these actions will build upon one another and lead to more enduring and protective solutions.

EPA's integrated approach to PFAS is focused on three central directives:

- **Research.** Invest in research, development, and innovation to increase understanding of PFAS exposures and toxicities, human health and ecological effects, and effective interventions that incorporate the best available science.
- **Restrict.** Pursue a comprehensive approach to proactively prevent PFAS from entering air, land, and water at levels that can adversely impact human health and the environment.
- **Remediate.** Broaden and accelerate the cleanup of PFAS contamination to protect human health and ecological systems.

The Agency's Approach

EPA's approach is shaped by the unique challenges to addressing PFAS contamination. EPA cannot solve the problem of "forever chemicals" by tackling one route of exposure or one use at a time. Rather, EPA needs to take a lifecycle approach to PFAS in order to make meaningful progress. PFAS pollution is not a legacy issue—these chemicals remain in use in U.S. commerce. As such, EPA cannot focus solely on cleaning up the downstream impacts of PFAS pollution. The Agency needs to also look upstream to prevent new PFAS contamination from entering air, land, and water and exposing communities. As the Agency takes tangible actions both upstream and downstream, EPA will continue to pursue a rigorous scientific agenda to better characterize toxicities, understand exposure pathways, and identify new methods to avert and remediate PFAS pollution. As EPA learns more about the family of PFAS chemicals, the Agency can do more to protect public health and the environment. In all this work, EPA will seek to hold polluters accountable for the contamination they cause and ensure disadvantaged communities equitably benefit from solutions.

Consider the Lifecycle of PFAS

EPA will account for the full lifecycle of PFAS, their unique properties, the ubiquity of their uses, and the multiple pathways for exposure.

PFAS are a group of synthetic chemicals that continue to be released into the environment throughout the lifecycle of manufacturing, processing, distribution in commerce, use, and disposal. Each action in this cycle creates environmental contamination and human and ecological exposure. Exacerbating this challenge is that some PFAS persist in the environment. PFAS are synthesized for many different uses, ranging from firefighting foams, to coatings for clothes and furniture, to food contact substances. Many PFAS are also used in industrial processes and applications, such as in the manufacturing of other chemicals and products. PFAS can be released into the environment during manufacturing and processing as well as during industrial and commercial use. Products known to contain PFAS are regularly disposed of in landfills and by incineration, which can also lead to the release of PFAS. Many PFAS have unique properties that prevent their complete breakdown in the environment, which means that even removing PFAS from contaminated areas can create PFAS-contaminated waste. This is currently unregulated in most cases.

Get Upstream of the Problem

EPA will bring deeper focus to preventing PFAS from entering the environment in the first place—a foundational step to reducing the exposure and potential risks of future PFAS contamination.

Intervening at the beginning of the PFAS lifecycle—before they have entered the environment—is a foundational element of EPA's whole-of-agency approach. While hundreds of individual PFAS compounds are in production and use,[i] a relatively

modest number of industrial facilities produce PFAS feedstock,[ii] and a relatively narrow set of industries directly discharge PFAS into water or soil or generate air emissions in large quantities.[iii] This context helps to pinpoint clear opportunities to restrict releases into the environment. EPA will use its authorities to impose appropriate limitations on the introduction of new unsafe PFAS into commerce and will, as appropriate, use all available regulatory and permitting authorities to limit emissions and discharges from industrial facilities. This approach does not eliminate the need for remediation where releases and exposures have already occurred, but it is a critical step to preventing ongoing concentrated contamination of soil and surface and groundwaters.

Hold Polluters Accountable

EPA will seek to hold polluters and other responsible parties accountable for their actions and for PFAS remediation efforts.

Many communities and ecosystems are continuously exposed to PFAS in soil, surface water, groundwater, and air. Areas can be exposed due to their proximity to industrial sites, airports, military bases, land where biosolids containing PFAS have been applied, and other sites where PFAS have been produced or used and disposed of for specific and repeated purposes. When EPA becomes aware of a situation that poses a serious threat to human health or the environment, the Agency will take appropriate action. For other sites where contamination may have occurred, the presence of certain PFAS in these environments necessitates coordinated action to understand what specific PFAS have been released, locations where they are found, where they may be transported through air, soil, and water in the future, and what remediation is necessary. EPA will seek to hold polluters and other responsible parties accountable for their actions, ensuring that they assume responsibility for remediation efforts and prevent any future releases.

Ensure Science-Based Decision-Making

EPA will invest in scientific research to fill gaps in understanding of PFAS, to identify which additional PFAS may pose human health and ecological risks at which exposure levels, and to develop methods to test, measure, remove, and destroy them.

EPA's decisions regarding PFAS will be grounded in scientific evidence and analysis. The current body of scientific evidence clearly indicates that there are real, present, and significant hazards associated with specific PFAS, but significant gaps remain related to the impacts of other PFAS on human health and in the environment. Regulatory development, either at the state or federal level, would greatly benefit from a deeper scientific understanding of the exposure pathways, toxicities, and potential health impacts of less-studied PFAS. The federal government, states, industry, academia, and nonprofit organizations—with appropriate coordination and resources—have the capability to conduct this necessary research.

EPA is conducting new research to better understand the similar and different characteristics of specific PFAS and whether and how to address groups and categories of PFAS. The Agency is focused on improving its ability to address multiple chemicals at once, thereby accelerating the effectiveness of regulations, enforcement actions, and the tools and technologies needed to remove PFAS from air, land, and water.

To break the cycle of contamination and exposure from PFAS, additional research is needed to identify and/or develop techniques to permanently dispose of or destroy these durable compounds. Government agencies, industry, and private laboratories need tools and validated methods to measure PFAS in air, land, and water to identify pollution sources, demonstrate facility compliance, hold polluters accountable, and support communities during and after cleanups.

Prioritize Protection of Disadvantaged Communities

When taking action on PFAS, EPA will ensure that disadvantaged communities have equitable access to solutions.

Many known and potential sources of PFAS contamination (including military bases, airports, industrial facilities, and waste management and disposal sites) are near low-income communities and communities of color. EPA needs to ensure these affected populations have an opportunity to participate in and influence the Agency's decision-making. This may call for the Agency to seek out and facilitate the communities' engagement by providing culturally appropriate information and accommodations for people with Limited English Proficiency, facilitating community access to public meetings and comment periods, and offering technical assistance to build community-based capacity for participation. EPA's actions need to consider the unique on-the-ground conditions in these communities, such as outdated infrastructure, to help ensure they benefit equitably from policy solutions.

EPA will also collect more data and develop new methodologies to understand PFAS exposure pathways in disadvantaged communities; to what extent PFAS pollution contributes to the cumulative burden of exposures from multiple sources in these communities; and how non-environmental stressors, such as systemic socioeconomic disparities, can exacerbate the impacts of pollution exposure and vice versa.

Goals and Objectives

EPA's comprehensive approach to addressing PFAS is guided by the following goals and objectives.

RESEARCH

Invest in research, development, and innovation to increase understanding of PFAS exposures and toxicities, human health and ecological effects, and effective interventions that incorporate the best available science.

Objectives

- Build the evidence base on individual PFAS and define categories of PFAS to establish toxicity values and methods.
- Increase scientific understanding on the universe of PFAS, sources of environmental contamination, exposure pathways, and human health and ecological effects.
- Expand research on current and emerging PFAS treatment, remediation, destruction, disposal, and control technologies.
- Conduct research to understand how PFAS contribute to the cumulative burden of pollution in communities with environmental justice concerns.

RESTRICT

Pursue a comprehensive approach to proactively prevent PFAS from entering air, land, and water at levels that can adversely impact human health and the environment.

Objectives

- Use and harmonize actions under all available statutory authorities to control and prevent PFAS contamination and minimize exposure to PFAS during consumer and industrial uses.
- Place responsibility for limiting exposures and addressing hazards of PFAS on manufacturers, processors, distributors, importers, industrial and other significant users, dischargers, and treatment and disposal facilities.
- Establish voluntary programs to reduce PFAS use and release.
- Prevent or minimize PFAS discharges and emissions in all communities, regardless of income, race, or language barriers.

REMEDIATE

Broaden and accelerate the cleanup of PFAS contamination to protect human health and ecological systems.

Objectives

- Harmonize actions under all available statutory authorities to address PFAS contamination to protect people, communities, and the environment.
- Maximize responsible party performance and funding for investigations and cleanup of PFAS contamination.
- Help ensure that communities impacted by PFAS receive resources and assistance to address contamination, regardless of income, race, or language barriers.
- Accelerate the deployment of treatment, remediation, destruction, disposal, and mitigation technologies for PFAS, and ensure that disposal and destruction activities do not create new pollution problems in communities with environmental justice concerns.

Key Actions

This section summarizes the bold actions that EPA plans to take from 2021 through 2024 on PFAS, as well as some ongoing efforts thereafter. The actions described in this roadmap are subject to the availability of appropriations and other resources. Each of these actions—led by EPA's program offices—are significant building blocks in the Agency's comprehensive strategy to protect public health and ecosystems by researching, restricting, and remediating PFAS contamination. As EPA takes each of these actions, it also commits to transparent, equitable, and inclusive engagement with all stakeholders to inform the Agency's work.

These are not the only actions underway at EPA, nor will they be the last. As the Agency does more, it will learn more. And as EPA learns more, it will do more. As EPA continues to build the evidence base, as regulatory work matures, and as EPA learns more from its partnerships across the country, the Agency will deliver additional actions commensurate with the urgency and scale of response that the PFAS problem demands.

Office of Chemical Safety and Pollution Prevention

Publish national PFAS testing strategy

Expected Fall 2021

EPA needs to evaluate a large number of PFAS for potential human health and ecological effects. Most PFAS have limited or no toxicity data. To address this data gap, EPA is developing a national PFAS testing strategy to deepen understanding of the impacts of categories of PFAS, including potential hazards to human health and the environment. This will help EPA identify and select PFAS for which the Agency will require testing using Toxic Substances Control Act (TSCA) authorities. In the 2020 National Defense Authorization Act (NDAA), Congress directed EPA to develop a process for prioritizing which PFAS or classes of PFAS should be subject to additional research efforts based on potential for human exposure to, toxicity of, and other available information. EPA will also identify existing test data for PFAS (both publicly available and submitted to EPA under TSCA) that will be considered prior to requiring further testing to ensure adherence to the TSCA goal of reducing animal testing. EPA will use the testing strategy to identify important gaps in existing data and to select representative chemical(s) within identified categories as priorities for additional studies. EPA expects to exercise its TSCA Section 4 order authority to require PFAS manufacturers to conduct and fund the studies. EPA plans to issue the first round of test orders on the selected PFAS by the end of 2021.

Ensure a robust review process for new PFAS

Efforts Ongoing

EPA's TSCA New Chemicals program plays an important gatekeeper role in ensuring the safety of new chemicals, including new PFAS, prior to their entry in U.S. commerce. Where unreasonable

risks are identified as part of the review process, EPA must mitigate those risks before any manufacturing activity can commence. The 2016 TSCA amendments require EPA to review and make a determination regarding the potential risks for each new chemical submission. Since early 2021, EPA has taken steps to ensure that new PFAS are subject to rigorous reviews and appropriate safeguards, including making changes to the policies and processes underpinning reviews and determinations on new chemicals to better align with the 2016 amendments. In addition, EPA has previously allowed some new PFAS to enter the market through low-volume exemptions (LVEs), following an expedited, 30-day review process. In April 2021, the Agency announced that it would generally expect to deny pending and future LVE submissions for PFAS based on the complexity of PFAS chemistry, potential health effects, and their longevity and persistence in the environment. Moving forward, EPA will apply a rigorous premanufacture notice review process for new PFAS to ensure these substances are safe before they enter commerce.

Review previous decisions on PFAS

Efforts Ongoing

EPA is also looking at PFAS that it has previously reviewed through the TSCA New Chemicals program, including those that it reviewed prior to the 2016 TSCA amendments. For example, EPA recently launched a stewardship program to encourage companies to voluntarily withdraw previously granted PFAS LVEs. EPA also plans to revisit past PFAS regulatory decisions and address those that are insufficiently protective. As part of this effort, the Agency could impose additional notice requirements to ensure it can review PFAS before they are used in new ways that might present concerns.

In addition, EPA plans to issue TSCA Section 5(e) orders for existing PFAS for which significant new use notices (e.g., a new manufacturing process for an existing PFAS, or a new use or user) have recently been filed with EPA. The orders would impose rigorous safety requirements as a condition of allowing the significant new use to commence.

More broadly, EPA is planning to improve approaches for overall tracking and enforcement of requirements in new chemical consent orders and significant new use rules (SNURs) to ensure that companies are complying with the terms of those agreements and regulatory notice requirements.

Close the door on abandoned PFAS and uses

Expected Summer 2022

Many existing chemicals (i.e., those that are already in commerce and listed on the TSCA Inventory of chemicals), including PFAS, are currently not subject to any type of restriction under TSCA. In some instances, the chemicals themselves have not been actively manufactured for many years. In others, chemicals may have certain past uses that have been abandoned. Absent restriction, manufacturers are free to begin using those abandoned chemicals or resume those abandoned uses at any time. Under TSCA, by rule, EPA can designate uses of a chemical that are not currently ongoing—and potentially *all* uses associated with an inactive chemical—as "significant new uses." Doing so ensures that an entity must first submit a notice and certain information to EPA before it can resume use of that chemical or use. TSCA then requires EPA to review and make an affirmative determination on the potential risks to health and the environment and to require safety measures to address unreasonable risks before allowing the PFAS use to resume. EPA is considering how it can apply this authority to help address abandoned uses of PFAS as well as future uses of PFAS on the inactive portion of the TSCA Inventory.

Enhance PFAS reporting under the Toxics Release Inventory

Expected Spring 2022

The Toxics Release Inventory (TRI) helps EPA compile data and information on releases of certain chemicals and supports informed decision-making by companies, government agencies, non-governmental organizations, and the public. Pursuant to the 2020 NDAA, certain industry sectors must report certain PFAS releases to TRI. However, certain

exemptions and exclusions remain for those PFAS reporters, which significantly limited the amount of data that EPA received for these chemicals in the first year of reporting.[iv] To enhance the quality and quantity of PFAS information collected through TRI, EPA intends to propose a rulemaking in 2022 to categorize the PFAS on the TRI list as "Chemicals of Special Concern" and to remove the de minimis eligibility from supplier notification requirements for all "Chemicals of Special Concern." EPA will also continue to update the list of PFAS subject to TRI and expects to announce an additional rulemaking to add more PFAS to TRI in 2022, as required by the 2020 NDAA.

Finalize new PFAS reporting under TSCA Section 8

Expected Winter 2022

TSCA Section 8(a)(7) provides authority for EPA to collect existing information on PFAS. In June 2021, EPA published a proposed data-gathering rule that would collect certain information on any PFAS manufactured since 2011, including information on uses, production volumes, disposal, exposures, and hazards. EPA will consider public comments on the proposal and finalize it before January 1, 2023. Ultimately, information received under this rule will enable EPA to better characterize the sources and quantities of manufactured PFAS in the United States and will assist the Agency in its future research, monitoring, and regulatory efforts.

Office of Water

Undertake nationwide monitoring for PFAS in drinking water

Final Rule Expected Fall 2021

The Safe Drinking Water Act (SDWA) establishes a data-driven and risk-based process to assess drinking water contaminants of emerging concern. Under SDWA, EPA requires water systems to conduct sampling for unregulated contaminants every five years. EPA published the proposed Fifth Unregulated Contaminant Monitoring Rule (UCMR 5) in March 2021. As proposed, UCMR 5 would provide new data that is critically needed to improve EPA's understanding of the frequency that 29 PFAS are found in the nation's drinking water systems and at what levels. The proposed UCMR 5 would significantly expand the number of drinking water systems participating in the program, pending sufficient appropriations by Congress. The data gathered from an expanded set of drinking water systems would improve EPA's ability to conduct state and local assessments of contamination, including analyses of potential environmental justice impacts. As proposed, and if funds are appropriated by Congress, all public water systems serving 3,300 or more people and 800 representative public water systems serving fewer than 3,300 would collect samples during a 12-month period from January 2023 through December 2025. EPA is considering comments on the proposed UCMR 5 and preparing a final rule. Going forward, EPA will continue to prioritize additional PFAS for inclusion in UCMR 6 and beyond, as techniques to measure these additional substances in drinking water are developed and validated.

Establish a national primary drinking water regulation for PFOA and PFOS

Proposed Rule Expected Fall 2022, Final Rule Expected Fall 2023

Under the SDWA, EPA has the authority to set enforceable National Primary Drinking Water Regulations (NPDWRs) for drinking water contaminants and require monitoring of public water

supplies. To date, EPA has regulated more than 90 drinking water contaminants but has not established national drinking water regulations for any PFAS. In March 2021, EPA published the Fourth Regulatory Determinations, including a final determination to regulate Perfluorooctanoic acid (PFOA) and Perfluorooctane sulfonic acid (PFOS) in drinking water. The Agency is now developing a proposed NPDWR for these chemicals. As EPA undertakes this action, the Agency is also evaluating additional PFAS and considering regulatory actions to address groups of PFAS. EPA expects to issue a proposed regulation in Fall 2022 (before the Agency's statutory deadline of March 2023). The Agency anticipates issuing a final regulation in Fall 2023 after considering public comments on the proposal. Going forward, EPA will continue to analyze whether NPDWR revisions can improve public health protection as additional PFAS are found in drinking water.

Publish the final toxicity assessment for GenX and five additional PFAS

Expected Fall 2021 and Ongoing

EPA plans to publish the toxicity assessments for two PFAS, hexafluoropropylene oxide dimer acid and its ammonium salt. These two chemicals are known as "GenX chemicals." GenX chemicals have been found in surface water, groundwater, drinking water, rainwater, and air emissions. GenX chemicals are known to impact human health and ecosystems. Scientists have observed liver and kidney toxicity, immune effects, hematological effects, reproductive and developmental effects, and cancer in animals exposed to GenX chemicals. Completing a toxicity assessment for GenX is essential to better understanding its effects on people and the environment. EPA can use this information to develop health advisories that will help communities make informed decisions to better protect human health and ecological wellness. The Office of Research and Development is also currently developing toxicity assessments for five other PFAS—PFBA, PFHxA, PFHxS, PFNA, and PFDA.

Publish health advisories for GenX and PFBS

Expected Spring 2022

PFAS contamination has impacted drinking water quality across the country, including in underserved rural areas and communities of color. SDWA authorizes EPA to develop non-enforceable and non-regulatory drinking water health advisories to help Tribes, states, and local governments inform the public and determine whether local actions are needed to address public health impacts in these communities. Health advisories offer a margin of protection by defining a level of drinking water concentration at or below which lifetime exposure is not anticipated to lead to adverse health effects. They include information on health effects, analytical methodologies, and treatment technologies and are designed to protect all lifestages. EPA will publish health advisories for Perfluorobutane sulfonic acid (PFBS) and GenX chemicals based on final toxicity assessments. The Agency will develop accompanying fact sheets in different languages to facilitate access to information on GenX and other PFAS. Going forward, EPA will develop health advisories as the Agency completes toxicity assessments for additional PFAS.

Restrict PFAS discharges from industrial sources through a multi-faceted Effluent Limitations Guidelines program

Expected 2022 and Ongoing

Effluent Limitations Guidelines (ELGs) are a powerful tool to limit pollutants from entering the nation's waters. ELGs establish national technology-based regulatory limits on the level of specified pollutants in wastewater discharged into surface waters and into municipal sewage treatment facilities. EPA has been conducting a PFAS multi-industry study to inform the extent and nature of PFAS discharges. Based on this study, EPA is taking a proactive approach to restrict PFAS discharges from multiple industrial categories. EPA plans to make significant progress in its ELG regulatory work by the end of 2024. EPA has established timelines for action—whether it is data collection

or rulemaking—on the nine industrial categories in the proposed PFAS Action Act of 2021, as well as other industrial categories such as landfills. EPA's multi-faceted approach entails:

- Undertake rulemaking to restrict PFAS discharges from industrial categories where EPA has the data to do so—including the guidelines for organic chemicals, plastics and synthetic fibers (OCPSF), metal finishing, and electroplating. Proposed rule is expected in Summer 2023 for OCPSF and Summer 2024 for metal finishing and electroplating.
- Launch detailed studies on facilities where EPA has preliminary data on PFAS discharges, but the data are currently insufficient to support a potential rulemaking. These include electrical and electronic components, textile mills, and landfills. EPA expects these studies to be complete by Fall 2022 to inform decision making about a future rulemaking by the end of 2022.
- Initiate data reviews for industrial categories for which there is little known information on PFAS discharges, including leather tanning and finishing, plastics molding and forming, and paint formulating. EPA expects to complete these data reviews by Winter 2023 to inform whether there are sufficient data to initiate a potential rulemaking.
- Monitor industrial categories where the phaseout of PFAS is projected by 2024, including pulp, paper, paperboard, and airports. The results of this monitoring, and whether future regulatory action is needed, will be addressed in the Final ELG Plan 15 in Fall 2022.

Leverage NPDES permitting to reduce PFAS discharges to waterways

Expected Winter 2022

The National Pollutant Discharge Elimination System (NPDES) program interfaces with many pathways by which PFAS travel and are released into the environment and ultimately impact people and water quality. EPA will seek to proactively use existing NPDES authorities to reduce discharges of PFAS at the source and obtain more comprehensive information through monitoring on the sources of PFAS and quantity of PFAS discharged by these sources. EPA will use the effluent monitoring data to inform which industrial categories the Agency should study for future ELGs actions to restrict PFAS in wastewater discharges.

- **Leverage federally-issued NPDES permits to reduce PFAS discharges.**[v] EPA will propose monitoring requirements at facilities where PFAS are expected or suspected to be present in wastewater and stormwater discharges, using EPA's recently published analytical method 1633, which covers 40 unique PFAS. In addition, EPA will propose, as appropriate, that NPDES permits: 1) contain conditions based on product elimination and substitution when a reasonable alternative to using PFAS is available in the industrial process; 2) require best management practices to address PFAS-containing firefighting foams for stormwater permits; 3) require enhanced public notification and engagement with downstream communities and public water systems; and 4) require pretreatment programs to include source control and best management practices to protect wastewater treatment plant discharges and biosolid applications.
- **Issue new guidance to state permitting authorities to address PFAS in NPDES permits.** EPA will issue new guidance recommending that state-issued permits that do not already include monitoring requirements for PFAS use EPA's recently published analytical method 1633, which covers 40 unique PFAS, at facilities where PFAS is expected or suspected to be present in wastewater and stormwater discharges. In addition, the new guidance will recommend the full suite of permitting approaches that EPA will use in federally-issued permits. The guidance will enable communities to work closely with their state permitting authorities to suggest monitoring at facilities suspected of containing PFAS.

Publish multi-laboratory validated analytical method for 40 PFAS

Expected Fall 2022

In September 2021, EPA (in collaboration with the Department of Defense) published a single-laboratory validated method to detect PFAS. The method can measure up to 40 specific PFAS compounds in eight environmental matrices (including wastewater, surface water and biosolids) and has numerous applications, including NPDES compliance monitoring. EPA and DOD are continuing this collaboration to complete a multi-laboratory validation of the method. EPA expects to publish the multi-lab validated method online by Fall 2022. Following the publication of the method, EPA will initiate a rulemaking to propose the promulgation of this method under the Clean Water Act (CWA).

Publish updates to PFAS analytical methods to monitor drinking water

Expected Fall 2024

SDWA requires EPA to use scientifically robust and validated analytical methods to assess the occurrence of contaminants of emerging concern, such as an unidentified or newly detected PFAS chemical. EPA will update and validate analytical methods to monitor additional PFAS. First, EPA will review reports of PFAS of concern and seek to procure certified reference standards that are essential for accurate and selective quantitation of emerging PFAS of concern in drinking water samples. EPA will evaluate analytical methods previously published for monitoring PFAS in drinking water (EPA Methods 533 and 537.1) to determine the efficacy of expanding the established target PFAS analyte list to include any emerging PFAS. Upon conclusion of this evaluation, EPA will complete multi-laboratory validation studies and peer review and publish updated EPA PFAS analytical methods for drinking water, making them available to support future drinking water monitoring programs.

Publish final recommended ambient water quality criteria for PFAS

Expected Winter 2022 and Fall 2024

EPA will develop national recommended ambient water quality criteria for PFAS to protect aquatic life and human health. Tribes and states use EPA-recommended water quality criteria to develop water quality standards to protect and restore waters, issue permits to control PFAS discharges, and assess the cumulative impact of PFAS pollution on local communities. EPA will publish recommended aquatic life criteria for PFOA and PFOS and benchmarks for other PFAS that do not have sufficient data to define a recommended aquatic life criteria value. EPA will first develop human health criteria for PFOA and PFOS, taking into account drinking water and fish consumption. This initiative will consider the latest scientific information and will develop human health criteria for additional PFAS when final toxicity assessments are available. Additionally, EPA will support Tribes in developing water quality standards that will protect waters under Tribal jurisdiction under the same framework as waters in adjacent states. Aquatic life criteria are expected in Winter 2022, and human health criteria are expected Fall 2024.

Monitor fish tissue for PFAS from the nation's lakes and evaluate human biomarkers for PFAS

Expected Summer 2022

States and Tribes have highlighted fish tissue data in lakes as a critical information need. Food and water consumption are important pathways of PFAS exposure, and PFAS can accumulate in fish tissue. In fact, EPA monitoring to date shows the presence of PFAS, at varying levels, in approximately 100 percent of fish tested in the Great Lakes and large rivers. In Summer 2022, EPA will collect fish tissue in the National Lakes Assessment for the first national study of PFAS in fish tissue in U.S. lakes. This will provide a better understanding of where PFAS fish tissue contamination is occurring, which

PFAS are involved, and the severity of the problem. The new data will complement EPA's analyses of PFAS in fish tissue and allow EPA to better understand unique impacts on subsistence fishers, who may eat fish from contaminated waterbodies in higher quantities. EPA's preliminary analysis on whether concentrations of certain PFAS compounds in human blood could be associated with eating fish using the Centers for Disease Control and Prevention's National Health and Nutrition Examination Survey (NHANES) data found a positive correlation. Completing this analysis will help make clear the importance of the fish consumption pathway for protecting communities. EPA will continue to pursue collaboration with Tribal and federal partners to investigate this issue of mutual interest.

Finalize list of PFAS for use in fish advisory programs

Expected Spring 2023

EPA will publish a list of PFAS for state and Tribal fish advisory programs that are either known or thought to be in samples of edible freshwater fish in high occurrence nationwide. This list will serve as guidance to state and Tribal fish tissue monitoring and advisory programs so that they know which PFAS to monitor and how to set fish advisories for PFAS that have human health impacts via fish consumption. This information will encourage more robust data collection from fish advisory programs and promote consistency of fish tissue PFAS monitoring results in EPA's publicly accessible Water Quality Portal. By issuing advisories for PFAS, state and Tribal programs can provide high-risk populations, including communities and individuals who depend on subsistence fishing, with more information about how to protect their health.

Finalize risk assessment for PFOA and PFOS in biosolids

Expected Winter 2024

Biosolids, or sewage sludge, from wastewater treatment facilities can sometimes contain PFAS. When spread on agricultural fields, the PFAS can contaminate crops and livestock. The CWA authorizes EPA to set pollutant limits and monitoring and reporting requirements for contaminants in biosolids if sufficient scientific evidence shows that there is potential harm to human health or the environment. A risk assessment is key to determining the potential harm associated with human exposure to chemicals. EPA will complete the risk assessment for PFOA and PFOS in biosolids by Winter 2024. The risk assessment will serve as the basis for determining whether regulation of PFOA and PFOS in biosolids is appropriate. If EPA determines that a regulation is appropriate, biosolids standards would improve the protection of public health and wildlife health from health effects resulting from exposure to biosolids containing PFOA and PFOS.

Office of Land and Emergency Management

Propose to designate certain PFAS as CERCLA hazardous substances

Proposed rule expected Spring 2022; Final rule expected Summer 2023

EPA is developing a Notice of Proposed Rulemaking to designate PFOA and PFOS as Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) hazardous substances. Such designations would require facilities across the country to report on PFOA and PFOS releases that meet or exceed the reportable quantity assigned to these substances. The hazardous substance designations would also enhance the ability of federal, Tribal, state, and local authorities to obtain information regarding the location and extent of releases. EPA or other agencies could also seek cost recovery or contributions for costs incurred for the cleanup. The proposed rulemaking will be available for public comment in Spring 2022. The Agency commits to conducting robust stakeholder engagement with communities near PFAS-contaminated sites.

Issue advance notice of proposed rulemaking on various PFAS under CERCLA

Expected Spring 2022

In addition to developing a Notice of Proposed Rulemaking designating PFOA and PFOS as hazardous substances under CERCLA, EPA is developing an Advance Notice of Proposed Rulemaking to seek public input on whether to similarly designate other PFAS. The Agency may request input regarding the potential hazardous substance designation for precursors to PFAS, additional PFAS, and groups or subgroups of PFAS. The Agency will engage robustly with communities near PFAS-contaminated sites to seek their input and learn about their lived experiences. Going forward, EPA will consider designating additional PFAS as hazardous substances under CERCLA as more specific information related to the health effects of those PFAS and methods to measure them in groundwater are developed.

Issue updated guidance on destroying and disposing of certain PFAS and PFAS-containing materials

Expected by Fall 2023

The 2020 NDAA requires that EPA publish interim guidance on destroying and disposing of PFAS and certain identified non-consumer PFAS-containing materials. It also requires that EPA revise that guidance at least every three years, as appropriate. EPA published the first interim guidance in December 2020 for public comment. It identifies three technologies that are commercially available to either destroy or dispose of PFAS and PFAS-containing materials and outlines the significant uncertainties and information gaps that exist concerning the technologies' ability to destroy or dispose of PFAS while minimizing the migration of PFAS to the environment. The guidance also highlights research that is underway and planned to address some of these information gaps. Furthermore, the interim guidance identifies existing EPA tools, methods, and approaches to characterize and assess the risks to disproportionately impacted people of color and low-income communities living near likely PFAS destruction or disposal sites. EPA's updated guidance will address the public comments and reflect newly published research results. Since the publication of the interim guidance, EPA and other agencies have been conducting relevant research on destruction and disposal technologies. EPA anticipates that additional research data will become available starting in 2022. EPA will update the guidance when sufficient useful information is available and no later than the statutory deadline of December 2023.

Office of Air and Radiation

Build the technical foundation to address PFAS air emissions

Expected Fall 2022 and Ongoing

The Clean Air Act requires EPA to regulate emissions of hazardous air pollutants (HAPs), which are pollutants that are known or suspected to cause cancer or other serious health effects. At present, EPA actively works with Tribal, state, and local governments to reduce air emissions of 187 HAPs to the environment. While PFAS are not currently listed as HAPs under the Clean Air Act, EPA is building the technical foundation on PFAS air emissions to inform future decisions. EPA is conducting ongoing work to:

- Identify sources of PFAS air emissions;
- Develop and finalize monitoring approaches for measuring stack emissions and ambient concentrations of PFAS;
- Develop information on cost-effective mitigation technologies; and
- Increase understanding of the fate and transport of PFAS air emissions to assess their potential for impacting human health via contaminated groundwater and other media pathways.

EPA will use a range of tools, such as EJSCREEN, to determine if PFAS air pollution disproportionately affects communities with environmental justice concerns. Data from other ongoing EPA activities, such as field tests, TRI submissions, and new TSCA reporting and recordkeeping requirements, will help EPA collect additional information on sources and releases. By Fall 2022, EPA will evaluate mitigation options, including listing certain PFAS as hazardous air pollutants and/or pursuing other regulatory and non-regulatory approaches. The Agency will continue to collect necessary supporting technical information on an ongoing basis.

Office of Research and Development

Develop and validate methods to detect and measure PFAS in the environment

Ongoing Actions

Robust, accurate methods for detecting and measuring PFAS in air, land, and water are essential for understanding which PFAS are in the environment and how much are present. These methods are also essential for evaluating the effectiveness of different technologies for removing PFAS from air, land, and water and for implementing future regulations. To date, EPA has developed validated methods to measure 29 PFAS in drinking water and 24 PFAS in groundwater, surface water, and wastewater. EPA has also developed a method for measuring selected PFAS in air emissions. EPA will build on this work by developing additional targeted methods for detecting and measuring specific PFAS and non-targeted methods for identifying unknown PFAS in the environment. EPA also recognizes the need for "total PFAS" methods that can measure the amount of PFAS in environmental samples without identifying specific PFAS. EPA will increase its efforts to develop and, if appropriate, validate "total PFAS" methods, focusing on air emissions, wastewater, and drinking water. Near-term deliverables include:

- Draft total adsorbable fluorine method for wastewater for potential laboratory validation (Fall 2021);
- Draft method for measuring additional PFAS in air emissions (Fall 2022); and
- Draft methods and approaches for evaluating PFAS leaching from solid materials (Fall 2022).

Advance the science to assess human health and environmental risks from PFAS

Ongoing Actions

EPA will expand understanding of the toxicity of PFAS through several ongoing research activities. First, EPA will continue to develop human health toxicity assessments for individual PFAS under EPA's Integrated Risk Information System (IRIS) Program,

and if needed, other fit-for-purpose toxicity values. When combined with exposure information and other important considerations, EPA can use these toxicity assessments to assess potential human health risks to determine if, and when, it is appropriate to address these chemicals. Most PFAS, however, have limited or no toxicity data to inform human health or ecological toxicity assessments. To better understand human health and ecological toxicity across a wider variety of PFAS, EPA will continue to compile and summarize available and relevant scientific information on PFAS and conduct toxicity testing on individual PFAS and PFAS mixtures. This will inform the development and refinement of PFAS categories for hazard assessment. EPA will also conduct research to identify PFAS sources in the outdoor and indoor environment, to characterize PFAS movement through the environment, and to identify the relative importance of different human exposure pathways to PFAS (e.g., ingestion of contaminated food or water, interaction with household articles or consumer products, and inhalation of indoor or outdoor air containing PFAS). EPA also will work to characterize how exposure to PFAS may contribute to cumulative impacts on communities, particularly communities with environmental justice concerns. Near-term deliverables include:

- Identify initial PFAS categories to inform TSCA test orders as part of the PFAS National Testing Strategy (Fall 2021)
- Consolidate and update data on chemical/physical properties, human health toxicity and toxicokinetics, and ecotoxicity (Spring 2022 – Fall 2024)
- Complete draft PFHxS, PFHxA, PFNA, and PFDA IRIS assessments for public comment and peer review (Spring – Fall 2022)
- Complete and publish the final PFBA IRIS assessment (Fall 2022)

Evaluate and develop technologies for reducing PFAS in the environment

Ongoing Actions

EPA needs new data and information on the effectiveness of different technologies and approaches for removing PFAS from the environment and managing PFAS and PFAS-containing materials to inform decisions on drinking water and wastewater treatment, contaminated site cleanup and remediation, air emission controls, and end-of-life materials management. This information is also needed to better ensure that particular treatment and waste management technologies and approaches do not themselves lead to additional PFAS exposures, particularly in overburdened communities where treatment and waste management facilities are often located. Toward that end, EPA will continue efforts to develop approaches for characterizing PFAS in source waters, at contaminated sites, and near PFAS production and treatment/disposal facilities. EPA will also continue to evaluate and develop technologies for drinking water and wastewater treatment, contaminated site remediation, air emission controls, and destruction and disposal of PFAS-containing materials and waste streams. These efforts include conducting laboratory- and pilot-scale studies, which will inform the design of full-scale field studies done in partnership with facilities and states to evaluate real-world applications of different PFAS removal technologies and management approaches.

EPA will prioritize efforts to evaluate conventional thermal treatment of PFAS-containing wastes and air emissions and assess the effectiveness of conventional drinking water and wastewater treatment processes. EPA will also continue to evaluate and advance the application of innovative, non-thermal technologies to treat PFAS waste and PFAS-contaminated materials. Building upon these evaluations, EPA will document the performance of PFAS removal technologies and establish technology-based PFAS categories that identify the list of PFAS that are effectively removed through the application of the associated technology. Near-term deliverables include:

- Collect data to inform the 2023 guidance on destroying and disposing of certain PFAS and PFAS-containing materials (Spring 2022 – Fall 2023);
- Identify initial PFAS categories for removal technologies (Summer 2022); and
- Develop effective PFAS treatment technologies for drinking water systems (Fall 2022).

Cross-Program

Engage directly with affected communities in every EPA Region

Expected Fall 2021 and Ongoing

EPA must fully understand the challenges facing individuals and communities grappling with PFAS contamination to understand their lived experiences and determine the most effective interventions. As recommended by the National Environmental Justice Advisory Council (NEJAC), EPA will meet with affected communities in each EPA Region to hear how PFAS contamination impacts their lives and livelihoods. EPA will use the knowledge from these engagements to inform the implementation of the actions described in this roadmap. EPA will also use the input to develop and share information to reduce potential health risks in the near term and help communities on the path to remediation and recovery from PFAS contamination.

Use enforcement tools to better identify and address PFAS releases at facilities

Ongoing Actions

EPA is initiating actions under multiple environmental authorities—RCRA, TSCA, CWA, SDWA and CERCLA—to identify past and ongoing releases of PFAS into the environment at facilities where PFAS has been used, manufactured, discharged, disposed of, released, and/or spilled. EPA is conducting inspections, issuing information requests, and collecting data to understand the level of contamination and current risks posed by PFAS to surrounding communities and will seek to address threats to human health with all its available tools. For example, EPA's enforcement authorities allow the Agency, under certain circumstances, to require parties responsible for PFAS contamination to characterize the nature and extent of PFAS contamination, to put controls in place to expeditiously limit future releases, and to address contaminated drinking water, soils, and other contaminated media. When EPA becomes aware of a potential imminent and substantial endangerment situation where PFAS poses a threat to human health, the Agency will swiftly employ its expertise to assess the situation and take appropriate action, including using statutorily authorized powers.

Accelerate public health protections by identifying PFAS categories

Expected Winter 2021 and Ongoing

To accelerate EPA's ability to address PFAS and deliver public health protections sooner, EPA is working to break the large, diverse class of PFAS into smaller categories based on similarities across defined parameters (such as chemical structure, physical and chemical properties, and toxicological properties). EPA plans to initially categorize PFAS using two approaches. In the first approach, EPA plans to use toxicity and toxicokinetic data to develop PFAS categories for further hazard assessment and to inform hazard- or risk-based decisions. In the second approach, EPA plans to develop PFAS categories based on removal technologies using existing understanding of treatment, remediation, destruction, disposal, control, and mitigation principles.

EPA plans to use the PFAS categories developed from these two approaches to identify gaps in coverage from either a hazard assessment or removal technology perspective, which will help EPA prioritize future actions to research, restrict, and remediate PFAS. For example, EPA may choose to prioritize research to characterize the toxicity of PFAS that are not being addressed by regulations that require the implementation of removal technologies. Conversely, EPA may prioritize research to evaluate the efficacy of technologies designed to remove PFAS that are included in a hazard-based category with relatively higher toxicities. To support coordination and integration of information across PFAS categories, EPA plans to develop a PFAS categorization database that will capture key characteristics of individual PFAS, including category assignments.

Establish a PFAS Voluntary Stewardship Program

Expected Spring 2022

Reduction of PFAS exposure through regulatory means can take time to develop, finalize, and implement. Moreover, current PFAS regulatory efforts do not extend to all of the approximately 600 PFAS currently in commerce. As a companion to other efforts described in this roadmap, EPA will establish a voluntary stewardship program challenging industry to reduce overall releases of PFAS into the environment. The program, which will not supplant industry's regulatory or compliance requirements, will call on industry to go beyond those requirements by reporting all PFAS releases in order to establish a baseline and then continuing to report to measure progress in reducing releases over time. EPA will validate industry efforts to meet reduction targets and timelines.

Educate the public about the risks of PFAS

Expected Fall 2021 and Ongoing

Addressing PFAS contamination is a critical part of EPA's mission to protect human health and the environment. This important mission cannot be achieved without effectively communicating with communities, individuals, businesses, the media, and Tribal, state, and local partners about the known and potential health risks associated with these chemicals. When EPA communicates risk, it is the Agency's goal to provide meaningful, understandable, and actionable information to many audiences. To accomplish this goal, EPA will make available key explainers that help the public understand what PFAS are, how they are used, and how PFAS can impact their health and their lives. These explainers and other educational materials will be published in multiple languages, and the Agency will work to ensure information reaches targeted communities (including those with limited access to technology and resources).

Issue an annual public report on progress towards PFAS commitments

Winter 2022 and Ongoing

EPA is committed to acting on PFAS with transparency and accountability. On an annual basis, EPA will report to the public on the status of the actions outlined in this roadmap, as well as future actions the Agency may take. EPA will also engage regularly with communities experiencing PFAS contamination, co-regulators, industry, environmental groups, community leaders, and other stakeholders to clearly communicate its actions and to stay abreast of evolving needs.

Conclusion

Every level of government—federal, Tribal, state, and local—needs to exercise increased and sustained leadership to accelerate progress to clean up PFAS contamination, prevent new contamination, and make game-changing breakthroughs in the scientific understanding of PFAS. This strategic roadmap represents the Agency's commitment to the American people on what EPA seeks to deliver from 2021 to 2024.

The risks posed by PFAS demand that the Agency take a whole-of-agency approach to attack the problem from multiple directions. Focusing only on remediating legacy contamination, for example, does nothing to prevent new contamination from occurring. Focusing only on preventing future contamination fails to minimize risks to human health that exist today. To build more enduring, comprehensive, and protective solutions, EPA seeks to leverage its full range of statutory authorities and work with its partners—including other federal agencies, state and Tribal regulators, scientists, industry, public health officials, and communities living with PFAS contamination—to implement this multi-media approach and achieve tangible benefits for human health and the environment.[vi]

Endnotes

[i] Approximately 650 PFAS are currently in commerce under TSCA, roughly half of which were grandfathered into the TSCA inventory.

[ii] EPA has identified 6-8 facilities that produce PFAS feedstock.

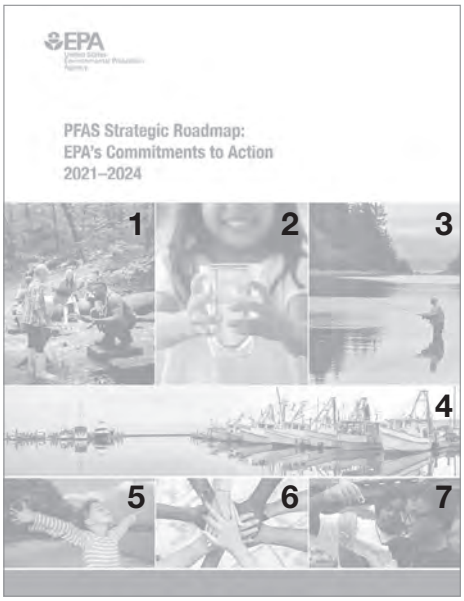
[iii] Key industries with significant documented discharges include PFAS production and processing, metal finishing, airports, pulp and paper, landfills, and textile and carpet manufacturing.

[iv] Examples include de minimis exemption, supplier notification requirements, and applicability of those requirements to wastes.

[v] Federally-issued permits are those that EPA issues in MA, NH, NM, DC, territories, federal waters, and Indian Country (and federal facilities in DE, CO, VT, WA).

[vi] This document provides information to the public on how EPA intends to exercise its discretion in implementing statutory and regulatory provisions that apply to PFAS. Those provisions contain legally binding requirements, and this document does not substitute for those statutory and regulatory provisions or regulations, nor is it a regulation itself.

Photo Credits



On the cover:

1. © istock.com

2. https://photostockeditor.com/free-images/girl-glass/page/2

3. Fly fishing, https://www.flickr.com/photos/umnak/, Joseph CC BY-SA 2.0

4. © istock.com

5. © istock.com

6. © Adobestock.com

7. High school students help with water monitoring and river cleanup, https://www.flickr.com/photos/usepagov/6237611883

page 4: Chesapeake Bay, Maryland, https://www.maxpixel.net/Sky-Maryland-Reflection-Chesapeake-Bay-Water-1310538

United States
Environmental Protection
Agency

EPA-100-K-21-002
October 2021

EXHIBIT I

International Journal of
Environmental Research and Public Health

MDPI

Review

Microplastics as Emerging Food Contaminants: A Challenge for Food Safety

Carmen Rubio-Armendáriz [1,*], Samuel Alejandro-Vega [1], Soraya Paz-Montelongo [1], Ángel J. Gutiérrez-Fernández [1], Conrado J. Carrascosa-Iruzubieta [1,2] and Arturo Hardisson-de la Torre [1]

[1] Grupo de Investigación en Toxicología Alimentaria y Ambiental, Universidad de La Laguna (ULL), 38200 San Cristóbal de La Laguna, Spain; alu0100992397@ull.edu.es (S.A.-V.); spazmont@ull.edu.es (S.P.-M.); ajguti@ull.edu.es (Á.J.G.-F.); conrado.carrascosa@ulpgc.es (C.J.C.-I.); atorre@ull.edu.es (A.H.-d.l.T.)
[2] Departamento de Patología Animal, Producción Animal, Bromatología y Tecnología de los Alimentos, Universidad de Las Palmas de Gran Canaria (ULPGC), 35001 Las Palmas de Gran Canaria, Spain
* Correspondence: crubio@ull.edu.es

Abstract: Microplastics (MPs) have been identified as emerging environmental pollutants classified as primary or secondary based on their source. Composition, shape, size, and colour, among other characteristics, are associated with their capacity to access the food chain and their risks. While the environmental impact of MPs has received much attention, the risks for humans derived from their dietary exposure have not been yet assessed. Several institutions and researchers support that the current knowledge does not supply solid data to complete a solid risk characterization of dietary MPs. The aim of this paper is to review the current knowledge about MPs in foods and to discuss the challenges and gaps for a risk analysis. The presence of MPs in food and beverages has been worldwide observed, but most authors considered the current data to be not only insufficient but of questionable quality mainly because of the outstanding lack of consensus about a standardized quantifying method and a unified nomenclature. Drinking water, crustaceans/molluscs, fish, and salt have been identified as relevant dietary sources of MPs for humans by most published studies. The hazard characterization presents several gaps concerning the knowledge of the toxicokinetic, toxicodynamic, and toxicity of MPs in humans that impede the estimation of food safety standards based on risk. This review provides a tentative exposure assessment based on the levels of MPs published for drinking water, crustaceans and molluscs, fish, and salt and using the mean European dietary consumption estimates. The intake of 2 L/day of water, 70.68 g/day of crustaceans/molluscs, 70.68 g/day of fish, and 9.4 g/day of salt would generate a maximum exposure to 33,626, 212.04, 409.94 and 6.40 particles of MPs/day, respectively. The inexistence of reference values to evaluate the MPs dietary intake prevents the dietary MPs risk characterization and therefore the management of this risk. Scientists and Food Safety Authorities face several challenges but also opportunities associated to the occurrence of MPs in foods. More research on the MPs characterization and exposure is needed bearing in mind that any future risk assessment report should involve a total diet perspective.

Keywords: microplastics; dietary MPs; risk analysis; hazard identification; hazard characterization; exposure assessment; risk characterization

Citation: Rubio-Armendáriz, C.; Alejandro-Vega, S.; Paz-Montelongo, S.; Gutiérrez-Fernández, Á.J.; Carrascosa-Iruzubieta, C.J.; Hardisson-de la Torre, A. Microplastics as Emerging Food Contaminants: A Challenge for Food Safety. *Int. J. Environ. Res. Public Health* **2022**, *19*, 1174. https://doi.org/10.3390/ijerph19031174

Academic Editors: William A. Toscano and Paul B. Tchounwou

Received: 21 November 2021
Accepted: 15 January 2022
Published: 21 January 2022

1. Introduction

Microplastics (MPs) have been identified as emerging environmental pollutants specially affecting the marine ecosystem, but they should also be considered as a growing food contaminant. Between five and thirteen tons of plastic (1.5–4% of the total global production) reach the marine ecosystems every year [1]. Furthermore, MPs also pose a growing risk for terrestrial ecosystems, as MPs have also been detected in farming soils [2]. Recently, the prevention measures against the spread of the COVID-19 virus have been

contributing to an increase of the plastic waste's accumulation, as protective clothing, accessories, masks, and additional plastic containers and bags are single use [3–5].

Primary MPs are made to be of this size and are intentionally added to commercial products, such as personal hygiene products and textile fibres, among others. They account for a small percentage of the total of MPs present in the oceans and seas, but sewage has been identified as the main source because purification systems do not seem to be able to remove them. The prevention of the environmental impact of primary MPs is simple. In fact, the EU, following the recommendations of the European Chemicals Agency (ECHA) [6], has started a process to limit the use of these materials, and industries have applied voluntary steps in this regard [7].

In 2017, the European Commission (EC) asked ECHA to evaluate the existing scientific evidence with the aim of establishing, at a European level, legal measures concerning the intentional addition of MPs in industrial production processes. In January 2019, ECHA proposed far-reaching restrictions about the use of MPs in products commercialized in the EU to minimize their release into the environment. The EC is also considering other options as part of its Plastic Strategy and the new circular economy action plan [8].

Secondary MPs come from the fragmentation of larger-sized plastics exposed to UV light, thermal degradation, thermo oxidative degradation, mechanic abrasion, biodegradation, and hydrolysis [8]. There are many sources of secondary MPs for fishing equipment, sewage, plastic bags, containers, industrial waste, textiles, and tyres are worth mentioning.

MPs are made from a wide variety of polymers, but the most abundant are polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET), and polyurethane (PU) [9,10]. Medical face masks can be manufactured from different nanofibre and/or microfibre polymeric materials, such as polypropylene (PP), polyurethane (PU), polyacrylonitrile (PAN), polystyrene (PS), polycarbonate (PC), polyethylene (PE), or polyester (PES) [11–13] (Annex 1). However, the emerging of new materials, such as Tritan, that look for the solution of different technological issues should also be considered in future research, as an increase of their use is expected [14].

Furthermore, the morphology of MPs fragments is highly diverse, including fibres, microbeads, films, foams, pellets, etc. (Figure 1).

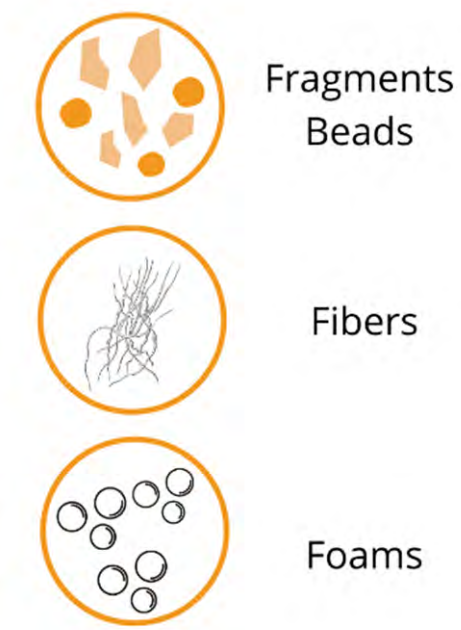


Figure 1. MPs morphology types [15].

In the marine ecosystem, MPs morphology, abundance, size, and density, among other variables, seem to affect the bioavailability of the MPs uptake by the zooplankton and therefore both the biomagnification process and the transfer between trophic levels [16,17].

Figure 1. MPs morphology types [15].

In the marine ecosystem, MPs morphology, abundance, size, and density, among other variables, seem to affect the bioavailability of the MPs uptake by the zooplankton and therefore both the biomagnification process and the transfer between trophic levels [16,17].

Current literature suggests that most marine organisms are at risk of interacting with MPs [18–22].

While the environmental impact of MPs has received much attention from the scientific community, regulators, and society in general, the health risk for humans derived from dietary exposure to MPs has not been assessed to date [23–28]. There is a persistent and considerable lack of knowledge on the major additives of concern that are used in plastic industry, on their fate once microplastics are disposed into the environment, and on their consequent effects on human health [24]. In 2019, Cox et al. [29] concluded that despite increasing evidence that MPs contaminate a large variety of food and beverages in addition to outdoor and indoor environments and the possibility of deleterious effects on human health following ingestion and/or inhalation, an investigation into the cumulative human exposure to MPs has not been conducted [29].

The toxicity of MPs needs to be considered not only the one from their moieties, even though most of the MPs intake is excreted (>90%), as only the particles smaller than 150 µm may translocate across the gut epithelium. [30] However, there is a great knowledge gap about the MPs health risk. It has been reported that there is potential immunotoxicity through immunosuppression and immune activation, disruption of the genetic expression of oxidative stress control, and activation the E2 (Nrf) nuclear factor expression, among others. [28,30].

Institutions, such as the European Food Safety Authority (EFSA) or the Spanish Food Safety and Nutrition Agency (AESAN), among others, affirm that with the available knowledge and data, the basis to make a risk characterization of MPs is not strong enough [2,28,30–33]. The growing awareness of this problem has led to several initiatives and projects even within the Horizon 2020 European program, including Imptox, Plasticsfate, Plasticsheal, and Polyrisk [34–37].

Since MPs entail potential risks to human health when ingested, the presence of MPs in foods and the magnitude of the dietary intake should be investigated. Therefore, the aim of this paper is not only to revise the current knowledge, knowledge gaps, and challenges about dietary MPs but also to assess them following the four steps of the risk analysis method concerning the dietary exposure from their main dietary sources.

2. Materials and Methods

Web of Science, PubMed, and Scopus were used to search those papers published from 2011 to 2021 related to the abundance, sources, and analytical methods of MPs in food and drinking water as well as dietary exposure studies. The keywords used were as follows: microplastics, nanoplastics, microplastic risk assessment, microplastic exposure assessment, microplastic hazard characterization, microplastic health, microplastic health effects, microplastic hazard identification, microplastic risk characterization, microplastic detection method, microplastic food, microplastic fish, microplastic salt, microplastic water, microplastic bivalves, and microplastic crustacean. Only the papers from first quartile or official sources and suitable information were selected.

The exposure assessment was performed using the Equation (1). MPs concentrations in the different food categories (water, fish, molluscs and crustaceans, and salt, among others) reported in the revised literature were used. The consumption portions used for these food categories are those published by EFSA, Eurobarometer for the European Market Observatory for Fisheries and Aquaculture Products (EUMOFA), and the European Commission [38–40].

$$\text{EDI} = \text{MPs concentration} \left[\frac{\text{particles}}{\text{g}}\right] \cdot \text{Daily ration} \left[\frac{\text{g}}{\text{day}}\right] \quad (1)$$

Equation used to calculate the Estimated Daily Intake.

3. Results

A total of 101 references were selected, and among them, eight were official reports about microplastics. All revised references that are not scientific reports from official bodies were included in the Q1. Nineteen references have as their main issue the MPs pollution, 44 the occurrence of MPs in different food matrix, 24 were mainly about MPs' toxicity in animals, 5 were about analytical method, and 1 mainly referred to challenges about MPs. From them, 74 were used for the results section.

There is a great lack of knowledge about the risk characterization of MPs as a growing food hazard. However, a few steps forward have been taken thanks to the application of the four-step risk assessment methodology, in other words, MPs hazard identification, the MPs hazard characterization, MPs exposure assessment, and MPs risk characterization.

Hazard identification is the first step in risk assessment and involves the identification of those biological, chemical, and physical agents capable of causing adverse health effects [41]. MPs are considered emerging food hazards that pose growing challenges and opportunities for researchers. Many studies have identified the presence of MPs in food and beverages, but the current available data could be considered not only insufficient but also of questionable quality. Even though Fourier Transform Infrared Spectroscopy (FTIR) is the most widely used detection method, the absence of consensus about unified nomenclature and a standardized quantifying method, as other techniques, such as Raman Spectroscopy or Thermo-extraction and desorption (TED) GC/MS, are also used [42–45], affects the quality of the data. The need of a standardized pre-treatment method for each matrix and the development of new ones for the study of new matrices to be able to accomplish a global dietary exposure assessment is also a great challenge. [42,44]

Fish [46–48], crustaceans and molluscs [49–51], drinking water [52,53], and salt are the main food categories with MPs occurrence data reports (Tables 1–4). According to Danapoulos et al., most studies identified MPs contamination in seafood and reported MPs content <1 MPs/g. These authors reported that molluscs collected off the coasts of Asia were the most heavily contaminated (0−10.5 MPs/g), followed by crustaceans (0.1–8.6 MPs/g) and fish (0–2.9 MPs/g) [54]. In 2021, Jin et al. [55] demonstrated that aquatic food products (fish and bivalves) have a wide range of MPs levels (0–10.5 items/g for bivalves and 0–20 items/individual for fish). These same authors reported that drinking water and salt are also a pathway of MPs exposure to humans, with concentrations ranging from 0–61 particles/L in tap water, from 0–3074 MPs/L in bottled water, and from 0–13,629 particles/kg for salt [55,56]. However, MPs have been also being identified in other foods, such as sugar (249 ± 130 particles/kg), fruits (5.2 particles/100 g), vegetables (6.4 particles/100 g), cereals (5.7 particles/100 g), honey (1992–9752 particles/kg), meats (9.6 particles/100 g), dairy products (8.1 particles/100 g), soft drinks (40 ± 24.53 particles/L), tea (11 ± 5.26 particles/L), energy drinks (14 ± 5.79 particles/L), and beers (152 ± 50.97 particles/L) [42,44,57–62].

Hazard characterization is the second step of any risk assessment and involves defining the nature of the adverse health effects associated with those biological, chemical, and physical agents that may be present in food. The hazard characterization should, if possible, involve an understanding of the doses involved and related responses [63]. As mentioned above, there are large knowledge gaps concerning the toxicokinetic, toxicodynamic, and toxicity effects of MPs in humans [28,64]. Therefore, the potential risks of dietary MPs to human health have been little explored. In other words, these knowledge gaps impede the estimation of food safety standards based on risk [2,30]. Therefore, more research in animals is needed to identify biomarkers of MPs toxicity, such as the disruption in immunity indices (acid phosphatase and alkaline phosphatase activity) and oxidative stress indices (total antioxidant capacity and malondialdehyde content) previously observed, for example, in juvenile and adult sea cucumbers [65,66]. Polyethylene microparticles have been shown to have an effect on haematological and biochemical indices, the antioxidant defence system, and expression of selected genes associated with the immune profile [67].

The size of MPs seems to have a relevant role in their toxicokinetic, as their gastrointestinal absorption has been observed to reach only 0.3% of ingested MPs and is limited to those MPs smaller than 1.5 µm [31,68]. Some evidence suggest that MPs are able to pass through the human placental barrier [69,70].

Regarding the toxicodynamic of these food pollutants, it is suspected that their action mechanism in humans is like that observed in animals [65]. Therefore, it is to be expected that the MPs could affect many molecular pathways [68,71], disrupt the genetic expression of oxidative stress control, and activate the E2 (Nrf) nuclear factor expression, among others. Alterations and changes in the oxidative stress, immune response, genomic instability, endocrine system alteration, neurotoxicity, reproductive abnormalities, embryotoxicity, and transgenerational toxicity, among others, may be a consequence of these action mechanisms [68].

Tissue abrasion, intestinal obstruction, chronic inflammation, body mass and metabolism reduction, neurotoxicity, behavior changes, cancer, fertility affectation, and mortality and morbidity increase, among many others, have been described as potential health effects associated with MP exposure [23,64,68,72–80]. These results were obtained after the administration of different doses of MPs (0.001 mg/L and 10 mg/L for 10 days, 0.1% of food weight for 90 days, 396 MPs per 100 mg of food for 28 and 56 days, 0.1 g/L for 4 days, 110 particles/mL for 14 days, 5 particles per 1.5 g of feed for 8 months, among other doses) in fishes, bivalves, mice, and nematodes [68,72–75,78–80]. The oral intake of PS MPs has been specifically associated with the decrease of intestinal mucosa, the malfunction of the intestinal barrier, and changes in the biodiversity of the intestinal microbiota and metabolism [81].

Exposure assessment is third step in any risk assessment study. This step relates to a thorough evaluation of who or what has been exposed to a hazard and a quantification of the amounts involved [82]. The need to know the total dietary exposure and the contribution of the different dietary sources have aroused researchers' interest in analysing and evaluating the MPs levels in the different food categories and assessing the dietary exposure in different scenarios.

The presence of MPs in drinking water has been confirmed by many studies in different locations and different types of waters (tap water, bottled, and groundwater) (Table 1). Oßmann et al. reported 2649 ± 2857 and 3074 ± 2531 particles of MPs/L in single-use plastic bottled water and glass bottled water, respectively [56]. The most common polymers found in drinking waters are PE ≈ PP > PS > PVC > PET [53], and the most frequent morphologies are fragments, fibres, films, foams, and pellets [53].

Some authors affirm that the dietary exposure to MPs from bottled water tends to be greater than from tap water [29,56]. The present study has considered the European Food Safety (EFSA) water daily intake estimation of 2 L to assess the dietary exposure to MPs from drinking water [38]. An estimated daily intake (EDI) has been calculated from this beverage observing a wide range of MPs intakes (2×10^{-5}–33,626 particles/day) considering the MPs levels observed in the different drinking water types shown in Table 1 and a 2 L/day ingestion (Table 1).

In Saudi Arabia, given a mean average recommended water intake of 3.7 and 2.7 L per day for men and women, respectively, the corresponding daily exposure to MPs would be 0.1–0.2 particles/Kg bw. This estimated dietary exposure for high consumers of water increases to a daily exposure of 1.7–1.9 particles/Kg bw based on the WHO recommended intake for drinking water in hot climates [84].

Seafood has been identified as the main dietary source of these food contaminants. Therefore, and due to the nutritional importance of seafood consumption, addressing any knowledge gap related to seafood hazards is a critical priority [85]. The studies reviewed evinced the presence of theses pollutants in crustaceans, molluscs, and fish (Tables 2 and 3). There are studies reporting noteworthy levels: 287,527 particles/fish, 103–183 particles/fish, and 2.19 particles/individual [86–88].

Table 1. MPs levels in different drinking waters and estimated dietary intake in a 2 L water/day consumption scenario.

Location	Food	Total Count of MPs	Estimated Intake of MPs When Drinking 2 L Water/Day	MPs Size	Composition of MPs	MPs Shape	Reference
Germany	Reusable plastic bottled water	3633 particles/L	7266 particles/day	90% < 5 µm	PET, PE, PP	Not specified	[56]
	Single use plastic bottled water	2649 ± 2857 particles/L	5298 ± 5714 particles/day				
	Glass bottled water	3074 ± 2531 particles/L	6148 ± 5062 particles/day				
Asia, Australia, Europe, and North America	Bottled water	4–16,813 particles/L	8–33,626 particles/day	1- > 5000 µm.	PE, PP, PS, PVC, PET	Fragments Fibres Films Foam Pellets	[53]
	Tap water	10^{-4}–100 particles/L	2×10^{-4}–200 particles/day				
Germany	Raw water (ground water)	7 particles/m^3 (7×10^{-3} particles/L)	0.014 particles/day	50–150 µm	PE, PA, PS, PVC	Fibres	[83]
Saudi Arabia	Drinking water	1.9–4.7 particles/L	3.8–9.4 particles/day	25–500 µm.	PE, PS, PET.	Not specified	[84]

MPs intake range: 2×10^{-5}–33,626 particles/day.

In Europe, seafood consumption has been estimated at 25.8 kg per capita/year, which means 494.76 g/week or 70.68 g/day [39]. Considering the MPs levels in the molluscs and crustaceans and a 70.68 g/day portion, an estimated daily intake has been calculated for each type of seafood. A wide range of MPs intakes (0–212.04 particles/day) is observed (Table 2). The EDI was only estimated for those types of seafood where the levels of MPs were reported in particles/g but not for those products where the units used were particles/individual. The highest intake levels of intakes are observed after the ingestion of Scotland coast mussels due to the high levels of MPs reported.

Table 2. MPs contents in bivalve molluscs and crustaceans and dietary intake estimation in a 70.68 g/day consumption scenario.

Location	Total Count of MPs	Estimated Intake (EDI) When a 70.68 g/day Edible Portion Is Ingested	MPs Size	Composition of MPs	MPs Shape	Reference
Germany	0.36–0.47 particles/g w.w.	25.44–33.22 particles/day	5–25 µm	Not specified	Fibres Particles	[89]
English Channel and Southern North Sea	0.68 ± 0.55 particles/g w.w.	48.06 ± 38.87 particles/day	200–1000 µm	Not specified	Fibres	[90]
Coast of Scotland	3.0 ± 0.9 particles/g w.w.	212.04 ± 63.612 particles/day	Not specified	PET, PU	Fibres	[51]
	3.2 ± 0.52 particles/mussel	-				
South Korea	0.15 ± 0.20 particles/g	10.60 ± 14.14 particles/day	43–4720 µm 65% < 300 µm	PE, PP. PS, PES	Fragments: 78% Fibres: 23%	[50]
	0.97 ± 0.74 particles/individual	-				
China	0.5–3.3 particles/individual	-	7–5000 µm	CPE, PET, PVDF, PVDC-PE, PVE, Nylon, PE, PEI, PVDC-PAN, PVC, CPE, Rayon.	Fibres Fragments Films Granules	[91]

Table 2. *Cont.*

Location	Total Count of MPs	Estimated Intake (EDI) When a 70.68 g/day Edible Portion Is Ingested	MPs Size	Composition of MPs	MPs Shape	Reference
South Korea	1.21–2.19 particles/individual	-	50–5000 µm	PP, PES, PET, PE, PS, PA, PVA, PU, PVC, PTFE.	Fragments Fibres Films Granules	[86]
India	0–0.008 particles/g	0–0.565 particles/g	100–300 µm	PS, PP, PE.	Fragments Sheets Fibres	[92]

MPs intake range: 0–212.04 ± 63.612 particles/day.

Table 3. MPs contents in fish and estimated daily intake in a 70.68 g fish/day consumption scenario.

Location	Total Count of MPs	Estimated Daily Intake (EDI) When a 70.68 g/day Edible Portion Is Ingested	MPs Size	Composition of MPs	MPs Shape	Reference
Portuguese coast	0.27 ± 0.63 particles/fish	-	217–4810 µm	PP, PE	Fibres: 65.8% Fragments: 34.2%	[48]
Portugal, Mondego estuary	1.67 ± 0.27 particles/fish	-	<1000–5000 µm	PES, PP	Fibres Fragments	[93]
Ireland	103 ± 41–183 ± 51 particles/fish	-	100–5000 µm	EVA, EPDM, PVF, PS, PTFE, PET, PP	Fibres Fragments Films	[88]
Adriatic Sea	2014: 1.73 ± 0.05 particles/fish	-	<100–500 µm	PVC, PP, PE, PES, PA	Fragments: 78% Fibres: 28%	[46]
	2015: 1.64 ± 0.1 particles/fish	-				[87]
Egypt	28–7527 particles/fish	-	≤25–≤2000 µm	PEVA, LDPE, HDPE, PET, PP, Nylon	Fragments Fibres Foam	[87]
USA, Charleston Harbour	5.8 ± 1.6 particles/g	409.94 ± 113.09 particles/day	Not specified	HDPE, LDPE, PS	Fibres Fragments Foam	[22]

As mentioned above, the exposure assessment faces the challenge of a non-existing normalized unit system for MPs. Only the study from Charleston Harbour (USA) [22] reports the MPs levels in particles/g. Therefore, this is the only study reviewed here that provided the MPs levels necessary for the calculation of the estimated daily intake (EDI) (409.94 ± 113.09 particles/day) derived from the consumption of a daily fish portion of 70.68 g [39].

Comparing the MPs levels detected in bivalves and crustaceans (range: 0.15–3.2 particles/g, Table 2) and the only study of MPs in fish expressed in particles/g (range: 5.8 ± 1.6 particles/g, Table 3), the fish food category presents higher levels of MPs than crustaceans. That is the reason why the dietary exposure to MPs after ingesting the same portion size would expose the consumer to a higher intake of MPs when eating fish. However, the exposure to MPs derived from fish intake could be lowered in those scenarios where the fish is consumed after removing the gastrointestinal tract, liver, and gills, which are known to be the main locations of MPs in fish. The dietary exposure is expected to be lower, as these parts are usually discarded. In the case of ingestion of small fish consumed without discarding any of its content, all the MPs present in the individual are ingested, and the consumer is expected to be exposed to the total count of the MPs detected in the fish. Therefore, it is recommended that future MPs studies in fish report its MPs contents in the edible parts, so the dietary exposure estimation would be more accurate.

Salt is another food product where MPs levels have been analysed and detected worldwide (Table 4). The occurrence of MPs in sea salt, rock salt, and lake salt demonstrate, as mentioned above, the ubiquity, diversity, and variability of MPs. Among all the data, the levels of MPs observed in salts from Croatia (27.13–31.68 particles/g) stand out [94].

Salt consumption in Europe has been estimated at 9.4 g/day [40]. Considering the reported MPs levels (Table 4) and this daily 9.4-g salt ingestion, an estimated daily intake (EDI) has been calculated for each type of salt. A wide range of MPs intakes derived from salt consumption has been observed (0.015–6.40 particles/day). Sea salt from China presented the highest total count of MPs (550–681 particles/kg) and therefore generated the greatest dietary exposure (5.17–6.40 particles/day) (Table 4). In the case of this food product, it was possible to calculate the EDI because all the studies reported the MPs levels using a normalized unit system of number of particles/g (Table 4).

Table 4. MPs contents in salts and estimated daily intake in a 9.4 g salt/day consumption scenario.

Location	Food	Total Count of MPs	Estimated Intake (EDI) When a 9.4 g/day Portion Is Ingested	MPs Size	Composition of MPs	MPs Shape	Reference
China	Sea Salt	550–681 particles/kg	5.17–6.40 particles/day	45–4300 µm	PE, PET, cellophane	Fragments Fibres Pellets	[95]
	Rock Salt	7–204 particles/kg	0.07–1.92 particles/day				
	Lake Salt	43–364 particles/kg	0.40–3.42 particles/day				
Spain	Table Salt	50–280 particles/kg	0.47–2.63 particles/day	10–3500 µm	PET, PP, PE	Fibres	[96]
Italy	Sea Salt	1.57–8.23 particles/g	0.015–0.08 particles/day	4–2100 µm	Not specified	Fragments Fibres Granules Films Foam	[94]
Croatia	Sea Salt	27.13–31.68 particles/g	0.26–0.29 particles/day	15–4628 µm			
India (Gujarat)	Salt	46–115 particles/200 g	0.43–1.08 particles/day	100–1000 µm	PE, PVC, PS.	Fragments Fibres Films	[97]
India (Tamil Nadu)		23–101 particles/200 g	0.22–0.95 particles/day				
India	Salt	5–21 particles/10 g	0.05–0.20 particles/day	Not specified	LDPE, PP, PET, Nylon.	Fibres	[98]

MPs intake range: 0.015–6.40 particles/day.

Some recent studies refer to the occurrence of MPs in other food groups, such as sugar (249 ± 130 particles/kg), fruits (5.2 particles/100 g), vegetables (6.4 particles/100 g), cereals (5.7 particles/100 g), honey (1992–9752 particles/kg), meats (9.6 particles/100 g), dairy products (8.1 particles/100 g), soft drinks (40 ± 24.53 particles/L), tea (11 ± 5.26 particles/L), energy drinks (14 ± 5.79 particles/L), and beers (152 ± 50.97 particles/L) [42,44,57–62], which had not yet been pointed as a dietary sources of MPs. MPs in agricultural soils create a potential impact on plants, including edible species, with relative concerns on food security [62]. Therefore, we suggest all food categories should be considered in the MPs dietary exposure assessment studies as any food group, if contaminated with quantifiable levels of MPs, may contribute to the total intake of MPs.

Even though, as stated above, the number of studies of MPs total dietary intake is low, Danopoulus et al. recently reported that the maximum annual human MPs uptake was estimated to be close to 55,000 MPs particles [54], which means an intake of 151 particles/day. In the present study, considering a consumption scenario where only the above-listed food categories (water, crustaceans and molluscs, fish, and salt) are included, and the upper intake of each one (Tables 1–4) is considered, the MPs estimated dietary intake would be 34,254 particles/day (33,626 particles/day from 2 L/day of water, 212 particles/day from 70.68 g/day of crustaceans/molluscs, 409.94 particles/day from 70.68 g/day of fish, and 6.40 particles/day from 9.4 g/day of salt) (Figure 2).

particles/day from 70.68 g/day of crustaceans/molluscs, 409.94 particles/day from 70.68 g/day of fish, and 6.40 particles/day from 9.4 g/day of salt) (Figure 2).

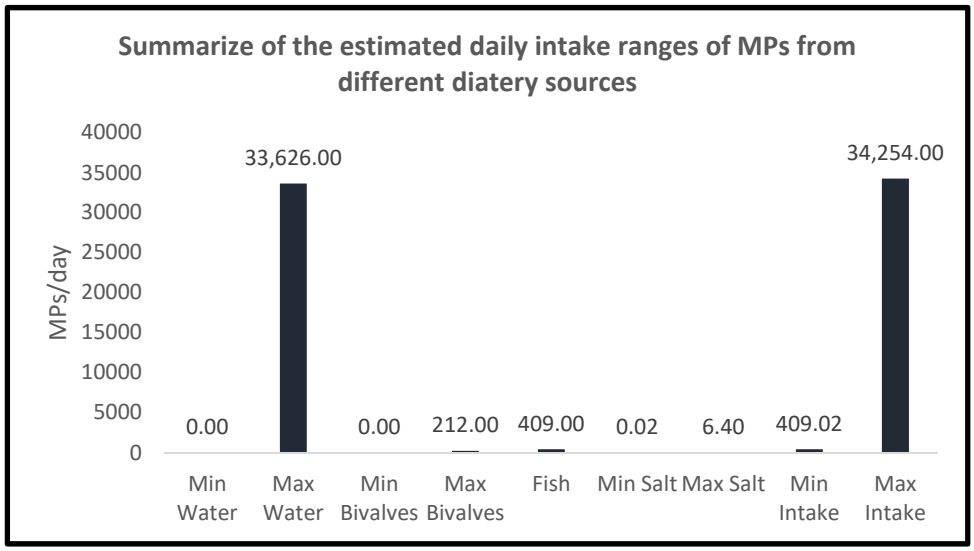


Figure 2. Summary of the MPs dietary intake ranges from each studied group.

There is no doubt that drinking-water data distorts the MPs dietary exposure estimation and suggests the need of developing, harmonizing, and standardizing not only a detection method for MPs but also the nomenclature to be used. The use of different nomenclatures in reporting the data not only makes the discussion and comparison of the results more difficult but also complicates the risk analysis derived from the dietary exposure to these growing pollutants.

Risk characterization is the final step of the risk assessment, in which the likelihood that a particular substance (MPs in this case) will cause harm is calculated in the light of the nature of the hazard and the extent to which people are exposed to it [99]. Some authors affirm that even though it has been observed to be able to cope with the toxic effects, their consumption could pose serious health risks to humans [67]. However, as there are insufficient reference values to evaluate the MPs dietary intake, the MPs risk characterization for dietary MPs is not possible at present. In 2019, however, Stock et al. affirmed that their results suggested that the oral exposure to PS microplastic particles did not pose acute health risks to mammals, as the data from in vivo studies did not provide any evidence of histologically detectable adverse effects [100]. In the same way, more recently, Almaiman et al. reported that the exposure to MPs from drinking water did not pose any concern to consumers in Saudi Arabia due to the low level of dietary intake of MPs from drinking water [84].

As the risk characterization derived from dietary MPs is not yet possible because of the existing knowledge gaps in the previous steps of the risk analysis, different authors have aimed to characterize the risks of the pollutants and pathogens adsorbed by the MPs [28,101], especially heavy metals.

Authors believe that further research is needed. There are huge opportunities and challenges for food-safety researchers, managers, and regulators. The occurrence of MPs should be monitored worldwide not only in drinking water and seafood but in all food categories. Further research on the kinetic and toxicity (dose–response assessment approach) of MPs, including a hazard characterization according to the type and composition of MPs in humans, is also required. Endpoints, such as NOAEL (no-observed-adverse-effect-level) or LOAEL (lowest-observed-adverse-effect-level), should be calculated because the setting of health-based guidance values would provide quantitative information from risk assessment for risk managers, enabling decision making. Food safety would benefit from the derivation of a health-based guidance values, such as an ADI, TDI, or acute reference dose (ARfD); estimation of the margin of exposure (MOE); or the quantification of the magnitude of the risk at specified levels of human exposure, among other initiatives and research.

Authors recognize as a limitation of this review the questionable quality of research revised on hazard identification.

4. Conclusions

While the environmental impact of MPs is receiving noticeable attention from the scientific community and society in general, the impact of dietary MPs in human health continues to present a challenge to risk evaluators. Human intake of MPs via ingestion is a non-negligible exposure route, and therefore, the determination of MPs not only needs a standardization of analytical methods but also a consensus in the definition, description, and expression of the results. It is still not possible to estimate qualitatively or quantitatively the possibility of occurrence of adverse effects derived from the dietary exposure to MPs based on a hazard identification, characterization, and exposure assessment. In the absence of MPs total diet studies, some exposure estimations identify drinking water and seafood as the main MPs dietary sources. However, MPs have also been found in other food categories and beverages. Future MPs dietary risk assessment reports should involve total diet studies.

Author Contributions: Conceptualization, C.R.-A.; methodology, C.R.-A. and A.H.-d.l.T.; software, S.P.-M.; validation, C.R.-A.; formal analysis, C.R.-A.; investigation, A.H.-d.l.T.; resources, Á.J.G.-F.; data curation, C.R.-A. and S.A.-V.; writing—original draft preparation, C.R.-A. and S.A.-V.; writing—review and editing, C.J.C.-I.; visualization, C.R.-A.; supervision, C.R.-A.; project administration, A.H.-d.l.T.; funding acquisition, A.H.-d.l.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

Polyethylene	PE
Polypropylene	PP
Polyvinyl chloride	PVC
Polystyrene	PS
Polyethylene terephthalate	PET
Polyurethane	PU
Polyacrylonitrile	PAN
Polycarbonate	PC
Polyester	PES
Acrylonitrile butadiene styrene	ABS
Polyphenylene sulfide	PPS
Polyamide	PA
Ethylene vinyl acetate	EVA
Chlorinated polyethylene	CPE
Polyvinylidene fluoride	PVDF
Polyvinylidene chloride	PVDC
Polyvinyl ethers	PVE
Polyethylenimine	PEI
Polyvinyl alcohol	PVA
Polytetrafluoroethylene	PTFE
High-density polyethylene	HDPE
Low-density polyethylene	LDPE
Ethylene propylene diene monomer	EPDM
Polyvinyl fluoride	PVF

References

1. Jambeck Jenna, R.; Roland, G.; Chris, W.; Siegler Theodore, R.; Miriam, P.; Anthony, A.; Ramani, N.; Law, K.L. Plastic waste inputs from land into the ocean. *Science* **2015**, *347*, 768–771. [CrossRef]
2. Alexy, P.; Anklam, E.; Emans, T.; Furfari, A.; Galgani, F.; Hanke, G.; Koelmans, A.; Pant, R.; Saveyn, H.; Sokull Kluettgen, B. Managing the analytical challenges related to micro- and nanoplastics in the environment and food: Filling the knowledge gaps. *Food Addit. Contam. Part A* **2020**, *37*, 1–10. [CrossRef] [PubMed]
3. Patrício Silva, A.L.; Prata, J.C.; Walker, T.R.; Duarte, A.C.; Ouyang, W.; Barcelò, D.; Rocha-Santos, T. Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations. *Chem. Eng. J.* **2021**, *405*, 126683. [CrossRef]
4. Jennifer, S.; Adyel Tanveer, M. Accumulation of plastic waste during COVID-19. *Science* **2020**, *369*, 1314–1315. [CrossRef]
5. Akhbarizadeh, R.; Dobaradaran, S.; Nabipour, I.; Tangestani, M.; Abedi, D.; Javanfekr, F.; Jeddi, F.; Zendehboodi, A. Abandoned COVID-19 personal protective equipment along the Bushehr shores, the Persian Gulf: An emerging source of secondary microplastics in coastlines. *Mar. Pollut. Bull.* **2021**, *168*, 112386. [CrossRef]
6. Microplásticos. Available online: https://echa.europa.eu/es/hot-topics/microplastics (accessed on 21 September 2021).
7. Guerranti, C.; Martellini, T.; Perra, G.; Scopetani, C.; Cincinelli, A. Microplastics in cosmetics: Environmental issues and needs for global bans. *Environ. Toxicol. Pharmacol.* **2019**, *68*, 75–79. [CrossRef]
8. Andrady, A.L. Microplastics in the marine environment. *Mar. Pollut. Bull.* **2011**, *62*, 1596–1605. [CrossRef] [PubMed]
9. Fotopoulou, K.; Karapanagioti, H. *Degradation of Various Plastics in the Environment*; Springer International Publishing: Cham, Switzerland, 2017.
10. Gewert, B.; Plassmann, M.M.; MacLeod, M. Pathways for degradation of plastic polymers floating in the marine environment. *Environ. Sci. Process Impacts* **2015**, *17*, 1513–1521. [CrossRef] [PubMed]
11. Shruti, V.C.; Pérez-Guevara, F.; Elizalde-Martínez, I.; Kutralam-Muniasamy, G. Reusable masks for COVID-19: A missing piece of the microplastic problem during the global health crisis. *Mar. Pollut. Bull.* **2020**, *161*, 111777. [CrossRef] [PubMed]
12. Fadare, O.O.; Okoffo, E.D. COVID-19 face masks: A potential source of microplastic fibers in the environment. *Sci. Total Environ.* **2020**, *737*, 140279. [CrossRef]
13. Aragaw, T.A. Surgical face masks as a potential source for microplastic pollution in the COVID-19 scenario. *Mar. Pollut. Bull.* **2020**, *159*, 111517. [CrossRef]
14. Holmes, R.; Ma, J.; Andra, S.S.; Wang, H. Effect of common consumer washing methods on bisphenol A release in tritan drinking bottles. *Chemosphere* **2021**, *277*, 130355. [CrossRef] [PubMed]
15. Rillig, M.C.; Lehmann, A.; Ryo, M.; Bergmann, J. Shaping Up: Toward Considering the Shape and Form of Pollutants. *Environ. Sci. Technol.* **2019**, *53*, 7925–7926. [CrossRef] [PubMed]
16. Da Costa, J.P.; Santos, P.S.M.; Duarte, A.C.; Rocha-Santos, T. (Nano)plastics in the environment—Sources, fates and effects. *Sci. Total Environ.* **2016**, *566–567*, 15–26. [CrossRef] [PubMed]
17. Lehtiniemi, M.; Hartikainen, S.; Näkki, P.; Engström-Öst, J.; Koistinen, A.; Setälä, O. Size matters more than shape: Ingestion of primary and secondary microplastics by small predators. *Food Webs* **2018**, *17*, e00097. [CrossRef]
18. Desforges, J.; Galbraith, M.; Dangerfield, N.; Ross, P. Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. *Mar. Pollut. Bull.* **2014**, *79*, 94–99. [CrossRef]
19. Sul, J.; Costa, M. The present and future of microplastic pollution in the marine environment. *Environ. Pollut.* **2013**, *185*, 352–364. [CrossRef]
20. Acosta-Coley, I.; Olivero-Verbel, J. Microplastic resin pellets on an urban tropical beach in Colombia. *Environ. Monit. Assess.* **2015**, *187*, 435–437. [CrossRef]
21. Napper, I.; Thompson, R. Plastic Debris in the Marine Environment: History and Future Challenges. *Global Chall.* **2020**, *4*, 1900081. [CrossRef]
22. Parker, B.W.; Beckingham, B.A.; Ingram, B.C.; Ballenger, J.C.; Weinstein, J.E.; Sancho, G. Microplastic and tire wear particle occurrence in fishes from an urban estuary: Influence of feeding characteristics on exposure risk. *Mar. Pollut. Bull.* **2020**, *160*, 111539. [CrossRef]
23. Barboza, L.G.A.; Dick Vethaak, A.; Lavorante, B.R.B.O.; Lundebye, A.; Guilhermino, L. Marine microplastic debris: An emerging issue for food security, food safety and human health. *Mar. Pollut. Bull.* **2018**, *133*, 336–348. [CrossRef]
24. Campanale, C.; Massarelli, C.; Savino, I.; Locaputo, V.; Uricchio, V.F. A Detailed Review Study on Potential Effects of Microplastics and Additives of Concern on Human Health. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1212. [CrossRef] [PubMed]
25. Toussaint, B.; Raffael, B.; Angers-Loustau, A.; Gilliland, D.; Kestens, V.; Petrillo, M.; Rio-Echevarria, I.; Van den Eede, G. Review of micro- and nanoplastic contamination in the food chain. *Food Addit. Contam. Part A* **2019**, *36*, 639–673. [CrossRef]
26. Waring, R.H.; Harris, R.M.; Mitchell, S.C. Plastic contamination of the food chain: A threat to human health? *Maturitas* **2018**, *115*, 64–68. [CrossRef]
27. Gallo, F.; Fossi, C.; Weber, R.; Santillo, D.; Sousa, J.; Ingram, I.; Nadal, A.; Romano, D. Marine litter plastics and microplastics and their toxic chemicals components: The need for urgent preventive measures. *Environ. Sci. Europe* **2018**, *30*, 13. [CrossRef] [PubMed]

28. Rubio Armendáriz, C.; Daschner, Á.; González Fandos, E.; González Muñoz, M.J.; Moreno-Arribas, M.V.; Talens Oliag, P.; de Castro, G.; Bustos, J. Informe del comité científico de la agencia española de seguridad alimentaria y nutrición (AESAN) sobre la presencia y la seguridad de los plásticos como contaminantes en los alimentos. *Agencia Española Segur. Aliment. Nutr. (AESAN)* **2019**, *30*, 49–84.
29. Cox, K.D.; Covernton, G.A.; Davies, H.L.; Dower, J.F.; Juanes, F.; Dudas, S.E. Human Consumption of Microplastics. *Environ. Sci. Technol.* **2019**, *53*, 7068–7074. [CrossRef]
30. Hantoro, I.; Löhr, A.J.; Van Belleghem, F.G.A.J.; Widianarko, B.; Ragas, A.M.J. Microplastics in coastal areas and seafood: Implications for food safety. *Food Addit. Contam. Part A* **2019**, *36*, 674–711. [CrossRef] [PubMed]
31. EFSA Panel on Contaminants in the Food Chain, (CONTAM) Presence of microplastics and nanoplastics in food, with particular focus on seafood. *EFSA J.* **2016**, *14*, e04501. [CrossRef]
32. SAPEA. *Working Group on Microplastics a Scientific Perspective on Microplastics in Nature and Society*; SAPEA: Berlin, Germany, 2019; Available online: https://doi.org/10.26356/microplastics (accessed on 19 August 2021). [CrossRef]
33. Skåre, J.U.; Alexander, J.; Haave, M.; Jakubowicz, I.; Knutsen, H.K.; Lusher, A.; Ogonowski, M.; Rakkestad, K.E.; Skaar, I.; Sverdrup, L.E.; et al. *Microplastics; Occurrence, Levels and Implications for Environment and Human Health Related to Food*; Scientific Opinion of the Scientific Steering Committee of the Norwegian Scientific Committee for Food and Environment: Oslo, Norway, 2019; Available online: http://hdl.handle.net/11250/2627485 (accessed on 19 August 2021).
34. Polyrisk. Polyrisk—Understanding Human Exposure and Health Hazard of Micro- and Nanoplastic Contaminants in our Environment. Available online: https://cordis.europa.eu/project/id/964766/es (accessed on 21 September 2021).
35. Plasticfate Plasticsheal. Plastics Fate and Effects in the Human Body. Available online: https://cordis.europa.eu/project/id/965367/es (accessed on 21 September 2021).
36. Imptox. An Innovative Analytical Platform to Investigate the Effect and Toxicity of Micro and Nano Plastics Combined with Environmental Contaminants on the Risk of Allergic Disease in Preclinical and Clinical. Available online: https://cordis.europa.eu/project/id/965173 (accessed on 21 September 2021).
37. Plasticsheal. Innovative Tools to Study the Impact and Mode of Action of Micro and Nanoplastics on Human Health: Towards a Knowledge Base for Risk Assessment. Available online: https://cordis.europa.eu/project/id/965196/es (accessed on 20 November 2021).
38. EFSA Panel on Dietetic Products, Nutrition, and Allergies, (NDA) Scientific Opinion on Dietary Reference Values for water. *EFSA J.* **2010**, *8*, 1459. [CrossRef]
39. Directorate-General for Maritime Affairs and Fisheries (European Commision). *EUMOFA EU Consumer Habits Regarding Fishery and Aquaulture Products-Final Report*; Publications Office of the European Union: Luxembourg, 2021.
40. Directorate-General Health and Consumers (European Commision). *Implementation of the EU Salt Reduction Framework Results of Member States survey Health and Consumers*; Publications Office of the European Union: Luxembourg, 2012.
41. EFSA. Glossary. Hazar Identification. Available online: https://www.efsa.europa.eu/en/glossary/hazard-identification (accessed on 30 August 2021).
42. Kwon, J.; Kim, J.; Pham, T.D.; Tarafdar, A.; Hong, S.; Chun, S.; Lee, S.; Kang, D.; Kim, J.; Kim, S.; et al. Microplastics in Food: A Review on Analytical Methods and Challenges. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6710. [CrossRef] [PubMed]
43. Ivleva, N.P. Chemical Analysis of Microplastics and Nanoplastics: Challenges, Advanced Methods, and Perspectives. *Chem. Rev.* **2021**, *121*, 11886–11936. [CrossRef]
44. Bai, C.; Liu, L.; Hu, Y.; Zeng, E.Y.; Guo, Y. Microplastics: A review of analytical methods, occurrence and characteristics in food, and potential toxicities to biota. *Sci. Total Environ.* **2022**, *806*, 150263. [CrossRef] [PubMed]
45. Vivekanand, A.C.; Mohapatra, S.; Tyagi, V.K. Microplastics in aquatic environment: Challenges and perspectives. *Chemosphere* **2021**, *282*, 131151. [CrossRef] [PubMed]
46. Pellini, G.; Gomiero, A.; Fortibuoni, T.; Ferrà, C.; Grati, F.; Tassetti, A.N.; Polidori, P.; Fabi, G.; Scarcella, G. Characterization of microplastic litter in the gastrointestinal tract of Solea solea from the Adriatic Sea. *Environ. Pollut.* **2018**, *234*, 943–952. [CrossRef] [PubMed]
47. Herrera, A.; Ŝtindlová, A.; Martínez, I.; Rapp, J.; Romero-Kutzner, V.; Samper, M.D.; Montoto, T.; Aguiar-González, B.; Packard, T.; Gómez, M. Microplastic ingestion by Atlantic chub mackerel (Scomber colias) in the Canary Islands coast. *Mar. Pollut. Bull.* **2019**, *139*, 127–135. [CrossRef]
48. Neves, D.; Sobral, P.; Ferreira, J.L.; Pereira, T. Ingestion of microplastics by commercial fish off the Portuguese coast. *Mar. Pollut. Bull.* **2015**, *101*, 119–126. [CrossRef]
49. Renzi, M.; Guerranti, C.; Blašković, A. Microplastic contents from maricultured and natural mussels. *Mar. Pollut. Bull.* **2018**, *131*, 248–251. [CrossRef]
50. Cho, Y.; Shim, W.J.; Jang, M.; Han, G.M.; Hong, S.H. Abundance and characteristics of microplastics in market bivalves from South Korea. *Environ. Pollut.* **2019**, *245*, 1107–1116. [CrossRef]
51. Catarino, A.I.; Macchia, V.; Sanderson, W.G.; Thompson, R.C.; Henry, T.B. Low levels of microplastics (MP) in wild mussels indicate that MP ingestion by humans is minimal compared to exposure via household fibres fallout during a meal. *Environ. Pollut.* **2018**, *237*, 675–684. [CrossRef]
52. Welle, F.; Franz, R. Microplastic in bottled natural mineral water—literature review and considerations on exposure and risk assessment. *Food Addit. Contam. Part A* **2018**, *35*, 2482–2492. [CrossRef] [PubMed]

53. Koelmans, A.A.; Mohamed Nor, N.H.; Hermsen, E.; Kooi, M.; Mintenig, S.M.; De France, J. Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. *Water Res.* **2019**, *155*, 410–422. [CrossRef]
54. Danopoulos, E.; Jenner, L.C.; Twiddy, M.; Rotchell, J.M. Microplastic Contamination of Seafood Intended for Human Consumption: A Systematic Review and Meta-Analysis. *Environ. Health Perspect.* **2020**, *128*, 126002. [CrossRef] [PubMed]
55. Jin, M.; Wang, X.; Ren, T.; Wang, J.; Shan, J. Microplastics contamination in food and beverages: Direct exposure to humans. *J. Food Sci.* **2021**, *86*, 2816–2837. [CrossRef]
56. Oßmann, B.E.; Sarau, G.; Holtmannspötter, H.; Pischetsrieder, M.; Christiansen, S.H.; Dicke, W. Small-sized microplastics and pigmented particles in bottled mineral water. *Water Res.* **2018**, *141*, 307–316. [CrossRef] [PubMed]
57. Dekimpe, M.; De Witte, B.; Deloof, D.; Hostens, K.; Van Loco, J.; Andjelkovic, M.; Van Hoeck, E.; Robbens, J. Dietary Exposure of the Belgian Population to Microplastics Through a Diverse Food Basket. In Proceedings of the Scientific Colloquium N°25: A Coordinated Approach to Assess Human Health Risks of Micro-and Nanoplastics in Food, Parma, Italy, 6–7 May 2021.
58. Kutralam-Muniasamy, G.; Pérez-Guevara, F.; Elizalde-Martínez, I.; Shruti, V.C. Branded milks—Are they immune from microplastics contamination? *Sci. Total Environ.* **2020**, *714*, 6823. [CrossRef] [PubMed]
59. Huang, Y.; Chapman, J.; Deng, Y.; Cozzolino, D. Rapid measurement of microplastic contamination in chicken meat by mid infrared spectroscopy and chemometrics: A feasibility study. *Food Control.* **2020**, *113*, 107187. [CrossRef]
60. Oliveri Conti, G.; Ferrante, M.; Banni, M.; Favara, C.; Nicolosi, I.; Cristaldi, A.; Fiore, M.; Zuccarello, P. Micro- and nano-plastics in edible fruit and vegetables. The first diet risks assessment for the general population. *Environ. Res.* **2020**, *187*, 109677. [CrossRef]
61. Shruti, V.C.; Pérez-Guevara, F.; Elizalde-Martínez, I.; Kutralam-Muniasamy, G. First study of its kind on the microplastic contamination of soft drinks, cold tea and energy drinks—Future research and environmental considerations. *Sci. Total Environ.* **2020**, *726*, 138580. [CrossRef]
62. Campanale, C.; Galafassi, S.; Savino, I.; Massarelli, C.; Ancona, V.; Volta, P.; Uricchio, V.F. Microplastics pollution in the terrestrial environments: Poorly known diffuse sources and implications for plants. *Sci. Total Environ.* **2022**, *805*, 150431. [CrossRef] [PubMed]
63. EFSA. Glossary. Hazard Characterization. Available online: https://www.efsa.europa.eu/en/glossary/hazard-characterisation (accessed on 30 August 2021).
64. Prata, J.C.; da Costa, J.P.; Lopes, I.; Duarte, A.C.; Rocha-Santos, T. Environmental exposure to microplastics: An overview on possible human health effects. *Sci. Total Environ.* **2020**, *702*, 134455. [CrossRef]
65. Usman, S.; Abdull Razis, A.F.; Shaari, K.; Amal, M.N.; Saad, M.Z.; Mat Isa, N.; Nazarudin, M.F.; Zulkifli, S.Z.; Sutra, J.; Ibrahim, M.A. Microplastics Pollution as an Invisible Potential Threat to Food Safety and Security, Policy Challenges and the Way Forward. *Int. J. Environ. Res. Public Health* **2020**, *17*, 9591. [CrossRef]
66. Mohsen, M.; Zhang, L.; Sun, L.; Lin, C.; Wang, Q.; Liu, S.; Sun, J.; Yang, H. Effect of chronic exposure to microplastic fibre ingestion in the sea cucumber Apostichopus japonicus. *Ecotoxicol. Environ. Saf.* **2021**, *209*, 111794. [CrossRef] [PubMed]
67. Hodkovicova, N.; Hollerova, A.; Caloudova, H.; Blahova, J.; Franc, A.; Garajova, M.; Lenz, J.; Tichy, F.; Faldyna, M.; Kulich, P.; et al. Do foodborne polyethylene microparticles affect the health of rainbow trout (Oncorhynchus mykiss)? *Sci. Total Environ.* **2021**, *793*, 148490. [CrossRef]
68. Alimba, C.G.; Faggio, C. Microplastics in the marine environment: Current trends in environmental pollution and mechanisms of toxicological profile. *Environ. Toxicol. Pharmacol.* **2019**, *68*, 61–74. [CrossRef]
69. Ragusa, A.; Svelato, A.; Santacroce, C.; Catalano, P.; Notarstefano, V.; Carnevali, O.; Papa, F.; Rongioletti, M.C.A.; Baiocco, F.; Draghi, S.; et al. Plasticenta: First evidence of microplastics in human placenta. *Environ. Int.* **2021**, *146*, 106274. [CrossRef]
70. Fournier, S.B.; D'Errico, J.N.; Adler, D.S.; Kollontzi, S.; Goedken, M.J.; Fabris, L.; Yurkow, E.J.; Stapleton, P.A. Nanopolystyrene translocation and fetal deposition after acute lung exposure during late-stage pregnancy. *Part Fibre Toxicol.* **2020**, *17*, 1–11. [CrossRef]
71. Avio, C.G.; Gorbi, S.; Regoli, F. Plastics and microplastics in the oceans: From emerging pollutants to emerged threat. *Mar. Environ. Res.* **2017**, *128*, 2–11. [CrossRef] [PubMed]
72. Pedà, C.; Caccamo, L.; Fossi, M.C.; Gai, F.; Andaloro, F.; Genovese, L.; Perdichizzi, A.; Romeo, T.; Maricchiolo, G. Intestinal alterations in European sea bass Dicentrarchus labrax (Linnaeus, 1758) exposed to microplastics: Preliminary results. *Environ. Pollut.* **2016**, *212*, 251–256. [CrossRef] [PubMed]
73. Rodriguez-Seijo, A.; Lourenço, J.; Rocha-Santos, T.A.P.; da Costa, J.; Duarte, A.C.; Vala, H.; Pereira, R. Histopathological and molecular effects of microplastics in Eisenia andrei Bouché. *Environ. Pollut.* **2017**, *220*, 495–503. [CrossRef]
74. Guzzetti, E.; Sureda, A.; Tejada, S.; Faggio, C. Microplastic in marine organism: Environmental and toxicological effects. *Environ. Toxicol. Pharmacol.* **2018**, *64*, 164–171. [CrossRef] [PubMed]
75. Wang, W.; Gao, H.; Jin, S.; Li, R.; Na, G. The ecotoxicological effects of microplastics on aquatic food web, from primary producer to human: A review. *Ecotoxicol. Environ. Saf.* **2019**, *173*, 110–117. [CrossRef]
76. Xie, X.; Deng, T.; Duan, J.; Xie, J.; Yuan, J.; Chen, M. Exposure to polystyrene microplastics causes reproductive toxicity through oxidative stress and activation of the p38 MAPK signaling pathway. *Ecotoxicol. Environ. Saf.* **2020**, *190*, 110133. [CrossRef]
77. Wang, Y.; Huang, J.; Zhu, F.; Zhou, S. Airborne Microplastics: A Review on the Occurrence, Migration and Risks to Humans. *Bull. Environ. Contam. Toxicol.* **2021**, 657–664. [CrossRef]

78. Karbalaei, S.; Hanachi, P.; Rafiee, G.; Seifori, P.; Walker, T.R. Toxicity of polystyrene microplastics on juvenile Oncorhynchus mykiss (rainbow trout) after individual and combined exposure with chlorpyrifos. *J. Hazard. Mater.* **2021**, *403*, 123980. [CrossRef] [PubMed]
79. Yu, S.; Chan, B.K.K. Intergenerational microplastics impact the intertidal barnacle Amphibalanus amphitrite during the planktonic larval and benthic adult stages. *Environ. Pollut.* **2020**, *267*, 115560. [CrossRef]
80. Umamaheswari, S.; Priyadarshinee, S.; Bhattacharjee, M.; Kadirvelu, K.; Ramesh, M. Exposure to polystyrene microplastics induced gene modulated biological responses in zebrafish (Danio rerio). *Chemosphere* **2021**, *281*, 128592. [CrossRef]
81. Jin, Y.; Lu, L.; Tu, W.; Luo, T.; Fu, Z. Impacts of polystyrene microplastic on the gut barrier, microbiota and metabolism of mice. *Sci. Total Environ.* **2019**, *649*, 308–317. [CrossRef] [PubMed]
82. EFSA. Glossary. Exposure Assessment. Available online: https://www.efsa.europa.eu/en/glossary/exposure-assessment (accessed on 30 August 2021).
83. Mintenig, S.M.; Löder, M.G.J.; Primpke, S.; Gerdts, G. Low numbers of microplastics detected in drinking water from ground water sources. *Sci. Total Environ.* **2019**, *648*, 631–635. [CrossRef]
84. Almaiman, L.; Aljomah, A.; Bineid, M.; Aljeldah, F.M.; Aldawsari, F.; Liebmann, B.; Lomako, I.; Sexlinger, K.; Alarfaj, R. The occurrence and dietary intake related to the presence of microplastics in drinking water in Saudi Arabia. *Environ. Monit. Assess.* **2021**, *193*, 390–399. [CrossRef]
85. Smith, M.; Love, D.C.; Rochman, C.M.; Neff, R.A. Microplastics in Seafood and the Implications for Human Health. *Curr. Environ. Health Rep.* **2018**, *5*, 375–386. [CrossRef]
86. Cho, Y.; Shim, W.J.; Jang, M.; Han, G.M.; Hong, S.H. Nationwide monitoring of microplastics in bivalves from the coastal environment of Korea. *Environ. Pollut.* **2021**, *270*, 116175. [CrossRef]
87. Shabaka, S.H.; Marey, R.S.; Ghobashy, M.; Abushady, A.M.; Ismail, G.A.; Khairy, H.M. Thermal analysis and enhanced visual technique for assessment of microplastics in fish from an Urban Harbor, Mediterranean Coast of Egypt. *Mar. Pollut. Bull.* **2020**, *159*, 111465. [CrossRef]
88. O'Connor, J.D.; Murphy, S.; Lally, H.T.; O'Connor, I.; Nash, R.; O'Sullivan, J.; Bruen, M.; Heerey, L.; Koelmans, A.A.; Cullagh, A.; et al. Microplastics in brown trout (Salmo trutta Linnaeus, 1758) from an Irish riverine system. *Environ. Pollut.* **2020**, *267*, 115572. [CrossRef]
89. Van Cauwenberghe, L.; Janssen, C.R. Microplastics in bivalves cultured for human consumption. *Environ. Pollut.* **2014**, *193*, 65–70. [CrossRef]
90. Devriese, L.I.; van der Meulen, M.D.; Maes, T.; Bekaert, K.; Paul-Pont, I.; Frère, L.; Robbens, J.; Vethaak, A.D. Microplastic contamination in brown shrimp (Crangon crangon, Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area. *Mar. Pollut. Bull.* **2015**, *98*, 179–187. [CrossRef] [PubMed]
91. Ding, J.; Sun, C.; He, C.; Li, J.; Ju, P.; Li, F. Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. *Sci. Total Environ.* **2021**, *782*, 146830. [CrossRef]
92. Daniel, D.B.; Ashraf, P.M.; Thomas, S.N.; Thomson, K.T. Microplastics in the edible tissues of shellfishes sold for human consumption. *Chemosphere* **2021**, *264*, 128554. [CrossRef] [PubMed]
93. Bessa, F.; Barría, P.; Neto, J.M.; Frias, J.P.G.L.; Otero, V.; Sobral, P.; Marques, J.C. Occurrence of microplastics in commercial fish from a natural estuarine environment. *Mar. Pollut. Bull.* **2018**, *128*, 575–584. [CrossRef] [PubMed]
94. Renzi, M.; Blašković, A. Litter & microplastics features in table salts from marine origin: Italian versus Croatian brands. *Mar. Pollut. Bull.* **2018**, *135*, 62–68.
95. Yang, D.; Shi, H.; Li, L.; Li, J.; Jabeen, K.; Kolandhasamy, P. Microplastic Pollution in Table Salts from China. *Environ. Sci. Technol.* **2015**, *49*, 13622–13627. [CrossRef]
96. Iñiguez, M.E.; Conesa, J.A.; Fullana, A. Microplastics in Spanish Table Salt. *Sci. Rep.* **2017**, *7*, 8620. [CrossRef] [PubMed]
97. Vidyasakar, A.; Krishnakumar, S.; Kumar, K.S.; Neelavannan, K.; Anbalagan, S.; Kasilingam, K.; Srinivasalu, S.; Saravanan, P.; Kamaraj, S.; Magesh, N.S. Microplastic contamination in edible sea salt from the largest salt-producing states of India. *Mar. Pollut. Bull.* **2021**, *171*, 112728. [CrossRef]
98. Nithin, A.; Sundaramanickam, A.; Surya, P.; Sathish, M.; Soundharapandiyan, B.; Balachandar, K. Microplastic contamination in salt pans and commercial salts—A baseline study on the salt pans of Marakkanam and Parangipettai, Tamil Nadu, India. *Mar. Pollut. Bull.* **2021**, *165*, 112101. [CrossRef] [PubMed]
99. EFSA. Glossary. Risk Characterisation. Available online: https://www.efsa.europa.eu/en/glossary/risk-characterisation (accessed on 30 August 2021).
100. Stock, V.; Böhmert, L.; Lisicki, E.; Block, R.; Cara-Carmona, J.; Pack, L.K.; Selb, R.; Lichtenstein, D.; Voss, L.; Henderson, C.J.; et al. Uptake and effects of orally ingested polystyrene microplastic particles in vitro and in vivo. *Arch. Toxicol.* **2019**, *93*, 1817–1833. [CrossRef]
101. Sana, S.S.; Dogiparthi, L.K.; Gangadhar, L.; Chakravorty, A.; Abhishek, N. Effects of microplastics and nanoplastics on marine environment and human health. *Environ. Sci. Pollut. Res.* **2020**, *27*, 44743–44756. [CrossRef] [PubMed]

EXHIBIT J

ZIONTZ CHESTNUT
ATTORNEYS AT LAW

RICHARD M. BERLEY
MARC D. SLONIM
BRIAN W. CHESTNUT
BRIAN C. GRUBER
BETH A. BALDWIN
WYATT F. GOLDING
ANNA E. BRADY

FOURTH AND BLANCHARD BUILDING
2101 FOURTH AVENUE, SUITE 1230
SEATTLE, WASHINGTON 98121-2331
TELEPHONE: (206) 448-1230
FAX: (206) 448-0962
WWW.ZIONTZCHESTNUT.COM

July 12, 2021

Submitted via the Online Public Comment Form

Washington State Department of Ecology
Solid Waste Program
P.O. Box 47600
Olympia, WA 98504-7600

Re: Comments on the New Draft Statewide General Permit for Biosolids Management and Associated SEPA Checklist

Ms. Kijowski,

Thank you for accepting and reviewing comments on the draft general permit for biosolids and septage application. These comments and materials are submitted on behalf of Ed Kenney, a Washington resident with deep concern for water quality, human health, and fisheries in the State.

Please consider these comments to apply both to the draft permit and the associated State Environmental Policy Act (SEPA) checklist and proposed determination of non-significance (DNS). In general, the proposed permit and DNS are inadequate in that they focus solely on regulated metals, nitrogen, and bacteria, without accounting for modern pollutants with significant human health risks: microplastics, PBDEs, PFAS, pharmaceuticals, and other contaminants of emerging concern. This deficiency means that Ecology cannot meaningfully assess environmental impacts of issuance of the general permit for application of biosolids, and that the protections for surface waters and groundwater are insufficiently protective.[1]

In a June 24, 2021 public meeting, Ecology stated that 86,000 tons of biosolids were land applied in Washington in 2019. Even under a conservative and unrealistic assumption that the use of biosolids will remain unchanged, that amounts to a total of 430,000 tons (860 million pounds) over the five-year life of the general permit. This staggering quantity mandates caution in regulating biosolids.

At the same meeting, Ecology asserted that it lacks means to regulate pollutants other than the nine metals identified by the United States Environmental Protection Agency (EPA) in 40 CFR § 503.13, and nitrogen. As explained herein, this position is both inaccurate and fails to meet Ecology's statutory duties to protect waters of the State. Given inadequate information and

[1] The term "biosolids" in this letter refers to both biosolids and septage unless specified. *See* RCW 70A.226.010(1).

reasonable risk of harm to the environment and human health, Ecology must take a precautionary approach, make a determination of significance, and prepare an environmental significance. While Mr. Kenney acknowledges that Ecology faces legislative direction to make beneficial use of biosolids in a manner that minimizes risk to public health and the environment, preparation of an environmental impact statement will allow the agency the time and information needed to balance these dual mandates. Careful consideration of alternatives is essential before approving such an extensive, impactful, and risky program.

A. Biosolids Statutory and Regulatory Criteria

The Department of Ecology is affirmatively responsible for ensuring that permitted activities, including land application of biosolids, protects waters of the State. RCW 90.48.010 states in part that:

> It is declared to be the public policy of the state of Washington to maintain the highest possible standards to insure the purity of all waters of the state consistent with public health and public enjoyment thereof, the propagation and protection of wild life, birds, game, fish and other aquatic life, and the industrial development of the state, and to that end require the use of all known available and reasonable methods by industries and others to prevent and control the pollution of the waters of the state of Washington. Consistent with this policy, the state of Washington will exercise its powers, as fully and as effectively as possible, to retain and secure high quality for all waters of the state.

As part of effectuating that policy, RCW 90.48.080 mandates that:

> It shall be unlawful for any person to throw, drain, run, or otherwise discharge into any of the waters of this state, or to cause, permit or suffer to be thrown, run, drained, allowed to seep or otherwise discharged into such waters any organic or inorganic matter that shall cause or tend to cause pollution of such waters according to the determination of the department, as provided for in this chapter.

This provision is broad in scope, covering any mechanism by which "any organic or inorganic matter" pollutes groundwater or surface waters. These broad provisions are reinforced by the State Environmental Policy Act, RCW 43.21C.020, which recognizes that "each person has a fundamental and inalienable right to a healthful environment," and commands that it is the "continuing responsibility of the state of Washington and all agencies of the state to use all practicable means" to protect a safe, healthful, and productive environment. SEPA further requires that "[t]he policies, regulations, and laws of the state of Washington shall be interpreted and administered in accordance with the policies set forth" in SEPA. RCW 43.21C.030.

With respect to biosolids specifically, RCW 70A.226.005(2) states:

> The legislature declares that a program shall be established to manage municipal sewage sludge and that the program shall, to the maximum extent possible, ensure

> that municipal sewage sludge is reused as a beneficial commodity and is managed in a manner that minimizes risk to public health and the environment.

This provision presents dual mandates that apply "to the maximum extent possible." While biosolids must be reused, Ecology may only authorize such reuse in a manner that minimizes environmental and health risk. If Ecology cannot ensure that environmental and health risks are minimized, the agency may not permit biosolids application.

Ecology implements RCW Chapter 70A.226 through the rules promulgated at WAC Chapter 173-308. The regulations detail testing requirements and concentration thresholds for certain pollutants, WAC 173-308-160, require pathogen and vector reduction, WAC 173-308-170 to -180, require screening of manufactured inerts, WAC 173-308-205, and set agronomic rate of application, WAC 173-308-190, among other requirements. Notably, WAC 173-308-190(6) provides that "[w]hen the potential for groundwater contamination due to biosolids application exists, the department may require groundwater monitoring or other conditions in accordance with the provisions of chapter 173-200 WAC. If it is determined that an enforcement criterion may be violated, an evaluation must be conducted to demonstrate compliance with the provisions of chapter 173-200 WAC." Finally, WAC 173-308-191 mandates that "[b]iosolids may not be applied to the land if they are likely to adversely affect a threatened or endangered species or its critical habitat."

While the biosolids regulations focus on specific pollutants, this does not mean that those are the only pollutants that are subject to regulation or that may cause contamination. WAC 173-380-030 confirms that "[b]iosolids facilities and sites where biosolids are applied to the land must comply with the requirements of chapter 90.48 RCW and chapters 173-200 and 173-201A WAC," which are the Water Pollution Control statute and regulations protecting groundwater and surface water. The regulations contain anti-degradation provisions which prohibiting contamination of waters of the State. WAC 173-200-030; WAC 173-201A-300. WAC 173-201A-240 prohibits introduction of toxic substances to surface waters beyond background levels.

The State law requirements are in addition to those imposed by the Federal Clean Water Act and implementing regulations. 40 CFR § 503.5 ("[n]othing in this part precludes a State or political subdivision thereof or interstate agency from imposing requirements for the use or disposal of sewage sludge more stringent than the requirements in this part or from imposing additional requirements for the use or disposal of sewage sludge."). Where there is land application within the confines of a wastewater treatment facility, a NPDES permit is required. 40 CFR § 122.26(b)(14)(ix).

B. SEPA Procedural Requirements

SEPA requires that Ecology prepare an environmental impact statement (EIS) for major actions having a probable significant, adverse environmental impact. RCW 43.21C.031. In order to determine whether an EIS is required, Ecology must prepare a threshold determination based on a rigorous review of direct, indirect, and cumulative effects of the proposal. WAC 197-11-330. Impacts likely to be significant include impacts "to environmentally sensitive or special areas,

such as loss or destruction of historic, scientific, and cultural resources, parks, prime farmlands, wetlands, wild and scenic rivers, or wilderness," impacts that "[a]dversely affect endangered or threatened species or their habitat," actions that "[c]onflict with local, state, or federal laws or requirements for the protection of the environment" and those impacts that "involve unique and unknown risks to the environment, or may affect public health or safety." WAC 197-11-330(3)(e).

Ecology must make the threshold determination "based upon information reasonably sufficient to evaluate the environmental impact of a proposal," and may require the applicant to submit more information or conduct independent further analysis if such reasonably sufficient information is not provided by the project proponent. WAC 197-11-335. The reasonably sufficient information requirement is ongoing. The lead agency "shall withdraw" the determination of nonsignificance if "[t]here is significant new information indicating, or on, a proposal's probable significant adverse environmental impacts" or "[t]he DNS was procured by misrepresentation or lack of material disclosure." WAC 197-11-340(3).

While SEPA review may reference thresholds and requirements set forth in other statutes and regulations, SEPA compliance is an independent legal duty, and SEPA supplements existing authority. *Polygon Corp. v. Seattle*, 90 Wash. 2d 59, 65, 578 P.2d 1309, 1313 (1978); *Columbia Riverkeeper v. Port of Vancouver USA*, 188 Wash. 2d 80, 95, 392 P.3d 1025, 1032 (2017).

C. The General Permit Fails to Protect Against Dangerous Chemicals

The fundamental failing of the general permit is that, even though Ecology knows and recognizes that biosolids contain dangerous contaminants of emerging concern and microplastics, Ecology requires no testing or control for these substances whatsoever. This is a very significant concern given the capacity of these substances to penetrate to groundwater and enter drinking water and surface waters. There is also concern that biosolids directly applied or in compost will expose farmworkers. Lack of adequate regulation of contaminants is a systemic concern which poses cumulative effects. The issues referenced in this letter should be dealt with at the programmatic general permit level and not deferred until site specific review.

Because the areas that produce the most biosolids tend to be the most populated and affluent urban areas in Washington, and the areas that receive biosolids tend to be less affluent, rural areas, the general permit raises serious environmental justice issues that Ecology has not evaluated.

1. Public health and environmental risk

The proposed general permit poses grave risk of contaminating both surface and groundwaters. Because biosolids derive from our collective waste stream, they contain concentrations of untreated chemicals from household and business use—everything we eat, drink, use for cleaning, and launder. This means that biosolids inherently contains myriad harmful substances, including: dozens of different chemicals derived from detergents, fragrances, and pharmaceuticals, that are collectively referred to as "contaminants of emerging concern,"

including PFAS;[2] polybrominated diphenyl ethers (PBDEs) and other dioxins;[3] phthalates; and biological contaminants such as norovirus and the novel coronavirus.[4] Many of these substances can cause significant short and long-term ecological and human health impacts at relatively low concentrations, raising significant public health and environmental risks.

Contaminants of emerging concern and dioxins found in biosolids evade treatment in municipal wastewater treatment plants. As such, they tend not to break down in soil, and can be transported by and to water. According to at least one peer-reviewed study of runoff following biosolids application, contaminants in biosolids are transported by runoff and can enter surface waters in dangerous concentrations.[5] Another peer-reviewed study states that "[r]ecent studies have demonstrated that the application of PFC contaminated biosolids can have important effects on local environments, ultimately leading to demonstrable human exposures," notes that "relatively high transport from soils to surface and well water is possible," and describes a case study in Alabama.[6]

Contamination would contribute to an already dangerous level of pollution in many areas. For example, the Nisqually River, Nisqually Reach, and McCallister Creek exceed water quality standards for fecal coliform, and water and sediments contain contaminants of emerging concern. According to a recent Seattle Times article summarizing an EPA study,

> The Nisqually estuary was more contaminated than expected with drugs, including cocaine, Cipro and Zantac. The source of the drugs there was unknown, the researchers reported. However, the Nisqually River, Nisqually Reach and McAllister Creek do not meet water-quality standards for fecal coliform. That makes leaking septic systems a possible source of the drugs.[7]

---

[2] These chemicals include perfluorinated chemicals (PFOS, PFOA); polychlorinated alkanes (PCAs), polychlorinated naphthalenes (PCNs); organotins (OTs), polybrominated diphenyl ethers (PBDEs), triclosan (TCS), triclocarban (TCC); benzothiazoles; antibiotics and pharmaceuticals; synthetic musks; bisphenol A, quaternary ammonium compounds (QACs), steroids; phthalate acid esters (PAEs) and polydimethylsiloxanes (PDMSs). *See* Bradley O. Clarke, Stephen R. Smith, Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids, Environment International, Volume 37, Issue 1, 2011, Pages 226-247, ISSN 0160-4120, https://doi.org/10.1016/j.envint.2010.06.004; *see also* Kinney et al., 2006, Survey of organic wastewater contaminants in biosolids destined for land application. Environmental Science and Technology, Vol. 40, No. 23, pp. 7207-7215.

[3] Kim et al., 2017, Review of contamination of sewage sludge and amended soils by polybrominated diphenyl ethers based on meta-analysis. Environmental Pollution, Vol. 220 Part B, pp. 763-765 (finding consistent presence of PBDEs in biosolids in varying concentrations across 288 samples).

[4] Viau et al., 2011, Toward a Consensus View on the Infectious Risks Associated with Land Application of Sewage Sludge. Environmental Science and Technology, Vol. 45, Issue 13, pp. 5459–5469.

[5] Yang et al., 2012, Steroid hormone runoff from agricultural test plots applied with municipal biosolids. Environmental Science and Technology, Vol. 46, No. 5, pp. 2746-2754, doi:10.1021/es203896t.

[6] Lindstrom AB, Strynar MJ, Delinsky AD, Nakayama SF, McMillan L, Libelo EL, Neill M, Thomas L. Application of WWTP biosolids and resulting perfluorinated compound contamination of surface and well water in Decatur, Alabama, USA. Environ Sci Technol. 2011 Oct 1;45(19):8015-21. doi: 10.1021/es1039425. Epub 2011 Apr 22. PMID: 21513287.

[7] Seattle Times, Drugs found in Puget Sound salmon from tainted wastewater (Feb. 23, 2016). Available at: https://www.seattletimes.com/seattle-news/environment/drugs-flooding-into-puget-sound-and-its-salmon/

If these chemicals are present in leaking septic effluent they are certainly also present in septage and biosolids. When present in water and sediments, the chemicals make their way into salmon and cause adverse health effects and death.[8]

Similarly, testing of sediment in outfall areas near the King County Elliott West CSO treatment plant has exceeded screening levels, including total PCBs, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, benzyl butyl phthalate, bis(2-ethylhexyl) phthalate, chrysene, dibenzo(a,h)anthracene, fluroanthene, indeno(1,2,3-c,d)pyrene, and mercury.[9] Like leaking septic, overflow sewage likely presents many of the same threats as biosolids.

One contaminant of particular concern is PFAS. According to the Department of Health, Per- and polyfluoroalkyl substances (PFAS) are a family of chemicals used since the 1950s to manufacture stain-resistant, water-resistant, and non-stick products. PFAS are widely used as coatings in common consumer products such as food packaging, outdoor clothing, carpets, leather goods, ski and snowboard waxes, and more. Ecology has recognized the risks posed by these chemicals, and has prioritized regulating them through a chemical action plan (CAP).

Federal and State agencies increasingly recognize PFAS as widespread and a serious health risk. On February 22, 2021, the United Stated Environmental Protection Agency (EPA) made final determinations to regulate PFOS and PFOA in drinking water. On April 27, 2021, Administrator Regan called for the creation of a new "EPA Council on PFAS" that is charged with building on the agency's ongoing work to better understand and ultimately reduce the potential risks caused by these chemicals. EPA has recognized that PFAS pose serious health risks that can no longer simply be ignored.

Likewise, the State has acknowledged that PFAS are chemicals of serious public health concern that is likely present in biosolids and wastewater, highly mobile in water and soil, do not degrade, bioaccumulate in humans and other animals, and cause likely human health effects.

Ecology's website provides a fact sheet for PFAS, reading in part that:

> **PFAS have become a serious public health concern across our country and state. Over time, some PFAS released from manufacturing sites, landfills, firefighting foam, and other products seep into surface soils. From there, PFAS leaches into groundwater and can contaminate drinking water.** PFAS have also been found in rivers, lakes, fish, and wildlife.
> …
> PFAS do not break down easily and stay in the environment for a long time. As a result, PFAS are widely detected in air, soil, water, and food. Exposure can occur when someone uses certain products that contain PFAS, eats PFAS-contaminated food, or drinks PFAS-contaminated water. When ingested, some PFAS can build

[8] Seattle Times, Puget Sound salmon do drugs, which may hurt their survival (April 16, 2018). Available at: https://www.seattletimes.com/seattle-news/puget-sound-salmon-do-drugs-which-may-hurt-their-survival/
[9] Fact Sheet for NPDES Permit WA0029181 West Point Wastewater Treatment Plant (WWTP) and Combined Sewer Overflow (CSO) System December 19, 2014.

> up in the body and, over time, these PFAS may increase to a level where health effects could occur.
>
> Studies in animals show that exposure to some PFAS can affect liver function, reproductive hormones, development of offspring, and mortality.
>
> Although nearly all of us are exposed to PFAS, their toxicity in humans is not completely understood. Experts investigating the effects on people have found probable links to immune system toxicity, high cholesterol, reproductive and developmental issues, endocrine system disruption, ulcerative colitis, thyroid issues, certain cancers, and pregnancy-induced hypertension. [10]

Media accounts and increasing science support these conclusions.[11] The Ecology fact sheet for PFAS similarly acknowledges that Ecology is "concerned" because

> Certain PFAS are highly mobile in the environment, meaning they can contaminate groundwater. Some PFAS transform into highly persistent perfluorinated chemicals—no natural processes can break these substances down. Once in the environment, PFAS can contaminate water and bioaccumulate in wildlife. The drinking water supplies in several parts of Washington are contaminated with PFAS above Environmental Protection Agency's health advisory level. They are costly to filter out.

Accordingly, the draft chemical action plan recognizes biosolids as potential sources of PFAS contamination to waters of the State, and calls for Ecology to, *inter alia*, "[e]stablish biosolids and soil sample collection and handling methods for PFAS analysis," "[a]ccredit Washington labs for EPA-validated analysis methods," "[i]nvestigate land application sites where procedures mimic rates and practices under current state rule (Chapter 173-308 WAC15)," "[e]valuate realistic exposure pathways," and "[e]valuate risk modeling using realistic input values."

For wastewater, the draft CAP recommends that "Ecology should evaluate PFAS in WWTP influent and effluent to better understand PFAS discharges in Washington state," "Ecology should develop a study design to sample PFAS in three different types of plants," "Ecology should consider additional monitoring requirements for WWTP dischargers…Based on this evaluation Ecology should require possible PFAS monitoring for some or all domestic and industrial WWTPs."

According to the draft CAP, the Legislature provided Ecology "$235,000 to conduct a WWTP sampling study by June 30, 2021. This includes costs for sample analysis, which can range from $1,000 to $1,500 per sample as well as project staff salaries."

---

[10] https://ecology.wa.gov/Waste-Toxics/Reducing-toxic-chemicals/Addressing-priority-toxic-chemicals/PFAS
[11] *See, e.g.*, https://www.nytimes.com/2020/09/23/parenting/pregnancy/pfas-toxins-chemicals.html?searchResultPosition=1 "These Everyday Toxins May Be Hurting Pregnant Women and Their Babies"

Despite a long record of Ecology recognizing the risks of PFAS, including those risks specific to wastewater treatment and biosolids land application, the draft general permit has no protections in place for PFAS which Ecology recognizes as a priority-toxic chemical. The same is true for pharmaceuticals and other contaminants of emerging concern. Lastly, pathogens deemed dead may actually be dormant. When applied to land in sewage wastes, dormant pathogens can regenerate when spread on the soil, especially wet soil.

There is also no meaningful discussion of contaminants beyond those specified in regulation in the draft general permit or associated documents, no disclosure of risk, and no indication that Ecology has seriously considered how to address PFAS, PBDE, and other contaminants.

2. *Proposed changes to the general permit and SEPA review*

Mr. Kenney acknowledges that Ecology has incomplete information and cannot fully know the contents of all biosolids. However, these challenges are not a valid reason to ignore the presence of harmful contaminants. Ecology has a duty to the public to protect waters of the State, and a duty under SEPA to obtain and consider all reasonable available information: "If information on significant adverse impacts essential to a reasoned choice among alternatives is not known, and the costs of obtaining it are not exorbitant, agencies shall obtain and include the information in their environmental documents." WAC 197-11-080(1).

Ecology's SEPA obligation requires the agency to consider environmental impacts of all contaminants likely present in biosolids, even if they are not specified under biosolids regulations. *Columbia Riverkeeper*, 188 Wash. 2d at 95.

Accordingly, Mr. Kenney requests that Ecology make the following changes to the general permit documentation and SEPA review to better protect the environment and public health:

- Coordinate internally with Ecology staff working on the PFAS CAP, and coordinate and consult with the Washington Department of Health, the Washington Department of Fish and Wildlife, and Washington tribal governments.

- Given the risk to groundwater and surface waters and limited testing conducted of biosolids available for a variety of contaminants, ban biosolids application on hydric soils and periodically inundated areas, impose greater buffers from surface waters, and require more distance to groundwater for all biosolids application.

- In the SEPA analysis, identify information gaps and obtain information to fill those gaps to the maximum extent feasible. To the extent information truly cannot be obtained, "indicate in the appropriate environmental documents its worst case analysis and the likelihood of occurrence." WAC 197-11-080(3)(b).

- Disclose and discuss the progress on the WWTP sampling study referenced in the draft PFAS CAP, including the methodology and any initial results.

- Identify and discuss all other States (such as Maine) that monitor, test, and/or regulate PBDEs or PFAS and other chemicals in biosolids. Explain the implications for this information on the Washington regulatory program.

- Prior to making a threshold determination, specifically identify a list of contaminants of priority concern (including PBDEs and PFAS) and: 1) assess their likely prevalence in biosolids, 2) assess their probable human health and environmental impacts given the scale of application in Washington, 3) test biosolids from various WWTPs, 3) test groundwater and runoff at application sites.

- Require as a condition of the general permit that WWTP operators test biosolids for PFAS and other contaminants of emerging concern and report to Ecology. Ecology indicates that these tests are available for $1,000-$1,500, which is a reasonable cost to impose on the regulated entity given the risk to public health. If entities profit from land application of biosolids, it is entirely appropriate and reasonable to pass through costs of testing to those companies to gather data. Requiring testing would provide Ecology with a broad data set to effectively regulate PFAS and other chemicals.

- Evaluate and disclose the extent to which biosolids application sites risk becoming contaminated over time in a manner that requires cleanup under State or Federal law (including the Model Toxics Cleanup Act, RCW 70A.305.010, *et. seq.*, and the Resource Conservation and Recovery Act, 42 U.S.C. § 6901 *et. seq.*).

In public meetings and comments on prior applications, the public has rightfully raised concerns regarding lack of testing and monitoring for PBDEs, PFAS and other chemicals in biosolids. In general, Ecology has responded that it is not financially or technically feasible to test for PFAS because there is not a validated testing methodology, and that the more efficient method of regulating PFAS is "upstream" in consumer products.

As an initial matter, many chemicals, such as PBDEs, phthalates, illegal drugs, and pharmaceuticals, are readily tested. To fulfill its statutory mandates and duties to protect the public and environment, Ecology must sample biosolids for these contaminants. Furthermore, as noted, Ecology has received funding to complete testing for PFAS associated with wastewater. This testing effort should be incorporated into permit review. Ecology should also draw from ongoing testing and information gathering from drinking water regulation to inform environmental review of the biosolids program, in consultation with the Department of Health.[12]

Mr. Kenney notes that other states require that WWTPs use an isotope dilution method like Method 537.1, ASTMD7979-19M, or CWA Method 1600 for PFAS analysis of biosolids in the interim and until EPA completes its work. Such methods are reliable for biosolids because they use an isotope-dilution method to measure sample extraction recoveries and correct for matrix

[12] https://www.doh.wa.gov/CommunityandEnvironment/DrinkingWater/RegulationandCompliance/RuleMaking

suppression effects in the LCMSMS. Ecology should allow the use of these methods as do other states.

Mr. Kenney also notes that PFAS is a nationally recognized concern on and around lands used for training by the Department of Defense. In these locations, the DOD regularly tests water using EPA-approved methods for PFAS. For example, testing has been underway for PFAS on Whidbey Island associated with the Naval training area since 2016.[13] Water sampling at Joint Base Lewis McChord revealed elevated levels of PFAS in 2018, which required cessation of drinking water use to protect public safety.[14] As such it is entirely possible for Ecology to test groundwater and surface water associated with biosolids applications sites.

With respect to consumer product regulation, Mr. Kenney welcomes those efforts. However, even if implemented immediately the benefits would be limited and long-term, given the prevalence of PFAS in widespread consumer products and the global nature of commerce.

D. The General Permit Fails to Protect Against Microplastics

WAC 173-308-205(1) requires that "all biosolids…must be treated by a process such as physical screening or another method to significantly remove manufactured inerts prior to final disposition." Additionally, "biosolids (including septage) that are land applied…must contain less than one percent by volume recognizable manufactured inerts." WAC 173-308-205(4).

Biosolids generally contain large volumes of small plastics, referred to as microplastics and nanoplastics. A recent synthesis of literature focused on microplastics in biosolids, titled "An overview of microplastic and nanoplastic pollution in agroecosystems" (Ng et al. 2018),[15] states that "polyethylene, plastic fibres, and polystyrene foam occupied up to 5% w/w in compost from mixed municipal solid waste for all size fractions between 420 μm and 25 mm; with around 0.5 to 0.6% having sizes b2 mm." Prevailing agronomic rates in the United States suggest maximum potential rate of microplastic inputs from biosolid in the order of 0.5 to 3.2 t·ha−1·yr−1. This unit measurement equates to 0.2 to 1.3 metric tons per acre per year of plastics present in biosolids (one hectare equals 2.471 acres). Plastics are "manufactured inerts." Extensive study, widespread publicity dedicated to microplastic contamination in soils and waters, and the ability to eliminate microplastics if desired indicates that microplastics are "recognizable." WAC 173-308-205(4).

The general permit would authorize approximately 430,000 tons of biosolids land application over a five-year period. Even a conservative estimate under which microplastics compose 2.5% of those biosolids would mean that 10,7050 tons of microplastics will be land applied under the

[13] https://www.navfac.navy.mil/navfac_worldwide/pacific/fecs/northwest/about_us/northwest_documents/environmental-restoration/pfas-groundwater-and-drinking-water-investigation/nswi_pfas.html; see also https://www.navfac.navy.mil/niris/SOUTHWEST/FALLON_NAS/N60495_000011.PDF (Naval Air Station Fallon);
[14] https://home.army.mil/lewis-mcchord/application/files/2015/6106/2504/CCR_2018_Lewis_DIGI_FINAL.pdf
[15] Ng et al., 2018, An overview of microplastic and nanoplastic pollution in agroecosystems. Science of the Total Environment, Vol. 627, pp. 1377-88.

general permit. Plastics take hundreds of years to break down: "projections indicate that the lifetime of polyolefins on land is in the vicinity of hundreds of years."[16] This means that microplastics not dispersed into surface or groundwaters (with resulting harm to aquatic species), or ingested and adsorbed by grazing cattle, will bioaccumulate on site and quickly add up. The plastics are harmful in their own right, and also can transport and degrade into a variety of contaminants. The health effects of microplastics are believed to be detrimental but are still poorly understood. According to Ng et al.:

> Classical soil ecotoxicological approaches use isolated organisms and standard substrates, with measures taken for survival, growth, reproduction and avoidance behaviour over a period of days and weeks. Such approaches may not capture the full impact of chemical additives in plastics that act as endocrine disruptors in addition to those which bioaccumulate, where long-term exposure at low doses may alter cell functions or cause DNA damage. Such damage manifests later in life or across generations as the damage accumulates.[17]

The most recent studies of microplastics suggest that they are highly mobile in water. Crossman et al. (2020) measured microplastics biosolids at various application sites, found high levels of contamination, and determined that 99 percent of the microplastics appeared to be transported by water over time.[18]

In short, the proposed application would put cumulatively significant amounts of plastic onto application sites, that would likely enter surrounding waters and organisms and cause uncertain long-term impacts to the native ecosystem and human health.

Despite these risks, the general permit does not specify any means by which to comply with the requirement to remove manufactured inerts. As a result the general permit is deficient and must be conditioned to require rigorous screening for microplastics and nanoplastics.

Accordingly, Mr. Kenney requests that Ecology make the following changes to the general permit documentation and SEPA review to better protect the environment and public health:

- Identify and discuss all other jurisdictions that monitor, test, and/or regulate microplastics in biosolids. Explain the implications for this information on the Washington regulatory program.

---

[16] Ng et al., 2018, An overview of microplastic and nanoplastic pollution in agroecosystems. Science of the Total Environment, Vol. 627, p. 1380.
[17] *Id.* at 1385.
[18] Crossman, Rachel R. Hurley, Martyn Futter, Luca Nizzetto,
Transfer and transport of microplastics from biosolids to agricultural soils and the wider environment,
Science of The Total Environment, Volume 724, 2020, 138334, ISSN 0048-9697,
https://doi.org/10.1016/j.scitotenv.2020.138334
(https://www.sciencedirect.com/science/article/pii/S0048969720318477)

- Identify mechanisms to remove microplastics from biosolids, and the viability of these methods.
- In the SEPA analysis, identify information gaps and obtain information to fill those gaps to the maximum extent feasible. To the extent information truly cannot be obtained, "indicate in the appropriate environmental documents its worst-case analysis and the likelihood of occurrence." WAC 197-11-080(3)(b).
- Require as a condition of the general permit that WWTP operators remove microplastics from biosolids in accordance with WAC 173-308-205.
- Ecology should test runoff and groundwater associated with select recent biosolids application sites after rain and report the results.

As with PFAS, PBDEs, and contaminants of emerging concern, Ecology cannot fulfill its public statutory obligations by simply ignoring microplastics. Mr. Kenney requests that Ecology take reasonable, affirmative steps to address this serious issue and comply with its statutory mandate to protect waters of the state.

E. The General Permit Fails to Protect Threatened and Endangered Species

Biosolids application is not allowed where the application is likely to adversely affect a threatened or endangered species or its critical habitat as listed under Title 232 WAC or section 4 of the Endangered Species Act. WAC 173-308-191. Notably, the regulation prohibits any likely harm to threatened or endangered species or their critical habitat and does not allow for *de minimus* exceptions or mitigation measures. This is a particularly significant issue for southern resident killer whales, which are top tier predators of salmon and marine life and thus bioaccumulate toxins.

Issuance of the general permit without protections for protected species would not only potentially violate State law, it would also likely violate the Federal Endangered Species Act (ESA). The ESA prohibits the "take" of species listed as threatened or endangered on the federal endangered species list. 16 U.S.C. § 1538(a)(1)(B). The ESA defines "take" as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." *Id.* § 1532(19). By regulation, the National Marine Fisheries Service has defined "harm" to include "significant habitat modification or degradation which actually kills or injures fish or wildlife by significantly impairing essential behavioral patterns, including, breeding, spawning, rearing, migrating, feeding or sheltering." 50 C.F.R. § 222.102; *Babbitt v. Sweet Home Chapter, Communities for Great Ore.*, 515 U.S. 687 (1995).

Under what is known as the "*Strahan* theory," a governmental entity may be liable under the ESA for authorizing harm carried out by private third parties. *See Strahan v. Coxe*, 127 F.3d 155, 158, 163 (1st Cir. 1997) (state agency caused takings of the endangered right whale because it "licensed commercial fishing operations to use gillnets and lobster pots in specifically the manner that is likely to result in violation of [the ESA]"), cert. denied, 1998 U.S. LEXIS 7103 (Nov. 2, 1998) (No. 97-1485); *Defenders of Wildlife v. Administrator, Envtl. Protection Agency*,

882 F.2d 1294, 1300-01 (8th Cir. 1989) (federal agency caused takes of the endangered black-footed ferret through its "decision to register pesticides" even though other persons actually distributed or used the pesticides); *Loggerhead Turtle v. Cty. Council of Volusia Cty.*, 148 F.3d 1231, 1251 (11th Cir. 1998) (finding plaintiffs had standing where they alleged harm from county's failure to regulate artificial beach lighting, which harmed turtles).

An agency may receive authorization from the U.S. Fish and Wildlife Service and/or National Marine Fisheries Service to issue permits that cause harm to listed species, under ESA Section 10. *See* 16 U.S.C. § 1539(a)(2)(B). For example, Washington State Department of Natural Resources has an incidental take permit for authorization of forest practices that cause likely harm to listed species. Ecology lacks such authorization for the biosolids program.

The ESA authorizes citizen suits "to enjoin any person, including the United States and any other governmental instrumentality or agency (to the extent permitted by the eleventh amendment to the Constitution), who is alleged to be in violation of any provision" of the Act. 16 U.S.C. § 1540(g)(1)(A). Agency officials acting in their official capacity are not protected by the eleventh amendment, and so state agencies are functionally subject to suit. Such suits may result in injunctive relief, civil penalties, and an award of costs and attorneys' fees.

In order to fully protect listed species and protect the State from liability, Mr. Kenney suggests that Ecology consult with the National Marine Fisheries Service and U.S. Fish and Wildlife Service to determine whether an incidental take permit and associated habitat conservation plan is required.

F. SEPA Checklist Specific Comments

The SEPA Checklist and associated threshold determination must fully disclose sufficient information to determine whether a proposal has probable significant adverse environmental impacts. WAC 197-11-335. The determination includes consideration of cumulative effects, WAC 197-11-330(3)(c), and may not weigh purported benefits of the proposal against the adverse impacts, WAC 197-11-330(5). "Significant" means "a reasonable likelihood of more than a moderate adverse impact on environmental quality."

The general permit authorizes millions of pounds of land application of biosolids over a period of five years, which, as documented above, contain unknown amounts of dangerous chemicals and microplastics. While Mr. Kenney recognizes that there would be phased SEPA review for individual projects, in order to be meaningful SEPA review must be carried out "at the earliest possible time to ensure that planning and decisions reflect environmental values, to avoid delays later in the process, and to seek to resolve potential problems." WAC 197-11-055(1). Early review is particularly necessary here, where there are significant cumulative effects of biosolids application across the State, and the identified issues are common to all biosolids. PFAS, contaminants of emerging concern, and microplastics exist in all biosolids, and are not site-specific issues well suited for later phased review. The programmatic phase is also the only meaningful opportunity to conduct environmental review of Class A "exceptional quality" biosolids, application of which is not subject to later SEPA review.

The general permit clearly creates "a reasonable likelihood of more than a moderate adverse impact on environmental quality," and thus is significant and requires preparation of an environmental impact statement. Because application of biosolids can reasonably be anticipated to contaminate both groundwater and surface waters across the State with chemicals already recognized by Ecology to pose a serious threat to human health, the proposal presents cumulative effects to wildlife, "unique and unknown risks to the environment," and "may affect public health or safety." WAC 197-11-330(3).

Ecology mainly points to data gaps as the explanation for why it cannot regulate acknowledged risks. Under SEPA regulations, significance depends on context and intensity. "The context may vary with the physical setting. Intensity depends on the magnitude and duration of an impact." WAC 197-11-794. Here, PFAS are "forever chemicals," so the duration of the impact is perpetuity. Furthermore, "[t]he severity of an impact should be weighed along with the likelihood of its occurrence. An impact may be significant if its chance of occurrence is not great, but the resulting environmental impact would be severe if it occurred." The impacts of widespread biosolids application are undoubtedly severe, given the reasonable threat of harm to human health of PFAS, including, according to Ecology, "probable links to immune system toxicity, high cholesterol, reproductive and developmental issues, endocrine system disruption, ulcerative colitis, thyroid issues, certain cancers, and pregnancy-induced hypertension."

Preparation of a programmatic EIS is the statutorily mandated mechanism by which to address these data gaps and assess associated risks and impacts. Rather than forge ahead in the face of admitted incomplete information, Ecology must carefully assess the likelihood and severity of impacts, reasonable alternatives, and the mechanism to mitigate them.

In addition to the general request for a determination of significance and preparation of an EIS, Mr. Kenney raises the following specific concerns with the SEPA checklist:

- ¶ 1. The checklist improperly excludes consideration of population growth, when Washington is a quickly growing State. The checklist should consider more recent population trends, including during the COVID pandemic.

- ¶ 1. The description of pollutants should distinguish between pollutants that are regulated, and pollutants more broadly, as this section appears to use the terms interchangeably. The SEPA analysis must consider impacts of all pollutants reasonably likely to be contained in biosolids irrespective of their regulation. The general statement that "Generally, pollutants in biosolids occur in very low concentrations, below the level where an adverse effect is expected" is inadequate. This cursory analysis lumps all pollutants together and contains no useful information.

  As detailed above, high priority pollutants (including PBDEs and PFAS) should be identified, along with a discussion of their likely presence of the pollutants and risks to

the environment and human health. The one summary sentence dedicated to a serious and complex systemic issue is clearly inadequate.

- ¶ 1. The citation to WAC 173-308-90003 should acknowledge that this is the minimum content of a land application plan, but not necessarily sufficient to protect groundwater or adequate to fulfill Ecology's duties to protect groundwater.

- ¶1. The checklist states that "If the regulation of other pollutants becomes necessary during the course of the permit cycle, that is sufficient cause for Ecology to open the permit for modification." This statement lacks basis or thresholds, and is circular in that it states that if regulation is necessary then it is necessary. In order to be meaningful, mitigation must include specific triggers, criteria, and regulatory responses as part of a robust adaptive management system with public involvement.

- ¶ 2. The general statements regarding "decades of science" are inadequate. Citation must be provided. Emphasis should be placed on recent science, rather than decades-old science, given the concerns regarding PFAS, microplastics and other more recently understood issues.

- ¶ 2. The purported benefits of biosolids are immaterial to the threshold determination.

- ¶ 4. The statement that "Parks, wilderness areas, and wild and scenic rivers are likely too remote to be desirable for the land application of non-EQ biosolids" is inaccurate.

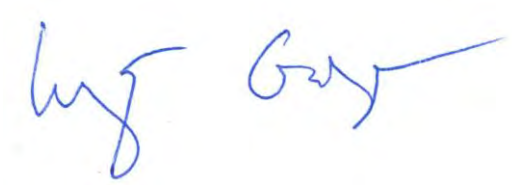
- ¶ 4. Application of biosolids to hydric soils raises high probability of groundwater contamination, which must be analyzed. As a mitigation measure, Mr. Kenney recommends barring biosolids applications from hydric soils and areas that are periodically inundated.

- ¶ 6. The analysis states that "[t]he permit itself will not increase demands on transportation or public services and utilities." This is the incorrect legal standard for SEPA review, which requires consideration of both direct and indirect effects. Ecology must consider the full impacts of biosolids application over time, including emissions and traffic associated with application.

Thank you for your consideration of these comments. Please contact me at wgolding@ziontzchestnut.com with any response to comments or follow up questions or concerns.

Sincerely,

ZIONTZ CHESTNUT



Wyatt Golding
Attorney for Ed Kenney

Science of the Total Environment 627 (2018) 1377–1388

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

An overview of microplastic and nanoplastic pollution in agroecosystems

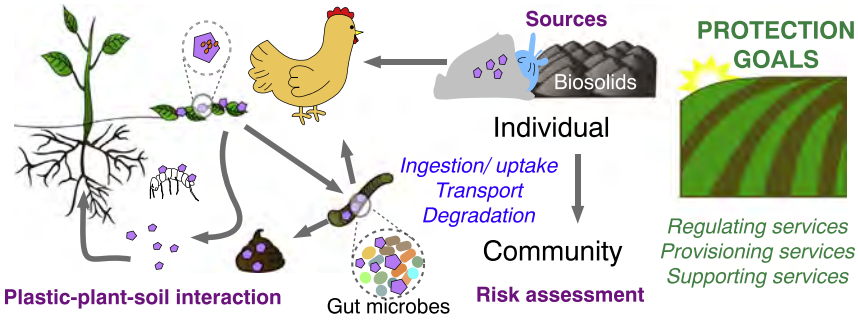
Ee-Ling Ng [a,*], Esperanza Huerta Lwanga [b,c], Simon M. Eldridge [a], Priscilla Johnston [d], Hang-Wei Hu [a], Violette Geissen [b], Deli Chen [a]

[a] School of Agriculture and Food, Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Victoria 3010, Australia
[b] Soil Physics and Land Management Group, Wageningen University & Research, Droevendaalsesteeg 4, 6708PB Wageningen, The Netherlands
[c] Agroecologia, El Colegio de la Frontera Sur, Unidad Campeche Av Polígono s/n, Cd. Industrial, Lerma, Campeche, Mexico
[d] CSIRO Manufacturing, Bayview Avenue, Clayton 3168, Victoria, Australia

HIGHLIGHTS

- We estimate maximum loadings in agroecosystem using existing regulations.
- Lifetime loading of 2.8–63 $t \cdot ha^{-1}$ of microplastics from biosolids use alone.
- Biotic response is mediated by the organism, soil and plastic properties.
- We deduce ecosystem impact by linking organismal response to ecological role.
- Estimated loadings can be used to set up ecotoxicology experiments.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 27 November 2017
Received in revised form 31 January 2018
Accepted 31 January 2018
Available online 20 February 2018

Editor: Jay Gan

Keywords:
Soils
Plant response
Ecotoxicology
Soil food web
Plastic degradation

ABSTRACT

Microplastics and nanoplastics are emerging pollutants of global importance. They are small enough to be ingested by a wide range of organisms and at nano-scale, they may cross some biological barriers. However, our understanding of their ecological impact on the terrestrial environment is limited. Plastic particle loading in agroecosystems could be high due to inputs of some recycled organic waste and plastic film mulching, so it is vital that we develop a greater understanding of any potentially harmful or adverse impacts of these pollutants to agroecosystems. In this article, we discuss the sources of plastic particles in agroecosystems, the mechanisms, constraints and dynamic behaviour of plastic during aging on land, and explore the responses of soil organisms and plants at different levels of biological organisation to plastic particles of micro and nano-scale. Based on limited evidence at this point and understanding that the lack of evidence of ecological impact from microplastic and nanoplastic in agroecosystems does not equate to the evidence of absence, we propose considerations for addressing the gaps in knowledge so that we can adequately safeguard world food supply.

Contents

* Corresponding author.
E-mail address: eeling.ng@unimelb.edu.au (E.-L. Ng).

https://doi.org/10.1016/j.scitotenv.2018.01.341
0048-9697/

1. Introduction: microplastics and nanoplastics as emerging environmental pollutants

Small plastic particles are ubiquitous throughout the environment, and cause considerable concern because micro (defined here as 100 nm to 5 mm in size) and nano (<100 nm in one dimension) sized particles are small enough to be taken up by many organisms (EFSA Panel on Contaminants in the Food Chain, 2016) and raises questions of potential bioaccumulation and biomagnification (see glossary in Box 1). There is growing evidence that microplastics are ingested by marine organisms, some evidence of translocation beyond the gut and fewer still evidence of transfer from one trophic level to the next (Galloway et al., 2017; GESAMP, 2015; Rochman et al., 2016). Nanoplastics are potentially more hazardous than microplastics because they can permeate biological membranes (Bouwmeester et al., 2015; EFSA Panel on Contaminants in the Food Chain, 2016; Nel et al., 2009). Terrestrial studies on microplastics ingestion are emerging for soil organisms (Huerta Lwanga et al., 2016; Rodriguez-Seijo et al., 2017). Recently, Horton et al. (2017) and Duis and Coors (2016) reviewed sources and fate of microplastics in terrestrial environment, and we build upon their work by exploring the extent to which plant and soil organisms in agroecosystems could be impacted, from individual level up to ecosystem level.

Leo Baekeland developed the world's first useful synthetic plastic in 1907 using formaldehyde and phenol (American Society of Chemistry National Historic Chemical Landmarks, 1993), but little was produced until around 1950s, when mass production of plastics begun and plastics found use in increasing range of applications; between 1950 and 2015, global plastic waste is estimated to be 6300 million tonnes, 79% of which has accumulated in landfills and other environmental compartments (Geyer et al., 2017). Based on the sources of microplastic pollution, agroecosystems are likely to be the most plastic-contaminated terrestrial system outside of landfills, urban spaces (Nizzetto et al., 2016) and beaches (Duis and Coors, 2016), and therefore they are excellent systems to study the implications of exposure to microplastic and nanoplastic. We will also include some findings from research on macro-plastics that we believe are relevant to understanding the overall effects of plastic pollution in agroecosystems.

In this synthesis, we present an overview of the multidisciplinary research on microplastics and nanoplastics in agroecosystems. While the relevant literature is vast, some aspects have fortunately been covered by recent reviews, which we will briefly summarise. Here, we emphasise on the following. Firstly, we identify the sources and estimate microplastics loading in agroecosystems, using reported estimates and our own calculations. Secondly, we examine the likely mechanisms and constraints underlying plastic degradation in soils and their dynamic behaviour. Thirdly, we report on the impact of these plastic

Box 1
Glossary.

Bioaccumulation	The process by which the amount of a substance, in this case, plastic particles, in an organism increases progressively because the rate of intake exceeds the rate of removal from the body.
Bioavailable	Amount of a substance that an organism absorbs (across a physiological membrane) as a result of physical, chemical and biological processes.
Biomagnification	Accumulation of a substance through a food chain by transfer of residues from diet to body tissue. The tissue concentration increases at each trophic level in the food web when uptake exceeds removal.
Cometabolism	The degradation of a substance catalyzed by an enzyme whose primary function is to react with another substrate. The other substrate is used as the primary carbon and energy source. For example, the breakdown of organopollutants, such as DDT, by white rot fungus *Phanerochaete chrysosporium* is catalyzed by enzymes responsible for breaking down lignin in plant material under normal conditions.
Home garden	Traditional, small scale agroforestry systems practiced in urban and rural areas, consisting of multipurpose trees and shrubs where livestock are often raised.
Nanoplastic	Plastic particles with one dimension between 1 and 100 nm.
Microplastic	Plastic particles in the size range between 100 nm and 5 mm.
Annual microplastic loading rate	The quantity of microplastic added per unit area per year.
Maximum or lifetime loading	This is the maximum amount of a substance per unit area given regulatory limits, e.g. contaminant limited biosolids application rate. In the case of biosolids, the limit is usually reached by a persistent contaminant such as heavy metals, thereby preventing further addition of biosolids to the land once this limit is reached.

particles on soil organisms and plants. This present work will serve as a synthesis of existing evidence as well as propose hypothetical implication at higher biological level of organisation built upon knowledge about plastic debris of all sizes and the ecological role of model organisms, such as earthworms. Finally, we propose approaches and considerations to determine the effects of microplastic and nanoplastic pollution.

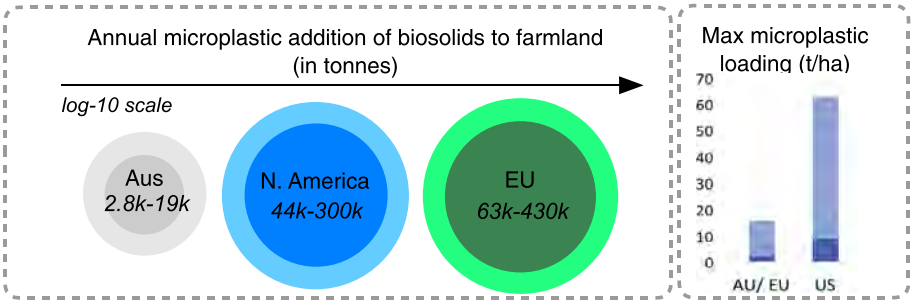
2. Major sources of microplastics and nanoplastics in agroecosytems

Microplastics and nanoplastics enter agroecosystems either as primary (manufactured) micro and nano materials (e.g. in waterborne paints, medical applications, electronics, coatings, adhesives), or indirectly as secondary microplastics and nanoplastics generated by the breakdown of larger plastic debris (Duis and Coors, 2016; Koelmans et al., 2015; Rillig, 2012). It was recently demonstrated that photodegradation of recovered marine microplastic debris (Gigault et al., 2016) and 1-cm^2-pieces of disposable polystyrene coffee cup lid (Lambert and Wagner, 2016) generated nanoplastics. Direct sources in agriculture include plastic mulch films and greenhouse materials and soil conditioners (e.g. polyurethane foam and polystyrene flakes). Indirect sources include general littering and the use of treated wastewater and biosolids (Duis and Coors, 2016; Horton et al., 2017). Microplastic and nanoplastic emissions per capita vary greatly between regions due to population size, affluence, presence and efficacy of waste management practices (Nizzetto et al., 2016; Ziajahromi et al., 2016). Here, we focus on plastics that end up in agroecosystems. Using existing data and estimates, we have derived potential annual and maximum plastic loadings in agroecosystems for Europe, USA and Australia, to illustrate the potential scale of the plastic problem.

Globally, between 0.8 and 2.5 million tonnes of microplastics – two-thirds of which are due to synthetic fibres released during washing and erosion of tyres while driving – are estimated to end up in oceans every year (Boucher and Friot, 2017). Of the microplastics that pass through wastewater treatment plants, some 95% of the microplastics are estimated to be retained in biosolids (Ziajahromi et al., 2016). As both treated wastewater and biosolids are used in agriculture for irrigation and as fertiliser (Mohapatra et al., 2016; Nizzetto et al., 2016), the microplastic loading on agricultural land is likely to be high. In Europe, Nizzetto et al. (2016) estimated that some 63,000 to 430,000 tonnes of microplastic enter agroecosystems annually through biosolids alone, while estimates for North America ranged from 44,000 to 300,000 tonnes of microplastics annually. We use Australia as a case study to further evaluate plastic particle loading rates per unit area per year and maximum (lifetime) loading given our in-depth knowledge of Australia's regulations on biosolids use. We estimate that between 2800 and 19,000 tonnes of microplastics are applied to Australian agroecosystems each year through biosolids (Box 2 and supplementary information, SI).

Besides biosolids, composts derived from non-source-separated residential waste or mixed municipal solid waste, and source-separated garden organic waste (to a lesser extent) are also sources of plastic pollution in agroecosystems. The physical degradation of plastics from these sources, abrasion and fragmentation due to mixing and transport,

Box 2
An estimation of loading rates and total loadings for microplastic from biosolids in agricultural soils in Australia, EU and USA.



In Australia, 1.5 million tonnes of wet biosolids were produced in 2015 (Australian and New Zealand Biosolids Partnership, 2016), with 64% of the biosolids used in agriculture and predicted to further increase in the future (Australian and New Zealand Biosolids Partnership, 2016). Using 125 to 850 tonnes of microplastics per million inhabitant (Nizzetto et al., 2016) as a basis, we estimate that between 2800 and 19,000 tonnes of microplastic could be applied to Australian agroecosystems each year through biosolids alone; Nizzetto et al. (2016) estimated 44,000–300,000 and 63,000–430,000 tonnes of microplastics could be applied to North American and European agroecosystems respectively. This estimate of between 2800 and 19,000 tonnes of microplastics in the 1.5 million wet tonnes of biosolids in Australia, equates to a likely presence of between 9 and 63 kg of microplastics per tonne of dry biosolids, assuming a total solids content of 20% (Eldridge et al., 2008) for the biosolids.

The application of biosolids in Australia is tightly regulated by state regulations which are largely derived from the New South Wales guidelines (EPA-NSW, 1997). Loading rates are limited by plant available N supply and contaminant loading to ensure that biosolids applications do not raise the level of contaminants in the soil above the accepted maximum allowable contaminant level for agricultural soils. There are also limits on the time interval between applications. Combined, these results in the theoretical maximum ceiling (lifetime loading) for biosolid application rate to agricultural land in Australia to be around 250 dry t·ha^{-1}. At 250 dry t·ha^{-1}, this would represent a maximum (lifetime) microplastic loading of between 2.3 and 15.8 t·ha^{-1} incorporated into the top 75 to 100 mm of soil.

A comparison of estimates of microplastic loadings through biosolid application

The US regulations pertaining to biosolid application to agricultural land (i.e. USEPA 40 CFR 503, 1993) are less stringent than EU regulations (EU Directive 86/278/EEC, 1986). These limits on biosolid application rates would suggest maximum potential rate of microplastic inputs from biosolid in the order of 0.5 to 3.2 t·ha^{-1}·yr^{-1} in the US and from 0.045 to 0.63 t·ha^{-1}·yr^{-1} in Europe. Based on copper and zinc contaminants limited biosolid application rate for the respective regions, we would expect similar maximum microplastic loadings for agricultural land between Australia and Europe, while maximum (lifetime) microplastic loadings for US farmland may be as high as 9 to 63 t·ha^{-1}. Details for the regulations, calculations and uncertainties of the estimates for Box 2 are elaborated in SI.

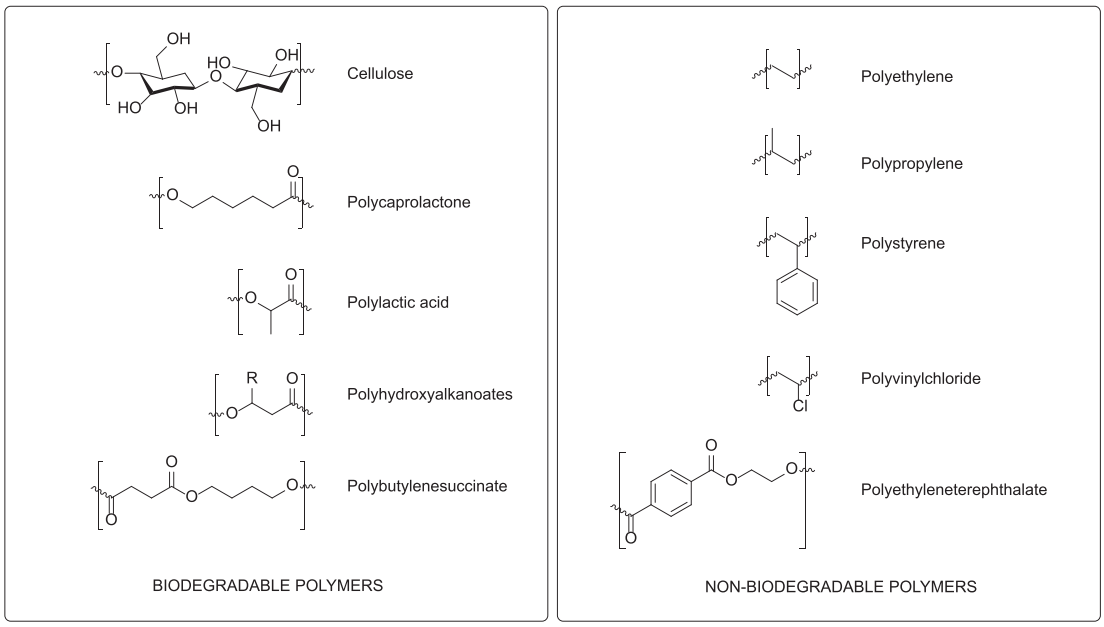


Fig. 1. Chemical structures of some important biodegradable polymers and examples of non-biodegradable polymers commonly contaminating soil.

is also likely to produce secondary microplastics. Brinton (2005) found that polyethylene, plastic fibres, and polystyrene foam occupied up to 5% w/w in compost from mixed municipal solid waste for all size fractions between 420 μm and 25 mm; with around 0.5 to 0.6% having sizes <2 mm. The quality and use of composts are regulated to varying degrees across the globe. For example, Australian standard (AS4454, 2012) for compost, soil conditioners and mulches retailed to backyard gardeners and farmers in Australia allows up to 0.5% dry matter w/w rigid plastic and 0.05% dry matter w/w of light, flexible or film plastics. This is equivalent to having up to 5 $t \cdot ha^{-1}$ of rigid plastic and 0.5 $t \cdot ha^{-1}$ of light plastic to a depth of 10 cm for a lifetime compost loading of 1000 $t \cdot ha^{-1}$. Hence, the potential contamination of agroecosystems by secondary microplastics and nanoplastics, could be significant.

In the early 2000s, 0.7 million tonnes of mulch film was used annually worldwide in agriculture, with China being the largest user (~80%; Espí et al., 2006). Plastic mulch film covers some 20 million hectares of farmland in China (Liu et al., 2014). Plastic mulch films with thicknesses between 6 μm and 20 μm are widely used in intensive production systems because of four perceived benefits: modification to soil temperatures, reduced evapotranspiration, better weed control, and reduced soil blemish of the product. As plastic mulch is applied with each crop cycle, soils become enriched with plastic residues that have been intentionally or unintentionally left behind on the field by farmers (Steinmetz et al., 2016). In the Xinjiang region of China, where plastic mulch is extensively used, the film residue content in soils ranged from 0 to 502 $kg \cdot ha^{-1}$ (mean 121.5 $kg \cdot ha^{-1}$), with the quantity being positively correlated with the number of years under mulching (Zhang et al., 2016).

3. Polymer degradation and dynamic behaviour of plastic particles on land

Polymer degradation refers to a chemical change in the molecular structure of the polymer that alters its properties. There exists an enormous number of polymers that, depending on their chemical structure, are rendered more or less susceptible to different types of degradation processes.

The biodegradable polymers possess heteroatoms (O, N, S) distributed along the polymer backbone that act as sites for hydrolytic or enzymatic reactions, leading to significant decreases in the molecular weight of the polymer in a relatively short timeframe (days to several years). These processes cause the structure of the polymer to break down into lower molecular weight molecular fragments that microbial cells can assimilate and subsequently mineralise to produce CO_2, H_2O and biomass in aerobic environments (or CO_2 and CH_4 in anaerobic environments). Examples of biodegradable polymers include aliphatic polyesters such as polylactic acid, polycaprolactone and polybutylenesuccinate, and natural biopolymers such as cellulose and polyhydroxyalkanoates (Fig. 1).

Many of the commonly used polymers contaminating our environment, such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC), possess a carbon backbone that is resistant to hydrolytic and enzymatic degradation (Fig. 1). As such, microbes are generally unable to assimilate and mineralise the polymers, resulting in the environmental accumulation of these materials. Some projections indicate that the lifetime of polyolefins on land is in the vicinity of hundreds of years (Kyrikou and Briassoulis, 2007). The ultimate degradation of these types of polymers in soil will involve several mechanisms including (i) photo- and thermo-oxidative degradation and (ii) some degree of biodegradation by microorganisms after a prolonged period of environmental exposure and oxidation. Nguyen (2008), and Singh and Sharma (2008) have authored thorough reviews on the general topic of plastic degradation. The present article will therefore provide an overview of the degradation processes on land.

3.1. Photo- and thermally-initiated oxidative degradation

Common polymer contaminants in or on soil are susceptible to some degree of photo- or thermo-oxidative degradation. The general mechanism for abiotic oxidative degradation of polymers with a carbon backbone is given in Box 3. Oxidative degradation is triggered by free radicals generated when the materials are exposed to ultraviolet or thermal energy under aerobic condition. As these degradation processes rely on the combination of radicals with oxygen, they will only occur when plastic is at, or very near to, the soil surface. In the field, radicals are most likely to form by (i) direct photolysis of C—C and C—H bonds in the polymer, (ii) residual catalyst or chromophoric chain defects present from synthesis, or (iii) as a result of other additives such as photosensitisers (e.g. TiO_2), pro-oxidants (usually salts of transition metals including iron, nickel, cobalt and manganese), fillers, dyes and pigments (Carlsson and Wiles, 1976; Gardette et al., 2013), which in

Box 3
General mechanisms for oxidative degradation of carbon-based polymers.

Initiation	$PH + X\bullet \rightarrow P\bullet + XH$	[1]
Propagation	$P\bullet + O_2 \rightarrow PO_2\bullet$	[2]
	$PO_2\bullet + PH \rightarrow POOH + P\bullet$	[3]
Chain branching (autocatalytic)	$POOH \rightarrow PO\bullet + \bullet OH$	[4]
	$PO\bullet + PH \rightarrow POH + P\bullet$	[5]
	$HO\bullet + PH \rightarrow HOH + P\bullet$	[6]
	$PO\bullet \rightarrow$ various chain scission reactions	[7]
Termination	$P\bullet + P\bullet \rightarrow P—P$ or $P—H + P(—H)$	[8]
	$PO_2\bullet + PO_2\bullet \rightarrow$ inactive products	[9]

PH designates the polymer, P• is a macroradical and X• is an unspecified radical (Hawkins, 1964; Nguyen, 2008). This is the general mechanism for the oxidative degradation of polyolefins such as PE and PP and it is also applicable to other types of polymers with a carbon backbone.
The first step of the oxidation pathway begins by abstraction of hydrogen from the polymer to produce the macroradical species, P•, regardless of how the radical is generated (Eq. (1); Hawkins, 1964). A chain reaction ensues in the propagation stage, involving combination of the macro-radical with oxygen (Eq. (2)) to produce a peroxy polymer radical. The peroxy radical then abstracts hydrogen from another polymer molecule to produce a molecule of hydroperoxide and a new macroradical (which subsequently undergoes reactions [2] and [3], and so on). Eqs. (4–7) show the autocatalytic chain branching phase which increases the oxidation rate further. Here, the hydroperoxides formed in the previous step decompose into radicals, which in turn abstract hydrogen from polymer molecules to generate more macroradicals. Termination eventually occurs when radicals couple together or undergo disproportionation. The interested reader is referred to the following articles for more specific details on the mechanisms of photo- and thermally-triggered oxidative degradation in PE (David et al., 1992; Gardette et al., 2013), PP (Carlsson and Wiles, 1976), PS (Grassie and Weir, 1965), PVC (Palma and Carenza, 1970) and PET (Jabarin and Lofgren, 1984).

some cases may involve the production of singlet oxygen as a reactive intermediate (Rabek and Rånby, 1975). The degree to which these oxidative processes can occur is highly dependent on the environmental conditions (e.g. UV exposure, temperature, soil composition, moisture, oxygen); as well as the chemical structure and crystallinity of the plastic (with oxygen diffusion and degradation occurring more readily in amorphous regions of the materials) (Nguyen, 2008).

At the macroscale, photo and thermally triggered oxidative degradation leads to the embrittlement, cracking and weakening of plastics with time. Thus the materials become more susceptible to fragmentation when they are exposed to abrasive or mechanical forces, e.g. from farm equipment, generating micro and nanoplastics. At the molecular level, the polymer chemical structure changes due to a combination of events including chain scission (decrease in polymer molecular weight), crosslinking (increase in molecular weight), branching (increase in molecular weight) and incorporation of oxygen containing functional groups at the surface of the plastic particle, e.g. esters, ketones and alcohols, which also reduces the surface hydrophobicity of the plastic (Singh and Sharma, 2008).

As plastic particles age in the environment, their movement through the soil profile is expected. Earthworms (Huerta Lwanga et al., 2017; Rillig et al., 2017) and collembola (Maaß et al., 2017) have been observed to transport microplastics, and agricultural practices such as ploughing, would also contribute to their vertical transport. This new subsurface location would negate photo and thermal degradation, which are crucial for reducing the size of polymers with carbon backbones like PE, PP, PS and PVC (as described above) before any substantial biodegradation can occur. Furthermore, anaerobic conditions may develop in deeper layers of the soil and inhibit oxidative degradation processes (Thomas et al., 2012).

3.2. Biodegradation

After extensive initial photo- or thermo-oxidative degradation, biodegradation plays an important role in the ultimate fate of plastics in soil. Biodegradation is the process of mineralisation of an organic material by microorganisms to generate CO_2 and H_2O under aerobic conditions, or CO_2 and CH_4 under anaerobic conditions (Mohan, 2011). The molecular weight, chemical structure and morphology, hydrophobicity, water absorption, and surface roughness of plastic materials all have an impact on their susceptibility to biodegradation (Table 1). Even low molecular weight components of PE subjected to extensive pre-oxidation in accelerated conditions (i.e. artificial weathering where UV light and/or heat between 50 and 70 °C is applied) not reflected in the field, can only be partly biodegraded (Thomas et al., 2012). The accelerated weathering conditions certainly decrease the molecular weight of the PE, a critical step towards achieving microbial degradation; however the majority of the oxidised sample is still too high in molecular weight to be mineralised (Table 1).

Although numerous organisms are recognised to biodegrade or partially biodegrade even some of the most persistant types of plastics – e.g.

Table 1
General rules of thumb indicating the likely impact of certain polymer properties on susceptibility to biodegradation.

Property	Impact on biodegradation	Sample format
Molecular weight	Only low molecular weight compounds can be assimilated by microbial cells and enzymatically degraded. Carbon-chain backbones do not biodegrade until the molecular weight is <1000 g/mol (Potts et al., 1973)	Molecular
Chemical structure and morphology	Certain functional groups provide sites for enzymatic cleavage (ester, ether, amide, urethane) (Kawai, 2010)	Molecular
	Branched structures are more difficult for microbes to assimilate (Potts et al., 1973)	Molecular
	Amorphous materials biodegrade faster than crystalline ones (Reed and Gilding, 1981; Yoo and Im, 1999)	Macro
Surface hydrophobicity	Hydrophobic surfaces inhibit biofilm formation, hydrophilic surfaces (water contact angle 40–70°) promote it (Lee et al., 1998)	Surfaces of thin films
Water absorption	Bulk hydrophilicity and water absorption give microbes access throughout the bulk material (Göpferich, 1997)	Macro
	Water absorption softens polymers, and softer materials biodegrade faster than harder ones (Foruzanmehr et al., 2015)	Macro
Surface roughness	Microbes adhere to rougher surfaces more easily than smooth ones (Wan et al., 2005)	Surfaces of thin films

certain bacteria (Huerta Lwanga et al., 2018; Yang et al., 2014; Yoshida et al., 2016) and insect larvae (Bombelli et al., 2017), these specific organisms (such as the bacteria *Ideonella sakaiensis* isolated from recycling site) and/or their hosts (such as the caterpillar of the moth *Galleria mellonella* or larvae of Indian mealmoth *Plodia interpunctella*) may not be naturally present in agroecosystems. Even if plastic-degrading organisms are present in soils, such as the plastic-degrading bacteria (*Microbacterium awajiense*, *Rhodococcus jostii*, *Mycobacterium vanbaalenii*, *Streptomyces fulvissimus*, *Bacillus simplex* and *Bacillus* sp.,) identified from earthworm's gut (Huerta Lwanga et al., 2018), less energetically expensive carbon resources would be present in soils, therefore biodegradation of such plastic particles would be less likely to become a relevant process, with cometabolism being a more likely scenario. Cometabolism, which is the degradation of a compound in the presence of another compound that is used as carbon source, has been extensively studied for bioremediation of organic pollutant such polyaromatic hydrocarbon, but its effectiveness in field is thus far limited and requires extensive and costly intervention (Ghosal et al., 2016).

3.3. Particle changes through biophysicochemical interactions at particle-soil interface

During oxidative degradation, anionic or polar surface groups are likely to be introduced on plastic particles, providing surfaces for further interaction with soil components. The interaction between plastic particles and soil components is a dynamic process involving a series of interconnected physical-biological-chemical changes. As a result, the physicochemical state of plastics in soils is likely to be highly dynamic. Moreover, plastics are typically a complex mixture of polymers, residual monomers, catalysts and additives (Teuten et al., 2009), which affect the plastic particle characteristics and behaviour, and therefore the interactions of different plastics with soil organic and inorganic matter.

Consider the apparently simple two-way relationship between plastic and an agrochemical (e.g. pesticide) present in the soil. Studies so far indicate that there is a subtle interplay between environmental factors and plastic composition that can affect the stability of both agrochemicals and plastics commonly used in agriculture. Various pesticides' accumulate and/or become stabilised on the surface of plastic mulch film (Ramos et al., 2015), while other plastics treated with agrochemicals actually become more susceptible to photodegradation and embrittlement than the corresponding clean plastics (Schettini et al., 2014).

Additionally, as degradation proceeds, smaller sized plastic particles are generated. Studies on nanomaterials indicate that the smaller the particle, the larger its surface-to-volume ratio and its reactivity, thus, the more dynamic the behaviour of nanoparticles (P. Wang et al., 2016; Wiesner et al., 2011). The fragmented microplastics released in the casts of *L. terrestris* (Huerta Lwanga et al., 2016) are surrounded by ecocoronas or biofilms comprising soil biota, and soil-derived organic and inorganic macromolecules. These ecocoronas change the density, surface charge, size and shape of micro or nanoplastic particles, and may therefore also alter the mobility, degradation, bioavailability and toxicity of the encapsulated plastic particles (Artham et al., 2009; Galloway et al., 2017; Nel et al., 2009).

When considering nano-sized particles in soils, it is argued that the prevalence of black carbon and natural carbonaceous nanoparticles in soils would exceed that of manufactured nanomaterials (Koelmans

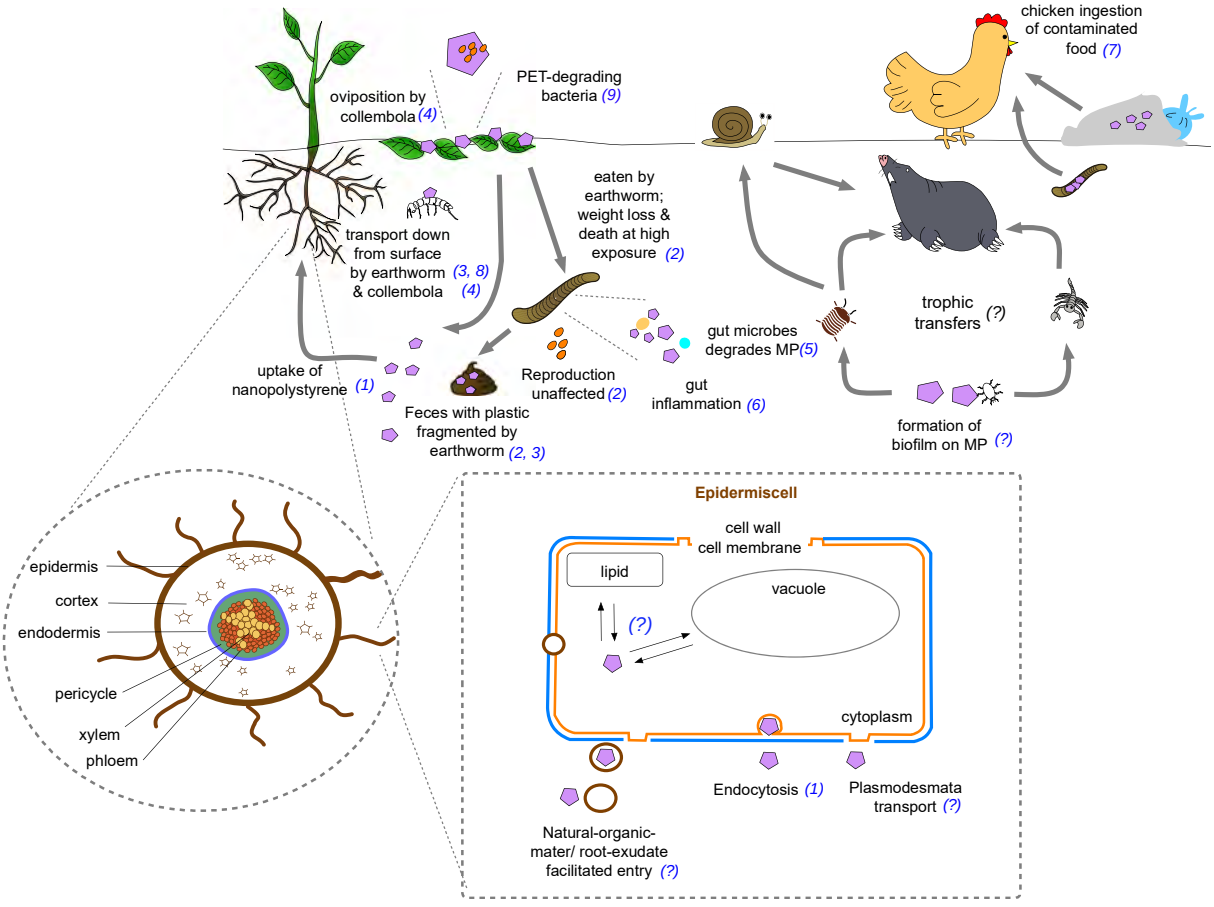


Fig. 2. Microplastic and nanoplastic uptake and interaction with soil biota and plants. (1) Bandmann et al. (2012); (2) Huerta Lwanga et al. (2016); (3) Huerta Lwanga et al. (2017); (4) Maaß et al. (2017); (5) Huerta Lwanga et al. (2018); (6) Rodriguez-Seijo et al. (2017); (7) Huerta Lwanga et al. (2017); (8) Rillig et al. (2017); (9) Yoshida et al. (2016); (?) refers to unknowns. MP refers to microplastic or nanoplastic.

et al., 2009). Using examples from Simpson and Hatcher (2004), there would be between 520 and 2010 $t \cdot ha^{-1}$ of black carbon to 7.5 cm depth for a Canadian Chernozem (5.2% total C) and German Mollisol (1.9% total C) respectively. In comparison, our estimates of maximum microplastic loading from biosolid use in agroecosystems in Box 2, assuming eventual 100% conversion into nano-sized particles, would correspond to between 2.3 and 63 $t \cdot ha^{-1}$ of nanoplastics in soils. This finding raises three questions: (1) what is the relative importance of plastic as a host or carrier of organic and inorganic matter relative to other carriers in the soil, such as mineral particles and natural soil carbonaceous polymers, (2) how will plastic interact with these soil carbonaceous materials, and (3) if soil biota and plants have historically evolved within this environment, do these materials pose no threat or has the biota developed mechanisms to live amidst these materials? These also highlight the crucial task to quantify actual plastic loading and their sizes in agroecosystems.

4. Response of soil biota to microplastic and nanoplastic pollution

4.1. Organismal-level response

It is reported by studies in marine environment that microplastic ingestion is rarely lethal at environmentally relevant concentrations (Galloway et al., 2017; Rochman et al., 2016). In earthworms, two outcomes have been observed so far in controlled experiments: i) the organism survives, the microplastics may be fragmented further internally, and plastic particles are transported in soil via defecation and when the organism moves or, ii) the organism suffers weight loss, and then dies at high exposure concentration (Fig. 2). In one study, earthworms *Lumbricus terrestris* exposed to concentration of 28% PE microplastics (w/w in dry plant litter) and above, experienced growth inhibition (<1.4 mg weight gain compared to 10.3 mg weight gain in control with no exposure to microplastic) and subsequently died (8–25% compared to 0% in control with no exposure to microplastic) even though their reproduction was unaffected (Huerta Lwanga et al., 2016). These are high exposure concentrations that could occur under contaminated land scenario. Another study using *Eisenia fetida* exposed to 0.25 and 0.5% of PS microplastic (w/w in dry soil) showed no growth inhibition, with growth inhibition only occurring at exposure concentrations >1% (Cao et al., 2017). In another study using *Eisenia fetida*, inflammation in the guts was observed when the earthworm is exposed to concentration of 0.0125% PE microplastic (w/w in dry soil) and above but this does not translate to any significant effects on survival, reproduction and biomass at concentration up to 0.1% of PE microplastic (w/w in dry soil) (Rodriguez-Seijo et al., 2017).

Studies on algae in the aquatic environment showed that nanoplastics are adsorbed onto the cell wall of microalgae such as *Scenedesmus*, *Chlorella* and *Pseudokirchneriella subcapitata* (Bhattacharya et al., 2010; Nolte et al., 2017a), with binding mediated by cell morphology (Bhattacharya et al., 2010), the particle's charge and ionic strength of the medium (Nolte et al., 2017a; Nolte et al., 2017b). These experiments, lasting for hours to a few days, indicated these nanopolystyrenes were not lethal to the algae at concentrations up to 100 $mg \cdot L^{-1}$. However, they did reveal that these nanoplastics can lead to the physical inhibition of algal photosynthesis due to increased water turbidity and light scattering, coverage of the algal cell surface with microplastics, or immobilisation of algae at concentration of around 1.5 $mg \cdot L^{-1}$ and above (Bhattacharya et al., 2010; Nolte et al., 2017a). It remains to be explored if interferences from nanoplastics in photosynthesis and induction of physiological stress responses can occur in soil-dwelling algae.

Despite their ecological importance, the exposure of soil filter feeders such as some nematodes, rotifers and ciliates to microplastics and nanoplastics have not yet been determined to our knowledge. Filter feeders in marine ecosystems have been shown to ingest microparticles (Van Cauwenberghe and Janssen, 2014; Wright et al., 2013) while filter feeders in freshwater ecosystems, *Daphnia magma* and *Thamnocephalus platyurus*, have been shown to be sensitive to nanoplastics (Besseling et al., 2014; Casado et al., 2013). Uptake by such organisms is determined by their ability to discriminate food and non-food, which depends on a mixture of chemical (taste and olfaction) and physical (size) mechanisms (Kiyama et al., 2012). Kiyama et al. (2012) demonstrated that the nematode *Caenorhabditis elegans* on buffer solution and agar plates take up PS microspheres of 0.5 and 1 μm, particularly in the absence of food bacteria. Organisms with other feeding modes are also susceptible to microplastic ingestion. Recently, Taylor et al. (Taylor et al., 2016) found synthetic microfibers on and inside six out of nine deep sea organisms from the phyla Cnidaria, Echinodermata and Arthropoda with predatory and detritivorous feeding mechanisms. As such, woodlice, snails, caecilians and other soil organisms with similar feeding mechanisms would be subjects of interest in agroecosystems.

Information about the bioavailability and bioaccumulation of microplastics in soil organisms is generally lacking. Early investigations indicate that mussels take up particles <10 μm and these particles were translocated from gut to the circulatory system and retained there for the duration of the testing period (48 days) (Browne et al., 2008). We know that nanoplastics can enter cells, as fluorescent nanoplastic polymers have been used as molecular probes for a wide range of biological studies with mammalian cells, for example to measure blood flow in tissue and as tracers for phagocytic processes (see e.g. carboxylate-modified microsphere F8888 by Invitrogen; Katz and Iarovici, 1990; Rembaum and Dreyer, 1980). The translocation of a range of microparticles by mammalian gut into the lymphatic system have been demonstrated in human (particle sizes 160 nm – 150 μm), rabbits (100 nm – 10 μm), dogs (3–100 μm) and rodents (10 nm – 40 μm) (see details in review by Hussain et al., 2001). There is no experimental evidence of nanoplastics being transferred from invertebrates to vertebrates in soils; there is evidence of the transfer of microplastics from contaminated land to vertebrates, and potentially from earthworm to chicken. In one study developed for homegardens, it was observed that chickens' digestive tract became polluted with plastic particles (62.6 ± 49.5 particles per gizzard, 16.45% of which were <5 mm and 83.55% were >5 mm; 11 ± 15.3 particles per crop, all of them macroplastics, no microplastics were found in crops; Huerta Lwanga et al., 2017).

Understanding organismal-level response is the basis for toxicological studies and risk assessments, and translating this response to population and ecosystem-level consequences upon which policy and decisions are often based, is a challenge. For the purpose of decision-making, complementing the above individual endpoint measurements with models could allow prediction of the pollutant burden over time and translate the individual-level response to a population model (Jager, 2016). For example, toxicokinetic and toxicodynamic models examine internal concentrations of a contaminant as function of uptake, transformation, distribution and elimination, and the subsequent response of the test organism (Rohr et al., 2016) could be applied to well-studied earthworm, where there is a strong understanding of the organism's biology.

4.2. Response of soil microbiome

The time and space scale for microbes, given their relatively short life history and small size, give us a chance to study processes that would be difficult at field scale (Jessup et al., 2004) and allow us to capture the emergent properties of a system which would be impossible with individual-level trait studies. While no studies have specifically examined micro- and nano-sized plastic particle effects on soil microbiome, an experimental study on plastic mulch residues provides some preliminary indication of potentially useful measures. In a pot trial experiment with 67.5 and 337.5 $kg \cdot ha^{-1}$ plastic mulch residues (20 mm × 20 mm) maintained at constant moisture content, soil microbial biomass, enzyme activities (dehydrogenase and fluorescein diacetate hydrolysis)

and functional diversity (community level physiological profile) tended to decrease with increasing concentrations of plastic mulch residue (J. Wang et al., 2016). The concentration (67.5 kg·ha^{-1}) used in this experiment is environmentally relevant for soils with over 5 years of plastic mulch film use (Zhang et al., 2016). Given the long-term use and misuse of plastic mulch in some agroecosystems, studying their soil microbiome may provide insights into the long-term implications of plastic pollution on land.

5. Response of plants to microplastic and nanoplastic pollution

5.1. Uptake of nanoplastic by plants

Uptake of microplastics by plants is not expected. The high molecular weight or large size of the plastic particles (Teuten et al., 2009) prevents their penetration through the cellulose-rich plant cell wall. In contrast to microplastics, nanoplastics indeed have been shown to enter plant cells (Fig. 2). Bandmann et al. (2012) have demonstrated uptake of 20 and 40 nm nanopolystyrene beads by tobacco BY-2 cells in cell culture via endocytosis, while 100 nm beads were excluded. However, no studies have investigated whole plant, instead of plant cell culture, uptake of nanoplastics to the best of our knowledge.

Plant species vary in their uptake, translocation and accumulation of contaminants due to a range of anatomical and physiological differences. Plant properties that are known to affect the uptake of organic compounds include root properties (volume, density, surface area), xylem properties (volume, surface area), transpiration, growth rate, water and lipid fractions, plasma membrane potential, tonoplast potential, cytoplasm pH and pH of vacuoles (Trapp, 2000). Characteristics and permeability of the plant cell wall varies, but as a rule-of-thumb, particles <6 nm in one dimension may be able to permeate the cell wall (Carpita et al., 1979).

Studies on plant uptake of engineered carbonaceous nanoparticles – structurally dissimilar to plastics but they can be produced with similar particle size, shape, surface functional groups to microplastics – may shed light on the possible modes of nanoplastic interaction with plants and bioavailability (see reviews by Ma et al., 2010; Rico et al., 2011; J. Wang et al., 2016). In plants, such engineered carbon-based nanoparticles are being targeted as molecular transporters to study plant cell biology, or deliver agrochemicals and biomolecules (Morales-Díaz et al., 2017; J. Wang et al., 2016). Uptake of these carbon-based nanoparticles has been documented in whole plants such as rice (*Oryza sativa*), maize (*Zea mays*), soybean (*Glycine* max) and arabidopsis (*Arabidopsis thaliana*) (Lin et al., 2009; Zhao et al., 2017). Based on the above studies, the proposed pathways for entry of carbonaceous nanoparticles into plants, depending on plant species and nanoparticle properties, include endocytosis through the plasmodesmata; passage via ion transport channels, carrier proteins or aquaporins; and also soil carbon or root exudate mediated entry (Fig. 2).

There are no studies on translocation and storage of nanoplastics in plants. However, the translocation of engineered carbon nanoparticles in the size range of 40 to 70 nm to stem and/or leaf have been demonstrated in rice using fullerene C_{70} (Lin et al., 2009) and soybean, maize, rice and Arabidopsis using carbon nanotubes (Zhao et al., 2017). There have not been any studies evaluating the transgenerational transmission of nanoplastics. Transmission, has been reported in rice using fullerene C_{70} mixed with natural organic matter obtained from natural waters, which contains a mixture of hydrophobic and hydrophilic acids and other soluble organic compounds (Lin et al., 2009). The transport and fate of the engineered carbon nanoparticle is strongly influenced by interaction with natural organic matter (Hyung and Kim, 2008), and therefore, the effect of soil organic matter adsorption to nanoplastics should be explored if we are to understand its effects on the fate of nanoplastics in soil and plant.

5.2. Toxicity, stress and response of plants to nanoplastic

Similarly, there is no data on the toxicity of nanoplastics on plants. Since the first studies reported plant cell uptake of engineered carbon-based nanotubes and fullerenes (Lin et al., 2009; Liu et al., 2009), studies on nanotubes and fullerenes indicate a range of positive, neutral and negative effects in a range of edible crops (see reviews by Husen and Siddiqi, 2014; Ma et al., 2010; Rico et al., 2011; J. Wang et al., 2016). All four reviews presented a sum of six studies (with numerous overlaps) on nanotubes and two studies on fullerene C_{60}, with all crops being grown under hydroponic and broth culture, except the studies by Kole et al. (2013) who used sphagnum moss and Torre-Roche et al. (2013) who used a mixed vermiculite-soil medium.

General observations on toxicity of carbon nanoparticles that may have relevance to future studies using nanoplastics, are: (1) phytotoxicity tests such as germination, root elongation and growth measures across studies indicate that sensitivity depends on plant species and the physicochemical properties of the engineered carbon nanoparticle; (2) cell damage occurs through genotoxicity and cytotoxicity (Shen et al., 2010; Tan et al., 2009); and (3) interactions between different types of engineered carbon nanoparticle with pesticides can increase or decrease the uptake of pesticides by different crops (Torre-Roche et al., 2013).

Plant can metabolize a range of pollutants, including polychlorinated and polycyclic hydrocarbons (Sandermann Jr., 1992). During pollutant metabolism, oxidative stress can result from a combination of (1) reactive oxygen species generated during cytochrome P450 mediated oxidation, and (2) glutathione depletion through gluthatione-S-transferases catalyzed conjugation with pollutant (Scandalios, 2001). Zhao et al. (2017) measured the uptake of ^{14}C-labelled carbon nanotubes (2.25 ppm) in rice, maize, soybean and arabidopsis; and found that biochemical parameters, such as antioxidant enzyme activities, were more sensitive than physiological measures, such as pigment and total protein contents. Biochemical parameters, therefore, may be a good indicator of plant response to nanoplastics. Pollutants are often stored as soluble and insoluble conjugates in various parts of the plants rather than degraded (Sandermann Jr., 1992). As such, it is also necessary to determine whether detoxification processes produce harmless metabolites, or whether new toxins might be introduced into the food chain. Estimates made using plant uptake models and quantities of micropollutants in irrigation water, indicate that human exposure to 27 emerging micropollutants (including pharmaceuticals, fragrances, flame retardants and plasticizers) range from <1 to >461 ng per person per day through vegetable and fruit consumption (Calderón-Preciado et al., 2011). Several of these chemicals are additives in plastic production. We have, to maintain brevity in this overview, refrained from discussing the residual monomers, catalysts and additives that are part of plastic and need to be considered in future studies. Readers interested in this matter are referred to reviews on biological effects of plastic additives (Meeker et al., 2009; Oehlmann et al., 2009), or phthalate esters occurrence and degradation in the environment (Gao and Wen, 2016; Staples et al., 1997).

6. From organismal to ecosystem-level responses

So far, studies on the ecological impact of plastic in soils are mostly at organismal level, or on the soil microbiome. This approach is not unique to soils, since a majority of impact studies in marine ecosystems have demonstrated impacts only at suborganismal and organismal levels (Browne et al., 2015). Clearly, more work needs to be done at higher biological organisation levels (Browne et al., 2015; Galloway et al., 2017; Rochman et al., 2016). But impact studies at higher biological organisation are difficult. Browne et al. (2015) suggests that existing knowledge of ecological linkages, where known, and population models, where the linkages are unknown, can be used to deduce such impact.

There is evidence that water infiltration is correlated to earthworm biomass and burrow length (Blouin et al., 2013), that is soil porosity is linked to earthworm presence. Using the approach suggested by Browne et al. (2015), one can then hypothesise that when earthworm mortality is high as a result of high microplastic contamination, as per reported by Huerta Lwanga et al. (2016) and discussed in Section 4.1, soil porosity would be impacted. Currently, only one laboratory study explored such ecological linkage. The study showed that *L. terrestris* had lower biomass under the exposure of microplastics at 7% microplastics (w/w in dry plant litter) while the burrows occurred in significantly higher numbers and the burrow walls were denser compared to the control without exposure to microplastics, however the burrow length was similar across all treatments during the 14 day experiment (Huerta Lwanga et al., 2017). These results indicate soil porosity may increase as a result of earthworm-microplastic interaction but further work is still necessary to validate their longer-term implications for soil porosity. Additionally, microplastics may also have direct effect on soil porosity, as both synthetic water-soluble and gel-forming polymers are used as soil conditioners to improve water infiltration, water retention and soil stabilisation (Bouranis et al., 1995).

In aquatic systems, microplastics have become a floating mobile habitat for algae, bryozoans, dinoflagellates, isopods, marine worms and microbes (Reisser et al., 2014). There is evidence that the ingestion of plastic debris by seabirds is linked to dimethyl sulfide, a chemical cue released by phytoplankton in response to foraging activity (Savoca et al., 2016). Savoca and colleagues demonstrated experimentally that PE and PP microplastics exposed in the ocean for three weeks produce dimethyl sulfide. The migration facilitated by microplastics can affect population and ecosystem dynamics. In soils, there is no lack of substrate compared to open water but plastic particles could serve similar habitat functions. Collembola has been observed to use microplastics as a site for oviposition (Maaß et al., 2017). Earthworm casts are naturally rich ecosystems of microbes (Gómez-Brandón et al., 2011; Toyota and Kimura, 2000) and casts enriched with plastic particles (Huerta Lwanga et al., 2016) would be hosting microbiomes. These findings suggest that biofilms on plastic in soils could promote uptake by other organisms higher up in the food chain.

7. Considerations for assessing risks of microplastics and nanoplastics in agroecosystems

7.1. Challenges and lessons from studies on plastic particles, engineered nanoparticles and other persistent contaminants

Current methodologies used to extract, quantify and characterise microplastics from water or sediment samples, would require adjustment to enable equivalent information from soil samples; not to mention the entire lack of nanoplastic isolation methods (Duis and Coors, 2016; EFSA Panel on Contaminants in the Food Chain, 2016; Syberg et al., 2015). Soil is a heterogeneous medium which makes the isolation or enrichment of plastic particles from it extremely challenging. The presence of soil organic matter, sometimes stabilised by interaction with soil minerals, complicates the removal of soil organic matter that distort spectroscopic techniques for identification of plastic particles. Recently, a method for extracting and quantifying the number, size and mass of micro-sized low-density polyethylene and polypropylene from soil using flotation and heating was published by Zhang et al. (2018). Some similarities can be drawn from sediment studies, and adaptation of recent procedures for the isolation of microplastics from fine sediments could potentially be used in the future to quantify micro and nanoplastic loads in agricultural soils (Coppock et al., 2017). These allows the identification of microplastics in soils, but more efficient and faster techniques are required. In addition, standardisation of the units of measurement in terms of weight, number and/or volume should be prioritised to allow comparison of results from different experiments.

The representativeness of synthetic plastic particles used in many experiments is questioned, since the aging of plastics in the environment alters their surface chemistry and behaviour. Rapid aging could be simulated by subjecting plastics containing pro-oxidant additives to artificial, accelerated weathering and abrasion, but we would still need to relate the structure and chemical properties of the artificially generated microplastic or nanoplastics with those isolated from field samples. An alternative approach is the preparation of a range of standard testing materials aged in a set of selected soils with different characteristics.

The adoption of high doses is often used in assessing effects of a pollutant in laboratory studies to elicit toxicological endpoint and determine dose-response curves. However, studies on pesticides and other endocrine-disrupting chemicals have shown that nonlinear or non-sigmoidal dose-response relationships are common, such as the U-shape or inverted U-shaped responses, (Clotfelter et al., 2004; Imfeld and Vuilleumier, 2012), and studies on nanoparticles indicated that particle surface area or particle number concentration may be more relevant than mass-based dose metric for determining biological effects for nanoparticles (Petersen et al., 2015). The range of doses could be narrowed down through spatiotemporal data detailing the occurrence of microplastic and nanoplastic debris in agroecosystems. This can be achieved by prioritising data collection in agroecosystems that receive recycled organic inputs or use plastic mulch.

Choosing the right subjects, variables and controls in the studies is also challenging (Horton et al., 2017; Syberg et al., 2015). If the test organisms are already exposed to high background levels of the pollutant, its lack of response compared to the treatment can be merely an artifact of the organism's prior exposure. Certain organisms are also more sensitive; such as root crops (Eggen et al., 2013), or juvenile organisms in early developmental stages (Clotfelter et al., 2004; Talsness et al., 2009), and these should be prioritised in initial screenings. Interspecific variation in susceptibility within a taxonomic group, intraspecific variations between age class, sexes and populations and ability to recover must all be carefully considered. Beyond individual species, choosing the right measures at the population and ecosystem level is also necessary as other abiotic or biotic stressors may enhance the sensitivity of the test organism or system to plastic pollution (Rohr et al., 2016).

Classical soil ecotoxicological approaches use isolated organisms and standard substrates, with measures taken for survival, growth, reproduction and avoidance behaviour over a period of days and weeks. Such approaches may not capture the full impact of chemical additives in plastics that act as endocrine disruptors in addition to those which bioaccumulate, where long-term exposure at low doses may alter cell functions or cause DNA damage. Such damage manifests later in life or across generations as the damage accumulates (Clotfelter et al., 2004). The use of short-lived organisms is the norm and provides an opportunity to study multigenerational effects of plastic pollution. However, great care must be taken in any attempt to extrapolate laboratory studies to spatially and temporally relevant scales for processes, ecological interactions and ecosystems.

7.2. Knowledge gaps and key research questions

This review highlights several major gaps in our understanding of what happens to microplastics and nanoplastics in soils and their ecological consequences. Some broad issues and key questions are briefly summarised below.

1. Shortcomings in defining and standardising parameters for determining magnitude of microplastic and nanoplastic contamination on land; e.g.

- What cost-efficient techniques can we use to detect, isolate, measure, and identify microplastics and nanoplastics in soils, and in organisms?
- Can artificially generated micro and nanoplastics be used as suitable models to gain an understanding of their potential ecotoxicity?

2. Improve understanding of the dynamics and fate of microplastics and nanoplastics in soils; e.g.

- What is the concentration of microplastics and nanoplastics in soils from each major pollution source?
- How do the products of fragmented plastic particles behave in the soil profile?
- How does the interaction of plastic particles with agrochemicals affect their behaviour?

3. Determine the bioavailability of plastic particles to plants and soil organisms; e.g.

- What are the features of plants and soil organisms that determine uptake, the capacity to exclude, or the capacity to isolate or sequester plastic particles internally?

4. Insufficient understanding of the consequences on plants and soil biota; e.g.

- What are the physical, physiological, and biochemical impacts of plastic residues – polymer, additives and their degradation products – within plants or soil organisms?
- How do nanoplastics affect the microbiome in phyllosphere, endosphere, spermosphere and rhizosphere of the plant?
- Do plastic pollution alter plant and soil biota response to other existing agrochemical or environmental stressors?
- What is the impacts of plastic pollution on the capacity of the agroecosystem to produce biomass?

8. Concluding remarks

Currently, considerable uncertainty exists because of the limited number of studies that have been published regarding the impact of microplastic and nanoplastic on most trophic levels in agroecosystems – demonstrated evidence of effects and demonstrated evidence of no-effects are equally few at this point in time. The existing regulations based on heavy metal contaminants and available nitrogen for land application of biosolids provide us with the possibility to estimate plastic loading in some agroecosystems. We could then use these loading rates to set up ecotoxicology experiments to determine if these loadings would pose acceptable ecological risk and if not, at what loading concentration would there be a problem.

Based on the mechanisms and constraints described above, the degradation of plastics applied to land is expected to be limited within the timescale of a human lifetime. As such, precautionary measures, even if the cause and effect relationships are not established for agroecosystems, may be warranted. Ultimately, many actions to mitigate microplastic and nanoplastic emissions on land will also benefit the wider environment. They are also likely to be less costly in the long-term and allow us to reap the benefits of plastics with much lower plastic pollution on land and in water.

Acknowledgements

This work was supported by funding from the Australia-China Joint Research Centre – Healthy Soils for Sustainable Food Production and Environmental Quality (ACSRF48165) and its industry partners including BASF, Incitec Pivot and Xinyangfeng. Special thanks to Pablo Galaviz for help with the diagrams; David Ugalde and seven other anonymous reviewers for their detailed comments that has immensely benefitted the ideas expressed in this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2018.01.341.

References

American Society of Chemistry National Historic Chemical Landmarks, 1993. Bakelite: The World's First Synthetic Plastic [WWW Document]. URL. https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/bakelite.html, Accessed date: 19 February 2017.

Artham, T., Sudhakar, M., Venkatesan, R., Madhavan Nair, C.s, Murty, K.V.G.K., Doble, M., 2009. Biofouling and stability of synthetic polymers in sea water. Int. Biodeterior. Biodegrad. 63:884–890. https://doi.org/10.1016/j.ibiod.2009.03.003.

AS4454, 2012. Australian Standard Composts, Soil Conditioners and Mulches. SAI Global Ltd. under licence from Standards Australia (80 p).

Australian and New Zealand Biosolids Partnership, 2016. Australian Biosolids Statistics [WWW Document]. URL. https://www.biosolids.com.au/guidelines/australian-biosolids-statistics/, Accessed date: 15 February 2017.

Bandmann, V., Müller, J.D., Köhler, T., Homann, U., 2012. Uptake of fluorescent nano beads into BY2-cells involves clathrin-dependent and clathrin-independent endocytosis. FEBS Lett. 586:3626–3632. https://doi.org/10.1016/j.febslet.2012.08.008.

Besseling, E., Wang, B., Lürling, M., Koelmans, A.A., 2014. Nanoplastic affects growth of S. obliquus and reproduction of D. magna. Environ. Sci. Technol. 48:12336–12343. https://doi.org/10.1021/es503001d.

Bhattacharya, P., Lin, S., Turner, J.P., Ke, P.C., 2010. Physical adsorption of charged plastic nanoparticles affects algal photosynthesis. J. Phys. Chem. C 114:16556–16561. https://doi.org/10.1021/jp1054759.

Blouin, M., Hodson, M.E., Delgado, E.A., Baker, G., Brussaard, L., Butt, K.R., Dai, J., Dendooven, L., Peres, G., Tondoh, J.E., Cluzeau, D., Brun, J.-J., 2013. A review of earthworm impact on soil function and ecosystem services. Eur. J. Soil Sci. 64:161–182. https://doi.org/10.1111/ejss.12025.

Bombelli, P., Howe, C.J., Bertocchini, F., 2017. Polyethylene bio-degradation by caterpillars of the wax moth Galleria mellonella. Curr. Biol. 27:R292–R293. https://doi.org/10.1016/j.cub.2017.02.060.

Boucher, J., Friot, D., 2017. Primary Microplastics in the Ocean: A Global Evaluation of Sources (Gland, Switzerland).

Bouranis, D.L., Theodoropoulos, A.G., Drossopoulos, J.B., 1995. Designing synthetic polymers as soil conditioners. Commun. Soil Sci. Plant Anal. 26:1455–1480. https://doi.org/10.1080/00103629509369384.

Bouwmeester, H., Hollman, P.C.H., Peters, R.J.B., 2015. Potential health impact of environmentally released micro- and nanoplastics in the human food production chain: experiences from nanotoxicology. Environ. Sci. Technol. 49:8932–8947. https://doi.org/10.1021/acs.est.5b01090.

Brinton, W.F., 2005. Characterization of man-made foreign matter and its presence in multiple size fractions from mixed waste composting. Compost Sci. Util. 13:274–280. https://doi.org/10.1080/1065657X.2005.10702251.

Browne, M.A., Dissanayake, A., Galloway, T.S., Lowe, D.M., Thompson, R.C., 2008. Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.). Environ. Sci. Technol. 42:5026–5031. https://doi.org/10.1021/es800249a.

Browne, M.A., Underwood, A.J., Chapman, M.G., Williams, R., Thompson, R.C., van Franeker, J.A., 2015. Linking effects of anthropogenic debris to ecological impacts. Proc. R. Soc. B Biol. Sci. 282.

Calderón-Preciado, D., Matamoros, V., Bayona, J.M., 2011. Occurrence and potential crop uptake of emerging contaminants and related compounds in an agricultural irrigation network. Sci. Total Environ. 412–413:14–19. https://doi.org/10.1016/j.scitotenv.2011.09.057.

Cao, D., Xiao, W., Luo, X., Liu, G., Zheng, H., 2017. Effects of polystyrene microplastics on the fitness of earthworms in an agricultural soil. IOP Conf. Ser. Earth Environ. Sci. 61, 12148.

Carlsson, D.J., Wiles, D.M., 1976. The photooxidative degradation of polypropylene. Part I. Photooxidation and photoinitiation processes. J. Macromol. Sci. Part C 14:65–106. https://doi.org/10.1080/15321797608076113.

Carpita, N., Sabularse, D., Montezinos, D., Delmer, D.P., 1979. Determination of the pore size of cell walls of living plant cells. Science 80 (205), 1144–1147.

Casado, M.P., Macken, A., Byrne, H.J., 2013. Ecotoxicological assessment of silica and polystyrene nanoparticles assessed by a multitrophic test battery. Environ. Int. 51:97–105. https://doi.org/10.1016/j.envint.2012.11.001.

Clotfelter, E.D., Bell, A.M., Levering, K.R., 2004. The role of animal behaviour in the study of endocrine-disrupting chemicals. Anim. Behav. 68:665–676. https://doi.org/10.1016/j.anbehav.2004.05.004.

Coppock, R.L., Cole, M., Lindeque, P.K., Queirós, A.M., Galloway, T.S., 2017. A small-scale, portable method for extracting microplastics from marine sediments. Environ. Pollut. 230:829–837. https://doi.org/10.1016/j.envpol.2017.07.017.

David, C., Trojan, M., Daro, A., Demarteau, W., 1992. Photodegradation of polyethylene: comparison of various photoinitiators in natural weathering conditions. Polym. Degrad. Stab. 37:233–245. https://doi.org/10.1016/0141-3910(92)90165-2.

Duis, K., Coors, A., 2016. Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. Environ. Sci. Eur. 28:1–25. https://doi.org/10.1186/s12302-015-0069-y.

EFSA Panel on Contaminants in the Food Chain, 2016. Presence of microplastics and nanoplastics in food, with particular focus on seafood. EFSA J. 14, e04501. https://doi.org/10.2903/j.efsa.2016.4501.

Eggen, T., Heimstad, E.S., Stuanes, A.O., Norli, H.R., 2013. Uptake and translocation of organophosphates and other emerging contaminants in food and forage crops. Environ. Sci. Pollut. Res. 20:4520–4531. https://doi.org/10.1007/s11356-012-1363-5.

Eldridge, S.M., Chan, K.Y., Xu, Z.H., Chen, C.R., Barchia, I., 2008. Plant-available nitrogen supply from granulated biosolids: implications for land application guidelines. Soil Res. 46, 423–436.

EPA-NSW, 1997. Environmental Guidelines: Use and Disposal of Biosolid Products (Chatswood, NSW, Australia).

Espí, E., Salmerón, A., Fontecha, A., García, Y., Real, A.I., 2006. PLastic films for agricultural applications. J. Plast. Film Sheeting 22:85–102. https://doi.org/10.1177/8756087906064220.
EU Directive 86/278/EEC, 1986. Council Directive on the Protection of the Environment, and in Particular of the Soil, When Sewage Sludge is Used in Agriculture.
Foruzanmehr, M., Elkoun, S., Fam, A., Robert, M., 2015. Degradation characteristics of new bio-resin based-fiber-reinforced polymers for external rehabilitation of structures. J. Compos. Mater. 50:1227–1239. https://doi.org/10.1177/0021998315590262.
Galloway, T.S., Cole, M., Lewis, C., 2017. Interactions of microplastic debris throughout the marine ecosystem. Nat. Ecol. Evol. 1, 116.
Gao, D.-W., Wen, Z.-D., 2016. Phthalate esters in the environment: a critical review of their occurrence, biodegradation, and removal during wastewater treatment processes. Sci. Total Environ. 541:986–1001. https://doi.org/10.1016/j.scitotenv.2015.09.148.
Gardette, M., Perthue, A., Gardette, J.-L., Janecska, T., Földes, E., Pukánszky, B., Therias, S., 2013. Photo- and thermal-oxidation of polyethylene: comparison of mechanisms and influence of unsaturation content. Polym. Degrad. Stab. 98:2383–2390. https://doi.org/10.1016/j.polymdegradstab.2013.07.017.
GESAMP, 2015. Sources, Fate and Effects of Microplastics in the Marine Environment: A Global Assessment.
Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3, e1700782.
Ghosal, D., Ghosh, S., Dutta, T.K., Ahn, Y., 2016. Current state of knowledge in microbial degradation of polycyclic aromatic hydrocarbons (PAHs): a review. Front. Microbiol. 7:1369. https://doi.org/10.3389/fmicb.2016.01369.
Gigault, J., Pedrono, B., Maxit, B., Ter Halle, A., 2016. Marine plastic litter: the unanalyzed nano-fraction. Environ. Sci. Nano 3:346–350. https://doi.org/10.1039/c6en00008h.
Gómez-Brandón, M., Aira, M., Lores, M., Domínguez, J., 2011. Epigeic earthworms exert a bottleneck effect on microbial communities through gut associated processes. PLoS One 6, e24786. https://doi.org/10.1371/journal.pone.0024786.
Göpferich, A., 1997. Polymer bulk erosion. Macromolecules 30:2598–2604. https://doi.org/10.1021/ma961627y.
Grassie, N., Weir, N.A., 1965. The photooxidation of polymers. III. Photooxidation of polystyrene. J. Appl. Polym. Sci. 9:987–998. https://doi.org/10.1002/app.1965.070090316.
Hawkins, W.L., 1964. Thermal and oxidative degradation of polymers. Polym. Eng. Sci. 4: 187–192. https://doi.org/10.1002/pen.760040309.
Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E., Svendsen, C., 2017. Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci. Total Environ. 586: 127–141. https://doi.org/10.1016/j.scitotenv.2017.01.190.
Huerta Lwanga, E., Gertsen, H., Gooren, H., Peters, P., Salánki, T., Van Der Ploeg, M., Besseling, E., Koelmans, A.A., Geissen, V., 2016. Microplastics in the terrestrial ecosystem: implications for Lumbricus terrestris (Oligochaeta, Lumbricidae). Environ. Sci. Technol. 50:2685–2691. https://doi.org/10.1021/acs.est.5b05478.
Huerta Lwanga, E., Gertsen, H., Gooren, H., Peters, P., Salánki, T., van der Ploeg, M., Besseling, E., Koelmans, A.A., Geissen, V., 2017. Incorporation of microplastics from litter into burrows of Lumbricus terrestris. Environ. Pollut. 220:523–531. https://doi.org/10.1016/j.envpol.2016.09.096.
Huerta L, E., Mendoza Vega, J., Ku Quej, V., de los A. Chi, J., Sanchez del Cid, L., Chi, C., Escalona Segura, G., Gertsen, H., Salánki, T., van der Ploeg, M., Koelmans, A.A., Geissen, V., 2017. Field evidence for transfer of plastic debris along a terrestrial food chain. Sci. Rep. 7:14071. https://doi.org/10.1038/s41598-017-14588-2.
Huerta Lwanga, E., Thapa, B., Yang, X., Gertsen, H., Salánki, T., Geissen, V., Garbeva, P., 2018. Decay of low-density polyethylene by bacteria extracted from earthworm's guts: a potential for soil restoration. Sci. Total Environ. 624:753–757. https://doi.org/10.1016/j.scitotenv.2017.12.144.
Husen, A., Siddiqi, K.S., 2014. Carbon and fullerene nanomaterials in plant system. J. Nanobiotechnol. 12:16. https://doi.org/10.1186/1477-3155-12-16.
Hussain, N., Jaitley, V., Florence, A.T., 2001. Recent advances in the understanding of uptake of microparticulates across the gastrointestinal lymphatics. Adv. Drug Deliv. Rev. 50:107–142. https://doi.org/10.1016/S0169-409X(01)00152-1.
Hyung, H., Kim, J.-H., 2008. Natural organic matter (NOM) adsorption to multi-walled carbon nanotubes: effect of NOM characteristics and water quality parameters. Environ. Sci. Technol. 42:4416–4421. https://doi.org/10.1021/es702916h.
Imfeld, G., Vuilleumier, S., 2012. Measuring the effects of pesticides on bacterial communities in soil: a critical review. Eur. J. Soil Biol. 49:22–30. https://doi.org/10.1016/j.ejsobi.2011.11.010.
Jabarin, S.A., Lofgren, E.A., 1984. Thermal stability of polyethylene terephthalate. Polym. Eng. Sci. 24:1056–1063. https://doi.org/10.1002/pen.760241311.
Jager, T., 2016. Predicting environmental risk: a road map for the future. J. Toxicol. Environ. Health, Part A 79:572–584. https://doi.org/10.1080/15287394.2016.1171986.
Jessup, C.M., Kassen, R., Forde, S.E., Kerr, B., Buckling, A., Rainey, P.B., Bohannan, B.J.M., 2004. Big questions, small worlds: microbial model systems in ecology. Trends Ecol. Evol. 19, 189–197.
Katz, L.C., Iarovici, D.M., 1990. Green fluorescent latex microspheres: a new retrograde tracer. Neuroscience 34:511–520. https://doi.org/10.1016/0306-4522(90)90159-2.
Kawai, F., 2010. The biochemistry and molecular biology of xenobiotic polymer degradation by microorganisms. Biosci. Biotechnol. Biochem. 74:1743–1759. https://doi.org/10.1271/bbb.100394.
Kiyama, Y., Miyahara, K., Ohshima, Y., 2012. Active uptake of artificial particles in the nematode Caenorhabditis elegans. J. Exp. Biol. 215:1178–1183. https://doi.org/10.1242/jeb.067199.
Koelmans, A.A., Nowack, B., Wiesner, M.R., 2009. Comparison of manufactured and black carbon nanoparticle concentrations in aquatic sediments. Environ. Pollut. 157: 1110–1116. https://doi.org/10.1016/j.envpol.2008.09.006.
Koelmans, A.A., Besseling, E., Shim, W.J., 2015. Nanoplastics in the aquatic environment. In: Bergmann, M., Gutow, L., Klages, M. (Eds.), Critical Review BT - Marine Anthropogenic Litter. Springer International Publishing, Cham:pp. 325–340 https://doi.org/10.1007/978-3-319-16510-3_12.
Kole, C., Kole, P., Randunu, K.M., Choudhary, P., Podila, R., Ke, P.C., Rao, A.M., Marcus, R.K., 2013. Nanobiotechnology can boost crop production and quality: first evidence from increased plant biomass, fruit yield and phytomedicine content in bitter melon (Momordica charantia). BMC Biotechnol. 13. https://doi.org/10.1186/1472-6750-13-37.
Kyrikou, I., Briassoulis, D., 2007. Biodegradation of agricultural plastic films: a critical review. J. Polym. Environ. 15:125–150. https://doi.org/10.1007/s10924-007-0053-8.
Lambert, S., Wagner, M., 2016. Characterisation of nanoplastics during the degradation of polystyrene. Chemosphere 145:265–268. https://doi.org/10.1016/j.chemosphere.2015.11.078.
Lee, J.H., Khang, G., Lee, J.W., Lee, H.B., 1998. Interaction of different types of cells on polymer surfaces with wettability gradient. J. Colloid Interface Sci. 205:323–330. https://doi.org/10.1006/jcis.1998.5688.
Lin, S., Reppert, J., Hu, Q., Hudson, J.S., Reid, M.L., Ratnikova, T.A., Rao, A.M., Luo, H., Ke, P.C., 2009. Uptake, translocation, and transmission of carbon nanomaterials in rice plants. Small 5:1128–1132. https://doi.org/10.1002/smll.200801556.
Liu, Q., Chen, B., Wang, Q., Shi, X., Xiao, Z., Lin, J., Fang, X., 2009. Carbon nanotubes as molecular transporters for walled plant cells. Nano Lett. 9:1007–1010. https://doi.org/10.1021/nl803083u.
Liu, E.K., He, W.Q., Yan, C.R., 2014. "White revolution" to "white pollution" - agricultural plastic film mulch in China. Environ. Res. Lett. 9. https://doi.org/10.1088/1748-9326/9/9/091001.
Ma, X., Geiser-Lee, J., Deng, Y., Kolmakov, A., 2010. Interactions between engineered nanoparticles (ENPs) and plants: phytotoxicity, uptake and accumulation. Sci. Total Environ. 408:3053–3061. https://doi.org/10.1016/j.scitotenv.2010.03.031.
Maaß, S., Daphi, D., Lehmann, A., Rillig, M.C., 2017. Transport of microplastics by two collembolan species. Environ. Pollut. 225:456–459. https://doi.org/10.1016/j.envpol.2017.03.009.
Meeker, J.D., Sathyanarayana, S., Swan, S.H., 2009. Phthalates and other additives in plastics: human exposure and associated health outcomes. Philos. Trans. R. Soc. B Biol. Sci. 364:2097–2113. https://doi.org/10.1098/rstb.2008.0268.
Mohan, K., 2011. Microbial deterioration and degradation of polymeric materials. J. Biochem. Technol. 2, 210–215.
Mohapatra, D.P., Cledón, M., Brar, S.K., Surampalli, R.Y., 2016. Application of wastewater and biosolids in soil: occurrence and fate of emerging contaminants. Water Air Soil Pollut. 227. https://doi.org/10.1007/s11270-016-2768-4.
Morales-Díaz, A.B., Ortega-Ortíz, H., Juárez-Maldonado, A., Cadenas-Pliego, G., González-Morales, S., Benavides-Mendoza, A., 2017. Application of nanoelements in plant nutrition and its impact in ecosystems. Adv. Nat. Sci. Nanosci. Nanotechnol. 8. https://doi.org/10.1088/2043-6254/8/1/013001.
Nel, A.E., Mädler, L., Velegol, D., Xia, T., Hoek, E.M.V., Somasundaran, P., Klaessig, F., Castranova, V., Thompson, M., 2009. Understanding biophysicochemical interactions at the nano-bio interface. Nat. Mater. 8:543–557. https://doi.org/10.1038/nmat2442.
Nguyen, T.Q., 2008. Polymer degradation and stabilization. Handbook of Polymer Reaction Engineering. Wiley-VCH Verlag GmbH:pp. 757–831 https://doi.org/10.1002/9783527619870.ch15.
Nizzetto, L., Futter, M., Langaas, S., 2016. Are agricultural soils dumps for microplastics of urban origin? Environ. Sci. Technol. 50:10777–10779. https://doi.org/10.1021/acs.est.6b04140.
Nolte, T.M., Hartmann, N.B., Kleijn, J.M., Garnæs, J., van de Meent, D., Jan Hendriks, A., Baun, A., 2017a. The toxicity of plastic nanoparticles to green algae as influenced by surface modification, medium hardness and cellular adsorption. Aquat. Toxicol. 183:11–20. https://doi.org/10.1016/j.aquatox.2016.12.005.
Nolte, T.M., Peijnenburg, W.J.G.M., Hendriks, A.J., van de Meent, D., 2017b. Quantitative structure-activity relationships for green algae growth inhibition by polymer particles. Chemosphere 179:49–56. https://doi.org/10.1016/j.chemosphere.2017.03.067.
Oehlmann, J., Schulte-Oehlmann, U., Kloas, W., Jagnytsch, O., Lutz, I., Kusk, K.O., Wollenberger, L., Santos, E.M., Paull, G.C., VanLook, K.J.W., Tyler, C.R., 2009. A critical analysis of the biological impacts of plasticizers on wildlife. Philos. Trans. R. Soc. B Biol. Sci. 364:2047–2062. https://doi.org/10.1098/rstb.2008.0242.
Palma, G., Carenza, M., 1970. Degradation of poly(vinyl chloride). I. Kinetics of thermal and radiation-induced dehydrochlorination reactions at low temperatures. J. Appl. Polym. Sci. 14:1737–1754. https://doi.org/10.1002/app.1970.070140708.
Petersen, E.J., Diamond, S.A., Kennedy, A.J., Goss, G.G., Ho, K., Lead, J., Hanna, S.K., Hartmann, N.B., Hund-Rinke, K., Mader, B., Manier, N., Pandard, P., Salinas, E.R., Sayre, P., 2015. Adapting OECD aquatic toxicity tests for use with manufactured nanomaterials: key issues and consensus recommendations. Environ. Sci. Technol. 49:9532–9547. https://doi.org/10.1021/acs.est.5b00997.
Potts, J.E., Clendinning, R.A., Ackart, W.B., Niegisch, W.D., 1973. The biodegradability of synthetic polymers. In: Guillet, J. (Ed.), Polymers and Ecological Problems. Springer US, Boston, MA:pp. 61–79 https://doi.org/10.1007/978-1-4684-0871-3_4.
Rabek, J.F., Rånby, B., 1975. Role of singlet oxygen in photo-oxidative degradation and photostabilization of polymers. Polym. Eng. Sci. 15:40–43. https://doi.org/10.1002/pen.760150107.
Ramos, L., Berenstein, G., Hughes, E.A., Zalts, A., Montserrat, J.M., 2015. Polyethylene film incorporation into the horticultural soil of small periurban production units in Argentina. Sci. Total Environ. 523:74–81. https://doi.org/10.1016/j.scitotenv.2015.03.142.
Reed, A.M., Gilding, D.K., 1981. Biodegradable polymers for use in surgery — poly(glycolic)/poly(lactic acid) homo and copolymers: 2. In vitro degradation. Polymer (Guildf.) 22:494–498. https://doi.org/10.1016/0032-3861(81)90168-3.
Reisser, J., Shaw, J., Hallegraeff, G., Proietti, M., Barnes, D.K.A., Thums, M., Wilcox, C., Hardesty, B.D., Pattiaratchi, C., 2014. Millimeter-sized marine plastics: a new pelagic

habitat for microorganisms and invertebrates. PLoS One 9. https://doi.org/10.1371/journal.pone.0100289.
Rembaum, A., Dreyer, W.J., 1980. Immunomicrospheres: reagents for cell labeling and separation. Science 80 (208), 364.
Rico, C.M., Majumdar, S., Duarte-Gardea, M., Peralta-Videa, J.R., Gardea-Torresdey, J.L., 2011. Interaction of nanoparticles with edible plants and their possible implications in the food chain. J. Agric. Food Chem. 59:3485–3498. https://doi.org/10.1021/jf104517j.
Rillig, M.C., 2012. Microplastic in terrestrial ecosystems and the soil? Environ. Sci. Technol. 46:6453–6454. https://doi.org/10.1021/es302011r.
Rillig, M.C., Ziersch, L., Hempel, S., 2017. Microplastic transport in soil by earthworms. Sci. Rep. 7:1362. https://doi.org/10.1038/s41598-017-01594-7.
Rochman, C.M., Browne, M.A., Underwood, A.J., van Franeker, J.A., Thompson, R.C., Amaral-Zettler, L.A., 2016. The ecological impacts of marine debris: unraveling the demonstrated evidence from what is perceived. Ecology 97:302–312. https://doi.org/10.1890/14-2070.1.
Rodriguez-Seijo, A., Lourenço, J., Rocha-Santos, T.A.P., da Costa, J., Duarte, A.C., Vala, H., Pereira, R., 2017. Histopathological and molecular effects of microplastics in Eisenia andrei Bouché. Environ. Pollut. 220:495–503. https://doi.org/10.1016/j.envpol.2016.09.092.
Rohr, J.R., Salice, C.J., Nisbet, R.M., 2016. The pros and cons of ecological risk assessment based on data from different levels of biological organization. Crit. Rev. Toxicol. 46:756–784. https://doi.org/10.1080/10408444.2016.1190685.
Sandermann Jr., H., 1992. Plant metabolism of xenobiotics. Trends Biochem. Sci. 17:82–84. https://doi.org/10.1016/0968-0004(92)90507-6.
Savoca, M.S., Wohlfeil, M.E., Ebeler, S.E., Nevitt, G.A., 2016. Marine plastic debris emits a keystone infochemical for olfactory foraging seabirds. Sci. Adv. 2.
Scandalios, J.G., 2001. Molecular responses to oxidative stress. In: Hawkesford, M.J., Buchner, P. (Eds.), Molecular Analysis of Plant Adaptation to the Environment. Springer, Netherlands, pp. 181–208.
Schettini, E., Stefani, L., Vox, G., 2014. Interaction between agrochemical contaminants and UV stabilizers for greenhouse EVA plastic films. Appl. Eng. Agric. 30:229–239. https://doi.org/10.13031/aea.30.10048.
Shen, C.-X., Zhang, Q.-F., Li, J., Bi, F.-C., Yao, N., 2010. Induction of programmed cell death in Arabidopsis and rice by single-wall carbon nanotubes. Am. J. Bot. 97:1602–1609. https://doi.org/10.3732/ajb.1000073.
Simpson, M.J., Hatcher, P.G., 2004. Overestimates of black carbon in soils and sediments. Naturwissenschaften 91:436–440. https://doi.org/10.1007/s00114-004-0550-8.
Singh, B., Sharma, N., 2008. Mechanistic implications of plastic degradation. Polym. Degrad. Stab. 93:561–584. https://doi.org/10.1016/j.polymdegradstab.2007.11.008.
Staples, C.A., Peterson, D.R., Parkerton, T.F., Adams, W.J., 1997. The environmental fate of phthalate esters: a literature review. Chemosphere 35:667–749. https://doi.org/10.1016/S0045-6535(97)00195-1.
Steinmetz, Z., Wollmann, C., Schaefer, M., Buchmann, C., David, J., Tröger, J., Muñoz, K., Frör, O., Schaumann, G.E., 2016. Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation? Sci. Total Environ. 550:690–705. https://doi.org/10.1016/j.scitotenv.2016.01.153.
Syberg, K., Khan, F.R., Selck, H., Palmqvist, A., Banta, G.T., Daley, J., Sano, L., Duhaime, M.B., 2015. Microplastics: addressing ecological risk through lessons learned. Environ. Toxicol. Chem. 34:945–953. https://doi.org/10.1002/etc.2914.
Talsness, C.E., Andrade, A.J.M., Kuriyama, S.N., Taylor, J.A., Saal, F.S.V., 2009. Components of plastic: experimental studies in animals and relevance for human health. Philos. Trans. R. Soc. B Biol. Sci. 364:2079–2096. https://doi.org/10.1098/rstb.2008.0281.
Tan, X.-m., Lin, C., Fugetsu, B., 2009. Studies on toxicity of multi-walled carbon nanotubes on suspension rice cells. Carbon N. Y. 47:3479–3487. https://doi.org/10.1016/j.carbon.2009.08.018.
Taylor, M.L., Gwinnett, C., Robinson, L.F., Woodall, L.C., 2016. Plastic microfibre ingestion by deep-sea organisms. Sci. Rep. 6, 33997.
Teuten, E.L., Saquing, J.M., Knappe, D.R.U., Barlaz, M.A., Jonsson, S., Björn, A., Rowland, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P.H., Tana, T.S., Prudente, M., Boonyatumanond, R., Zakaria, M.P., Akkhavong, K., Ogata, Y., Hirai, H., Iwasa, S., Mizukawa, K., Hagino, Y., Imamura, A., Saha, M., Takada, H., 2009. Transport and release of chemicals from plastics to the environment and to wildlife. Philos. Trans. R. Soc. B Biol. Sci. 364:2027–2045. https://doi.org/10.1098/rstb.2008.0284.
Thomas, N.L., Clarke, J., McLauchlin, A.R., Patrick, S.G., 2012. Oxodegradable plastics: degradation, environmental impact and recycling. Proc. Inst. Civ. Eng. Waste Resour. Manag. 165:133–140. https://doi.org/10.1680/warm.11.00014.
Torre-Roche, R.D.L., Hawthorne, J., Deng, Y., Xing, B., Cai, W., Newman, L.A., Wang, Q., Ma, X., Hamdi, H., White, J.C., 2013. Multiwalled carbon nanotubes and C60 fullerenes differentially impact the accumulation of weathered pesticides in four agricultural plants. Environ. Sci. Technol. 47. https://doi.org/10.1021/es4034809.
Toyota, K., Kimura, M., 2000. Microbial community indigenous to the earthworm Eisenia foetida. Biol. Fertil. Soils 31, 187–190.
Trapp, S., 2000. Modelling uptake into roots and subsequent translocation of neutral and ionisable organic compounds. Pest Manag. Sci. 56:767–778. https://doi.org/10.1002/1526-4998(200009)56:9<767::AID-PS198>3.0.CO;2-Q.
USEPA 40 CFR 503, 1993. Standards for the Use or Disposal of Sewage Sludge.
Van Cauwenberghe, L., Janssen, C.R., 2014. Microplastics in bivalves cultured for human consumption. Environ. Pollut. 193:65–70. https://doi.org/10.1016/j.envpol.2014.06.010.
Wan, Y., Wang, Y., Liu, Z., Qu, X., Han, B., Bei, J., Wang, S., 2005. Adhesion and proliferation of OCT-1 osteoblast-like cells on micro- and nano-scale topography structured poly(l-lactide). Biomaterials 26:4453–4459. https://doi.org/10.1016/j.biomaterials.2004.11.016.
Wang, J., Lv, S., Zhang, M., Chen, G., Zhu, T., Zhang, S., Teng, Y., Christie, P., Luo, Y., 2016. Effects of plastic film residues on occurrence of phthalates and microbial activity in soils. Chemosphere 151:171–177. https://doi.org/10.1016/j.chemosphere.2016.02.076.
Wang, P., Lombi, E., Zhao, F.-J., Kopittke, P.M., 2016. Nanotechnology: a new opportunity in plant sciences. Trends Plant Sci. 21:699–712. https://doi.org/10.1016/j.tplants.2016.04.005.
Wiesner, M.R., Lowry, G.V., Casman, E., Bertsch, P.M., Matson, C.W., Di Giulio, R.T., Liu, J., Hochella, M.F., 2011. Meditations on the ubiquity and mutability of nano-sized materials in the environment. ACS Nano 5:8466–8470. https://doi.org/10.1021/nn204118p.
Wright, S.L., Thompson, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: a review. Environ. Pollut. 178:483–492. https://doi.org/10.1016/j.envpol.2013.02.031.
Yang, J., Yang, Y., Wu, W.-M., Zhao, J., Jiang, L., 2014. Evidence of polyethylene biodegradation by bacterial strains from the guts of plastic-eating waxworms. Environ. Sci. Technol. 48:13776–13784. https://doi.org/10.1021/es504038a.
Yoo, E.S., Im, S.S., 1999. Effect of crystalline and amorphous structures on biodegradability of poly(tetramethylene succinate). J. Environ. Polym. Degrad. 7:19–26. https://doi.org/10.1023/A:1021838017958.
Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., Toyohara, K., Miyamoto, K., Kimura, Y., Oda, K., 2016. A bacterium that degrades and assimilates poly(ethylene terephthalate). Science 80 (351):1196–1199. https://doi.org/10.1126/science.aad6359.
Zhang, D., Liu, H., Hu, W., Qin, X., Ma, X., Yan, C., Wang, H., 2016. The status and distribution characteristics of residual mulching lm in Xinjiang, China. J. Integr. Agric. 15:2639–2646. https://doi.org/10.1016/S2095-3119(15)61240-0.
Zhang, S., Yang, X., Gertsen, H., Peters, P., Salánki, T., Geissen, V., 2018. A simple method for the extraction and identification of light density microplastics from soil. Sci. Total Environ. 616-617:1056–1065. https://doi.org/10.1016/j.scitotenv.2017.10.213.
Zhao, Q., Ma, C., White, J.C., Dhankher, O.P., Zhang, X., Zhang, S., Xing, B., 2017. Quantitative evaluation of multi-wall carbon nanotube uptake by terrestrial plants. Carbon N. Y. 114:661–670. https://doi.org/10.1016/j.carbon.2016.12.036.
Ziajahromi, S., Neale, P.A., Leusch, D.D.L., 2016. Wastewater treatment plant effluent as a source of microplastics: review of the fate, chemical interactions and potential risks to aquatic organisms. Water Sci. Technol. 74, 2253–2269.

Environment International 37 (2011) 226–247

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Review

Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids

Bradley O. Clarke, Stephen R. Smith *

Department of Civil and Environmental Engineering, South Kensington Campus, Imperial College London, London, SW7 2AZ, United Kingdom

ARTICLE INFO

Article history:
Received 3 December 2009
Accepted 9 June 2010
Available online 24 August 2010

Keywords:
Sewage sludge
Biosolids
Land application
Antibiotics
Pharmaceuticals
Benzothiazoles
Bisphenol A
Organotins
Polybrominated diphenyl ethers
Polychlorinated alkanes
Polychlorinated naphthalenes
Polydimethylsiloxanes
Perfluorochemicals
Phthalate acid esters
Quaternary ammonium compounds
Steroids
Hormones
Synthetics musks
Triclosan
Triclocarban

ABSTRACT

A broad spectrum of organic chemicals is essential to modern society. Once discharged from industrial, domestic and urban sources into the urban wastewater collection system they may transfer to the residual solids during wastewater treatment and assessment of their significance and implications for beneficial recycling of the treated sewage sludge biosolids is required. Research on organic contaminants (OCs) in biosolids has been undertaken for over thirty years and the increasing body of evidence demonstrates that the majority of compounds studied do not place human health at risk when biosolids are recycled to farmland. However, there are 143,000 chemicals registered in the European Union for industrial use and all could be potentially found in biosolids. Therefore, a literature review of 'emerging' OCs in biosolids has been conducted for a selection of chemicals of potential concern for land application based upon human toxicity, evidence of adverse effects on the environment and endocrine disruption.

To identify monitoring and research priorities the selected chemicals were ranked using an assessment matrix approach. Compounds were evaluated based upon environmental persistence, human toxicity, evidence of bioaccumulation in humans and the environment, evidence of ecotoxicity and the number and quality of studies focussed on the contaminant internationally. The identified chemicals of concern were ranked in decreasing order of priority: perfluorinated chemicals (PFOS, PFOA); polychlorinated alkanes (PCAs), polychlorinated naphthalenes (PCNs); organotins (OTs), polybrominated diphenyl ethers (PBDEs), triclosan (TCS), triclocarban (TCC); benzothiazoles; antibiotics and pharmaceuticals; synthetic musks; bisphenol A, quaternary ammonium compounds (QACs), steroids; phthalate acid esters (PAEs) and polydimethylsiloxanes (PDMSs).

A number of issues were identified and recommendations for the prioritisation of further research and monitoring of 'emerging' OCs for the agricultural use of biosolids are provided. In particular, a number of 'emerging' OCs (PFOS, PFOA and PCAs) were identified for priority attention that are environmentally persistent and potentially toxic with unique chemical properties, or are present in large concentrations in sludge, that make it theoretically possible for them to enter human and ecological food-chains from biosolids-amended soil.

Abbreviations: <dl, Less than detection limit; ADBI, Synthetic polycyclic musk — Celestolide™; AHMI, Synthetic polycyclic musk — Phantolide™; AHTN, Synthetic polycyclic musk — Tonalide™; ATII, Synthetic polycyclic musks — Traseolide™; BFR, Brominated flame retardant; CAS, Chemical abstract service; CP, Chlorinated parrafin; DBT, Dibutyltin; DEHP, Di2-(ethylhexyl) phthalate; DPMI, Synthetic polycyclic musk — Cashmeran™; dw, Dry weight; GC, Gas chromatography; HBCB, Hexabromocyclododecane; HHCB, Synthetic polycyclic musk — Galaxolide™; HRGC, High resolution gas chromatography; IARC, International Agency for Research on Cancer; IPCS, International Programme on Chemical Safety; K_{OW}, Octanol–water partition coefficient; LCCP, Long-chain chlorinated parrafin; lPCA, Long-chain chlorinated alkane; MA, Musk ambrette; Max, Maximum concentration; MBT_{tin}, Monobutyltin; $MBT_{thiazole}$, Mercaptobenzothiazole; MCCP, Medium-chain chlorinated parrafin; Min, Minimum concentration; MK, Musk ketone; MM, Musk moskene; mPCA, Medium-chain chlorinated parrafin; MS, Mass spectrometer; MT, Musk tibetene; MX, Musk xlyene; n, Number of samples; OBT, 2-hydroxybenzothiazole; OC, Organic contaminant; OT, Organotin; PAE, Phthalate acid ester; PBB, Polybrominated biphenyl; PBDE, Polybrominated diphenyl ether; PCA, Polychlorinated alkane; PCB, Polychlorinated biphenyl; PCDD, Polychlorinated dibenzo-p-dioxin; PCDF, Polychlorinated dibenzofuran; PCN, Polychlorinated naphthalene; PDMS, Polydimethylsiloxane; PEC, Predicted environmental concentration; PFAC, Perfluoroalkyl carboxylate; PFAS, Perfluoroalkyl sulfonate; PFDA, Perfluorodecanoic acid; PFDoDA, Perfluorododecanoic acid; PFHxS, Perfluorohexane sulfonate; PFNA, Perfluorononanoic acid; PFOA, Perfluooctanoic acid; PFOS, Perfluorooctane sulfonate; PFOSA, Perfluorooctane sulfonamide; PFUnDA, Perfluoroundecanoic acid; PHS, Priority hazardous substance; PNEC, Predicted no-effect environmental concentration; POP, Persistent organic pollutant; PVC, Polyvinyl chloride; QAC, Quaternary ammonium compound; SCCP, Short-chain chlorinated parrafin; sPCA, Short-chain chlorinated parrafin; TBT, Tributyltin; TCC, Triclocarbam; TCDD, Tetrachloro dibenzo-p-dioxin; TCS, Triclosan; TEF, Toxicity equivalency factors; TEQ, Toxicity equivalency — TCDD equivalence; TPhT, Triphenyltin; UNEP, United Nations Environment Program; US EPA, United States Environmental Protection Agency; Vp, Vapour pressure; WFD, European Water Framework Directive; WHO, World Health Organization; WWTP, Wastewater treatment plant.

* Corresponding author. Tel.: +44 20 75946051; fax: +44 20 75941511.
E-mail address: s.r.smith@imperial.ac.uk (S.R. Smith).

0160-4120/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envint.2010.06.004

Contents

1. Introduction

The land application of biosolids (treated sewage sludge) is the option favoured internationally for sludge management as it contributes positively to recycling nutrients, soil properties and fertility (CEC, 1986; CEC, 1991; US EPA, 1993; European Commission, 2010). Land application of biosolids is also likely to become an increasingly essential aspect of sustainable nutrient management as phosphorus resources become depleted (Steen, 1998).

Modern society depends on a large range of organic chemicals and these may ultimately enter urban wastewater. Degradation and attenuation during wastewater and sludge treatment remove significant amounts of organic contaminants (OCs). However, many OCs have lipophilic properties and hence transfer to sewages sludge and may be present in residual concentrations ranging from $<$ng kg^{-1} to % values in the dry solids depending on the initial amounts present, their lipophilicity and the extent of destruction during wastewater and sludge treatment.

Over the past thirty years a significant volume of research has been completed on this topic. Particular attention has been given to selected priority groups of persistent organic pollutants (POPs) such as chlorinated dioxins/furans (PCDD/Fs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (Wild et al., 1991; Alcock et al., 1996; Stevens et al., 2001). The body of published work on OCs in sludge covers: organochlorine pesticides (McIntyre and Lester, 1984; Clarke et al., 2010), PCBs (Alcock and Jones, 1993; Wilson et al., 1997), dioxin-like compounds (Sewart et al., 1995; Stevens et al., 2001; Clarke et al., 2008a); and more recently: chlorinated napthalenes (PCNs), PAHs, polychlorinated alkanes (PCAs), synthetic musks (Stevens et al., 2003), oestrogens (Gomes et al., 2009), organotin compounds (Voulvoulis et al., 2004; Voulvoulis and Lester, 2006) and nonyl phenol (NP) (Sjöström et al., 2008). The concentrations of 'traditional' POPs (eg PAHs, PCBs, PCDD/Fs) in sludge have declined substantially due to effective source control (Wild et al., 1990; Clarke et al., 2008a, 2010).

The 'traditional' POPs were considered as a risk to human health and the environment from biosolids land application due to their persistence, potential to bioaccumulate up foodwebs and toxicity (Chaney et al., 1996). However, hydrophobic non-ionic OCs are tightly sorbed to sludge and soil organic matter, thus reducing their bioavailablility to microorganisms and for plant uptake, but this characteristic also increases their persistence in soil (Alexander, 2000). Risk assessments also found that entry into the human foodchain resulting from biosolids land application was negligible because plant uptake is minimal (Briggs et al., 1982; O'Connor et al., 1990; Hundal et al., 2008), the strong sorption to the soil matrix prevents groundwater contamination (Wilson et al., 1996), while restrictions on surface application to pasture for grazing and the promotion of biosolids incorporation reduces the likelihood of OC accumulation by grazing animals. The assimilation of the available international research through risk assessment in the majority of studies concludes that the OCs examined do not pose a risk to human health when land applying biosolids (Dean and Suess, 1985; Jackson and Eduljee, 1994; Wild et al., 1994; Chaney et al., 1996; Schowanek et al., 2004; Eriksen et al., 2009). Nevertheless, it is recognised that continued vigilance is required to monitor and determine the significance and implications of 'emerging' OCs for the land application of biosolids.

The aim of this review is to identify research and monitoring priorities for 'emerging' OCs in biosolids, and particularly identify chemicals that may be potentially significant for agricultural use of biosolids, requiring further assessment and investigation. A list of compounds was selected and the available published information for these chemicals was critically examined and reviewed. The OCs were selected for evaluation on the basis that they exhibited one or more of the following properties: environmental persistence, bioaccumulation, toxicity or endocrine disruption. Research and monitoring priorities for the 'emerging' OCs considered have been evaluated using a matrix assessment approach to rank the chemicals of concern. The assessment of OCs was based on the following criteria:

- persistence of the OC in soil;
- potential risks to the human foodchain from biosolids land application;
- evidence of bioaccumulation in ecological receptors;
- evidence of ecotoxicity;
- the extent, quality and consistency of the research conducted.

The OCs selected for review were:

- antibiotics and pharmaceuticals
- benzothiazoles

- bisphenol A
- organotins (OTs)
- polybrominated diphenyl ethers (PBDEs)
- polychlorinated alkanes (PCAs)
- polychlorinated naphthalenes (PCNs)
- polydimethylsiloxanes (PDMSs)
- perfluorochemicals (PFCs)
- phthalate acid esters (PAEs)
- quaternary ammonium compounds (QACs)
- steroids
- synthetics musks
- triclosan (TCS) and triclocarban (TCC).

Chemical properties and structure of the selected compounds or class of compound are described in Table 1.

2. Review of emerging organic contaminants

2.1. Antibiotics and pharmaceuticals

The main transfer pathway for antibiotics and pharmaceuticals used in human medicine to enter the environment is via wastewater treatment plants (WWTPs). Antibiotics have been detected in sewage effluents (Golet et al., 2002), ground and river water (Hirsch et al., 1999; Golet et al., 2001; Kolpin et al., 2002), sewage sludge (Gobel et al., 2005), as well as soil and manure (due to veterinary use) (Golet et al., 2003). Studies on the fate of antibiotics and pharmaceuticals in wastewater, surface water and biosolids are primarily motivated by the question of whether antibiotics in the environment may contribute to the spread of antibiotic resistant bacterial pathogens (McArdell et al., 2003). However, concern regarding antibiotics and pharmaceuticals is also driven by understanding the ecological consequences of widespread environmental contamination and the possible entry of pharmaceuticals into the human foodchain (Daughton and Ternes, 1999; Thiele-Bruhn, 2003).

The chemical properties of antibiotics and pharmaceuticals can vary widely, however many contain a non-polar core with a polar functional moiety (Thiele-Bruhn, 2003). The varying chemical properties will influence the behaviour of the chemical through wastewater treatment as well as the mobility, persistence and bioavailability in the soil matrix. Antibiotics can be categorised into the following groups:

- fluoroquinolone (FQ)
- sulfonamide (SA)
- penicillin (PE)
- cephalosporin (CE)
- nitroimidazole (NI)
- tetracycline (TC)
- macrolide (MA)

In a study of antibiotics in Swedish WWTP, the most commonly detected antibiotics were: norfloxacin, ofloxacin, ciprofloxacin, trimethoprim, sulfamethoozole and doxycycline. Norfloxacin, ofloxacin, ciprofloxacin and doxycycline were the main antibiotics detected in sludge at the low mg kg^{-1} dry weight (dw) range (Lindberg et al., 2005). A mass balance study indicated that these chemicals passed unchanged through the WWTP and concentrations could be predicted based upon consumption and use data (Lindberg et al., 2005). Similar concentrations (low mg kg^{-1} dw) were reported in a Swiss study that detected ciprofloxacin and norfloxacin in sewage sludge (Golet et al., 2002). These compounds were also measured in biosolids-amended soil 21 months after application in the μg kg^{-1} dw range (Golet et al., 2003). The longer environmental persistence of antibiotics in biosolids-amended soil is apparently in contrast to aquatic environments, where degradation occurs in a matter of days (Andreozzi et al., 2003), and could be explained by increased sorption to the sludge/soil matrix reducing bioavailability for microbial biodegradation (Alexander, 2000; Drillia et al., 2005; Williams and Adamsen, 2006). Greenhouse plant uptake experiments have demonstrated that certain compounds, such as carbamazepine and sulfamethazine, can be translocated from the soil matrix and into the aerial plant components (Dolliver et al., 2007; Winker et al., 2010). However, the risk of human exposure via this pathway is considered low and unlikely to exceed acceptable daily intakes (Thiele-Bruhn, 2003; Boxall et al., 2006).

A recent Norwegian risk assessment (Eriksen et al., 2009) screened pharmaceutical compounds in sludge against consumption, estimated mass entering WWTP, human metabolism, biodegradation and behaviour in WWTP. Of the 1400 pharmaceutical compounds currently prescribed in Norway and screened in the risk assessment, only 14 were identified for further detailed investigation. The predicted environmental concentration (PEC) and the predicted no-effect environmental concentration (PNEC) of these compounds are presented in Table 2. The concentrations of drug substances in agricultural soils amended with biosolids were estimated to be <1 mg kg^{-1} dw and were significantly below the estimated soil PNEC values. The overall conclusion was that drug substances in sewage sludge constitute a low risk to the soil compartment (Eriksen et al., 2009).

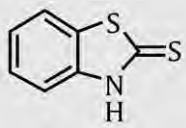
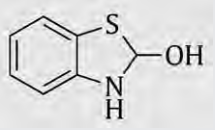
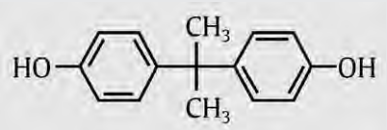
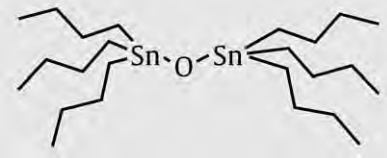
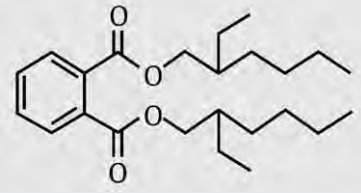
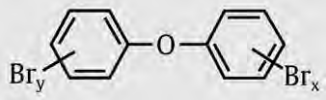
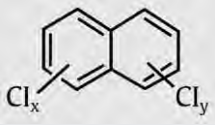
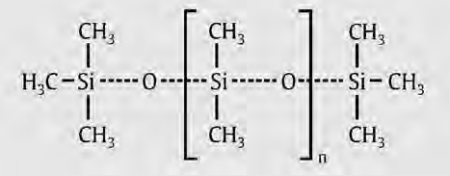
A survey of US biosolids found that, for 72 pharmaceuticals, two (viz. ciprofloxacin, diphenhydramine) were found in all samples ($n=84$) and eight were found in at least 80 of the biosolids samples analysed. However, 15 pharmaceuticals were not found in any sample and 29 were present in fewer than three samples (US EPA, 2009). Many of the compounds identified as priorities in the Norwegian biosolids risk assessment were not included for analysis in the US biosolids survey. However, maximum concentrations of tetracycline (range: 0.04–5.3 and mean: 1.3 mg kg^{-1} dw) and ciprofloxacin (range: 0.08–41.0 and mean: 10.5 mg kg^{-1} dw) measured in the US survey (Table 3) were 12 and 24 times larger, respectively, than the amounts estimated in sludge for risk assessment by Eriksen et al. (2009). Nevertheless, applying these factors to the Norwegian $soil_{PEC}$ for the drug compounds (Eriksen et al., 2009) still results in a value that is well below the estimated $soil_{PNEC}$.

The potential implications for human health of increased antibiotic resistance in soil bacteria are clearly a matter of concern (Nwosu, 2001). A large variety of soil-borne saprophytes including actinomycetes, fungi and bacteria are capable of synthesizing antibiotics and resistance develops in soil microbial communities to overcome the effects of natural microbial antibiotics released into the soil. However, antibiotic resistance levels may rise due to inputs of anthropogenic sources (eg antibiotics in wastes from intensively reared livestock for instance). These are apparently short-lived and return to the background level once the selection pressure has been removed, through biodegradation of the antibiotic, as there is no competitive advantage in maintaining this characteristic, which is subsequently lost from the soil microbial community (Sengeløv et al., 2003; Rysz and Alvarez, 2004). The Panel on Contaminants in the Norwegian Scientific Committee for Food Safety (Eriksen et al., 2009) noted the fluoroquinolone antibiotic drug, ciprofloxacin, could potentially lead to the development of antibacterial resistance, due to its persistence and limited mobility in soil. However, the risk assessment of biosolids application to agricultural land indicated that it was unlikely that antibacterial resistance would be promoted in treated effluent from WWTP, sewage sludge or amended soil (Eriksen et al., 2009).

2.2. Benzothiazoles

The German Government has proposed limit values in biosolids for two rubber vulcanising agents: 2-mercaptobenzothiazole ($MBT_{thiazole}$) and 2-hydroxybenzothiazole (OBT) (BMU, 2007). These chemicals, referred to as accelerators, are used for the polymerisation of sulphur with rubber (vulcanisation). They have been detected in wastewater in

Table 1
Chemical structure and properties of 'emerging' organic contaminants.

Compound	Chemical structure	Chemical properties
Benzothiazoles		
2-Mercaptobenzothiazole ($MBT_{thiazole}$)		CAS No: 149-30-4 Formula: $C_7H_5NS_2$ Log K_{OW}: 2.42 Vp: <0.0014 Pa (25 °C) Half-life (soil): unknown (US EPA, 1984)
2-Hydroxybenzothiazole (OBT)		CAS No: 934-34-9 Formula: C_7H_5NOS Log K_{OW}: 1.76 Vp: 466 (25 °C) Half life (soil): unknown (Reddy and Quinn, 1997)
Bisphenol A		CAS No: 56-35-9 Formula: $C_{15}H_{16}O_2$ Log K_{OW}: 3.40 Vp: 1.15×10^{-5}-0.005 Pa (20 °C) Half life (soil): days Staples et al. (1998); Oehlmann et al. (2008)
Organotin compounds Tributyltin (TBT) oxide		CAS No: 56-35-9 Formula: $C_{24}H_{54}OSn_2$ Log K_{OW}: 3.19–3.84 Vp: 1×10^{-3} Pa (20 °C) Half life (soil): 70 days IPCS (1990)
Phthalate acid esters Di (2-ethylhexyl) phthalate		CAS No: 84-74-2 Formula: $C_{16}H_{22}O_4$ Log K_{OW}: 4.31–4.79 Vp: 0.01 Pa (25 °C) Half life (soil): 23–100 days IPCS (1992)
Polybrominated diphenyl ethers (PBDEs)		CAS No: varied Formula: $C_{12}H_{(10-x,y)}Br_{x,y}O$ Log K_{OW}: 4.28–9.9 Vp: 3.85–13.3 Pa (20–25 °C) Half life (soil): 4–20 years IPCS (1994); Sellstrom et al. (2005); Eljarrat et al. (2008)
Polychlorinated alkanes (PCAs)	Numerous isomers with varying degrees of chlorine substitution. Short-chain PCAs–C_{10-13} Medium-chain PCAs–C_{14-17} Long-chain PCAs–C_{18-30}	CAS No: varied Formula: $C_xH_{(2x+2)-y}Cl_y$ Log K_{OW}: varied Vp: varied Half life (soil): unknown
Polychlorinated naphthalenes (PCNs)		CAS No: varied Formula: $C_{12}H_{(8-x,y)}Cl_{x,y}$ Log K_{OW}: 6.42–10.11 Vp: 3×10^{-11}–4.2×10^{-9} Pa Half life (soil): unknown/persistent IPCS (2001)
Polydimethylsiloxanes (PDMSs)		CAS No: varied Formula: $Me_3SiO(SiMe_2O)_nSiMe_3$; n varies between 100 and >10,000 Log K_{OW}: non-polar Vp: variable Half life (soil): 2–28 days Griessbach and Lehmann (1999)

(continued on next page)

Table 1 (*continued*)

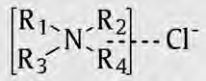
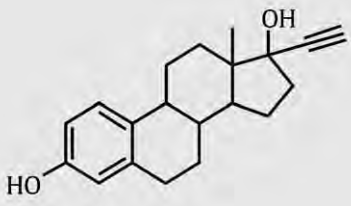
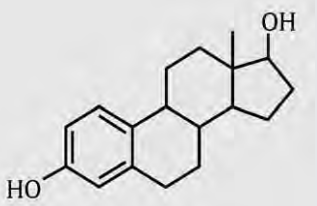
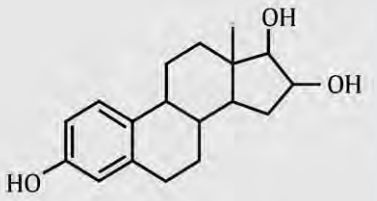
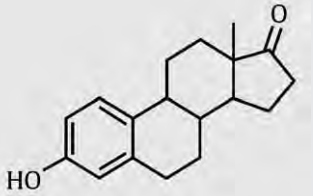
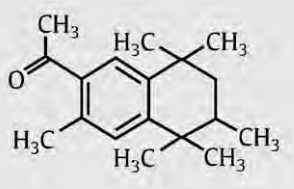
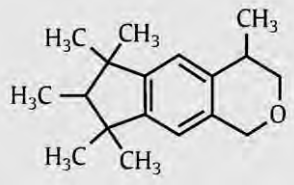
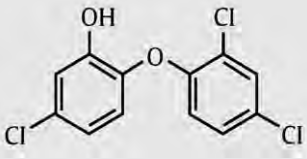
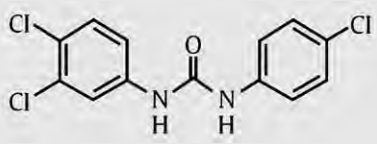
Compound	Chemical structure	Chemical properties
Perfluorochemicals		
Perfluorooctane sulphonate (PFOS)		CAS No: no specific number Formula: $C_8F_{17}SO_3^-$ Log K_{OW}: cannot be determined Vp: 3.31×10^{-4} Pa (20 °C) Half life (soil): unknown/persistent OECD (2002)
Perfluorooctanoic acid (PFOA)		CAS No: 335-67-1 Formula: $C_7F_{15}COOH$ Log K_{OW}: unknown Vp: unknown Half life (soil): unknown/persistent
Quaternary ammonium compounds (QACs)	 R1-4 represent alkyl or aryl substituents	Generalised structure of QACs. High variation in substitution and therefore, chemical properties IPCS (1999)
Steroids		
17 α-ethinyloestradiol		CAS No: 57-63-6 Formula: $C_{20}H_{24}O_2$ Log K_{OW}: 3.67 Vp: 6.0×10^{-9} Pa Half life (soil): a few days Ternes et al. (2002); Lai et al. (2002)
17 β-Oestradiol		CAS No: 50-28-2 Formula: $C_{18}H_{24}O_2$ Log K_{OW}: 4.01 Vp: 3.0×10^{-8} Pa Half life (soil): a few days Ternes et al. (2002); Lai et al. (2002)
Oestriol		CAS No: 5864-38-0 Formula: $C_{18}H_{24}O_2$ Log K_{OW}: 2.81 Vp: 9.0×10^{-13} Pa Half life (soil): a few days Ternes et al. (2002); Lai et al. (2002)
Oestrone		CAS No: 53-16-7 Formula: $C_{18}H_{22}O_2$ Log K_{OW}: 3.13 Vp: 3.0×10^{-8} Pa Half life (soil): a few days Ternes et al. (2002); Lai et al. (2002)

Table 1 (*continued*)

Compound	Chemical structure	Chemical properties
Synthetic musks		
AHTN (Tonalide™)		CAS No: 1506-02-1 Formula: $C_{18}H_{26}O$ Log Kow: 5.7 Vp: 0.0682 Pa Half life (soil): 180 days Balk and Ford (1999a)
HHCB (Galaxolide™)		CAS No: 1222-05-5 Formula: $C_{18}H_{26}O$ Log K_{OW}: 5.9 Vp: 0.0727 Pa Half life (soil): 180 days Balk and Ford (1999a)
Triclosan (TCS)		CAS No: 3380-34-5 Formula: $C_{12}H_7Cl_3O_2$ Log K_{OW}: 4.8 Vp: 0.00069 Pa (25 °C) Half life (soil): 266 days NICNAS (2008); Topp et al. (2008)
Triclocarban (TCC)		CAS No: 101-20-2 Formula: $C_{13}H_9Cl_3N_2O$ Log K_{OW}: 3.5–4.2 (22.6 °C) Vp: <100 Pa Half life (soil): unknown EC (2005); Snyder et al. (2010)

the low ng L^{-1} range (Kloepfer et al., 2004). Degradation rates are reported in days and there are contradictory studies claiming that the dominant removal mechanisms involved are biological (de Wever and Verachtert, 1997) or chemical (Gaja and Knapp, 1998). These compounds have a degree of aquatic toxicity and have also been employed as fungicide, herbicide and anti-algal agents (de Wever and Verachtert, 1997). Not only are there no studies reporting the concentrations of $MBT_{thiazole}$ or OBT in sludge, but there also few studies reporting their environmental distribution (Spies et al., 1987). Only once empirical measurements of $MBT_{thiazole}$ and OBT in sewage sludge have been completed will it be possible to assess whether these chemicals pose a risk to human health and/or the environment when land applying biosolids.

2.3. Bisphenol A

Bisphenol A (2,2-Bis-(4-hydroxyphenyl)propane) is a plasticiser manufactured in high quantities and is used as a monomer for the production of polycarbonate and epoxy resins, unsaturated polyester-

Table 2
Risk assessment evaluation concentrations (mg kg^{-1} dw) of selected pharmaceutical compounds in sludge-amended soil (Eriksen et al., 2009).

Therapeutical group	Drug substance	Predicted environmental concentration (PEC)		Predicted no-effect concentration (PNEC)
		Agricultural soil (60 t ha^{-1})	Park areas	
Alimentary tract and metabolism	Mesalazin	0.98	6.70	12
	Ranitidin	0.04	0.30	5277
Blood and blood forming organs	Dipyridamole	0.03	0.17	–
Cardiovascular system	Sotalol	0.02	0.15	4095
	Metoprolol	0.02	0.13	589
	Losartan	0.03	0.23	–
	Atorvastatin	0.05	0.34	11
Antibacterial drugs	Tetracycline	0.01	0.08	8.8
	Ciprofloxacin	0.04	0.29	26
Muscular–skeletal system	Carisoprodol	0.10	0.68	24368
Nervous system	Gabapentin	0.06	0.39	20460
	Levetiracetam	0.02	0.12	–
	Chlorprothixene	0.02	0.16	–
Respiratory organs	Fexofenadine	0.03	0.17	–

Table 3
Concentrations (mg kg^{-1} dw) of 'emerging' organic contaminants in sewage sludge/biosolids.

Contaminant	Country	Year	n	Mean	Min	Max	Reference
Antibiotics and pharmaceuticals							
4-Epitetracylcine	USA	2009	84	1.14	0.04	4.38	US EPA (2009)
Azithromycin	USA	2009	84	0.83	0.008	5.21	US EPA (2009)
Carbamazepine	USA	2009	84	0.14	0.009	6.03	US EPA (2009)
Cimetidine	USA	2009	84	1.33	0.004	8.33	US EPA (2009)
Ciprofloxacin	Germany	2002	2	2.35	2.27	2.42	Golet et al. (2002)
	Sweden	2005	10	2.5	0.5	4.8	Lindberg et al. (2005)
	USA	2009	84	10.5	0.075	40.8	US EPA (2009)
Diphenhydramine	USA	2009	84	0.871	0.037	5.73	US EPA (2009)
Doxycycline	Sweden	2005	10	1.4	<dl	1.5	Lindberg et al. (2005)
	USA	2009	84	0.877	0.034	5.09	US EPA (2009)
Erthromycin (Total)	USA	2009	84	0.036	0.002	0.18	US EPA (2009)
Fluoxetine	USA	2009	84	0.245	0.010	3.13	US EPA (2009)
Miconazole	USA	2009	84	1.239	0.007	9.21	US EPA (2009)
Norfloxacin	Germany	2002	2	2.25	2.13	2.37	Golet et al. (2002)
	Sweden	2005	10	1.51	0.1	4.2	Lindberg et al. (2005)
Ofloxacin	Sweden	2005	10	0.73	<0.1	2.0	Lindberg et al. (2005)
	USA	2009	84	8.573	0.025	58.10	US EPA (2009)
Tetracycline	USA	2009	84	1.278	0.038	5.27	US EPA (2009)
Bisphenol A							
	Germany	2002	38	*	0.004	1.363	Fromme et al. (2002)
	Germany	2002	18	*	~40	~325	Meesters and Schroder (2002)
	Australia	2007	4	0.089	0.004	0.158	Tan et al. (2007)
	Greece	2007	1	0.62	*	*	Gatidou et al. (2007)
	Greece	2008	1	0.03	*	*	Pothitou and Voutsa (2008)
	Greece	2008	27	0.53	<0.56	1.75	Stasinakis et al. (2008)
	China	2009	2	0.11	0.10	0.13	Nie et al. (2009)
	Overall		91	0.28	0.004	~325	
Organotins							
Monobutyltin (MBT_{tin})	Switzerland	1987	4	3.3	0.2	6	Mueller (1987)
	Switzerland	1991	3	0.78	0.10	0.97	Fent et al. (1991)
	Canada	1992	36	0.02	*	*	Chau et al. (1992)
	Switzerland	1996	25	0.5	*	*	Fent (1996b)
	France	2000	1	0.24	*	*	Bancon-Montigny et al. (2000)
	UK	2004	40	0.71	*	*	Voulvoulis et al. (2004)
	Overall		109	0.93	0.10	6	
Dibutyltin (DBT)	Switzerland	1987	4	5	0.7	7.5	Mueller (1987)
	Switzerland	1987	4	0.98	0.41	1.24	Fent et al. (1991)
	Canada	1991	3	0.04	*	*	Chau et al. (1992)
	Switzerland	1992	36	1.5	*	*	Fent (1996b)
	France	1996	25	0.08	*	*	Bancon-Montigny et al. (2000)
	UK	2004	40	0.06	*	*	Voulvoulis et al. (2004)
	Overall		112	1.28	0.41	7.5	
Tributyltin (TBT)	Switzerland	1987	4	3.5	0.3	6	Mueller (1987)
	Switzerland	1991	3	0.99	0.28	1.51	Fent et al. (1991)
	Canada	1992	36	0.1	*	*	Chau et al. (1992)
	Switzerland	1996	25	1.1	*	*	Fent (1996b)
	France	2000	1	0.05	*	*	Bancon-Montigny et al. (2000)
	Switzerland	2004	24	0.15	0.02	0.65	Plagellat et al. (2004)
	UK	2004	40	0.13	*	*	Voulvoulis et al. (2004)
	Overall		133	0.86	0.02	6	
Triphenyltin (TPhT)	Switzerland	1987	4	2.3	<0.02	9	Mueller (1987)
	Canada	1991	36	0.3	*	*	Chau et al. (1992)
	Switzerland	1992	25	0.5	*	*	Fent (1996b)
	France	1996	1	0.01	*	*	Bancon-Montigny et al. (2000)
	Switzerland	2000	24	0.02	<dl	0.28	Plagellat et al. (2004)
	Overall		90	0.63	<0.02	9	
Phthalate acid esters (PAEs)							
DEHP	Canada	1989	6	65	3	176	Webber and Lesage (1989)
	Germany	2002	15	~67	~28	~154	Fromme et al. (2002)
	Canada	2003	20	2.7	<0.02	11	Bright and Healey (2003)
	Finland	2003	13	95	28	122	Marttinen et al. (2003a)
	Spain	2005	134	67	2	3514	Abad et al. (2005)
	UK	2005	1	62	*	*	Gibson et al. (2005)
	UK	2005	*	30	*	*	Oliver et al. (2005)
	Denmark	2007	*	67	61	78	Roslev et al. (2007)
	Australia	2007	5	11.2	0.26	45.1	Tan et al. (2007)
	Australia	2008	14	17	2	44	Clarke et al. (2008b)
	France	2009	10	72.1	*	*	Dargnat et al. (2009)
	Spain	2009	4	159	13	345	Aparicio et al. (2009)
	USA	2009	84	53	<dl	310	US EPA (2009)
	Overall		306	58	<0.02	3514	

Table 3 (*continued*)

Contaminant	Country	Year	n	Mean	Min	Max	Reference
Polybrominated diphenyl ethers (PBDEs)							
BDE47	Sweden	1992	2	0.015	0.015	0.015	Nylund et al. (1992)
	Sweden	1999	3	0.065	0.036	0.080	Sellstrom et al. (1999)
	USA	2001	11	0.568	0.359	0.754	Hale et al. (2001)
	Netherlands	2003	3	0.020	0.010	0.040	de Boer et al. (2003)
	Spain	2004	6	0.037	0.002	0.050	Fabrellas et al. (2004)
	Germany	2004	8	0.047	0.025	0.088	Hamm (2004)
	USA	2004	1	0.757	*	*	(North, 2004)
	Sweden	2006	50	0.049	0.007	0.100	Law et al. (2006)
	Germany	2007	19	0.052	0.020	0.115	Knoth et al. (2007)
	China	2007	31	0.005	0.0004	0.059	Wang et al. (2007)
	Australia	2008	16	0.126	<0.001	0.410	Clarke et al. (2008c)
	Kuwait	2008	21	0.002	0.0002	0.008	Gevao et al. (2008)
	Antarctica	2008	2	0.776	0.132	1.420	Hale et al. (2008)
	USA	2009	84	0.709	0.073	5.000	US EPA (2009)
	USA	2010	15	0.161	0.128	0.238	Andrade et al. (2010)
	Overall		272	0.226	0.0002	5.000	
BDE99	Sweden	1992	2	0.019	0.019	0.019	Nylund et al. (1992)
	Sweden	1999	3	0.085	0.056	0.100	Sellstrom et al. (1999)
	USA	2001	11	0.661	0.391	1.157	Hale et al. (2001)
	Netherlands	2003	3	0.021	0.011	0.038	de Boer et al. (2003)
	Spain	2004	6	0.037	0.023	0.064	Fabrellas et al. (2004)
	Germany	2004	8	0.070	0.037	0.127	Hamm (2004)
	USA	2004	1	0.940	*	*	North (2004)
	Sweden	2006	50	0.060	0.008	0.150	Law et al. (2006)
	Germany	2007	39	0.057	0.024	0.124	Knoth et al. (2007)
	China	2007	31	0.005	0.003	0.068	Wang et al. (2007)
	Australia	2008	14	0.141	0.0004	0.400	Clarke et al. (2008c)
	Kuwait	2008	21	0.005	0.0004	0.015	Gevao et al. (2008)
	Antarctica	2008	2	0.735	0.200	1.270	Hale et al. (2008)
	USA	2009	84	0.716	0.064	4.000	US EPA (2009)
	USA	2010	15	0.169	0.128	0.245	Andrade et al. (2010)
	Overall		290	0.248	0.0004	4.000	
BDE209	Sweden	1999	3	0.220	0.170	0.270	Sellstrom et al. (1999)
	USA	2001	11	1.370	0.085	4.890	Hale et al. (2001)
	Netherlands	2003	3	0.096	0.009	0.190	de Boer et al. (2003)
	Spain	2004	6	5.968	0.756	18.632	Fabrellas et al. (2004)
	Germany	2004	8	0.326	0.100	0.639	Hamm (2004)
	USA	2004	1	1.183	*	*	North (2004)
	Sweden	2006	50	0.120	0.006	1.000	Law et al. (2006)
	Germany	2007	39	0.442	0.113	1.339	Knoth et al. (2007)
	China	2007	31	0.069	<0.001	1.109	Wang et al. (2007)
	Australia	2008	14	0.705	0.003	3.780	Clarke et al. (2008c)
	Kuwait	2008	21	0.182	0.005	1.596	Gevao et al. (2008)
	Antarctica	2008	2	0.770	0.219	1.320	Hale et al. (2008)
	USA	2009	84	2.180	0.150	17.000	US EPA (2009)
	USA	2010	15	0.920	0.792	1.220	Andrade et al. (2010)
	Overall		288	1.039	0.003	18.632	
ΣPBDEs	USA	2004	1	3.381	*	*	North (2004)
	Germany	2007	39	0.555	0.142	2.491	Knoth et al. (2007)
	China	2007	31	0.094	0.005	1.115	Wang et al. (2007)
	Australia	2008	14	1.137	0.005	4.230	Clarke et al. (2008c)
	Kuwait	2008	21	0.191	0.006	1.600	Gevao et al. (2008)
	Antarctica	2008	2	2.664	0.637	4.690	Hale et al. (2008)
	USA	2010	15	1.496	1.330	1.820	Andrade et al. (2010)
	Overall		123	1.360	0.005	4.690	
Polychlorinated alkanes (PCAs)							
sPCA	Germany	1995	2	56	47	65	Rieger and Ballschmiter (1995)
	UK	2003	14	42	7	200	Stevens et al. (2003)
	Overall		16	49	7	200	
mPCA	UK	2001	9	19.6	1.8	93	Nicholls et al. (2001)
	UK	2003	14	1800	30	9700	Stevens et al. (2003)
	Overall		23	910	1.8	9700	
Polychlorinated napthalenes (PCNs)							
	Sweden	1992	2	0.005	0.003	0.006	Nylund et al. (1992)
	UK	2003	14	0.083	0.050	0.190	Stevens et al. (2003)
	China	2008	8	*	0.001	0.028	Guo et al. (2008)
	Overall		24	0.044	0.001	0.190	
Polydimethylsiloxanes (PDMSs)							
	Japan	1984	1	144	*	*	Watanabe et al. (1984)
	USA	1997	12	1120	122	5155	Fendinger et al. (1997)
	Overall		13	632	122	5155	

(*continued on next page*)

Table 3 (*continued*)

Contaminant	Country	Year	n	Mean	Min	Max	Reference
Perfluorochemicals							
PFOS	USA	2001	12	0.58	0.06	3.12	3M Environmental Laboratory (2001)
	USA	2006	*	0.100	0.081	0.160	Schultz et al. (2006)
	USA	2006	10	0.031	<0.010	0.065	Sinclair and Kannan (2006)
	USA	2007	8	0.073	0.008	0.110	Loganathan et al. (2007)
	Denmark	2008	7	*	0.005	0.074	Bossi et al. (2008)
	Overall		37	0.196	0.005	3.12	
PFOA	USA	2001	5	0.049	0.002	0.244	3M Environmental Laboratory (2001)
	USA	2006	*	<0.003	*	*	Schultz et al. (2006)
	USA	2006	10	0.107	0.018	0.241	Sinclair and Kannan (2006)
	USA	2007	8	0.068	0.0083	0.219	Loganathan et al. (2007)
	Denmark	2008	7	*	0.001	0.020	Bossi et al. (2008)
	Overall		30	0.075	0.001	0.244	
Quaternary ammonium compounds (QACs)							
DTDMAC	Switzerland	1991	5	3670	2570	5870	Fernandez et al. (1996)
	Switzerland	1992	5	960	730	1510	Fernandez et al. (1996)
	Switzerland	1993	5	470	300	570	Fernandez et al. (1996)
	Switzerland	1994	5	210	150	300	Fernandez et al. (1996)
Total QACs	Austria	2007	6	*	22	103	Martìnez-Carballo et al. (2007)
	Overall		26	1328	22	5870	
Steroids							
Beta stigmastanol	USA	2009	84	168	3.44	1330	US EPA (2009)
Campesterol	USA	2009	84	101	2.84	524	US EPA (2009)
Cholestanol	USA	2009	84	680	3.86	4590	US EPA (2009)
Cholesterol	USA	2009	84	1129	2.34	5390	US EPA (2009)
Coprostanol	USA	2009	84	4367	7.72	43700	US EPA (2009)
Epicoprostanol	USA	2009	84	1703	0.87	6030	US EPA (2009)
Stigmasterol	USA	2009	84	321	0.46	569	US EPA (2009)
17α-Ethinyloestradiol	Germany	2002	4	0.005	<0.004	0.017	Ternes et al. (2002)
	China	2009	2	*	<dl	<dl	Nie et al. (2009)
	USA	2009	84	*	<dl	0.355	US EPA (2009)
17β-Oestradiol	Germany	2002	4	0.020	0.005	0.049	Ternes et al. (2002)
	China	2009	2	*	<dl	<dl	Nie et al. (2009)
	USA	2009	84	*	<dl	0.355	US EPA (2009)
Oestriol	China	2009	2	0.010	0.010	0.011	Nie et al. (2009)
	USA	2009	84	*	<dl	0.232	US EPA (2009)
Oestrone	Germany	2002	4	0.027	<0.002	0.037	Ternes et al. (2002)
	China	2009	2	0.016	0.011	0.022	Nie et al. (2009)
	USA	2009	84	*	<dl	0.965	US EPA (2009)
Synthetic musks							
AHTN (tonalid)	Switzerland	2000	12	1.54	0.74	4.16	Herren and Berset (2000)
	Germany	2002	4	3.56	2.52	5.07	Heberer (2002)
	Spain	2003	1	0.052			Llompart et al. (2003)
	UK	2003	14	4.7	0.12	16	Stevens et al. (2003)
	Switzerland	2004	16	7.3	2.5	11.2	Kupper et al. (2004)
	China	2005	3	2.56	0.72	6.20	Zeng et al. (2005)
	Hong Kong	2008	30	5.85	0.475	13.9	Shek et al. (2008)
	Overall		80	3.65	0.12	16	
HHCB (galaxolide)	Switzerland	2000	12	4.85	2.29	12.16	Herren and Berset (2000)
	Germany	2002	4	8.26	6.03	11.45	Heberer (2002)
	Spain	2003	1	0.162			Llompart et al. (2003)
	UK	2003	14	27	1.9	81	Stevens et al. (2003)
	Switzerland	2004	16	20.3	7.4	36.0	Kupper et al. (2004)
	China	2005	3	10.76	5.42	21.21	Zeng et al. (2005)
	Hong Kong	2008	30	27.1	3.58	78.6	Shek et al. (2008)
	Overall		80	14.06	1.9	81	
Triclosan							
	USA	2002	10	4.55	0.53	15.6	McAvoy et al. (2002)
	Germany	2003	20	*	0.40	8.80	Bester (2003)
	Spain	2005	7	2.83	0.42	5.40	Morales et al. (2005)
	Canada	2007	12	3.21	0.62	11.55	Chu and Metcalfe (2007)
	Australia	2007	19	5.58	0.09	16.79	Ying and Kookana (2007)
	Greece	2007	1	1.84	*	*	Gatidou et al. (2007)
	Greece	2008	5	0.46	*	*	Pothitou and Voutsa (2008)
	Greece	2008	27	3.21	0.19	9.85	Stasinakis et al. (2008)
	USA	2009	4	1.87	0.09	7.06	Cha and Cupples (2009)
	USA	2009	84	16.10	0.33	133	US EPA (2009)
	Overall		189	4.41	0.09	133	
Triclocarban							
	USA	2006	3	51	*	*	Heidler et al. (2006)
	Canada	2007	12	4.17	2.17	5.97	Chu and Metcalfe (2007)

Table 3 (*continued*)

Contaminant	Country	Year	n	Mean	Min	Max	Reference
Triclocarban	USA	2007	5	19.3	7.5	25.9	Sapkota et al. (2007)
	USA	2009	4	7.19	4.89	9.28	Cha and Cupples (2009)
	USA	2009	84	39.43	0.19	441	US EPA (2009)
	Overall		108	24.2	0.19	441	

*No data; <dl — less than detection limit.

styrene resins and flame retardants (Staples et al., 1998). The final products are used as coatings on cans, as powder paints, as additives in thermal paper, in dental fillings and as antioxidants in plastics (Staples et al., 1998). Release into the environment is possible during manufacturing processes and by leaching from final products (Fromme et al., 2002). Bisphenol A has been shown to be weakly oestrogenic and to possess some anti-androgenic activity (Sohoni and Sumpter, 1998). However, the relative potency ranges are approximately 1×10^{-6} to 5×10^{-7} times less than 17β-oestradiol (Harris et al., 1997). Based on *in vitro* receptor-interaction studies, the oestrogenic activity was estimated to be 2×10^{-3} fold lower than for oestradiol. Bisphenol A has been implicated as an endocrine disrupting chemical and laboratory studies (using mice) indicate that development problems can be associated with environmentally relevant exposure (Newbold et al., 2009). The chemical structure of bisphenol A is given in Table 1.

Bisphenol A is regularly detected in surface waters primarily because it is continuously released into the environment (Heemken et al., 2001; Fromme et al., 2002; Oehlmann et al., 2008) and not because it is environmentally persistent (Dorn et al., 1987). While there is no direct evidence to confirm a detrimental causal link from exposure to bisphenol A (human or environmental) concern exists about this compound due to reports of adverse reproductive and developmental effects in wildlife that are possibly mediated *via* endocrine disruptive pathways (Fürhacker et al., 2000; Vandenberg et al., 2007; Oehlmann et al., 2008; Newbold et al., 2009).

Bisphenol A is widely used in households and industry, therefore, it can be expected to be present in raw sewage (Fürhacker et al., 2000). A German study identified that the paper industry was the major contributor of bisphenol A in wastewater (Fürhacker et al., 2000). WWTP mass balance studies have detected bisphenol A in raw water, sewage sludge and effluents (Meesters and Schroder, 2002). Significant reductions (up to 99%) during wastewater treatment have been reported (Fürhacker et al., 2000; Tan et al., 2007) and biodegradation is thought to be the principal removal mechanism (Pothitou and Voutsa, 2008).

There is a large variation in reported bisphenol A concentrations in sludges internationally, with values ranging from low μg kg^{-1} dw (Fromme et al., 2002; Gatidou et al., 2007; Tan et al., 2007; Pothitou and Voutsa, 2008; Nie et al., 2009) to mid mg kg^{-1} dw (Meesters and Schroder, 2002). Bisphenol A is a bulk chemical manufactured in similar quantities to phthalates acid esters (PAEs), however, concentrations of bisphenol A are two orders of magnitude smaller in sludge than PAEs. This suggests that bisphenol A is considerably more degradable during wastewater and sludge treatment compared to phthalates. Similarly, bisphenol A is reported to rapidly dissipate in soil and has an estimated half-life of <3 days (Fent et al., 2003). A study of the toxic effects of bisphenol A to soil isopods has been reported, however, the concentrations used (10–300 mg kg^{-1} dw) were far higher than environmentally relevant values and the toxicity was associated with the delivery solvent rather than bisphenol A solely (Lemos et al., 2009). Few studies have examined the ecotoxicological effects of bisphenol A in soil and this requires further attention. Studies are also required to more accurately determine the concentrations of bisphenol A in sludge. Nevertheless, the concentrations of bisphenol A reported in sludge are not high and, coupled with its rapid biodegradation during wastewater treatment, this compound is unlikely to pose an issue when land applying biosolids. Bisphenol A is under review for possible identification as a European Water Framework Directive (WFD) Priority Substance or Priority Hazardous Substance (PHS) to control emission sources (EPCEU, 2008). While evidence is indicating that bisphenol A is an endocrine disrupting chemical (Li et al., 2009; Newbold et al., 2009) that can be found in the human body (Lee et al., 2008), exposure primarily occurs in the domestic environment and via direct ingestion (Vandenberg et al., 2007). Transfer to humans from biosolids-amended soil, by contrast, is extremely unlikely since there is little evidence that bisphenol A is environmentally persistent or bioaccumulates via food-chain mediated pathways.

2.4. Organotins (OTs)

Organotin compounds (OTs) have been used since the 1960s for industrial and agricultural purposes viz., polyvinyl chloride (PVC) stabilisers, fungicides, bactericides, insecticides, industrial catalysts and wood preservatives (Hoch, 2001). This includes the use of monobutyltin (MBT_{tin}) and dibutyltin (DBT) as heat and light stabilisers in PVC processing, the use of tributyltin (TBT) in antifouling formulations and as a general-purpose wood preservative, as well as the use of triphenyltins (TPhT) in agriculture. The use of TBT as an antifouling agent for ship hulls and as a general wood preservative has ceased in the UK and internationally because of high toxicity in aquatic ecosystems (Alzieu, 1991; Fent, 1996a; Voulvoulis et al., 2004).

Mass balances for OTs in WWTP demonstrate that they are effectively removed during wastewater treatment and are concentrated in the sludge. Reported removal rates of MBT_{tin}, DBT and TBT are 95%, 84% and 86%, respectively (Voulvoulis et al., 2004). OT concentrations in wastewater show diurnal fluctuations, however there is no explanation for this apparent behaviour (Voulvoulis et al., 2004).

There is contradictory evidence from laboratory studies concerning the biodegradation of TBT and TPhT by the activated sludge process. For example, Stasinakis et al. (2005) showed these compounds were degraded by biological wastewater treatment, whereas Voulvoulis and Lester (2006) found minimal degradation. In a laboratory study, 50% of TBT and 20% of TPhT applied to soil in biosolids remained in the soil after 2 months (Marcic et al., 2006). The biodegradability of OTs in soil is also reported to decline with increasing substitution (Heroult et al., 2008).

The concentration of OT compounds in sewage sludge (Table 3) has been reported from Switzerland (Mueller, 1987; Fent and Mueller, 1991; Fent, 1996b), Canada (Chau et al., 1992), France (Bancon-Montigny et al., 2000) and the UK (Voulvoulis et al., 2004; Voulvoulis and Lester, 2006). There is no consistent trend in the concentration data, however, values for the main OTs rarely exceed 1 mg kg^{-1} dw in contemporary sludge samples, which may reflect the declining use of these compounds (Table 3).

2.5. Phthalate acid esters (PAEs)

Phthalate acid esters (PAEs) have been in use for over 50 years, mainly in the manufacture of resins and plastics such as PVC (Fromme et al., 2002). PAEs are also used in other non-PVC applications such as paints, rubber products, adhesives and some cosmetics. PAEs soften plastic resins without chemically binding with them and as a consequence leach from plastic products into the surrounding environment. The PAE content of plastic generally ranges from 20 to 40%, but in

some cases is as high as 55% (Fatoki and Vernon, 1990). The most common PAE is di(2-ethylhexyl)phthalate (DEHP) and approximately 95% of DEHP production is directed towards plasticizer use, particularly in PVC products such as tubing and medical device components. The chemical structure and properties of DEHP are given in Table 1. Recently, use of DEHP has declined to an extent, due to concerns that it may disrupt endocrine systems, and the use of other phthalate plasticizers has increased, in particular diisononyl phthalate (DINP) and diisodecyl phthalate (DIDP), which may, in fact be more environmentally persistent (Cadogan, 2002). There is contradictory information published regarding the impact and significance of phthalates for human health and the environment. A recent Chinese study found that significant contamination of the aerial components of vegetable plants occurred from a plastic based mulch with a DEHP concentration of 16.5% (Du et al., 2009). The results of this study appear contrary to currently accepted models of organic pollutants movement into plants (Briggs et al., 1982; Travis and Arms, 1988) and other experimental investigations that show there is minimal uptake of DEHP by crop plants (Schmitzer et al., 1988; Yin et al., 2003). Given that Du et al. (2009) report that the DEHP concentration was smaller in the roots of the plant it is possible that volatilisation or direct contamination might have played a significant role in the accumulation of DEHP in leaves and stems in this case. However, evidence from biosolids-amended systems indicates the minimal uptake of DEHP into plants (Aranda et al., 1989). In contrast to the apparent uptake of DEHP by vegetables from plastic in direct contact with the soil and crop, the sorption of DEHP onto the sludge matrix may thus control its bioavailability preventing movement and transfer into crops. Nevertheless, further research is warranted to clarify the bioavailability of DEHP to plants and whether contamination of aerial plant components can occur from contaminated soil. There is no reported evidence that DEHP has a negative impact upon the soil ecosystem (Kirchmann et al., 1991; Cartwright et al., 2000; Jensen et al., 2001).

PAEs are not environmentally persistent and are readily degraded in soils and sewage sludge under both aerobic and anaerobic conditions (Keyser et al., 1976; Walker et al., 1984; Shanker et al., 1985; Group, 1986; Staples et al., 1997). They are readily metabolised and do not accumulate in mammals even when fed artificially in diets high in PAEs (Giam et al., 1984). Organisms ingesting high doses of PAEs were quickly able to remove phthalate compounds from their body tissues once the chemical was excluded from the feed (Giam et al., 1984).

Only a relatively small number of international studies were found reporting PAE concentrations in sewage sludge. It may be expected that PAEs would increase in sewage sludge and the environment generally in proportion to their use within society, however, there is no evidence indicating that this is the case. The concentration of PAEs in sludge is reported from Canada (Webber and Lesage, 1989; Bright and Healey, 2003), Germany (Fromme et al., 2002), Finland (Marttinen et al., 2003a,b), Spain (Abad et al., 2005), the UK (Gibson et al., 2005; Oliver et al., 2005), Australia (Tan et al., 2007; Clarke et al., 2008b) and the USA (US EPA, 2009). A summary of DEHP concentration data is compiled in Table 3.

Abad et al. (2005) reported the concentration of DEHP in Spanish sewage sludge (n = 139) over a number of years and for different WWTPs (n = 20). The concentration of DEHP was highly variable ranging from 1.5 to 3513.8 mg kg^{-1} dw. DEHP concentrations varied from 18.4 → 16.9 → 76.8 → 3513.8 → 157.4 → 11.4 mg kg^{-1} dw over a two-year period at one WWTP demonstrating the high variability in the DEHP content of sewage sludge. Nevertheless, the DEHP concentration was typically between 10 and 50 mg kg^{-1} dw (Abad et al., 2005) and was consistent with other survey data for DEHP in sewage sludge (Marttinen et al., 2004; Bago et al., 2005; Gibson et al., 2005; Oliver et al., 2005).

PAEs are well known to degrade during wastewater treatment and degradation under both aerobic and anaerobic conditions increases with water solubility (Shelton et al., 1984; Ziogou et al., 1989; Jianlong et al., 2000; Fauser et al., 2003; Marttinen et al., 2004; Amir et al., 2005). PAEs characteristically have high log K_{ow} values >4 and therefore partition strongly to the sewage sludge during wastewater treatment (Table 1). They are rapidly degraded by aerobic sludge treatment processes, such as composting (Cheng et al., 2008; Pakou et al., 2009), but reported removals by anaerobic digestion vary from no observed anaerobic biodegradation up to 23–61% removal of DEHP in digested sludge (Fountoulakis et al., 2006). Consequently DEHP is typically present in sewage sludge from the low mg kg^{-1} to <200 mg kg^{-1} dw range (Table 3).

2.6. Polybrominated diphenyl ethers (PBDEs)

PBDEs are a class of brominated fire retardants (BFRs) that were used in plastics, textiles, electronic circuitry, and other materials. There are 209 PBDE congeners and they are numbered according to the IUPAC system for PCBs (Ballscmitter and Zell, 1980). PBDEs were sold in three commercial formulations; each named for the prominent homologue in the mixture viz., pentaBDE (BDE 47, 99, 100, 153, 154), octaBDE (BDE 183), and decaBDE (BDE 209) (Sjödin et al., 1998). Despite the commercial formulation names each contains many BDE congeners (BSEF, 2005). PBDEs have low vapour pressures ($4.69\times10^{-5} - 6.59\times10^{-6}$ Pa) and are highly lipophilic (log K_{ow} values of 5.9–10) (IPCS, 1994; Braekevelt et al., 2003). Due to the potential threat to human health and the environment, PBDEs (specifically pentaBDE and octaBDE) were listed as United Nations Environment Programme (UNEP) Persistent Organic Pollutants (POPs) in 2008 (UNEP, 2001; UNEP, 2009).

Assessment of health risks associated with human exposure and accumulation of PBDEs is complicated and has not been adequately characterized. However, the potential risks associated with exposure to the most bioactive congeners (tri- to octa-BDE) include thyroid hormone disruption, neuro-developmental defects and cancer. Several studies have shown that PBDEs share similar general properties to organo-halogenated compounds as *in vivo* exposure of rodents resulted in reduction of serum total and free thyroid hormone (thyroxine T4) levels (Darnerud et al., 2001; McDonald, 2002). Altered thyroid hormone function, particularly during development, is profound and has been hypothesized to lead to disrupted brain development and permanent neurological damage (Legler and Brouwer, 2003).

PBDEs are routinely detected in sewage sludge in the low mg kg^{-1} dw range (Table 3) and values have been reported from Sweden (Nylund et al., 1992; Sellstrom et al., 1999; Law et al., 2006), USA (de Carlo, 1979; Hale et al., 2001; North, 2004), Germany (Knoth et al., 2007), The Netherlands (de Boer et al., 2003), China (Wang et al., 2007), Australia (Clarke et al., 2008c), Kuwait (Gevao et al., 2008) and Antarctica (Hale et al., 2008).

Three congeners account for the majority of ΣPBDEs in sewage sludge and include: BDE47, 99 (pentaBDE) and BDE209 (decaBDE); the concentrations of these congeners are summarised in Table 3. PBDE congeners representative of the pentaBDE (BDE47, 99, 100, 153, 154) formulations are often present at similar concentrations regardless of the catchment type indicating domestic origin (Hale et al., 2001; Hale et al., 2008). The primary congener of the decaBDE formulation, BDE209, is consistently detected in the highest concentrations in sewage sludge and, in national surveys, its concentrations are also highly variable, suggesting important industrial inputs (Clarke et al., 2008c). Trace PBDE amounts (ng L^{-1}) have also been detected in treated effluent (de Boer et al., 2000; Hamm, 2004; North, 2004; Knoth et al., 2007) and recent studies have demonstrated this as a point source of environmental PBDE contamination (Toms et al., 2006; Toms et al., 2008). The contamination of sludges and effluents with PBDEs could therefore have potential implications for disposal and beneficial reuse strategies. However, action has been taken in Europe to significantly restrict the use of pentaBDE and octaBDE and the placing on the market of articles containing one or both of these

substances taking effect from 15 August 2004 (EPCEU, 2003). PentaBDE is also a WFD PHS (EPCEU, 2001). Therefore, emissions to wastewater and presence in sludge are expected to decrease through source controls thus reducing the significance of these compounds for agricultural recycling of biosolids.

2.7. Polychlorinated alkanes (PCAs)

Technical mixtures of polychlorinated alkanes (PCAs), often referred to as chlorinated paraffins (CPs), are a class of industrial chemicals comprising of chlorinated straight-chain hydrocarbons. They have been produced since the 1930s for use as extreme pressure lubricant additives, plasticizers, flame retardants, and paint additives (IPCS, 1996). World production of PCAs was estimated to be 300,000 t in 1985 (IPCS, 1996) and a similar amount was produced in 2009 (Eurochlor, 2009). They are manufactured in the European Union, North America, South Africa, Australia, India, China, Taiwan and Japan (Eurochlor, 2009). Following their widespread and unrestricted use, PCAs are now present in a range of environmental compartments (Campbell and McConnell, 1980). They have been detected in human milk (Thomas et al., 2006), environmental samples (Campbell and McConnell, 1980; Bayen et al., 2006) and in air over the UK, including remote regions (Peters et al., 2000). The International Agency for Research into Cancer (IARC) has classified PCAs as Class 2B "possibly carcinogenic to humans" (IARC, 1998).

PCAs are chlorinated linear chain alkanes with the general formula $C_xH_{(2x+2)-y}Cl_y$. They are produced from the n-alkane fractions derived from petroleum distillation by chlorination, with the degree of chlorination ranging between 30% and 72% by weight (IPCS, 1996). They are divided into three groups: short-chain PCAs (noted as sPCAs or SCCPs) comprising 10 to 13 carbon atoms, medium-chain PCAs (mPCAs or MCCPs) comprising 14 to 17 carbon atoms and long-chain PCAs (lPCAs or LCCPs) with 18 or more carbon atoms. PCAs are viscous liquid or yellowish dense oils, except for some lPCAs (C20- to C30- with a chlorine content of >70%) which are solid and are practically insoluble in water (IPCS, 1996). There are many possible positions for the chlorine atoms and presence of chiral carbon atoms lead to a large number of potential positional isomers, enantiomers and diastereoisomers. PCAs therefore represent a difficult analytical problem because of the complexity inherent in industrial mixtures. The total number of possible congeners is unknown, but far exceeds 10,000 (Eljarrat and Barceló, 2006).

Reports of PCA concentrations in sewage sludge samples are very limited in the literature (Table 3). In the early 1990s sPCAs were measured in two German sludge samples from an industrial area, which contained 65 and 47 mg kg^{-1} dw of sPCAs (Rieger and Ballschmiter, 1995). Concentrations of mPCAs in samples of digested sludge (n = 9) from the UK were in the range 1.8 to 93 mg kg^{-1} dw (Nicholls et al., 2001). In another UK survey (n = 14), sPCAs and mPCAs concentrations were between 7–200 mg kg^{-1} dw and 30–9700 mg kg^{-1} dw, respectively (Stevens et al., 2003). Comparison of data from the limited amount of information available is difficult.

sPCAs are an identified WFD PHS and are therefore subject to controls that should ultimately lead to the cessation or phasing out of discharges, emissions and losses to the environment (EPCEU, 2001). Nevertheless, concentrations of PCAs reported in sludge remain significantly higher than the regulated PCBs, which are typically <1 mg kg^{-1} dw in sludge.

A preliminary human health exposure assessment, comparing the ratio of the PCA contaminant concentration in biosolids to the tolerable daily intake of 100 μg kg^{-1} day^{-1}, demonstrated that PCAs could potentially represent a risk to human health from worse case exposure by the direct ingestion pathway for biosolids (IPCS, 1996). The mean concentration in UK sludge was used for the calculations (1800 mg kg^{-1} dw from Stevens et al., 2003). Thus, the direct ingestion of 100 mg day^{-1} of sludge (US EPA, 1997) by a child with a body weight of 15 kg would contribute 12% of the child's tolerable daily intake of PCAs. By contrast, a 15 kg child suffering from the pica medical condition (deliberate ingestion of soil) is assumed to ingest 10 g of soil per day (US EPA, 1997) and would therefore be exposed to 514% of their tolerable daily exposure to PCAs. The concentrations of PCAs in sewage sludge, evidence of accumulation in human and environmental biota, as well as toxicity data indicate that further research is necessary to assess the risk to human health and the environment from the industrial use of this chemical group.

2.8. Polychlorinated naphthalenes (PCNs)

Technical mixtures of PCNs have been used since the early 1900s as dielectric fluids, engine oil additives, electroplating masking compounds, wood preservatives, lubricants, and for dye production (Falandysz, 1998). The historical use of PCNs precedes PCBs, however their applications are similar. They are also structurally similar and have similar physico-chemical properties. There are 75 PCN congeners, substituted with one to eight chlorine atoms per naphthalene molecule (Table 1). They were voluntarily phased out in the 1970s in the USA, but global production of PCN mixtures was estimated to be approximately 150,000 t in the 1990s (Falandysz, 1998).

PCNs are ubiquitous environmental contaminants sharing many of the characteristics of UNEP POPs (Alcock and Jones, 1999): bioaccumulation (Falandysz, 1998), toxicity (Blankenship et al., 2000), long-range atmospheric transport (Harner et al., 1998) and environmental persistence. Several PCN congeners exhibit dioxin-like toxicity and have been assigned TEF values similar to the coplanar PCBs (Blankenship et al., 2000; Villeneuve et al., 2000). There are three known main sources of PCNs in the environment: technical PCN formulations, technical PCB formulations, and thermal (e.g. combustion, roasting, metal reclamation) and other processes (e.g. chloro-alkali industry) in the presence of chlorine (Falandysz, 1998).

Very limited data on PCN concentrations in sludge was found in the literature (Table 3), with reports from Sweden (Nylund et al., 1992), the UK (Stevens et al., 2003) and recently, China (Guo et al., 2008). In the early 1990s, the ΣPCN (9 congeners) concentration in sewage sludge from Sweden ranged between 3.2 and 5.9 μg kg^{-1} dw (Nylund et al., 1992). Slightly higher concentrations were reported in the UK where the mean ΣPCN value was 83 μg kg^{-1} dw and range was 50 to 190 μg kg^{-1} dw (Stevens et al., 2003). Total PCN concentrations in sludge samples from eight Chinese WWTPs, measured for >70 of the 75 PCN congeners, were between 1.48 and 21.21 μg kg^{-1} dw, and the 'dioxin' toxicity equivalent (TEQ) was in the range 0.11–2.45 ng WHO_{05} kg^{-1} dw (Guo et al., 2008). This contribution of dioxin-like PCNs is not high when compared to recently reported dioxin-like compound concentrations in English and European sludges (Stevens et al., 2001).

2.9. Polydimethylsiloxanes (PDMSs)

Polydimethylsiloxanes (PDMSs) are man-made organosilicone compounds that range from low molecular weight volatile materials to high molecular weight polymeric substances (Fendinger et al., 1997). They are widely used in industrial applications and consumer products, such as textile treatments, household and personal care products and antifoams for food processing or WWTP (Griessbach and Lehmann, 1999). These applications all result in discharges to WWTP and the potential to enter the environment as a component of effluents and in sewage sludge (Fendinger et al., 1997). PDMSs have been detected in environmental samples such as surface water, sediments and fish tissue (Watanabe et al., 1984, 1988). PDMSs have low ecological toxicity, which occurs at higher concentrations than those observed in the environment (Hobbs et al., 1975), and are not considered to pose an ecologically significant threat (Frye, 1988).

PDMSs have a very low water solubility and are primarily removed by sorption to solids during wastewater treatment (Varaprath et al., 1996; Fendinger et al., 1997). At least 94% of PDMSs are unchanged during wastewater treatment because of high chemical and thermal stabilities (Watts et al., 1995; Fendinger et al., 1997). PDMSs are not toxic to wastewater microbial communities and do not affect treatment performance (Watts et al., 1995). PDMSs not removed on the sludge solids are present in wastewater treatment effluent as a component of the suspended solids (Fendinger et al., 1997) and this accounts for their environmental distribution in sediments and surface waters (Watanabe et al., 1988).

PDMSs degrade in the soil environment as a result of abiotic processes rather than biodegradation, and have a half-life estimated to range from 4 to 28 days (Carpenter et al., 1995; Lehmann and Miller, 1996; Lehmann et al., 1998; Griessbach and Lehmann, 1999). Increased soil moisture retards the degradation of PDMSs in soil (Griessbach and Lehmann, 1999). Clays appear to be the component responsible for catalysing oligomerization and hydrolysis reactions of PDMSs in soil (Buch and Ingebrigtson, 1979; Xu et al., 1998). A multiyear field dissipation study and laboratory studies, to evaluate the persistence or degradation of PDMSs in biosolids-amended soils, found that soil moisture was the factor controlling the persistence or degradation of PDMSs and that there was no direct effect of biosolids on PDMS persistence or degradation (Traina et al., 2002). As may be expected, the half-life for PDMS determined under field conditions (876 to 1443 days) was longer than that estimated in laboratory studies and this was attributed to the higher moisture contents of the field soils (Traina et al., 2002). PDMSs eventually mineralise in soil to carbon dioxide and silicic acid (Stevens, 1998). A study examining the ecotoxicity of PDMS found no effects on seed germination, seed survival, plant yields or soil microorganisms (Tolle et al., 1995).

Few studies have reported the concentrations of PDMSs present in sewage sludge (Table 3). The most comprehensive study available (Fendinger et al., 1997) indicated PDMS concentrations in US sludges were in the range 290 and 5155 mg kg^{-1} dw with a mean value of 1120 mg kg^{-1} dw. This is approaching a magnitude higher than the concentration (144 mg kg^{-1} dw) reported in a Japanese sludge (Watanabe et al., 1984). Further work would appear to be necessary to determine the concentrations of PDMSs in sewage sludges internationally.

2.10. Perfluorochemicals (PFCs)

Perfluorochemicals (PFCs) are a family of anthropogenic chemicals that have been used since the late 1950s to make products resistant to heat, oil, stains, grease and water. Common applications include non-stick cookware, breathable membranes for clothing, stain-resistant carpets and fabrics, components of fire fighting foam, surfactants and other industrial applications (US EPA, 2008). They have been used in many industry sectors, including the aerospace, automotive, building/construction, chemical processing, electronics, semiconductors, and textile industries (US EPA, 2008).

PFCs are persistent and widely dispersed in the environment (Giesy and Kannan, 2001; Kannan et al., 2001). Accumulation of PFCs has been detected in ocean animals, such as birds and mammals, and in human tissues throughout the world (Olsen et al., 2003; Kannan et al., 2004). The human and environmental toxicological response to such exposure is not known, but could include endocrine disruption (Lau et al., 2004).

The chemical structures of PFCs make them very resistant to degradation in the environment; the carbon–fluorine bonds are extremely strong and are stronger relative to other commonly used halogens viz., bromine and chlorine. Consequently, perfluorocarbon chains do not readily biodegrade and any biodegradation may be limited to attached hydrocarbon moieties. The two most common groups of PFCs that are measured and detected in environmental matrices are:

- Perfluoroalkyl sulphonates (PFASs) — perfluorooctane sulphonate (PFOS), perfluorohexane sulphonate (PFHxS), perfluorooctane sulphonamide (PFOSA)
- Perfluoroalkyl carboxylates (PFACs) — perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnDA), perfluorododecanoic acid (PFDoDA)

PFASs and PFACs are synthetic chemicals that do not occur naturally in the environment (US EPA, 2008). They are employed as a base chemical in the preparation of fluoropolymers and upon degradation can release the environmentally persistent monomers (Boulanger et al., 2005).

Directive 2006/122/EC (EPCEU, 2006) places restrictions on the marketing and use of PFOS and there are also voluntary reductions on PFOA although it is still manufactured. PFOS is also under review for possible identification as a WFD Priority Substance or PHS (EPCEU, 2008). The EU is currently assessing PFOA and, whilst there are no restrictions in place in the EU at present, a ban could be imposed in the future. However, these substances have been extensively used in the built environment and therefore could represent a significant, long-term diffuse input into wastewater and sludge.

The earliest available report of PFCs in sewage sludge is a study of sludges collected from six USA cities (3M Environmental Laboratory, 2001). PFOS and PFOA were the most common PFCs present and were detected in all samples analysed at the low μg kg^{-1} dw range (Table 3). A sludge sample was tested from a WWTP serving a fluorochemical manufacturer and this correlated with substantial increases in PFOS (2980 μg kg^{-1} dw) and PFOA (173 μg kg^{-1} dw) concentrations. This study demonstrated that PFCs, in particular PFOS and PFOA, are likely to be present in sludge in Western countries where PFCs are manufactured and used. Domestic sources are also likely to be a major contributor of PFCs in sewage sludge.

Other studies in the USA (Schultz et al., 2006; Sinclair and Kannan, 2006; Loganathan et al., 2007) and Europe (Bossi et al., 2008) report similar concentration ranges. No differences in PFC levels were apparent in sludges from urban and rural WWTPs, however, major seasonal variations in concentrations were observed (Loganathan et al., 2007). Whilst PFCs have been investigated at WWTPs in other countries (Alzaga and Bayona, 2004; Boulanger et al., 2005), sewage sludge concentrations have mainly been reported in the US. This is largely a consequence of the analytical difficulties associated with quantification of PFCs in sewage sludge matrices.

Mass balance studies of PFCs at WWTP commonly report higher mass loadings of PFOA and PFOS in WWTP effluent compared to raw influent (Schultz et al., 2006; Sinclair and Kannan, 2006; Loganathan et al., 2007). This suggests the degradation of other fluorinated organic compounds (i.e. fluoropolymers) into PFOA and PFOS may take place during wastewater treatment (Loganathan et al., 2007).

Field investigations have demonstrated that PFCs in sludge-amended soil can be mobilised by rainfall (Gottschall et al., 2010).

2.11. Quaternary ammonium compounds (QACs)

Quaternary ammonium compounds (QACs) are cationic surfactants. The molecules contain at least one hydrophobic hydrocarbon alkyl chain linked to a positively charged nitrogen atom. The other alkyl groups are typically short-chain substituents such as methyl or benzyl groups. Cationic surfactants are positively charged in aqueous solutions (Madsen et al., 2001; Ying, 2006). QACs are commonly used in domestic products such as fabric softeners, hair conditioners and other hair preparations. Other applications of cationic surfactants include disinfectants and biocides, emulsifiers, wetting agents, and processing additives. By volume, the most important cationic surfactants in household products are the alkyl ester ammonium salts that are used in fabric softeners (Madsen et al., 2001).

Ditallow dimethyl ammonium chloride (DTDMAC) was the most widely used active ingredient in fabric softeners. However DTDMAC is toxic to aquatic organisms (Roghair et al., 1992; Versteeg et al., 1992) and was therefore voluntarily phased out by industry following an ecological risk assessment (van Leeuwen et al., 1992) in preference of more biodegradable QACs, such as diethyl ester dimethyl ammonium chloride (DEEDMAC) (Giolando et al., 1995). Fernandez et al. (1996) monitored the DTDMAC concentrations in sewage sludge in Switzerland, which declined from 3.67 g kg^{-1} dw in 1991 to 0.21 g kg^{-1} dw in 1994 due to its replacement with the alternative QACs.

Domestic use of QACs is the primary source of these compounds entering WWTPs. Due to their positive charge, cationic surfactants sorb strongly to the negatively charged surfaces of sludge, soil and sediments (Madsen et al., 2001; Ying, 2006; Clara et al., 2007), and it is estimated that ~90% of QACs associate with sludge during wastewater treatment (van Leeuwen et al., 1992). Removal of QACs in wastewater treatment can also be attributed to biodegradation (Nishiyama et al., 1995), where degradation rates are typically reported in days or hours (Giolando et al., 1995; Sütterlin et al., 2008). WWTP discharges can result in environmental contamination of marine sediments with QACs (Li and Brownawell, 2009).

There are very few reports of QAC concentrations in sludge in the scientific peer-reviewed literature (Table 3). A recent study from Austria reported that the total QAC concentration was in the range 22 to 103 mg kg^{-1} dw (MartÌnez-Carballo et al., 2007), suggesting further substantial reductions in QACs have taken place compared to earlier work addressing the impact of phasing out DTDMAC (Fernandez et al., 1996).

It has been controversially argued that QACs have biocidal properties that may confer antibiotic resistance to bacteria (Gaze et al., 2005; Gaze, 2008). However, it is difficult to reconcile this firstly because QACs are not disinfectants, but are in fact surfactants with low toxicity and ecotoxicity (Giolando et al., 1995). Secondly, modern QAC formulations are designed to rapidly biodegrade during wastewater treatment and anaerobic digestion, and are almost completely removed by these processes (Giolando et al., 1995). In soil QACs rapidly degrade with short half-lives (17–40 d) (Giolando et al., 1995).

2.12. Steroids

Natural endogenous (17β-oestradiol, oestrone, oestriol) and synthetic steroids (17α-ethinyloestradiol, mestranol) are excreted by humans and WWTP effluent is the primary source of synthetic steroids entering the environment (Snyder et al., 2001). Livestock (particularly lactating cows) are also a major source of endogenous oestrogen inputs to soil (Kolodziej et al., 2004). Over 99% of oestrogenic activity in sewage effluents and surface waters may be attributable to the presence of 17β-oestradiol (E2) and 17α-ethinyloestradiol (EE2) at concentrations in the ng L^{-1} range (Snyder et al., 2001). Oestrogenic activity in WWTP effluents has resulted in adverse effects on environmental biota (Jobling et al., 1998). Natural and synthetic steroids are excreted from the human body as inactive polar conjugates, but are present in sewage influent and effluent as free, active steroids (Belfroid et al., 1999). Once released from the body conjugated oestrogens undergo chemical or enzymatic dissociation in bacterial sludge and re-form as active oestrogens (Belfroid et al., 1999; Reddy et al., 2005).

Several investigations have examined the fate of oestrogens in WWTPs, however, few studies have measured the concentrations of oestrogenic compounds in sludge due to the analytical difficulties involved (Gomes et al., 2004). The presence of 'free' oestrogens in WWTP effluents and receiving waters is commonly reported (Shore et al., 1993; Desbrow et al., 1998; Ternes et al., 1999b), demonstrating that the conversion of oestrogen metabolites into active forms occurs somewhere between the domestic discharge and WWTP outlet. However, the degradation of all steroid-like compounds (natural and synthetic) occurs rapidly and typically within a few days or less (Ternes et al., 1999a; Korner et al., 2000; Layton et al., 2000; Hashimoto and Murakami, 2009). Natural oestrogens biodegrade in the order: 17β-oestradiol → oestrone → oestriol and at a faster rate compared to synthetic mestranol and 17α-ethinyloestradiol (Ternes et al., 1999a). Research at full-scale WWTPs indicates that operational retention times may only allow partial degradation as concentrations of oestrone measured in treated effluent are frequently increased compared to the influent raw wastewater (Barontri et al., 2000).

Mass balance studies of WWTPs consistently show high removal rates of oestrogens during wastewater treatment, equivalent to: 64–99.9% for 17β-oestradiol, and 78–83% for oestrone and 17α-ethinyloestradiol (Ternes et al., 1999b). While many studies do not distinguish between degradation and sludge partitioning (Schlusener and Bester, 2008), laboratory experiments indicate the high biodegradability of steroids (Ternes et al., 1999a). Such laboratory studies indicate that degradation processes contribute significantly to steroid removal (Ternes et al., 1999a). The removal rate of the natural hormones 17β-oestradiol, oestrone and 17α-ethinyloestradiol during wastewater treatment was >90% and only 5% of the mass of oestrogens entering the WWTP was sorbed to the final digested sewage sludge, indicating high biodegradability in the WWTP (Andersen et al., 2003).

Few studies have reported steroid concentrations in sewage sludge due to analytical difficulties, as well as high degradation rates. The concentrations of oestrone (<2–37 μg kg^{-1} dw), 17β-oestradiol (5–49 μg kg^{-1} dw), 17α-ethinyloestradiol (<4–17 μg kg^{-1} dw) and mestranol (<2 μg kg^{-1} dw) were measured by Ternes et al. (2002) in German sludges (Table 3). A recent survey of US sludges (n = 84) quantified 25 steroids (US EPA, 2009), but only three steroid compounds (i.e., campesterol, cholestanol, and coprostanol) were found (US EPA, 2009). 17α-ethinyloestradiol was not detected in any sample and five hormones were found in fewer than six samples. Other oestrogenic steroids were not frequently detected and when detected were in the low μg kg^{-1} dw concentration range (US EPA, 2009).

These low concentrations, combined with fast biodegradation rates in WWTP mass balance and laboratory studies suggest that steroids are unlikely to pose a risk to human health or the environment when land applying biosolids.

2.13. Synthetic musks

Synthetic musks are inexpensive substitutes for natural musks and have been used since the 1930s as fragrances in a variety of domestic and industrial products viz., detergent, cosmetics, shampoo, perfume, food and cigarette additives (Rimkus, 1999). Synthetic musks can be broadly categorised into two groups: nitromusks and polycyclic musks. Nitro musks were the first commonly used synthetic musks, but their use was reduced in the 1950s due to evidence of toxicity to humans and the environment (Tas et al., 1997). They were largely replaced with the polycyclic musks, which account for approximately 85% of worldwide production, while nitro musks account for the remaining 15% (Tas et al., 1997).

The most commonly used synthetic musks are:

- nitromusks — musk moskene (MM), musk tibetene (MT), musk xylene (MX), musk ketone (MK) and musk ambrette (MA).
- polycyclic musks — Galaxolide™ (HHCB), Tonalide™ (AHTN), Celestolide™ (ADBI), Phantolide™ (AHMI), Cashmeran™ (DPMI) and Traseolide™ (ATII).

The majority of synthetic musk applications occur in the domestic environment and are found in personal care products that will be released into the sewer after use and, consequently, the principal source of synthetic musks to the environment is thought to be WWTP effluents and sludges (Rimkus, 1999). WWTP mass balance studies indicate removal rates of between 83 and 91%, whereas

approximately 40% of AHTN and HHCB were eliminated during anaerobic sludge digestion (Balk and Ford, 1999a). The concentrations of synthetic musks in sewage sludge have been reported from Switzerland (Herren and Berset, 2000), Germany (Heberer, 2002), Spain (Llompart et al., 2003), UK (Stevens et al., 2003), China (Zeng et al., 2005) and Hong Kong (Shek et al., 2008).

The nitromusks (MA, MX, MM, and MT) were generally not detected in these studies and when present were found at low μg kg^{-1} dw values. This is consistent with use patterns of nitromusks that have largely been replaced by the polycyclic musks (Rimkus, 1999). MX is currently under review for possible identification as a WFD Priority Substance or PHS (EPCEU, 2008).

The polycyclic musks most frequently detected and at the highest concentrations in sludge are HHCB (0.1–81 mg kg^{-1} dw) and AHTN (0.03–16 mg kg^{-1} dw) (Table 3). Again, this is consistent with use patterns as, together, HHCB and AHTN account for >95% of the market share of polycyclic musks (Tas et al., 1997). Current German proposals are to set biosolids limits for HHCB and AHTN of 10 mg kg^{-1} dw and 15 mg kg^{-1} dw, respectively (BMU, 2007). Other polycyclic musks (ADBI, DPMI) are typically present in lower concentration ranges (<1 mg kg^{-1} dw). The mean HHCB concentration in UK sewage sludges (27 mg kg^{-1} dw) was larger than in other European sludges, such as Switzerland (4.85 mg kg^{-1} dw), Germany (8.26 mg kg^{-1} dw) or Spain (0.16 mg kg^{-1} dw). However, concentrations of HHCB measured in sludge in China and Hong Kong are similar to the UK. Soil ecotoxicity studies report a PNEC for HHCB and AHTN of 0.32 mg kg^{-1} dw that incorporates a fifty fold safety factor and is based upon earthworm and springtail no observable effects concentrations of 45 mg kg^{-1} dw for both chemicals (Balk and Ford, 1999b). The concentrations of these compounds found in biosolids are relatively high when compared to other POPs and therefore, further investigation is warranted to elucidate their fate, behaviour, and persistence in biosolids-amended soils (Stevens et al., 2003).

2.14. Triclosan and triclocarban

Triclosan (TCS; 5-chloro-2-[2,4-dichloro-phenoxy]-phenol) and triclocarban (TCC; 3,4,4′-trichlorocarbanilide) are antimicrobial agents widely used in personal care products such as shampoos, soaps, deodorants, cosmetics, skin-care lotions and creams, mouth rinses, and toothpastes. These domestic applications are likely to be the major source of TCS and TCC to WWTPs (Bester, 2003). The amount of TCS and TCC used in consumer products typically ranges from 0.1 to 0.3% (w/w). At these levels they exhibit a broad-spectrum activity against bacteria, molds and yeasts (McAvoy et al., 2002).

TCS and TCC are both relatively hydrophobic, with log K_{OW} values at neutral pH of 3.5–4.8 and 4.9, respectively (Halden and Paull, 2005; Snyder et al., 2010). The octanol–water distribution of TCS, however, depends on the pH of the environmental matrix that the compounds are exposed to, since the hydroxyl groups (–OH) in the molecule are capable of deprotonation allowing water solubility.

Mass balance studies at WWTP show the incomplete removal of TCC and TCS during wastewater treatment (Heidler et al., 2006; Sapkota et al., 2007). Therefore, TCS and TCC are released into the environment in WWTP effluents and by land application of biosolids. Consequently, they are regularly detected in surface waters receiving WWTP inputs (Halden and Paull, 2004; Halden and Paull, 2005). However, they can also be found upstream of WWTP discharges indicating environmental persistence (Sapkota et al., 2007). Potential environmental problems from the release of TCC and TCS from WWTP effluent in surface water include bioaccumulation in algae and snails (Coogan et al., 2007; Coogan and La Point, 2008), algal growth inhibiting effects (Yang et al., 2008) and endocrine disruption (Ahn et al., 2008).

A mass balance for TCC at a WWTP showed that approximately 75% of the initial mass of TCC was recovered in sludge, with a concentration of 51 mg kg^{-1} dw (Heidler and Halden, 2007). It is commonly reported that TCS and TCC partition to sludge during wastewater treatment (Ying and Kookana, 2007). Mass balance studies indicate that losses of between 48 and 65% occur possibly due to volatilization or biodegradation (Bester, 2003; Heidler and Halden, 2007), but biodegradation is the more likely removal mechanism (Ying and Kookana, 2007). Laboratory studies have also confirmed the degradation of TCS (Federle et al., 2002; Stasinakis et al., 2007). Biosolids were identified as a source of TCS in agricultural soil contributing to the bioaccumulation of TCS in earthworm tissue with bioaccumulation factors ranging from 0.05 to 27 (Kinney et al., 2008). Furthermore, two recent studies have detected the movement of several pharmaceuticals and personal care products from agricultural areas amended with biosolids into tile drainage water (Lapen et al., 2008) and runoff (Topp et al., 2008). Water run-off experiments found that TCS leached only from surface applied biosolids and not

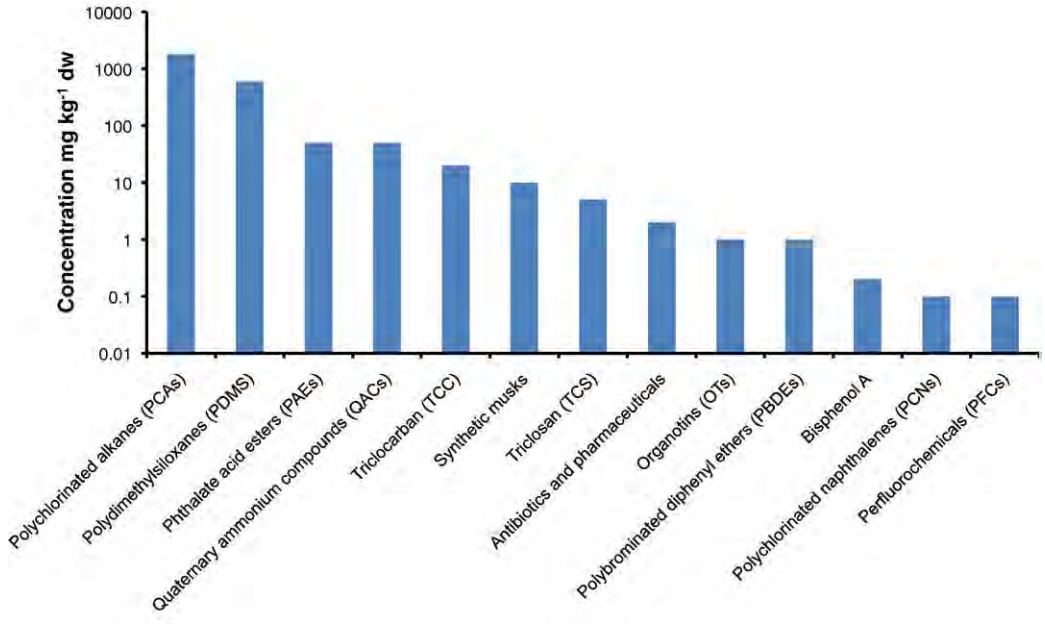


Fig. 1. Typical concentrations of selected 'emerging' organic contaminants in sewage sludge (mg kg^{-1} dw).

Table 4
Assessment matrix to determine research priorities for selected 'emerging' organic contaminants in sewage sludge with respect to their potential significance for agricultural utilisation.

Emerging organic contaminant	Persistent in soil (>6 months) 2 — yes 1 — uncertain 0 — no	Human food chain 2 — possible 1 — uncertain 0 — no	Ecological bioaccumulation 2 — yes 1 — possible 0 — no	Soil ecotoxicity 2 — yes 1 — uncertain 0 — no	Research quality 3 — lack of empirical data 2 — few reported studies 1 — a number of consistent studies 0 — many consistent studies	Score (/11)
Antibiotics and pharmaceuticals[a]	0	2	0	1	2	5
Benzothiazoles	1	1	0	1	3	6
Bisphenol A	0	0	0	0	2	2
Organotins	1	1	2	1	2	7
Phthalate acid esters (PAEs)	0	0	0	0	1	1
Polybrominated diphenyl ethers (PBDEs)	2	2	2	1	0	7
Polychlorinated alkanes (PCAs)	2	2	1	1	3	9
Polychlorinated naphthalenes (PCNs)	2	2	1	1	3	9
Polydimethylsiloxanes (PDMSs)	0	0	0	0	1	1
Perfluorochemicals (PFCs)	2	2	2	1	3	10
Quaternary ammonium compounds (QACs)	0	0	0	0	2	2
Steroids	0	0	0	0	2	2
Synthetic musks	1	0	1	0	1	3
Triclosan	1	0	2	2	2	7
Triclocarban	1	0	2	2	2	7

[a] The chemical properties of antibiotics and pharmaceuticals and subsequent behaviour in the environment can vary greatly. The scores are considered generally for antibiotics and pharmaceuticals, certain exceptions such as carbamazepine may exhibit longer soil persistence.

from subsurface application. Therefore, land application practices for biosolids in the UK are likely to prevent surface water contamination from TCS or TCC, although a potential risk to groundwater by leaching has been suggested (Topp et al., 2008).

Reports of TCS and TCC concentrations in activated sludges and biosolids have been reported from the USA (McAvoy et al., 2002; Heidler et al., 2006; Kinney et al., 2006; Sapkota et al., 2007; US EPA, 2009), Germany (Bester, 2003), Spain (Morales et al., 2005), Canada (Chu and Metcalfe, 2007), Australia (Ying and Kookana, 2007) and Greece (Gatidou et al., 2007; Pothitou and Voutsa, 2008; Stasinakis et al., 2008). The ranges of concentrations reported for TCS and TCC are 0.5–16 mg kg^{-1} dw and 4–50 mg kg^{-1} dw, respectively (Table 3). Recent biosolids surveys in the USA show that TCC and TCS are routinely detected in biosolids and that the concentrations are higher than previously reported (McAvoy et al., 2002; Heidler et al., 2006; Kinney et al., 2006; Sapkota et al., 2007; US EPA, 2009).

3. Assessment and ranking of emerging contaminants

3.1. Typical concentrations of organic contaminants in sewage sludge

A summary of reported concentrations of the selected 'emerging' contaminants examined here is presented in Fig. 1. The concentrations in Fig. 1 are presented on a logarithmic scale in descending order of reported mean concentrations, ranging from PCAs (g kg^{-1} dw) to PFCs (μg kg^{-1} dw). The concentrations of the industrial chemical PCAs are much higher compared to contaminants from domestic sources i.e., QACs, TCS. These concentrations suggest significant industrial discharges of PCAs occur into the wastewater collection system. Chemicals utilized in the domestic environment were in the next 'high-level' concentration range (PAEs, QACs, TCC, synthetic musks, TCS), followed by less commonly used industrial and domestic chemicals (OTs, PBDEs, PCNs, PFCs).

3.2. Matrix assessment

Research and monitoring priorities were identified from an assessment matrix consisting of five criteria applied to the selected 'emerging' contaminants (Table 4). These included:

- environmental persistence in soil environment (>6 months);
- potential for human health impacts resulting from the land application biosolids;
- evidence or likelihood of bioaccumulation in humans or the environment;
- evidence of ecotoxicity, and
- the quality of empirical data and trends on the contaminant in biosolids internationally.

3.3. Assessment results

The 'emerging' contaminants were ranked in decreasing order of priority as follows (maximum possible score of 11):

- perfluorinated chemicals (10)
- polychlorinated alkanes (9), polychlorinated naphthalenes (9)
- polybrominated diphenyl ethers (7), organotins (7), triclosan (7), triclocarban (7)
- benzothiazoles (6)
- antibiotics and pharmaceuticals (5)
- synthetic musks (3)
- bisphenol A (2), quaternary ammonium compounds (2), steroids (2)
- phthalate acid esters (1), polydimethylsiloxanes (1).

PFCs represent a potentially major environmental uncertainty. They have been detected in human blood (Olsen et al., 2003) and environmental samples (Giesy and Kannan, 2001) throughout the world. They have a unique chemistry that facilitates a degree of water solubility, which is not observed with other POPs. Thus, the barriers that normally prevent human and ecological exposures to POPs in biosolids-amended soil may not prevent movement of PFCs. For example, increased water solubility raises the likelihood of exposure through all pathways — water contamination, plant accumulation and grazing animal accumulation (Chaney et al., 1996). Water contamination and plant accumulation are considered to be the priority pathways of concern, as grazing animal accumulation is not unique to PFCs. Whilst measures are in place in Europe to restrict the major exposure risks to PFOS (EPCEU, 2006), and could be extended to PFOA in future, transfer to biosolids could continue to occur over a long period due to the ubiquitous use of these substances within the built environment.

PCAs and PCNs were both detected in recent surveys of UK biosolids (Stevens et al., 2003). PCAs were found at relatively high concentrations (mean concentration 1800 mg kg^{-1} dw), while PCNs were typically less than 1 mg kg^{-1} dw. By comparing the concentrations of these

compounds to PCBs and PCDD/Fs it is apparent that PCAs warrant further investigation, as the concentrations of PCAs are three orders of magnitude higher than those of PCBs found in contemporary sewage sludge. Also, there is mounting evidence that PCAs are accumulating in the human population and the impact of these chemicals on human health and the environment has not yet been explored (Nicholls et al., 2001; Thomas et al., 2006). A preliminary human health exposure assessment indicated that the concentrations of PCAs in sludge could be harmful to human health through the direct ingestion exposure pathway. The concentrations of PCNs are small in contrast and are unlikely to pose a threat to human health or the environment at the concentrations measured in sewage sludge internationally.

PBDEs have been the subject of increasing international research (Clarke et al., 2008c). PBDE concentrations in biosolids may be similar throughout the world, however, manufacturing can add significant quantities of PBDEs to the burden derived from domestic sources (Fabrellas et al., 2004). Furthermore, restrictions applied to the penta- and octa-PBDE commercial formulations may increase demand and consumption of the decaBDE formulation. The deca-formulation is the source of BDE 209, the major congener detected in sludges internationally and field studies have shown that this compound is persistent in the environment (Eljarrat et al., 2008).

Antimicrobial agents TCS and TCC have received increasing research attention internationally (Singer et al., 2002; Ying and Kookana, 2007) and are capable of ecological toxicity (Yang et al., 2008) and bioaccumulation in environmental biota (Kinney et al., 2008). However, a recent risk assessment (Reiss et al., 2009) showed that TCS was unlikely to pose a significant problem for sensitive environmental compartments from the agricultural use of biosolids. Nevertheless, field studies have demonstrated that TCS and TCC may exhibit some environmental persistence in biosolids-amended soil (Topp et al., 2008; Cha and Cupples, 2009). The biodegradation of these compounds is reported in laboratory (McAvoy et al., 2002) and WWTP studies (Ying and Kookana, 2007), but further evaluation of the persistence and toxicity of TCS and TCC in biosolids-amended soil is required. It is also important to recognise that the primary route of human exposure to TCS and TCC will occur in the domestic environment and not as a result of land applying biosolids.

Organotin compounds were present in small concentrations in biosolids in the studies reported, but are potentially ecotoxic. There are limited empirical biosolids measurements internationally, so it is difficult to draw definitive conclusions about typical biosolids concentrations. Furthermore, they warrant further investigation to determine their significance in biosolids-amended soil.

Limit values for benzothiazoles in sludge are proposed and under consideration by the German Government. However, there are insufficient data concerning these chemicals to make an informed assessment of their potential significance. Nevertheless, benzothiazoles have not been detected in environmental media and laboratory studies indicate that they are biodegradable (de Wever and Verachtert, 1997; Gaja and Knapp, 1998). Therefore, it would appear that there are no specific scientific grounds for regulating this group of OCs in biosolids. Nevertheless, further research is required to determine typical concentrations in sewage sludge, environmental persistence, ecological toxicity and persistence in biosolids-amended soil.

A recent risk assessment completed in Norway evaluated over 1400 pharmaceutical compounds based upon a tired approach where chemicals were screened against consumption, volume wastewater of influent, human metabolism, biodegradation and behaviour in WWTP (Eriksen et al., 2009). Fourteen pharmaceuticals were identified for further risk assessment investigation as the only compounds that potentially may pose risk to human health or the environment. These were: atorvastatin, carisoprodol, chlorprothixene, ciprofloxacin, dipyridamole, fexofenadinesotalol, gabapentin, levetiracetam, losartan, mesalazin, metoprolol, ranitidin and tetracycline. The estimated soil concentrations of drug substances (PEC) were low (concentration range 0.01–1 mg kg^{-1} dw) and well below the estimated PNEC values. Therefore Eriksen et al. (2009) concluded that drug substances in sewage sludge constitute a low risk to the soil compartment.

The polycyclic musks are unlikely to pose a risk to human health from land application of biosolids and the majority of human exposure will occur in the domestic environment. The environmental risk assessment of AHTN and HHCB indicates that these substances are unlikely to pose a significant hazard to the ecosystem at the concentrations likely to be found in biosolids-amended soil (Balk and Ford, 1999a,1999b). Therefore, proposals for AHTN and HHCB contaminant limits in biosolids appear unfounded. However, further research is warranted to understand the ecological risk of polycyclic musks with respect to fate, mobility and persistence given the relatively high concentrations of these compounds detected in sludge.

Four high-volume production chemicals were included for assessment and all were indicated as having a low research priority. Concern has been raised over QACs due to potential development of antibiotic resistance and endocrine disruption for bisphenol A and phthalates. However, these chemicals are not environmentally persistent, they biodegrade rapidly and humans are routinely exposed to these compounds through more important pathways via dermal and ingestion routes in the domestic environment. PDMS is another high-volume production chemical that is not considered to pose a risk to humans or the environment when land applying biosolids due to low toxicity.

Steroid concentrations in sludge were only found in two international studies. There are analytical difficulties that may prevent the detection and measurement of this group of compounds, however, they are also readily degradable and are therefore not present in significant quantities in stabilised biosolids.

4. Conclusions

There are 50 million chemicals entered in the Chemical Abstracts Registry and of these 143,000 chemicals are registered with the European Chemicals Agency for industrial use (ECHA, 2009; Toussant, 2009). Once discharged from industrial, domestic and urban sources into the urban wastewater collection system they may transfer to the residual sewage sludge during wastewater treatment. Continued vigilance is therefore required to monitor and determine the significance and implications of ‘emerging’ OCs for the land application of treated wastewater biosolids. The significance of a selection of key contaminants for the agricultural use of biosolids was examined here based upon persistence, human health impacts, bioaccumulation, ecotoxicity and quality of published research for the given chemicals. The concentrations of the 'emerging' OCs in biosolids were also considered.

Two chemical classes warrant particular note. These are the PFCs and PCAs. PFCs are an emerging environmental concern as they have been detected in human blood (Olsen et al., 2003) and environmental samples (Giesy and Kannan, 2001) throughout the world. They have a unique chemistry for a chemical defined as a POP that facilitates a degree of water solubility, and therefore, there is an increased likelihood of exposure through all pathways (water contamination, plant accumulation and grazing animal accumulation) compared to other POPs (Chaney et al., 1996). PCAs were found at relatively high concentrations in sludge (mean concentration 1800 mg kg^{-1} dw). Comparison of the concentrations of these compounds to PCBs and PCDD/Fs shows that the PCA content in sludge is three orders of magnitude higher than PCB values for instance, and signals the importance of further investigations into the significance of PCAs in biosolids for land application.

Recycling biosolids on land is recognised internationally as the most sustainable option for managing the residual sludge from urban wastewater treatment and most risk assessments demonstrate that this practice does not place human health at risk from the OCs studied.

However, continued vigilance in assessing the significance and implications of 'emerging' OCs in sludge is necessary to support and ensure the long-term sustainability and security of the beneficial agricultural route for biosolids management. The research and monitoring priorities for 'emerging' OCs in sludge we have identified and discussed here would further contribute to the technical evidence base to protect human health and the environment when sewage sludge biosolids are recycled in agriculture as soil improvers and fertilisers.

References

3M Environmental Laboratory (2001) Environmental Monitoring — Multi-City Study Water, Sludge, Sediment, POTW Effluent and Landfill Leachate Samples 3M, United States.

Abad E, Martinez K, Planas C, Palacios O, Caixach J, Rivera J. Priority organic pollutant assessment of sludges for agricultural purposes. Chemosphere 2005;61:1358.

Ahn KC, Zhao B, Chen J, Cherednichenko G, Sanmarti E, Denison MS, et al. In vitro biologic activities of the antimicrobials triclocarban, its analogs, and triclosan in bioassay screens: receptor-based bioassay screens. Environ Health Perspect 2008;116:1203–10.

Alcock RE, Jones KC. Polychlorinated biphenyls in digested UK sewage sludges. Chemosphere 1993;26:2199.

Alcock R, Jones K. New directions: "new" organic compounds in the environment. Atmos Environ 1999;33:1645–6.

Alcock RE, Bacon J, Bardget RD, Beck AJ, Haygarth PM, Lee RGM, et al. Persistence and fate of polychlorinated biphenyls (PCBs) in sewage sludge-amended agricultural soils. Environ Pollut 1996;93:83.

Alexander M. Aging, bioavailability, and overestimation of risk from environmental pollutants. Environ Sci Technol 2000;34:4259–65.

Alzaga R, Bayona JM. Determination of perfluorocarboxylic acids in aqueous matrices by ion-pair solid-phase microextraction-in-port derivatization–gas chromatography–negative ion chemical ionization mass spectrometry. J Chromatogr A 2004;1042:155–62.

Alzieu C. Environmental problems caused by TBT in France: assessment, regulations, prospects. Mar Environ Res 1991;32:7-17.

Amir S, Hafidi M, Merlina G, Hamdi H, Jouraiphy A, El Gharous M, et al. Fate of phthalic acid esters during composting of both lagooning and activated sludges. Process Biochem 2005;40:2183–90.

Andersen H, Siegrist H, Halling-Sorensen B, Ternes TA. Fate of estrogens in a municipal sewage treatment plant. Environ Sci Technol 2003;37:4021–6.

Andrade NA, Mcconnell LL, Torrents A, Ramirez M. Persistence of polybrominated diphenyl ethers in agricultural soils after biosolids applications. J Agric Food Chem 2010;58:3077–84.

Andreozzi R, Raffaele M, Nicklas P. Pharmaceuticals in STP effluents and their solar photodegradation in aquatic environment. Chemosphere 2003;50:1319–30.

Aparicio I, Santos JL, Alonso E. Limitation of the concentration of organic pollutants in sewage sludge for agricultural purposes: a case study in South Spain. Waste Manage 2009;29:1747–53.

Aranda JM, O'connor GA, Eiceman GA. Effects of sewage sludge on di-(2-ethylhexyl) phthalate uptake by plants. J Environ Qual 1989;18:45–50.

Bago B, Martin Y, Mejia G, Broto-Puig F, Diaz-Ferrero J, Agut M, et al. Di-(2-ethylhexyl) phthalate in sewage sludge and post-treated sludge: quantitative determination by HRGC-MS and mass spectral characterization. Chemosphere 2005;59:1191–5.

Balk F, Ford RA. Environmental risk assessment for the polycyclic musks AHTN and HHCB in the EU: I. Fate and exposure assessment. Toxicol Lett 1999a;111:57–79.

Balk F, Ford RA. Environmental risk assessment for the polycyclic musks, AHTN and HHCB: II. Effect assessment and risk characterisation. Toxicol Lett 1999b;111:81–94.

Ballscmitter K, Zell M. Analysis of polyhlorinated biphenyls (PCB) by glass capillary gas chromatography. Fresenius J Anal Chem 1980;302:20–31.

Bancon-Montigny C, Lespes G, Potin-Gautier M. Improved routine speciation of organotin compounds in environmental samples by pulsed flame photometric detection. J Chromatogr A 2000;896:149–58.

Barontri CRC, D'ascenzo G, Di Corcia A, Gentili A, Samperi R. Monitoring natural and synthetic estrogens at activated sludge sewage treatment plants and in a receiving river water. Environ Sci Technol 2000;34:5059–66.

Bayen S, Obbard JP, Thomas GO. Chlorinated paraffins: a review of analysis and environmental occurrence. Environ Int 2006;32:915–29.

Belfroid AC, van der Horst A, Vethaak AD, Schafer AJ, Rijs GBJ, Wegener J, et al. Analysis and occurrence of estrogenic hormones and their glucuronides in surface water and waste water in The Netherlands. Sci Total Environ 1999;225:101–8.

Bester K. Triclosan in a sewage treatment process — balances and monitoring data. Water Res 2003;37:3891–6.

Blankenship AL, Kannan K, Villalobos SA, Villeneuve DL, Falandysz J, Imagawa T, et al. Relative potencies of individual polychlorinated naphthalenes and halowax mixtures to induce Ah receptor-mediated responses. Environ Sci Technol 2000;34:3153–8.

BMU (2007) BUNDESMINISTREIUM FUER UMWELT (BMU), *Novellierung der Klaerschlammverordnung,* http://www.bmu.de/files/pdfs/allgemein/application/pdf/novellierung_klaerschlammverordnung.pdf. Accessed 20 July 2010.

Bossi R, Strand J, Sortkjær O, Larsen MM. Perfluoroalkyl compounds in Danish wastewater treatment plants and aquatic environments. Environ Int 2008;34:443–50.

Boulanger B, Vargo JD, Schnoor JL, Hornbuckle KC. Evaluation of perfluorooctane surfactants in a wastewater treatment system and in a commercial surface protection product. Environ Sci Technol 2005;39:5524–30.

Boxall ABA, Johnson P, Smith EJ, Sinclair CJ, Stutt E, Levy LS. Uptake of veterinary medicines from soils into plants. J Agric Food Chem 2006;54:2288–97.

Braekevelt E, Tittlemier SA, Tomy GT. Direct measurement of octanol–water partition coefficients of some environmentally relevant brominated diphenyl ether congeners. Chemosphere 2003;51:563–7.

Briggs GG, Bromilow RH, Evans AA. Relationships between lipophilicity and root uptake and translocation of non-ionised chemicals by barley. Pesticide Sci 1982;13:495–504.

Bright DA, Healey N. Contaminant risks from biosolids land application: contemporary organic contaminant levels in digested sewage sludge from five treatment plants in Greater Vancouver, British Columbia. Environ Pollut 2003;126:39–49.

BSEF (2005) Bromine Science and Environmental Forum Bromine Science and Environment forum, Accessed 9th July 2008 <www.bsef.com>.

Buch RR, Ingebrigtson DN. Rearrangement of poly (dimethylsiloxane) fluids on soil. Environ Sci Technol 1979;13:676–9.

Cadogan D. Health and environmental impact of phthalates. Plastics Addit Compounding 2002;4:28–9.

Campbell I, McConnell G. Chlorinated paraffins and the environment. 1. Environmental occurrence. Environ Sci Technol 1980;14:1209–14.

Carpenter JC, Cella JA, Dorn SB. Study of the degradation of polydimethylsiloxanes on soil. Environ Sci Technol 1995;29:864–8.

Cartwright CD, Thompson IP, Burns RG. Degradation and impact of phthalates plasticizers on soil microbial communities. Environ Toxicol Chem 2000;19:1253–61.

CEC (1986) *Council Directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC).* Official Journal of the European Communities No. L 181/6–12, Brussels.

CEC (1991) *Council Directive of 21 May 1991 concerning urban waste water treatment (91/271/EEC).* Official Journal of the European Communities No. L 135/40–52, Brussels.

Cha J, Cupples AM. Detection of the antimicrobials triclocarban and triclosan in agricultural soils following land application of municipal biosolids. Water Res 2009;43:2522–30.

Chaney RL, Ryan JA, O'Connor GA. Organic contaminants in municipal biosolids: risk assessment, quantitative pathways analysis, and current research priorities. Sci Total Environ 1996;185:187–216.

Chau YK, Zhang S, Maguire RJ. Occurrence of butyltin species in sewage and sludge in Canada. Sci Total Environ 1992;121:271–81.

Cheng H-F, Kumar M, Lin J-G. Degradation kinetics of di-(2-ethylhexyl) phthalate (DEHP) and organic matter of sewage sludge during composting. J Hazard Mater 2008;154:55–62.

Chu S, Metcalfe CD. Simultaneous determination of triclocarban and triclosan in municipal biosolids by liquid chromatography tandem mass spectrometry. J Chromatogr A 2007;1164:212–8.

Clara M, Scharf S, Scheffknecht C, Gans O. Occurrence of selected surfactants in untreated and treated sewage. Water Res 2007;41:4339–48.

Clarke B, Porter N, Symons R, Blackbeard J, Ades P, Marriott P. Dioxin-like compounds in Australian sewage sludge — review and national survey. Chemosphere 2008a;72:1215–28.

Clarke B, Porter N, Symons R, Blackbeard J, Ades P, Marriott P. Persistent organic pollutants in Australian sewage sludge. AWA biosolids speciality conference. Adelaide, Australia; 2008b.

Clarke B, Porter N, Symons R, Marriott P, Ades P, Stevensen G, et al. Polybrominated diphenyl ethers and polybrominated biphenyls in Australian sewage sludge. Chemosphere 2008c;73:980–9.

Clarke BO, Porter NA, Marriott PJ, Blackbeard JR. Investigating the levels and trends of organochlorine pesticides and polychlorinated biphenyl in sewage sludge. Environ Int 2010;36:323–9.

Coogan MA, Edziyie RE, La Point TW, Venables BJ. Algal bioaccumulation of triclocarban, triclosan, and methyl-triclosan in a North Texas wastewater treatment plant receiving stream. Chemosphere 2007;67:1911–8.

Coogan MA, La Point TW. Snail boaccumulation of triclocarban, triclosan, and methyltriclosan in a North Texas, USA, stream affected by wastewater treatment plant runoff. Environ Toxicol Chem 2008;27:1788–93.

Dargnat C, Teil M-J, Chevreuil M, Blanchard M. Phthalate removal throughout wastewater treatment plant: case study of Marne Aval station (France). Sci Total Environ 2009;407:1235–44.

Darnerud PO, Eriksen GS, Johannesson T, Larsen PB, Viluksela M. Polybrominated diphenyl ethers: occurances, dietary exposure, and toxicology. Environ Health Perspect 2001;109(suppl 1):48–68.

Daughton CG, Ternes TA. Pharmaceuticals and personal care products in the environment: agents of subtle change? Environ Health Perspect 1999;107:907–38.

de Boer J, Horst A, Wester PG. PBDEs and PBBs in suspended particulate matter, sediments, sewage treatment plant in- and effluents and biota from the Netherlands. Organohalogen Comp 2000;27:85–8.

de Boer J, Wester PG, van der Horst A, Leonards PEG. Polybrominated diphenyl ethers in influents, suspended particulate matter, sediments, sewage treatment plant and effluents and biota from the Netherlands. Environ Pollut 2003;122:63–74.

de Carlo VJ. Studies of brominanted chemicals in the environment. Ann NY Acad Sci 1979;320:678–81.

de Wever H, Verachtert TH. Biodegradation and toxicity of benzothiazoles. Water Res 1997;31:2673–84.

Dean RB, Suess MJ. The risk to health of chemicals in sewage sludge applied to land. Waste Manage Res 1985;3:251–78.
Desbrow C, Routledge E, Brighty G, Sumpter J, Waldock M. Identification of estrogenic chemicals in STW effluent. 1. Chemical fractionation and in vitro biological screening. Environ Sci Technol 1998;32:1549–58.
Dolliver H, Kumar K, Gupta S. Sulfamethazine uptake by plants from manure-amended soil. J Environ Qual 2007;36:1224–30.
Dorn PB, Chou C-S, Gentempo JJ. Degradation of bisphenol A in natural waters. Chemosphere 1987;16:1501–7.
Drillia P, Stamatelatou K, Lyberatos G. Fate and mobility of pharmaceuticals in solid matrices. Chemosphere 2005;60:1034–44.
Du QZ, Fu XW, Xia HL. Uptake of di-(2-ethylhexyl)phthalate from plastic mulch film by vegetable plants. Food Addit Contam A Chem Anal Control Expo Risk Assess 2009;26:1325–9.
EC. Scientific committee on consumer products opinion on triclocarban. Brussels: European Commission, Health & Consumer Protection Directorate-General; 2005.
ECHA (2009) List of pre-registered substances. European Chemicals Agency (ECHA), Helsinki, Accessed 22nd October 2009 <http://echa.europa.eu/home_en.asp>.
Eljarrat E, Barceló D. Quantitative analysis of polychlorinated n-alkanes in environmental samples. TrAC Trends Anal Chem 2006;25:421–34.
Eljarrat E, Marsh G, Labandeira A, Barcelo D. Effect of sewage sludges contaminated with polybrominated diphenylethers on agricultural soils. Chemosphere 2008;71:1079–86.
EPCEU (2001) *Decision No 2455/2001/EC of the European Parliament and of the Council of 20 November 2001 establishing the list of priority substances in the field of water policy and amending Directive 2000/60/EC.* The European Parliament and the Council of the European Union, Official Journal of the European Communities L 331/1-5, Brussels.
EPCEU (2003) *Directive 2003/11/EC of the European Parliament and of the Council of 6 February 2003 amending for the 24th time Council Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations (pentabromodiphenyl ether, octabromodiphenyl ether).* The European Parliament and the Council of the European Union, Official Journal of the European Union L42/45–46., Brussels.
EPCEU (2006) *Directive 2006/122/EC of The European Parliament and of the Council of 12 December 2006 amending for the 30th time Council Directive 76/769/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations (perfluorooctane sulfonates).* The European Parliament and the Council of the European Union, Official Journal of the European Communities L 372/32–34, Brussels.
EPCEU (2008) *Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council.* The European Parliament and the Council of the European Union, Official Journal of the European Union L348/84–93, Brussels.
Eriksen GS, Amundsen CE, Bernhoft A, Eggen T, Grave K, Halling-Sørensen B, et al. Risk assessment of contaminants in sewage sludge applied on Norwegian soils. Norway: Panel on Contaminants in the Norwegian Scientific Committee for Food Safety; 2009.
Eurochlor (2009) Chlorinated paraffins. Chlorine Online Information Resource, Euro Chlor, Accessed 1st September 2009 <http://www.eurochlor.org/paraffins>.
European Commission (2010) Sewage sludge. European Commission, Brussels. Accessed 25th May 2010 <http://ec.europa.eu/environment/waste/sludge/index.htm>.
Fabrellas B, Larrazabal D, Martinez MA, Eljarrat E, Barcelo D. Presence of polybrominated diphenyl ethers in Spanish sewage sludges: important contribution of deca-BDE. Organohalogen Comp 2004;66:3755–60.
Falandysz J. Polychlorinated naphthalenes: an environmental update. Environ Pollut 1998;101:77–90.
Fatoki OS, Vernon F. Phthalate esters in rivers of the greater Manchester area, U.K. Sci Total Environ 1990;95:227–32.
Fauser P, Vikelsoe J, Sorensen PB, Carlsen L. Phthalates, nonylphenols and LAS in an alternately operated wastewater treatment plant—fate modelling based on measured concentrations in wastewater and sludge. Water Res 2003;37:1288–95.
Federle TW, Kaiser SK, Nuck BA. Fate and effects of triclosan in activated sludge. Environ Toxicol Chem 2002;21:1330–7.
Fendinger NJ, McAvoy DC, Eckhoff WS, Price BB. Environmental occurrence of polydimethylsiloxane. Environ Sci Technol 1997;31:1555–63.
Fent K. Ecotoxicology of organotin compounds. Crit Rev Toxicol 1996a;26:3-117.
Fent K. Organotin compounds in municipal wastewater and sewage sludge: contamination, fate in treatment process and ecotoxicological consequences. Sci Total Environ 1996b;185:151–9.
Fent K, Mueller MD. Occurrence of organotins in municipal wastewater and sewage sludge and behavior in a treatment plant. Environ Sci Technol 1991;25:489–93.
Fent K, Hunn J, Renggli D, Siegrist H. Fate of tributyltin in sewage sludge treatment. Mar Environ Res 1991;32:223–31.
Fent G, Hein WJ, Moendel MJ, Kubiak R. Fate of 14C-bisphenol A in soils. Chemosphere 2003;51:735–46.
Fernandez P, Alder AC, Suter MJF, Giger W. Determination of the quaternary ammonium surfactant ditallowdimethylammonium in digested sludges and marine sediments by supercritical fluid extraction and liquid chromatography with postcolumn ion-pair formation. Anal Chem 1996;68:921–9.
Fountoulakis MS, Stamatelatou K, Batstone DJ, Lyberatos G. Simulation of DEHP biodegradation and sorption during anaerobic digestion of secondary sludge. Water Sci Technol 2006;54:119–28.
Fromme H, Kuchler T, Otto T, Pilz K, Muller J, Wenzel A. Occurrence of phthalates and bisphenol A and F in the environment. Water Res 2002;36:1429.
Frye CL. The environmental fate and ecological impact of organosilicon materials: a review. Sci Total Environ 1988;73:17–22.
Fürhacker M, Schard S, Weber H. Bisphenol A: emissions from point sources. Chemosphere 2000;41:751–6.
Gaja MA, Knapp JS. Removal of 2-mercaptobenzothiazole by activated sludge: a cautionary note. Water Res 1998;32:3786–9.
Gatidou G, Thomaidis NS, Stasinakis AS, Lekkas TD. Simultaneous determination of the endocrine disrupting compounds nonylphenol, nonylphenol ethoxylates, triclosan and bisphenol A in wastewater and sewage sludge by gas chromatography–mass spectrometry. J Chromatogr A 2007;1138:32–41.
Gaze WH. Is pollution driving antibiotic resistance? Planet Earth (quarterly magazine of the Natural Environment Research Council); 2008. p. 14–5. Winter.
Gaze WH, Abdouslam N, Hawkey PM, Wellington EMH. Incidence of class 1 integrons in a quaternary ammonium compound-polluted environment. Antimicrob Agents Chemother 2005;49:1802–7.
Gevao B, Muzaini S, Helaleh M. Occurrence and concentrations of polybrominated diphenyl ethers in sewage sludge from three wastewater treatment plants in Kuwait. Chemosphere 2008;71:242–7.
Giam CS, Powers MA, Leonard JE. Phthalic acid esters. In: Hutzinger, editor. Handbook of environmental chemistry 3 part C. Springer; 1984.
Gibson R, Wang M-J, Padgett E, Beck AJ. Analysis of 4-nonylphenols, phthalates, and polychlorinated biphenyls in soils and biosolids. Chemosphere 2005;61:1336–44.
Giesy JP, Kannan K. Global distribution of perfluorooctane sulfonate in wildlife. Environ Sci Technol 2001;35:1339–42.
Giolando ST, Rapaport RA, Larson RJ, Federle TW, Stalmans M, Masscheleyn P. Environmental fate and effects of DEEDMAC: a new rapidly biodegradable cationic surfactant for use in fabric softeners. Chemosphere 1995;30:1067–83.
Gobel A, Thomsen A, Mcardell CS, Alder AC, Giger W, Theif N, et al. Extraction and determination of sulfonamides, macrolides, and trimethoprim in sewage sludge. J Chromatogr A 2005;1085:179–89.
Golet EM, Alder AC, Hartmann A, Ternes TA, Giger W. Trace determination of fluoroquinolone antibacterial agents in urban wastewater by solid-phase extraction and liquid chromatography with fluorescence detection. Anal Chem 2001;73:3632–8.
Golet EM, Strehler A, Alder AC, Giger W. Determination of fluoroquinolone antibacterial agents in sewage sludge and sludge-treated soil using accelerated solvent extraction followed by solid-phase extraction. Anal Chem 2002;74:5455–62.
Golet EM, Xifra I, Siegrist H, Alder AC, Giger W. Environmental exposure assessment of fluoroquinolone antibacterial agents from sewage to soil. Environ Sci Technol 2003;37:3243–9.
Gomes RL, Avcioglu E, Scrimshaw MD, Lester JN. Steroid-estrogen determination in sediment and sewage sludge: a critique of sample preparation and chromatographic/mass spectrometry considerations, incorporating a case study in method development. TrAC Trends Anal Chem 2004;23:737–44.
Gomes RL, Scrimshaw MD, Lester JN. Fate of conjugated natural and synthetic steroid estrogens in crude sewage and activated sludge batch studies. Environ Sci Technol 2009;43:3612–8.
Gottschall N, Topp E, Edwards M, Russell P, Payne M, Kleywegt S, et al. Polybrominated diphenyl ethers, perfluorinated alkylated substances, and metals in tile drainage and groundwater following applications of municipal biosolids to agricultural fields. Sci Total Environ 2010;408:873–83.
Griessbach EFC, Lehmann RG. Degradation of polydimethylsiloxane fluids in the environment — a review. Chemosphere 1999;38:1461–8.
Group EF. Environmental fate and aquatic toxicology studies on phthalate esters. Environ Health Perspect 1986;65:337–40.
Guo L, Zhang B, Xiao K, Zhang Q, Zheng M. Levels and distributions of polychlorinated naphthalenes in sewage sludge of urban wastewater treatment plants. Chin Sci Bull 2008;53:508–13.
Halden RU, Paull DH. Analysis of triclocarban in aquatic samples by liquid chromatography electrospray ionization mass spectrometry. Environ Sci Technol 2004;38:4849–55.
Halden RU, Paull DH. Co-occurrence of triclocarban and triclosan in U.S. water resources. Environ Sci Technol 2005;39:1420–6.
Hale R, Guardia ML, Harvey E, Gaylor M, Mainor T, Duff W. Persistent pollutants in land-applied sludges. Nature 2001;412:140–1.
Hale RC, Kim SL, Harvey E, La Guardia MJ, Mainor TM, Bush EO, et al. Antarctic research bases: local sources of polybrominated diphenyl ether (PBDE) flame retardants. Environ Sci Technol 2008;42:1452–7.
Hamm S. Polybrominated diphenyl ethers in sewage sludge and effluents of sewage plants from a central region of Germany. Organohalogen Comp 2004;66:1629–34.
Harner T, Kylin H, Bidleman TF, Halsall C, Strachan WMJ, Barrie LA, et al. Polychlorinated naphthalenes and coplanar polychlorinated biphenyls in Arctic air. Environ Sci Technol 1998;32:3257–65.
Harris CA, Henttu P, Parker MG, Sumpter JP. The estrogenic activity of phthalate esters In vitro. Environ Health Perspect 1997;105:802–11.
Hashimoto T, Murakami T. Removal and degradation characteristics of natural and synthetic estrogens by activated sludge in batch experiments. Water Res 2009;43:573–82.
Heberer T. Occurrence, fate, and assessment of polycyclic musk residues in the aquatic environment of urban areas — a review. Acta Hydrochim Hydrobiol 2002;30:227–43.
Heemken OP, Reincke H, Stachel B, Theobald N. The occurrence of xenoestrogens in the Elbe river and the North Sea. Chemosphere 2001;45:245–59.
Heidler J, Halden RU. Mass balance assessment of triclosan removal during conventional sewage treatment. Chemosphere 2007;66:362–9.
Heidler J, Sapkota A, Halden RU. Partitioning, persistence, and accumulation in digested sludge of the topical antiseptic triclocarban during wastewater treatment. Environ Sci Technol 2006;40:3634–9.

Heroult J, Nia Y, Denaix L, Bueno M, Lespes G. Kinetic degradation processes of butyl- and phenyltins in soils. Chemosphere 2008;72:940–6.
Herren D, Berset JD. Nitro musks, nitro musk amino metabolites and polycyclic musks in sewage sludges: quantitative determination by HRGC-ion-trap-MS/MS and mass spectral characterization of the amino metabolites. Chemosphere 2000;40:565–74.
Hirsch R, Ternes T, Haberer K, Kratz K-L. Occurrence of antibiotics in the aquatic environment. Sci Total Environ 1999;225:109–18.
Hobbs EJ, Keplinger ML, Calandra JC. Toxicity of polydimethylsiloxanes in certain environmental systems. Environ Res 1975;10:397–406.
Hoch M. Organotin compounds in the environment - an overview. Appl Geochem 2001;16:719–43.
Hundal LS, Cox A, Granato TC, Abedin Z. Levels of dioxins in soil and corn tissues after 30 years of biosolids application. J Environ Qual 2008;37:1497–500.
IARC (1998) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans; Volume 48 Some Flame Retardants and Textile Chemicals, and Exposures in the Textile Manufacturing Industry*. World Health Organization, International Agency for Research on Cancer, Lyon, France. <http://monographs.iarc.fr/ENG/Monographs/vol18/volume18.pdf>.
IPCS (1990) *Environmental Health Criteria 116: Tributyltin Compounds*. International Programme on Chemical Safety, Geneva, Switzerland. <http://www.inchem.org/documents/ehc/ehc/ehc116.htm#SectionNumber:1.1>.
IPCS (1992) Environmental Health Criteria 131: Diethylhexyl phthalate. International Programme on Chemical Safety, Switzerland, Geneva. <http://www.inchem.org/documents/ehc/ehc/ehc131.htm>.
IPCS. Environmental health criteria 162: brominated diphenyl ethers. Geneva, Switzerland: International Programme on Chemical Safety; 1994.
IPCS. Environmental health criteria 181: chlorinated paraffins. Geneva, Switzerland: International Programme on Chemical Safety; 1996.
IPCS. Poisons information monograph G022 (Group PIM): quaternary ammonium compounds. Switzerland, Geneva: International Programme on Chemical Safety; 1999.
IPCS. Concise international chemical assessment document (CICAD) chlorinated napthalenes no. 34. Geneva: World Health Organisation, International Program on Chemical Safety; 2001.
Jackson AP, Eduljee GH. An assessment of the risks associated with PCDDs and PCDFs following the application of sewage sludge to agricultural land in the UK. Chemosphere 1994;29:2523–43.
Jensen J, Langevelde JV, Pritzl G, Krogh PH. Effects of di(2-ethylhexyl) phthalate and dibutyl phthalate on the collembolan *Folsomia fimetaria*. Environ Toxicol Chem 2001;20:1085–91.
Jianlong W, Lujun C, Hanchang S, Yi Q. Microbial degradation of phthalic acid esters under anaerobic digestion of sludge. Chemosphere 2000;41:1245–8.
Jobling S, Nolan M, Tyler C, Brightly G, Sumpter J. Widespread sexual disruption in wild fish. Environ Sci Technol 1998;32:2498–506.
Kannan K, Franson JC, Bowerman WW, Hansen KJ, Jones PD, Giesy JP. Perfluorooctane sulfonate in fish-eating water birds including bald eagles and albatrosses. Environ Sci Technol 2001;35:3065–70.
Kannan K, Corsolini S, Falandysz J, Fillmann G, Kumar KS, Loganathan BG, et al. Perfluorooctanesulfonate and related fluorochemicals in human blood from several countries. Environ Sci Technol 2004;38:4489–95.
Keyser P, Pujar BG, Eaton RW, Ribbons DW. Biodegradation of the phthalates and their esters by bacteria. Environ Health Perspect 1976;18:159–66.
Kinney CA, Furlong ET, Zaugg SD, Burkhardt MR, Werner SL, Cahill JD, et al. Survey of organic wastewater contaminants in biosolids destined for land application. Environ Sci Technol 2006;40:7207–15.
Kinney CA, Furlong ET, Kolpin DW, Burkhardt MR, Zaugg SD, Werner SL, et al. Bioaccumulation of pharmaceuticals and other anthropogenic waste indicators in earthworms from agricultural soil amended with biosolid or swine manure. Environ Sci Technol 2008;42:1863–70.
Kirchmann H, Åström H, Jönsäll G. Organic pollutants in sewage sludge 1. Effect of toluene, naphthalene, 2-metholnaphthalene, 4-n-nonylphenol and di-2-ethylhexyl phthalate on soil biological processes and their decomposition in soil. Swed J Agric Res 1991;21:107–13.
Kloepfer A, Jekel M, Reemtsma T. Determination of benzothiazoles from complex aqueous samples by liquid chromatography–mass spectrometry following solid-phase extraction. J Chromatogr A 2004;1058:81–8.
Knoth W, Mann W, Meyer R, Nebhuth J. Polybrominated diphenyl ether in sewage sludge in Germany. Chemosphere 2007;67:1831–7.
Kolodziej EP, Harter T, Sedlak DL. Dairy wastewater, aquaculture, and spawning fish as sources of steroid hormones in the aquatic environment. Environ Sci Technol 2004;38:6377–84.
Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB, et al. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. Streams, 1999–2000: a national reconnaissance. Environ Sci Technol 2002;36:1202–11.
Korner W, Bolz U, Süssmut W, Hiller G, Schuller W, Hanf V, et al. Input/output balance of estrogenic active compounds in a major municipal sewage plant in Germany. Chemosphere 2000;40:1131–42.
Kupper T, Berset JD, Etter-Holzer R, Furrer R, Tarradellas J. Concentrations and specific loads of polycyclic musks in sewage sludge originating from a monitoring network in Switzerland. Chemosphere 2004;54:1111–20.
Lai KM, Scrimshaw MD, Lester JN. Prediction of the bioaccumulation factors and body burden of natural and synthetic estrogens in aquatic organisms in the river systems. Sci Total Environ 2002;289:159–68.
Lapen DR, Topp E, Metcalfe CD, Ll H, Edwards M, Gottschall N, et al. Pharmaceutical and personal care products in tile drainage following land application of municipal biosolids. Sci Total Environ 2008;399:50–65.
Lau C, Butenhoff JL, Rogers JM. The developmental toxicity of perfluoroalkyl acids and their derivatives. Toxicol Appl Pharmacol 2004;198:231–41.
Law RJ, Allchin CR, de Boer J, Covaci A, Herzke D, Lepom P, et al. Levels and trends of brominated flame retardants in the European environment. Chemosphere 2006;64:187–208.
Layton AC, Gregory BW, Seward JR, Schultz TW, Sayler GS. Mineralization of steroidal hormones by biosolids in wastewater treatment systems in Tennessee U.S.A. Environ Sci Technol 2000;34:3925–31.
Lee YJ, Ryu H-Y, Kim H-K, Min CS, Lee JH, Kim E, et al. Maternal and fetal exposure to bisphenol A in Korea. Reprod Toxicol 2008;25:413–9.
Legler J, Brouwer A. Are brominated flame retardants endocrine disruptors? Environ Int 2003;29:879–85.
Lehmann RG, Miller JR. Volatilization and sorption of dimethylsilanediol in soil. Environ Toxicol Chem 1996;15:1455–60.
Lehmann RG, Miller JR, Xu S, Singh UB, Reece CF. Degradation of silicone polymer at different soil moistures. Environ Sci Technol 1998;32:1260–4.
Lemos M, van Gestel C, Soares A. Endocrine disruption in a terrestrial isopod under exposure to bisphenol A and vinclozolin. J Soils Sed 2009;9:492–500.
Li X, Brownawell BJ. Analysis of quaternary ammonium compounds in estuarine sediments by LC–ToF–MS: very high positive mass defects of alkylamine ions as powerful diagnostic tools for identification and structural elucidation. Anal Chem 2009;81:7926–35.
Li Y-J, Song T-B, Cai Y-Y, Zhou J-S, Song X, Zhao X, et al. Bisphenol A exposure induces apoptosis and upregulation of Fas/FasL and caspase-3 expression in the testes of mice. Toxicol Sci 2009;108:427–36.
Lindberg RH, Wennberg P, Johansson MI, Tysklind M, Andersson BAV. Screening of human antibiotic substances and determination of weekly mass flows in five sewage treatment plants in sweden. Environ Sci Technol 2005;39:3421–9.
Llompart M, Garcìa-Jares C, Salgado C, Polo M, Cela R. Determination of musk compounds in sewage treatment plant sludge samples by solid-phase microextraction. J Chromatogr A 2003;999:185–93.
Loganathan BG, Sajwan KS, Sinclair E, Senthil Kumar K, Kannan K. Perfluoroalkyl sulfonates and perfluorocarboxylates in two wastewater treatment facilities in Kentucky and Georgia. Water Res 2007;41:4611–20.
Madsen, T., Boyd, H. B., Nylen, D., Rathmann-Pedersen, A., Petersen, G. I. & Simonsen, F. (2001) Environmental and health assessment of substances in household detergents and cosmetic detergent products. Environmental Project No. 615, Final Report. IN DANISH ENVIRONMENTAL PROTECTION AGENCY (Ed.).
Marcic C, Le Hecho I, Denaix L, Lespes G. TBT and TPhT persistence in a sludged soil. Chemosphere 2006;65:2322–32.
Martìnez-Carballo E, Gonzalez-Barreiro C, Sitka A, Kreuzinger N, Scharf S, Gans O. Determination of selected quaternary ammonium compounds by liquid chromatography with mass spectrometry. Part II. Application to sediment and sludge samples in Austria. Environ Pollut 2007;146:543–7.
Marttinen SK, Kettunen RH, Rintala JA. Occurrence and removal of organic pollutants in sewages and landfill leachates. Sci Total Environ 2003a;301:1-12.
Marttinen SK, Kettunen RH, Sormunen KM, Rintala JA. Removal of bis(2-ethylhexyl) phthalate at a sewage treatment plant. Water Res 2003b;37:1385–93.
Marttinen SK, Hanninen K, Rintala JA. Removal of DEHP in composting and aeration of sewage sludge. Chemosphere 2004;54:265–72.
McArdell CS, Molnar E, Suter MJF, Giger W. Occurrence and fate of macrolide antibiotics in wastewater treatment plants and in the Glatt Valley Watershed, Switzerland. Environ Sci Technol 2003;37:5479–86.
McAvoy DC, Schatowitz B, Jacob M, Hauk A, Eckhoff WS. Measurement of triclosan in wastewater treatment systems. Environ Toxicol Chem 2002;21:1323–9.
McDonald TA. A perspective on the potential health risks of PBDEs. Chemosphere 2002;46:745–55.
McIntyre A, Lester J. Occurrence and distribution of persistent organochlorine compounds in U.K. sewage sludges. Water Air Soil Pollut 1984;23:397–415.
Meesters RJW, Schroder HF. Simultaneous determination of 4-nonylphenol and bisphenol A in sewage sludge. Anal Chem 2002;74:3566–74.
Morales S, Canosa P, Rodrìguez I, Rubì E, Cela R. Microwave assisted extraction followed by gas chromatography with tandem mass spectrometry for the determination of triclosan and two related chlorophenols in sludge and sediments. J Chromatogr A 2005;1082:128–35.
Mueller MD. Comprehensive trace level determination of organotin compounds in environmental samples using high-resolution gas chromatography with flame photometric detection. Anal Chem 1987;59:617–23.
Newbold RR, Jefferson WN, Padilla-Banks E. Prenatal exposure to bisphenol A at environmentally relevant soses adversely affects the murine female reproductive tract later in life. Environ Health Perspect 2009;117:879–85.
Nicholls CR, Allchin CR, Law RJ. Levels of short and medium chain length polychlorinated n-alkanes in environmental samples from selected industrial areas in England and Wales. Environ Pollut 2001;114:415–30.
NICNAS. Triclosan. Canberra: Australian Government, Department of Health and Ageing, National Industrial Chemicals Notification and Assessment Scheme; 2008.
Nie Y, Qiang Z, Zhang H, Adams C. Determination of endocrine-disrupting chemicals in the liquid and solid phases of activated sludge by solid phase extraction and gas chromatography–mass spectrometry. J Chromatogr A 2009;1216:7071–80.
Nishiyama N, Toshima Y, Ikeda Y. Biodegradation of alkyltrimethylammonium salts in activated sludge. Chemosphere 1995;30:593–603.
North KD. Tracking polybrominated diphenyl ether releases in a wastewater treatment plant effluent, Palo Alto, California. Environ Sci Technol 2004;38:4484–8.
Nwosu VC. Antibiotic resistance with particular reference to soil microorganisms. Res Microbiol 2001;152:421–30.

Nylund K, Asplund L, Jansson B, Jonsson P, Litzen K, Sellstrom U. Analysis of some polyhalogenated organic pollutants in sediment and sewage sludge. Chemosphere 1992;24:1721–30.
O'Connor GA, Kiehl D, Eiceman GA, Ryan JA. Plant uptake of sludge-borne PCBs. J Environ Qual 1990;19:113–8.
OECD. Co-operation on existing chemicals hazard assessment of perfluorooctane sulfonate (PFOS) and its salts. Paris: Organisation for Economic Co-operation and Development; 2002.
Oehlmann J, Oetken M, Schulte-Oehlmann U. A critical evaluation of the environmental risk assessment for plasticizers in the freshwater environment in Europe, with special emphasis on bisphenol A and endocrine disruption. Environ Res 2008;108:140–9.
Oliver R, May E, Williams J. The occurrence and removal of phthalates in a trickle filter STW. Water Res 2005;39:4436–44.
Olsen GW, Church TR, Miller JP, Burris JM, Hansen KJ, Lundberg JK, et al. Perfluorooctanesulfonate and other fluorochemicals in the serum of American Red Cross adult blood donors. Environ Health Perspect 2003;111:1892–901.
Pakou C, Kornaros M, Stamatelatou K, Lyberatos G. On the fate of LAS, NPEOs and DEHP in municipal sewage sludge during composting. Bioresour Technol 2009;100: 1634–42.
Peters AJ, Tomy GT, Jones KC, Coleman P, Stern GA. Occurrence of C10–C13 polychlorinated n-alkanes in the atmosphere of the United Kingdom. Atmos Environ 2000;34:3085–90.
Plagellat C, Kupper T, de Alencastro LF, Grandjean D, Tarradellas J. Biocides in sewage sludge: quantitative determination in some swiss wastewater treatment plants. Bull Environ Contam Toxicol 2004;73:794–801.
Pothitou P, Voutsa D. Endocrine disrupting compounds in municipal and industrial wastewater treatment plants in Northern Greece. Chemosphere 2008;73:1716–23.
Reddy CM, Quinn JG. Environmental chemistry of benzothiazoles derived from rubber. Environ Sci Technol 1997;31:2847–53.
Reddy S, Iden CR, Brownawell BJ. Analysis of steroid conjugates in sewage influent and effluent by liquid chromatography–tandem mass spectrometry. Anal Chem 2005;77:7032–8.
Reiss R, Lewis G, Griffin J. An ecological risk assessment for triclosan in the terrestrial environment. Environ Toxicol Chem 2009;28:1546–56.
Rieger R, Ballschmiter K. Semivolatile organic compounds – polychlorinated dibenzo-p-dioxins (PCDD), dibenzofurans (PCDF), biphenyls (PCB), hexachlorobenzene (HCB), 4, 4'-DDE and chlorinated paraffins (CP) – as markers in sewer films. Fresenius J Anal Chem 1995;352:715–24.
Rimkus GG. Polycyclic musk fragrances in the aquatic environment. Toxicol Lett 1999;111:37–56.
Roghair CJ, Buijze A, Schoon HNP. Ecotoxicological risk evaluation of the cationic fabric softener DTDMAC. I. Ecotoxicological effects. Chemosphere 1992;24:599–609.
Roslev P, Vorkamp K, Aarup J, Frederiksen K, Nielsen PH. Degradation of phthalate esters in an activated sludge wastewater treatment plant. Water Res 2007;41:969–76.
Rysz M, Alvarez PJJ. Amplification and attenuation of tetracycline resistance in soil bacteria: aquifer column experiments. Water Res 2004;38:3705–12.
Sapkota A, Heidler J, Halden RU. Detection of triclocarban and two co-contaminating chlorocarbanilides in US aquatic environments using isotope dilution liquid chromatography tandem mass spectrometry. Environ Res 2007;103:21–9.
Schlusener MP, Bester Kai. Behavior of steroid hormones and conjugates during wastewater treatment — a comparison of three sewage treatment plants. CLEAN Soil Air Water 2008;36:25–33.
Schmitzer JL, Scheunert I, Korte F. Fate of bis(2-ethylhexyl) [14C]phthalate in laboratory and outdoor soil-plant systems. J Agric Food Chem 1988;36:210–5.
Schowanek D, Carr R, David H, Douben P, Hall J, Kirchmann H, et al. A risk-based methodology for deriving quality standards for organic contaminants in sewage sludge for use in agriculture — conceptual framework. Regul Toxicol Pharmacol 2004;40:227–51.
Schultz MM, Higgins CP, Huset CA, Luthy RG, Barofsky DF, Field JA. Fluorochemical mass flows in a municipal wastewater treatment facility. Environ Sci Technol 2006;40:7350–7.
Sellstrom U, Kierkegaard A, Alsberg T, Jonsson P, Wahlberg C, Wit CD. Brominated flame retardants in sediments from European estuaries, the Baltic Sea and in sewage sludge. Organohalogen Comp 1999;40:383–6.
Sellstrom U, de Wit CA, Lundgren N, Tysklind M. Effect of sewage-sludge application on concentrations of higher-brominated diphenyl ethers in soils and earthworms. Environ Sci Technol 2005;39:9064–70.
Sengeløv G, Agersø Y, Halling-Sørensen B, Baloda SB, Andersen JS, Jensen LB. Bacterial antibiotic resistance levels in Danish farmland as a result of treatment with pig manure slurry. Environ Int 2003;28:587–95.
Sewart A, Harrad SJ, McLachlan MS, Mcgrath SP, Jones KC. PCDD/Fs and non-o-PCBs in digested U.K. sewage sludges. Chemosphere 1995;30:51.
Shanker R, Ramakrishma C, Seth PK. Degradation of some phthalic acid esters in soil. Environ Pollut A Ecol Biol 1985;39:1–7.
Shek WM, Murphy MB, Lam JCW, Lam PKS. Synthetic polycyclic musks in Hong Kong sewage sludge. Chemosphere 2008;71:1241–50.
Shelton DR, Boyd SA, Tiedje JM. Anaerobic biodegradation of phthalic acid esters in sludge. Environ Sci Technol 1984;18:93–7.
Shore LS, Gurevitz M, Shemesh M. Estrogen as an environmental pollutant. Bull Environ Contam Toxicol 1993;51:361–6.
Sinclair E, Kannan K. Mass loading and fate of perfluoroalkyl surfactants in wastewater treatment plants. Environ Sci Technol 2006;40:1408–14.
Singer H, Muller S, Tixier C, Pillonel L. Triclosan: Occurrence and fate of a widely used biocide in the aquatic environment: field measurements in wastewater treatment plants, surface waters, and lake sediments. Environ Sci Technol 2002;36: 4998–5004.
Sjödin A, Jakobsson E, Kierkegaard A, Marsh G, Sellstrom U. Gas chromatographic identification and quantification of polybrominated diphenyl ethers in a commercial product, Bromkal 70-5DE. J Chromatogr A 1998;822:83–9.
Sjöström E, Collins CD, Smith SR, Shaw G. Degradation and plant uptake of nonylphenol (NP) and nonylphenol-12-ethoxylate (NP12EO) in four contrasting agricultural soils. Environ Pollut 2008;156:1284–9.
Snyder SA, Villeneuve DL, Snyder EM, Giesy JP. Identification and quantification of estrogen receptor agonists in wastewater effluents. Environ Sci Technol 2001;35: 3620–5.
Snyder EH, O'Connor GA, McAvoy DC. Measured physicochemical characteristics and biosolids-borne concentrations of the antimicrobial triclocarban (TCC). Sci Total Environ 2010;408:2667–73.
Sohoni P, Sumpter J. Several environmental oestrogens are also anti-androgens. J Endocrinol 1998;158:327–39.
Spies RB, Anderesen BD, JR DWR. Benzothiazoles in estuarine sediments as indicators of street runoff. Nature 1987;327:697.
Staples CA, Peterson DR, Parkerton TF, Adams WJ. The environmental fate of phthalate esters: a literature review. Chemosphere 1997;35:667.
Staples CA, Dome PB, Klecka GM, Oblock ST, Harris LR. A review of the environmental fate, effects, and exposures of bisphenol A. Chemosphere 1998;36:2149–73.
Stasinakis AS, Thomaidis NS, Nikolaou A, Kantifes A. Aerobic biodegradation of organotin compounds in activated sludge batch reactors. Environ Pollut 2005;134:431–8.
Stasinakis AS, Petalas AV, Mamais D, Thomaidis NS, Gatidou G, Lekkas TD. Investigation of triclosan fate and toxicity in continuous-flow activated sludge systems. Chemosphere 2007;68:375–81.
Stasinakis AS, Gatidou G, Mamais D, Thomaidis NS, Lekkas TD. Occurrence and fate of endocrine disrupters in Greek sewage treatment plants. Water Res 2008;42:1796–804.
Steen I. Phosphorus recovery — phosphorus availability in the 21st century, management of a non-renewable resource. Phosphorus Potassium 1998;217.
Stevens C. Environmental degradation pathways for the breakdown of polydimethylsiloxanes. J Inorg Biochem 1998;69:203–7.
Stevens J, Green NJL, Jones KC. Survey of PCDD/Fs and non-ortho PCBs in UK sewage sludges. Chemosphere 2001;44:1455.
Stevens JL, Northcott GL, Stern GA, Tomy GT, Jones KC. PAHs, PCBs, PCNs, organochlorine pesticides, synthetic musks, and polychlorinated n-alkanes in U.K. sewage sludge: Survey results and implications. Environ Sci Technol 2003;37:462–7.
Sütterlin H, Alexy R, Coker A, Kümmerer K. Mixtures of quaternary ammonium compounds and anionic organic compounds in the aquatic environment: elimination and biodegradability in the closed bottle test monitored by LC–MS/MS. Chemosphere 2008;72:479–84.
Tan BLL, Hawker DW, Müller JF, Leusch FDL, Tremblay LA, Chapman HF. Comprehensive study of endocrine disrupting compounds using grab and passive sampling at selected wastewater treatment plants in South East Queensland, Australia. Environ Int 2007;33:654–69.
Tas JW, Balk F, Ford RA, van de Plassche EJ. Environmental risk assessment of musk ketone and musk xylene in the Netherlands in accordance with the EU-TGD. Chemosphere 1997;35:2973–3002.
Ternes TA, Kreckel P, Mueller J. Behaviour and occurrence of estrogens in municipal sewage treatment plants—II. Aerobic batch experiments with activated sludge. Sci Total Environ 1999a;225:91–9.
Ternes TA, Stumpf M, Mueller J, Haberer K, Wilken RD, Servos M. Behavior and occurrence of estrogens in municipal sewage treatment plants—I. Investigations in Germany, Canada and Brazil. Sci Total Environ 1999b;225:81–90.
Ternes TA, Andersen H, Gilberg D, Bonerz M. Determination of estrogens in sludge and sediments by liquid extraction and GC/MS/MS. Anal Chem 2002;74:3498–504.
Thiele-Bruhn S. Pharmaceutical antibiotic compounds in soils — a review. J Plant Nutr Soil Sci 2003;166:145–67.
Thomas GO, Farrar D, Braekevelt E, Stern G, Kalantzi OI, Martin FL, et al. Short and medium chain length chlorinated paraffins in UK human milk fat. Environ Int 2006;32:34–40.
Tolle DA, Frye CL, Lehmann RG, Zwick TC. Ecological effects of PDMS-augmented sludge amended to agricultural microcosms. Sci Total Environ 1995;162:193–207.
Toms L, Mueller J, Mortimer M, Symons R, Stevenson G, Gaus C. Assessment of concentrations of polybrominated diphenyl ether flame retardants in aquatic environments in Australia. Canberra: Australian Government, Department of the Environment and Water Resources; 2006.
Toms LL, Mortimer M, Symons RK, Paepke O, Mueller JF. Polybrominated diphenyl ethers (PBDEs) in sediment by salinity and land-use type from Australia. Environ Int 2008;34:58–66.
Topp E, Monteiro SC, Beck A, Coelho BB, Boxall ABA, Duenk PW, et al. Runoff of pharmaceuticals and personal care products following application of biosolids to an agricultural field. Sci Total Environ 2008;396:52–9.
Toussant M. Editorial: a scientific milestone. Chem Eng News 2009;87:3.
Traina SJ, Fendinger NJ, Mcavoy DC, Kerr KM, Gupta S. Fate of polydimethylsilicone in biosolids-amended field plots. J Environ Qual 2002;31:247–55.
Travis CC, Arms AD. Bioconcentration of organics in beef, milk, and vegetation. Environ Sci Technol 1988;22:271–4.
UNEP. Stockholm convention of persistent organic pollutants. Stockholm, Sweden: United Nations Environment Programme; 2001.
UNEP (2009) *Governments unite to step-up reduction on global DDT reliance and add nine new chemicals under international treaty*. United Nations Environment Programme, Geneva, Accessed 3rd July 2009 <http://chm.pops.int/Convention/Pressrelease/COP4Geneva8May2009/tabid/542/language/en-US/Default.aspx>.
US EPA (1984) Fifteenth Report of the Interagency Testing Committee to the Administrator; Receipt of Report and Request for Comments Regarding Priority List of Chemicals, US Environmental Protection Agency, Washington.

US EPA (1993) *Federal Register: Vol 58, No. 32. 40 CFR Part 257* et al. *Standards for the Use or Disposal of Sewage sludge; Final Rules* United States Environmental Protection Agency, Washington.
US EPA. Exposure factors handbook. Washington: National Center for Environmental Assessment; 1997.
US EPA (2008) Perfluorooctanoic acid (PFOA) and fluorinated telomers: Basic information US EPA, Washington, 19th March 2010 <http://www.epa.gov/oppt/pfoa/pubs/pfoainfo.html>.
US EPA (2009) Targeted National Sewage Sludge Survey Statistical Analysis Report. United States Environmental Protection Agency Office of Water. EPA-822-R-08-018. Washington, DC.
Van Leeuwen K, Roghair C, De Nijs T, De Greef J. Ecotoxicological risk evaluation of the cationic fabric softener DTDMAC. III. Risk assessment. Chemosphere 1992;24:629–39.
Vandenberg LN, Hauser R, Marcus M, Olea N, Welshons WV. Human exposure to bisphenol A (BPA). Reprod Toxicol 2007;24:139–77.
Varaprath S, Frye CL, Hamelink J. Aqueous solubility of permethylsiloxanes (silicones). Environ Toxicol Chem 1996;15:1263–5.
Versteeg DJ, Feijtel TCJ, Cowan CE, Ward TE, Rapaport RA. An environmental risk assessment for DTDMAC in The Netherlands. Chemosphere 1992;24:641–62.
Villeneuve DL, Kannan K, Khim JS, Falandysz J, Nikiforov VA, Blankenship AL, et al. Relative potencies of individual polychlorinated naphthalenes to induce dioxin-like responses in fish and mammalian in vitro bioassays. Arch Environ Contam Toxicol 2000;39:273–81.
Voulvoulis N, Lester JN. Fate of organotins in sewage sludge during anaerobic digestion. Sci Total Environ 2006;371:373–82.
Voulvoulis N, Scrimshaw MD, Lester JN. Removal of organotins during sewage treatment: a case study. Environ Technol 2004;25:733–40.
Walker WW, Cripe CR, Pritchard PH, Bourquin AW. Dibutylphthalate degradation in estuarine and freshwater sites. Chemosphere 1984;13:1283–94.
Wang Y, Zhang Q, Lv J, Li A, Liu H, Li G, et al. Polybrominated diphenyl ethers and organochlorine pesticides in sewage sludge of wastewater treatment plants in China. Chemosphere 2007;68:1683–91.
Watanabe N, Nakamura T, Watanabe E, Sato E, Ose Y. Distribution of organosiloxanes (silicones) in water, sediments and fish from the Nagara River watershed, Japan. Sci Total Environ 1984;35:91–7.
Watanabe N, Nagase H, Ose Y. Distribution of silicones in water, sediment and fish in Japanese rivers. Sci Total Environ 1988;73:1–9.
Watts RJ, Kong S, Haling CS, Gearhart L, Frye CL, Vigon BW. Fate and effects of polydimethylsiloxanes on pilot and bench-top activated sludge reactors and anaerobic/aerobic digesters. Water Res 1995;29:2405–11.
Webber MD, Lesage S. Organic contaminants in canadian municipal sludges. Waste Manage Res 1989;7:63–82.
Wild SR, Waterhouse KS, McGrath SP, Jones KC. Organic contaminants in an agricultural soil with a known history of sewage sludge amendments: polynuclear aromatic hydrocarbons. Environ Sci Technol 1990;24:1706–11.
Wild SR, Berrow ML, Jones KC. The persistence of polynuclear aromatic hydrocarbons (PAHs) in sewage sludge amended agricultural soils. Environ Pollut 1991;72:141–57.
Wild SR, Harrad SJ, Jones KC. The influence of sewage sludge applications to agricultural land on human exposure to polychlorinated dibenzo-p-dioxins (PCDDs) and -furans (PCDFs). Environ Pollut 1994;83:357.
Williams CF, Adamsen FJ. Sorption–desorption of carbamazepine from irrigated soils. J Environ Qual 2006;35:1779–83.
Wilson SC, Duarte-Davidson R, Jones KC. Screening the environmental fate of organic contaminants in sewage sludges applied to agricultural soils: 1. The potential for downward movement to groundwaters. Sci Total Environ 1996;185:45–57.
Wilson SC, Alcock RE, Sewart AP, Jones KC. Organic chemicals in the environment — persistence of organic contaminants in sewage sludge-amended soil: a field experiment. J Environ Qual 1997;26:1467–77.
Winker M, Clemens J, Reich M, Gulyas H, Otterpohl R. Ryegrass uptake of carbamazepine and ibuprofen applied by urine fertilization. Sci Total Environ 2010;408:1902–8.
Xu S, Lehmann RG, Miller JR, Chandra G. Degradation of polydimethylsiloxanes (silicones) as influenced by clay minerals. Environ Sci Technol 1998;32:1199–206.
Yang L-H, Ying G-G, Su H-C, Stauber JL, Adams MS, Binet MT. Growth-inhibiting effects of 12 anitbacterial agents and their mixtures on the freshwater microbial GA pseudokirchneriella subcapitata. Environ Toxicol Chem 2008;27:1201–8.
Yin R, Lin XG, Wang SG, Zhang HY. Effect of DBP/DEHP in vegetable planted soil on the quality of capsicum fruit. Chemosphere 2003;50:801–5.
Ying G-G. Fate, behavior and effects of surfactants and their degradation products in the environment. Environ Int 2006;32:417–31.
Ying G-G, Kookana RS. Triclosan in wastewaters and biosolids from Australian wastewater treatment plants. Environ Int 2007;33:199–205.
Zeng X, Sheng G, Xiong Y, Fu J. Determination of polycyclic musks in sewage sludge from Guangdong, China using GC–EI–MS. Chemosphere 2005;60:817–23.
Ziogou K, Kirk PWW, Lester JN. Behaviour of phthalic acid esters during batch anaerobic digestion of sludge. Water Res 1989;23:743.

STATE OF MAINE
DEPARTMENT OF ENVIRONMENTAL PROTECTION

JANET T. MILLS
GOVERNOR

GERALD D. REID
COMMISSIONER

Memorandum

To: Licensed facilities that land apply, compost, or process sludge in Maine
From: David Burns, P.E., Acting Director, Bureau of Remediation and Waste Management
Date: March 22, 2019
Re: Requirement to analyze for PFAS compounds

Background:

Per- and polyfluoroalkyl substances (PFAS) are a group of man-made chemicals that includes PFOA, PFOS, PFBS, and many other compounds. PFAS have been manufactured and used by a variety of industries around the globe, including in the United States since the 1940s. PFOA and PFOS have been the most extensively produced and studied of these chemicals. Both chemicals are persistent in the environment and in the human body – meaning they don't readily break down and can accumulate over time. Additionally, there is evidence that exposure to PFAS can lead to adverse human health effects.[1] PFAS can be found in many places including food packaging, water and stain resistant products, non-stick products, certain firefighting foams, and many others. Because these chemicals are so prevalant and don't easily break down, they can be concentrated through the wastewater treatment process. In 2016, the US Environmental Protection Agency (EPA) established a health advisory level in drinking water of 70 parts per trillion (ppt) combined for two PFAS compounds – PFOA and PFOS.

In late 2016, the Department became aware that a monitoring well located at a dairy farm in southern Maine which had previously agronomically utilized residuals had groundwater which exceeded the EPA health advisory level. The Department sampled drinking water, groundwater, surface water, soil, manure, hay, feed, and milk at this farm. Although not conclusive, results of this testing indicate that the land application of wastewater treatment plant sludge/biosolids may have contributed to the contamination of this farm with PFAS compounds.

On July 8, 2018, the *Solid Waste Management Rules: Beneficial Use of Solid Wastes*, 06-096 C.M.R. ch. 418, Appendix A was revised to include screening concentrations for three PFAS compounds: PFOA (0.0025 mg/kg), PFOS (0.0052 mg/kg), and PFBS (1.9 mg/kg).

Pertinent Regulations and Licensing Authority:

The *Solid Waste Management Rules: Agronomic Utilization of Residuals*, 06-096 C.M.R. ch. 419, § 4(A) requires that a residual must be physically and chemically suitable for the intended utilization activity, must be non-hazardous, and must be of a known and consistent quality. 06-096 C.M.R. ch. 419, § 4(C) further requires that the residual generator must develop and implement a waste characterization sampling and analytical work plan in accordance with the *Solid Waste Management Rules: Water Quality Monitoring, Leachate Monitoring, and Waste Characterization*, 06-096 C.M.R. ch. 405.

AUGUSTA
17 STATE HOUSE STATION
AUGUSTA, MAINE 04333-0017
(207) 287-7688 FAX: (207) 287-7826

BANGOR
106 HOGAN ROAD, SUITE 6
BANGOR, MAINE 04401
(207) 941-4570 FAX: (207) 941-4584

PORTLAND
312 CANCO ROAD
PORTLAND, MAINE 04103
(207) 822-6300 FAX: (207) 822-6303

PRESQUE ISLE
1235 CENTRAL DRIVE, SKYWAY PARK
PRESQUE ISLE, MAINE 04769
(207) 764-0477 FAX: (207) 760-3143

website: www.maine.gov/dep

06-096 C.M.R. ch. 405, § 6(B)(2) requires the development of a waste characterization sampling and analytical work plan for initial and ongoing characterization. Further, 06-096 C.M.R. ch. 405, § 6(D) requires that solid wastes proposed for agronomic utilization must be characterized based on specific characteristics. The group of parameters that the generator may be required to analyze for depends upon the processes that generate the residual and inputs to that process. 06-096 C.M.R. ch. 405, § 6(D)(2)(o) further requires that in addition to specific parameters already identified in 06-096 C.M.R. ch. 405, § 6(D)(2), the Department may require analysis for other parameters that, based on a description of the process generating the residual, may be in the residual in significant concentrations to adversely impact the utilization program. Standard Condition 3 to all solid waste facility licenses requires a licensee to submit all reports and information requested by the Department demonstrating that the licensee has complied or will comply with all terms and conditions of their approval. License terms and conditions include compliance with all applicable operating rules in accordance with 06-096 C.M.R. ch. 400, § 3(E).

Sampling and Analysis Required:

The Department is now requiring all sludge/biosolids program licensees and sludge/biosolids composting facilities to test their material for PFOA, PFOS, and PFBS. Your Sampling and Analytical Work Plan (SAWP) must be updated to include sampling and analysis for these compounds on an ongoing basis. We recommend you follow the Department's PFAS sampling guidance (Attachment 1) and update your SAWP accordingly. Please pay particular attention to the summary of prohibited and acceptable items for use in PFAS sampling (appended as Attachment 1). PFAS sampling requires specific procedures to prevent inadvertent cross-contamination of samples. Your updated SAWP must be submitted to the Department for review and approval by April 12, 2019 and all initial sampling must be conducted in accordance with the Department's guidance no later than May 7, 2019. You must use one of the laboratories approved by the Department to test for these compounds. A list of prequalified laboratories is appended as Attachment 2. All data must be submitted to the Department in Electronic Data Deliverable (EDD) format, Version 6.0, along with a .pdf copy of the complete laboratory report including quality control and quality assurance information within 10 days of receipt. Results from this initial round of testing will provide the Department with critical data which will inform our determination regarding the need for and frequency of additional testing for these compounds.

Prohibition:

Pursuant to the provisions of 06-096 C.M.R. ch. 419, § 5(A), sludge/biosolids and sludge/biosolids-derived compost or products may not be land applied if the screening concentrations for PFOA, PFOS or PFBS in 06-096 C.M.R. ch. 418, Appendix A are exceeded unless and until the provisions of 06-096 C.M.R. ch. 419, § 5(B) are met. The land application and/or distribution of sludge or sludge-derived products cannot resume until approved by the Department.

Questions:

If you have any questions, please contact Carla Hopkins at Carla.J.Hopkins@maine.gov or 207-215-3314.

[1] https://www.epa.gov/pfas/basic-information-pfas

COVER SHEET
STANDARD OPERATING PROCEDURE-ADDENDUM

OPERATION TITLE: **DEVELOPMENT OF A SAMPLING AND ANALYSIS PLAN-**

ADDENDUM - A – ADDITIONAL REQUIREMENTS FOR THE SAMPLING OF PERFLUORINATED ALKYLATED SUBSTANCES (PFASs), PERFLUOROOCTANOIC ACID (PFOA) and PERFLUOROOCTANE SULFONATE (PFOS).

1.0 APPLICABILITY

This Standard Operating Procedure (SOP) ADDENDUM applies to all programs in the Maine Department of Environmental Protection's (MEDEP) Division of Remediation (DR). It is also applicable to all parties that may submit data that will be used by the DEP/DR.

This SOP ADDENDUM is not a rule and is not intended to have the force of law, nor does it create or affect any legal rights of any individual, all of which are determined by applicable statutes and law. This SOP does not supersede statutes or rules.

2.0 PURPOSE

The purpose of this document is to describe the MEDEP/DRs requirements for the development of a Sampling and Analysis Plan (SAP) with specific requirements for the sampling of compounds related to Per- and Polyfluoroalkyl Substances (PFASs), including Perfluorooctanoic acid (PFOA) and Perfluorooctane sulfonate (PFOS).

Prior to conducting any investigative field work, routine monitoring, post closure sampling or any data gathering/sample collection project, a SAP will be developed that outlines the goals of the activity and methodology to achieve that goal. A well-developed SAP that is reviewed by all field team members will assure that the goals are obtainable, the methodology is consistent, and the data generated will meet the Data Quality Objectives (DQOs) for the project.

Given the ubiquitous nature of PFAS compounds, the low detection levels that are generally requested, and the different methodologies for which these compounds are tested, additional requirements regarding sampling methodology, equipment, and analysis for PFAS compounds should be included as part of the sampling plan and during the sampling event. This document outlines those specific requirements to be included in a PFAS sampling plan and during sampling.

3.0 GUIDELINES AND PROCEDURES

3.1 INTRODUCTION

A sampling and analysis plan, regardless of whether sampling for PFAS compounds or other potential contaminants, should include all the elements in SOP RWM-DR-014 – Development of a Sampling and Analysis Plan. Although not required to be included in the SAP, (as outlined in SOP RWM-DR-014), an assessment of the existing data should be conducted, a site reconnaissance completed, a conceptual site model developed, and data quality objectives determined as part of planning to assure the SAP will meet the goals of the sampling.

The SAP itself should include the goal of the sampling, end use of data, data quality objectives, schedule, sampling methodology, sampling locations, media to be sampled, analytical parameters, and QA/QC samples. Additionally, a site specific health and safety plan may be necessary (see SOP-DR-014) depending on the scope of the sampling event. For example, collection of samples in a large or moving water body, or as part of large sampling effort

involving drilling rigs and/or excavation equipment would require a health and safety plan; residential well sampling would likely not.

3.2 SAMPLING METHODOLOGY/EQUIPMENT

A description of the sampling methodology will be included in the SAP. Generally, reference to an appropriate SOP for the sample methodology will be sufficient. The Division has developed multiple SOPs for sample collection of most media; please refer to the Division of Remediation's Quality Assurance Plan - Attachment B – Data Collection SOPs for a list of all data collection standard operating procedures.

3.2.1 Sampling Methodology

Sampling for PFAS will follow the standard procedures as outlined in the specific sampling method SOPs. In addition, the following task must be included in the SAP and field staff must perform the task as described below to prevent contamination of the sample:

> "Prior to sampling each location the sample handler must wash their hands and don nitrile gloves. PFAS contamination during sample collection can occur from several common sources, including food packaging and certain foods and beverages. Proper hand washing and wearing nitrile gloves will help to minimize this type of accidental contamination of the samples."

It should be noted that samples collected for PFAS analysis do not have to be headspace free.

3.2.2 Sampling Equipment/Supplies/Personal Protective Equipment (PPE)

The low detection limits required for PFAS water analysis and their common occurrence in frequently used items warrant attention to equipment and PPE used for sampling. A sampling equipment list for PFAS projects should follow the material guidelines in Table 1 of Attachment A, avoiding use of LDPE and any Teflon-lined equipment or tubing. If field decontamination of non-disposable equipment is necessary, washing with an approved soap solution, rinsing with DI water and then a rinse with laboratory-supplied PFAS-free water is recommended. New nitrile gloves should be used between locations and activities. Other recommended clothing and PPE requirements are noted in Table 1 of Attachment A.

3.3 Media Sampled/Analytical Parameters

A chart outlining the media collected and sample analysis methodology will be included in the SAP.

PFOA and PFOS are the typical potential contaminants of concern (COCs) at PFAS sites, although laboratory reporting lists may include 12 to 26 PFAS compounds depending upon method and laboratory. An additional analysis that may be warranted is the sum of all PFAS present, either by total extractable fluorinated compounds (TOP analysis) or evaluation of total

fluorine by a method such as proton induced gamma-ray emission (PIGE). Both of these techniques can be followed by analysis of specific compounds, to assess the presence of precursors in environmental media that are not captured by the compound specific methods.

Parameters will be identified by either laboratory analysis methodology number, or generally accepted name of analysis. Given the different methods currently available for sampling PFAS, there must be a clear understanding between the project manager and the laboratory providing the analysis as to what the media sampled, test methodology, and detection levels will be.

Table 1 provides several current methods with their associated media:

TABLE 1
Media/Analytical Methodology

MEDIA	LABORATORY METHOD	HOLD TIME*/ PRESERVATION	ANALYSIS TIME	Reporting List
Drinking Water**	USEPA Method 537	14 days to extraction/Trizma***	28 days after extraction	Method specific
Groundwater	Modified Method 537	14 days to extraction/<6°C	28 days after extraction	DEP Minibid list ****
Surface Water	Modified Method 537	14 days to extraction/<6°C	28 days after extraction	DEP Minibid list ****
Soil/Sediment/sludge	Modified Method 537	14 days to extraction/<6°C	28 days after extraction	DEP Minibid list ****
Other (vegetation…)	Modified Method 537	Lab specific	Lab specific	DEP Minibid list ****
Water or Soil	TOP or other total fluorinated analysis	Lab specific/<6°C	Lab specific	Method specific

* Hold times may vary with contracted laboratory
** USEPA 537 is the only certified method for drinking water
*** Trizma needed for samples that may contain residual chlorine from treated water sources
*** Longer reporting lists may vary between laboratories, generally the DEP mini-bid list can be used for comparison to other selected laboratories

Other methods may be appropriate based on the data quality objectives of the sampling project.

The contracted analytical laboratory must be Maine certified to perform any method for which Maine provides certification. The contract lab must be able to accommodate the sample load and perform the analyses within holding times. The contract lab must be able to achieve PQLs, for all analyses, which are below the associated regulatory guideline value.

Deviations can be made from the laboratory method on a site or event specific basis, based on the goals of the sampling, end use of the data, and the data quality objectives. Rationale for deviations from these methods should be described in the SAP and/or the final report.

As with all parameters, containers, preservation, and holding times will be as recommended by the laboratory providing analytical services. Special or out of the ordinary containers or preservation should be noted in the SAP.

3.4 FIELD QC SAMPLES

Sample collection for PFAS analysis does not require specific field QC samples outside the normal requirements.

General recommendations for all sampling include one aqueous field blank, per field event, to be analyzed for PFASs to determine if water samples have been contaminated by sources unrelated to the project area, and to assess the overall field procedures. An equipment blank may be needed if non-dedicated equipment is used. The field blank is typically one bottle of PFAS-free water supplied by the laboratory, which is uncapped and poured to a second bottle. For multi-day events, one blank per day should be considered. If non-disposable equipment is used a PFAS-free water equipment blank is warranted to check field decontamination procedures.

4.0 PFAS SPECIFIC TEMPLATE

In the instances of a PFAS only sampling event, in which samples are being collected from a project which has a history of sampling for other analytes and a well-developed conceptual site model and/or an SAP already exists, a PFAS sampling specific template has been developed which provides the general requirements of a sampling plan. This template can be found in Attachment A of this Addendum.

5.0 REPORT GENERATION

As stated in SOP RWM-DR-014, A Sampling Event Trip Report (SETR) will be developed for every sampling event (see MEDEP/DR SOP# RWM-DR-013). The staff person responsible for developing the SETR will be stated in the SAP. Data obtained as part of the SAP will be assessed in the final report for which the data has been collected.

ATTACHMENT A
PFOA SAMPLING AND ANALYSIS PLAN FORM TEMPLATE

1.1 INTRODUCTION

The introduction will state the objectives of the sampling plan which include:

- Goals of the sampling plan;
- End use of data.

2.0 BACKGROUND INFORMATION

A BRIEF explanation of the background of the Site and/or conceptual site model (CSM) and reason for sampling for PFAS will be presented.

3.0 SITE SPECIFIC HEALTH AND SAFETY PLAN

If determined necessary, a Site Specific Health and Safety plan (HASP) will be developed and attached.

4.1 SAMPLING METHODOLOGY/ EQUIPMENT

A description of the sampling methodology will be included in the SAP. In instances where a MEDEP/DR SOP is available, reference to SOPs by either name or document number is sufficient.

Currently, the MEDEP/DR QAP has SOPs for the following sample collection tasks which may be pertinent to PFAS sampling:

- 001-Water-Sample-Colllection-From-Water-Supply-Wells;
- 002-Groundwater-for-Site-Investigation;
- 003-Low-Flow-Groundwater-Sampling;
- 004-surface-water-sediment;
- 006-soil-sampling;
- 010-Container-Sampling;
- 015-Incremental-sample-methodology;
- 023-Pore-Water-Sampling.

Other SOPs may be utilized on a project specific basis if MEDEP/DR does not have a current SOP for sampling a particular media or situation. Prior Department approval is necessary.

Prior to sampling each location the sample handler must wash their hands and don nitrile gloves. PFAS contamination during sample collection can occur from a number of common sources, including food packaging and certain foods and beverages. Proper hand washing and wearing nitrile gloves will help to minimize this type of accidental contamination of the samples.

Some sampling equipment, field supplies, field clothing and personal protective equipment are prohibited when sampling for PFAS. T able 1 outlines the prohibited items. This table must be included in the SOP and field staff informed as to what equipment is allowed.

Table 1: Summary of Prohibited and Acceptable Items for Use in PFAS Sampling

Prohibited Items	Acceptable Items
Field Equipment	
Teflon® containing materials. Aluminum foil.	High-density polyethylene (HDPE) and stainless steel materials
Storage of samples in containers made of LDPE materials	Acetate direct push liners
Teflon® tubing	Silicon or HDPE tubing
Waterproof field books. Water resistant sample bottle labels.	Loose paper (non-waterproof). Paper sample labels covered with clear packing tape.
Plastic clipboards, binders, or spiral hard cover notebooks	Aluminum or Masonite field clipboards
	Sharpies®, pens
Post-It Notes	
Chemical (blue) ice packs	Regular ice
Excel Purity Paste TFW Multipurpose Thread Sealant Vibra-Tite Thread Sealant	Gasoils NT Non-PTFE Thread Sealant Bentonite
Equipment with Viton Components (need to be evaluated on a case by case basis, Viton contains PTFE, but may be acceptable if used in gaskets or O - rings that are sealed away and will not come into contact with sample or sampling equipment.)	
Field Clothing and PPE	
New clothing or water resistant, waterproof, or stain treated clothing, clothing laundered with fabric softeners, clothing containing Gore-TexTM	Well-laundered clothing, defined as clothing that has been washed 6 or more times after purchase, made of synthetic or natural fibers (preferable cotton)
Clothing laundered using fabric softener	No fabric softener
Boots containing Gore-TexTM	Boots made with polyurethane and PVC
	Reflective safety vests, Tyvek®, Cotton Clothing, synthetic under clothing, body braces
No cosmetics, moisturizers, hand cream, or other related products as part of personal cleaning/showering routine on the morning of sampling	**Sunscreens** - Alba Organics Natural Sunscreen, Yes To Cucumbers, Aubrey Organics, Jason Natural Sun Block, Kiss my face, Baby sunscreens that are “free” or “natural” **Insect Repellents** - Jason Natural Quit Bugging Me, Repel Lemon Eucalyptus Insect repellant, Herbal Armor, California Baby Natural Bug Spray, BabyGanics

	Sunscreen and insect repellant - Avon Skin So Soft Bug Guard Plus – SPF 30 Lotion
Sample Containers	
LDPE, glass containers or passive diffusion bags.	HDPE (any media) or polypropylene (only for EPA Method 537 samples)
Teflon®-lined caps	Lined or unlined HDPE or polypropylene caps
Rain Events	
Waterproof or resistant rain gear	Polyurethane, vinyl, wax or rubber-coated rain gear. Gazebo tent that is only touched or moved prior to and following sampling activities
Equipment Decontamination	
Decon 90	Alconox® and/or Liquinox®
Water from an on-site well	Potable water from municipal drinking water supply (if tested as PFAS-free)
Food Considerations	
All food and drink, with exceptions noted on the right	Bottled water and hydration drinks (i.e. Gatorade® and Powerade®) to be brought and consumed only in the staging area

It is recommended that all water samples will be collected using dedicated or disposable sampling equipment where possible. Any re-usable equipment, such as plumbing fittings, that may be needed in certain cases to obtain a sample from the pressure tank tap, should be deconned using Alconox/Liquinox soap and rinsed with DI or PFAS-free water prior to use and between locations.

5.0 Sample Locations

A map showing planned sampling locations will be included in the sampling plan. If locations are not pre - determined, the method that samples will be chosen and collected (field observations, random, etc.) will be outlined in the SAP. Field or laboratory compositing procedures will also be described, if applicable.

This section should also indicate sampling collection priority and order, to assure that the most important samples are obtained, and that sampling is generally done from low areas of contamination to higher levels of contamination. It is recommended that critical samples be collected in duplicate.

6.0 Media Sampled

A chart outlining the media collected and sample analysis will be included in the SAP. Table 2 provides several current methods with their associated media:

TABLE 2
Media/Analytical Methodology

MEDIA	LABORATORY METHOD	HOLD TIME*/ PRESERVATION	ANALYSIS TIME	Reporting List
Drinking Water	USEPA Method 537	14 days to extraction/Trizma**	28 days after extraction	Method specific
Groundwater	Modified Method 537	14 days to extraction/<6°C	28 days after extraction	DEP Minibid list ***
Surface Water	Modified Method 537	14 days to extraction/<6°C	28 days after extraction	DEP Minibid list ***
Soil/Sediment/ Sludge	Modified Method 537	14 days to extraction/<6°C	28 days after extraction	DEP Minibid list ***
Other (vegetation…)	537 Modified	Lab specific	Lab specific	DEP Minibid list ***
Water or Soil	TOP or other total fluorinated analysis	Lab specific/<6°C	Lab specific	Method specific

* Hold times may vary with contracted laboratory, listed times from Vista Analytical Inc.
** Trizma needed for samples that may contain residual chlorine from treated water sources
*** Longer reporting lists may vary between laboratories, generally the DEP mini-bid list can be used for comparison to other selected laboratories

Other methods may be appropriate based on the data quality objectives of the sampling project.

The contracted analytical laboratory must be Maine certified to perform any method for which Maine provides certification. The contract lab must be able to accommodate the sample load and perform the analyses within holding times. The contract lab must be able to achieve PQLs, for all analyses, which are below the associated regulatory guideline value.

Containers, preservation, and holding times will be as recommended by the laboratory providing analytical services. Special or out of the ordinary containers or preservation should be noted in the SAP.

7.0 FIELD QC SAMPLES

The specific needs for QC samples for the project will be outlined. General requirements for PFAS sampling events include one aqueous field blank, per field event, to be tested for PFASs to determine if water samples have been contaminated by sources unrelated to the project area, and to assess the overall field procedures. The field blank is typically one bottle of PFAS-free water supplied by the laboratory, which is uncapped and poured to a second bottle. An equipment blank should be collected if non-dedicated equipment is used. For multi-day events, one blank per day should be considered, and for large events one blank per 10 or 20 samples is warranted, depending upon the project requirements. All blanks should be collected with laboratory supplied PFAS-free water. A source-water blank is handled like a trip blank, and assesses the laboratory supplied water and sample containers. This blank may be warranted depending on DEP experience with the laboratory or sensitivity of the project.

Additionally, any QC samples that will be collected in the field that are required as part of laboratory QC requirements and to allow data validation will be outlined.

4.9 REPORT GENERATION

A Sampling Event Trip Report (SETR) will be developed for every sampling event (See MEDEP/DR SOP# RWM-DR-013). Staff person responsible for developing the SETR will be stated.

LABORATORIES APPROVED BY DEP FOR PFAS ANALYSIS

Alpha Analytical

72 Center Street, Suite 3, Brewer, ME 04412
Contact name: Stephen Knollmeyer
Email address: sknollmeyer@alphalab.com
Phone: (603) 498-7213

222 International Drive, Suite 155, Portsmouth, NH 03801
Contact name: Melissa Gulli
Email address: mgulli@alphalab.com
Phone: (603) 319-5010

ALS Environmental

1317 South 13th Avenue, Kelso, WA 98626
Contact name: Howard Boorse
Email address: Howard.Boorse@alsglobal.com
Phone: (360) 577-7222

Eurofins Lancaster

2425 New Holland Pike, Lancaster, PA 17601
Contact name: Jane Huber
Email address: JaneHuber@EurofinsUS.com
Phone: (717) 209-1438

Eurofins TestAmerica Laboratories, Inc

880 Riverside Parkway, West Sacramento, CA 95605
Contact name: Debby Wilson
Email name: Debby.Wilson@testamericainc.com
Phone: (949) 260-3228

SGS AXYS

2045 Mills Road West, Sidney, British Columbia, Canada V8L 5X2
Contact name: Nicholas Corso
Email address: nicholas.corso@sgs.com
Phone: (250) 655-5800

SGS North America, Inc

4405 Vineland Road, Orlando, FL 32811
Contact name: Geoffrey Pellechia
Email address: Geoffrey.pellechia@sgs.com
Phone: (508) 630-4940

Vista Analytical Laboratory, Inc

1104 Windfield Way, El Dorado Hills, CA 95762
Contact name: Jennifer Miller
Email address: jmiller@vista-analytical.com
Phone: (916) 673-1520

Science of the Total Environment 724 (2020) 138334

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Transfer and transport of microplastics from biosolids to agricultural soils and the wider environment

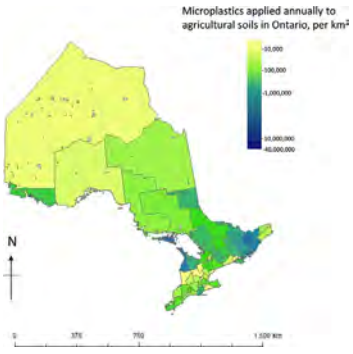
Jill Crossman [a,*,1], Rachel R. Hurley [b,1], Martyn Futter [c], Luca Nizzetto [b]

[a] School of the Environment, University of Windsor, Sunset Avenue, Windsor, Ontario N9B 3P4, Canada
[b] Norwegian Institute for Water Research (NIVA), Gaustadelléen 21, 0349 Oslo, Norway
[c] Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Science, Uppsala, Sweden

HIGHLIGHTS

- Microplastic (MP) concentrations of up to 1.4×10^4 MP kg^{-1} were found in biosolids.
- Storage of biosolids should be explored as a method for reducing biosolids' MP content.
- Some MP fibers are retained in soils, while fragments are predominantly exported.
- >99% of MPs applied from biosolids were likely exported to the aquatic environment.
- Biosolids application legislation may need revisions to incorporate MP management.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 January 2020
Received in revised form 28 March 2020
Accepted 29 March 2020
Available online 1 April 2020

Editor: Damia Barcelo

Keywords:
Microplastics
Soil
Agriculture
Biosolids
Management
Export
Aquatic

ABSTRACT

Between April to November of 2017, microplastics (MPs) were analysed in biosolids from two separate suppliers, and in the soils of three agricultural fields to which they were applied, in Ontario, Canada. Soils of a control site with no history of biosolid application were also examined. High MP concentrations of between 8.7×10^3 MP kg^{-1} and 1.4×10^4 MP kg^{-1} were found in biosolids samples. Lower MP concentrations observed in Provider 2 biosolids may be due to storage, settling and supernatant removal prior to applications. Annual MP additions to agricultural soils across Ontario were estimated at between 4.1×10^{11} and 1.3×10^{12} particles. All fields receiving biosolids had higher soil pre-treatment MP concentrations than the control. The field with the greatest number of previous biosolid treatments had the highest pre-treatment soil MP concentrations; suggesting some MP retention in soils between applications. Immediately following biosolids applications, two fields demonstrated significant increases in soil MP concentrations, with preferential retention of MP fibers over fragments observed, while a reduction in soil MP concentrations were observed in the third. Surprisingly, only one field demonstrated a net gain in soil MPs over the course of the study. At all three fields, >99% of MPs applied in biosolids in 2017 were unaccounted for. The study suggests that despite adhering to applicable legislation, biosolids applications at all sites likely result in high rates of MP export. This study is the first to track MP transport through soils following their application in biosolids, and contributes to filling current knowledge gaps regarding export of MPs to aquatic systems from the terrestrial environment.

* Corresponding author.
E-mail address: jhc@uwindsor.ca (J. Crossman).
[1] These authors contributed equally.

https://doi.org/10.1016/j.scitotenv.2020.138334

1. Introduction

Plastic items with a longest dimension smaller than 5 mm are defined as microplastics (MPs) and include both intentionally manufactured particles (primary MPs) and those originating from the breakdown of larger macroplastics (secondary MPs). Although secondary MPs are more common in the environment, primary MPs have gained the greatest public attention, and been the target of most legislation and management (Rochman et al., 2015; Xanthos and Walker, 2017). Due to their ubiquitous presence in environmental matrices and potential interaction with biota, MPs have emerged as a serious global concern.

While the generation of MPs is largely terrestrial, their transmission to the aquatic environment is believed to be driven primarily by urban surface runoff and wastewater discharge (Galafassi et al., 2019). Large volumes of MPs can be removed, however, when stormwater runoff, industrial effluent and household drainage pass through wastewater treatment plants (WWTP) (Carr et al., 2016). Despite this, MP concentrations in lakes and oceans continue to rise; there are an estimated 2.69×10^5 tons of MPs in the ocean (Xanthos and Walker, 2017), and an average of 4.30×10^4 MP km^{-2} in the surface waters of the Laurentian Great Lakes (Eriksen et al., 2013).

Once removed from wastewater, MPs culminate in biosolids; a nutrient-rich semi-solid waste product, created during the wastewater treatment process. In many countries, biosolids are applied to agricultural lands as a soil amending agent and fertilizer (Nizzetto et al., 2016a). It has been calculated that each year farmed soils in North America may receive to up to 300,000 tonnes of MPs through biosolid applications (Nizzetto et al., 2016a), however very little is known about their fate and transport through the terrestrial environment (Nizzetto et al., 2016a; Rocha-Santos and Duarte, 2015; Rillig, 2012; Ng et al., 2018; de Souza Machado et al., 2018). Specifically, no empirical information is available on whether subsequent to biosolids application, the soils act as an MP source to rivers and lakes, with MPs moving laterally towards watercourses; or whether soils act as a sink, with downward vertical movement dominating. Under repeated biosolids applications, some MPs may be retained in soils, which could result in significant MP accumulation over time (Brodhagen et al., 2017; Corradini et al., 2019), although MP retention has not yet been quantified. While the notion of a soil MP 'store' might be desirable for reducing transfer of MPs to aquatic systems, the permanence of such a store and its impacts on plant growth, soil biota and overall soil health are largely unknown.

Through the analysis of 1300 soil samples collected before, during and after biosolids applications from three cultivated fields and from one control site in 2017 (Fig. 1), in addition to samples of the biosolids applied, we aimed to quantify the spatial and temporal variability in MP fate and transport through agricultural soils in Ontario, Canada. Key objectives were to 1) identify MPs in biosolids applied to agricultural soils; 2) quantify impacts of biosolid applications on the MP content of agricultural soils; and 3) to identify biosolids management strategies to reduce MP inputs to agricultural soils.

2. Methods

2.1. Site description

Four agricultural fields in Ontario, Canada, were studied. Three active treatment sites were sampled (Field 1, Field 2 and Field 3) where biosolids had been previously applied between 2012 and 2016, and where applications were planned for 2017. A fourth control field with no history of biosolids use was selected within the same region. Proximity was important for minimizing between-site variability in exposure to airborne MP contamination. All sites were located proximal to tributaries which drained into large economically important waterbodies (Lake Simcoe and Lake Scugog) and were situated in sandy loam soils (Fig. 1).

Field 1 (10.24 ha) and Field 3 (34.4 ha) were treated with biosolids from the same supplier (Provider 1) whereas biosolids applied to Field 2 (26.1 ha) were supplied by a separate haulage company (Provider 2). Although the two providers obtained biosolids from different WWTPs, all treatment plants had separate stormwater and sanitary systems and served similar sized cities (≈140,000 people). There are, however, notable differences in biosolid treatment and storage methods between WWTPs. The WWTP supplying Provider 1 anaerobically digests solids in mixing tanks, whereas the WWTP supplying Provider 2 uses an additional aeration pre-treatment process to promote bacterial breakdown. Provider 1 transports biosolids directly from the WWTP to the fields on the day of application and incinerates waste from fall to spring when biosolids spreading is prohibited. Provider 2 collects biosolids from a centralized facility, used year-round by the WWTP for biosolid storage and settling (Albert, 2013), where the top liquid supernatant is syphoned off and returned to the WWTP for additional treatment. Thus, Provider 2 uses only the thicker portion of the settled biosolids for land applications.

In Ontario, biosolids may be either surface applied or injected into the soils, although restrictions exist as to time and conditions of use (Ontario Nutrient Management Act, 2002). Permitted application rates vary depending on soil saturation levels, season, proximity to watercourse and slope. Opportunities to apply biosolids were limited in early 2017 by heavy and frequent rainfall, resulting in soil saturation. Soil conditions improved sufficiently by April 27th for treatment to proceed at Field 3, where Provider 1 applied biosolids to the surface using precision methods with a tanker and hose, simultaneously applying and ploughing biosolids into the top soil layer. At the other two treatment sites, conditions were unfavorable for surface application until May 23rd (Field 2, Provider 2) and June 13th (Field 1, Provider 1), by which time crops had already been planted, precluding post-application ploughing. At all sites, heavy rainfall events combined with high runoff volumes were observed shortly after application. Application rates and total amounts of biosolids applied are summarized in Table 1.

2.2. Sample collection

A cylindrical stainless steel corer, 5x8cm was used to extract soil samples from three depths; 0–5 cm, 5–10 cm and 10–15 cm. Soil samples were not taken below 15 cm due to heavy soil compaction at all sites at this depth, making MP transport below this level unlikely. The 5 cm corer was chosen to minimize soil compaction during sampling. Samples from each profile depth were separately wrapped in aluminum foil on site, and frozen until analysis. Soil samples were taken before, during and after biosolid application (Table S1). Following biosolids application, soil samples were taken monthly and following heavy rainfall events. Coring locations were selected according to observed field characteristics. Fields 2 and 3 had relatively steep slopes and a clear ridge and furrow pattern. At these fields, on each collection date 11 cores were taken across a transect at each profile depth (between two ridges and furrows), and four additional cores collected at each profile depth across ridges and furrows at the highest and lowest points of the field. Field 1 and the control site were predominantly flat, with less variable microtopography (i.e., no ridge or furrow patterns). In these fields, 14 soil cores were taken at each depth on each collection date. Locations of soil cores in these fields were randomly selected, although the existence of dense alfalfa crops in Field 1 restricted sampling to the southern field perimeter. Biosolid samples were also collected directly from the trucks and hoses during application. Three to five liters of biosolids were collected during each event and stored in a fridge prior to analysis.

Due to highly localized precipitation patterns and biosolids application times, sampling dates did not necessarily coincide at all sites. Precipitation was monitored using electronic tipping bucket rain gauges

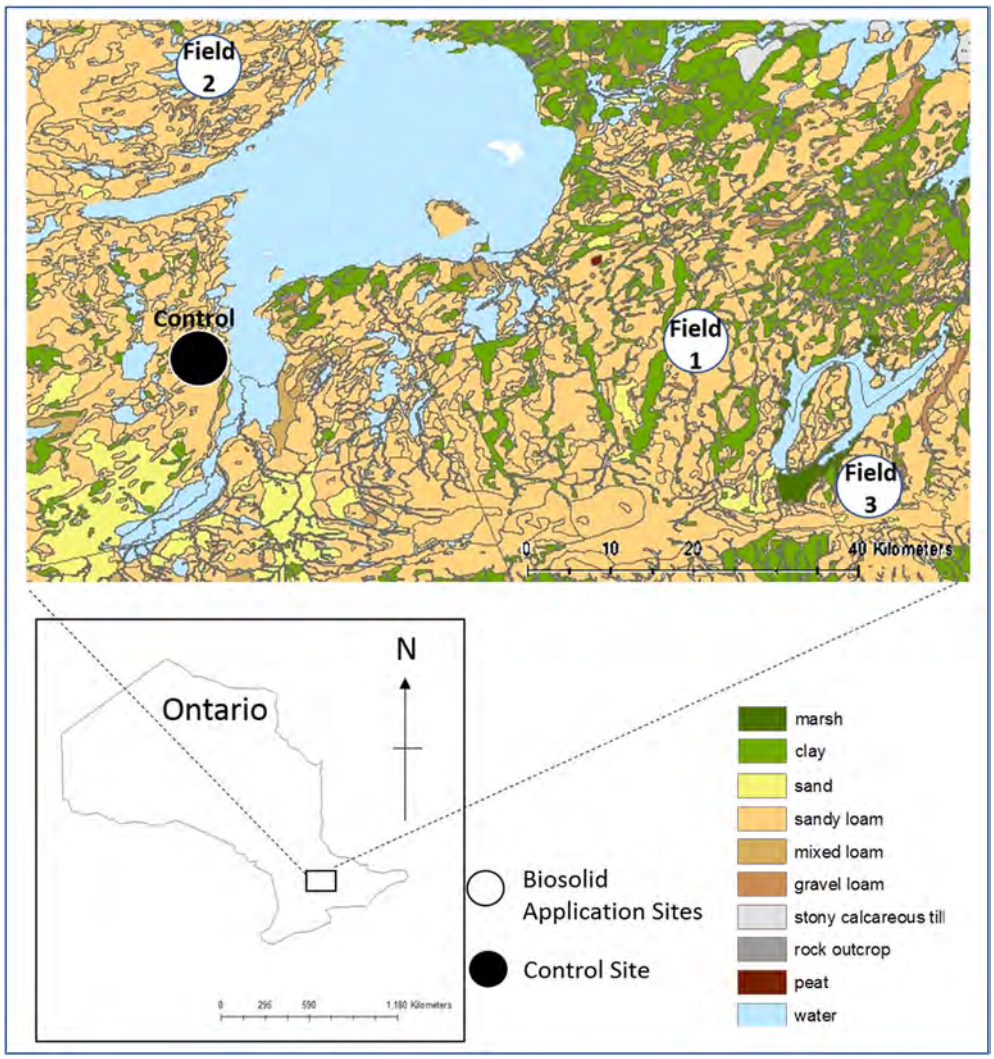


Fig. 1. Study sites, Ontario, Canada. Soils data derived from Soil Landscape of Canada Working Group (2010). Only approximate field locations are provided to ensure landowner anonymity.

installed in Fields 1 and 2. At the Control site and Field 3, established meteorological stations were used which were located within close proximity.

As with any field study, there remain limitations to the numbers of samples which can be collected. For example, fewer samples were taken from Field 3 due to limited site access. Every effort was made however to obtain a representative sample of the soil landscape, with over 1300 cores collected across the four fields. Through taking such a large number of samples, we incorporated variance in soil MP content across a range of soil depths, slope, ridges, furrows and general patchiness in soil matrices. This is the first MP study conducted within the soil environment at such a large spatial and temporal scale.

2.3. Analytical methods

At the University of Windsor, Ontario, soil samples were defrosted and 10 cm^3 selected for analysis from each core. This volume was weighed, and then placed in an oven at 65 °C until dry (with a minimum drying duration of 24 h). During drying, samples were covered with foil lids, with small holes inserted, to minimize likelihood of contamination.

Table 1
Biosolid application rates, and total amounts of MPs applied.

Site	Distance to water	Area (ha)	Biosolids provider	Biosolids application rate[a] (m^3 ha^{-1})	Application method	Total biosolids applied (m^3)	Biosolids dry weight MP concentration (MP kg^{-1})	Biosolids dry weight MP mass (mg kg^{-1})	Biosolids wet weight MP content (MP L^{-1})	Total number of MPs applied to field
Field 1	<150 m	10.24	1	78	Surface	799	11,469.4	Min: 1180 Max: 1276	686	5.48×10^8
	>150 m	N/A	1	N/A						
Field 2	<150 m	3.79	2	75	Surface	3183.2	8678	Min: 626 Max: 654	275	8.74×10^8
	>150 m	22.39	2	130						
Field 3	<150 m	3.67	1	74	Surface with post-application ploughing	4258.7	14,407	Min: 471 Max: 536	884	3.77×10^9
	>150 m	30.67	1	130						

[a] Biosolid application rates for Field 1 and 3 were supplied by Provider 1. Application rates for Field 2 were derived from regulatory guidelines (Ontario Nutrient Management Act, 2002).

Soil dry weights were calculated, and a composite sample for each field and sampling event created by combining dry samples from the same depth; resulting in 3 dried soil samples for each site sample date; vis, a 0–5 cm, 5–10 cm and 10–15 cm sample. Total volumes of biosolids sampled at each field were measured in a volumetric flask. Samples were poured into aluminum trays, covered, oven dried at 65 °C and then weighed. Temperatures were maintained ≤65 °C at all times to minimize plastic degradation. Finally, all dried samples were wrapped in aluminum foil, inserted in paper sampling bags, and shipped to the Norwegian Institute for Water Research (NIVA) for separation and identification of MPs.

As MPs in this study are encased in organic matrices (soils and biosolids), several processing steps are required for extraction including organic matter digestion, density separation, microscopic selection of MPs and identification of polymer types. All samples were first treated to remove organic matter using Fenton's reagent for digestion, following Hurley et al. (2018). MPs were then isolated from the sediment matrix through a series of density separations (SI). Following extraction, MPs were first visually identified using a Nikon SMZ 745T stereomicroscope at 20–40× magnification. Larger microplastics >300 μm, excluding fibers, were analysed on an Agilent Cary 630 single bounce ATR-FTIR. All smaller particles and fibers were analysed on a PerkinElmer Spotlight 400 μFT-IR. Spectra were compared to several libraries: including the Agilent Polymer and Elastomer, Oring and Seal ATR, PerkinElmer ATR Polymer, and BASEMAN libraries (Primpke et al., 2018). The a, b and c axis of each identified particle was recorded and used to establish particle volume, to facilitate a mass-based conversion between particle counts and particle masses. A detailed methodological description is provided in SI, including quality assurance and control (QA/QC) measures. Raw MP data are reported in Tables S5 and S6.

2.4. Contamination control

Throughout the study, care was taken to minimize MP contamination. During sample collection and drying, only glass or metal containers and instruments were used. Containers and instruments were prewashed with millipore water. Samples were covered where possible using aluminum foil or glass. At NIVA, sample processing and analysis was performed using a series of QA/QC measures, including measures to limit contamination, and the use of controls (SI), both positive (spiked matrix samples) and negative (blanks). The positive controls confirmed high extraction efficiencies for different particle types (PE beads: 97.3% ± 4.67%; PVC fragments: 92.7% ± 6.17%; Car tyre particles: 88.2% ± 5.75%; PET fibers: 80.0% ± 9.53%). For negative controls, only cellulosic particles were observed in biosolid samples, although viscose fibers were identified in soil samples. As viscose fibers represent <3% of MP types found within the soil samples, they were excluded from the dataset to account for a possible lab contamination source.

2.5. Data analysis

Three replicates of each composite soil sample were analysed, with dry weights between 19.3 and 30.8 g. The size, type (fragment/fiber), and polymer of each MP was recorded. Concentrations of MPs kg^{-1} in dried biosolid or soil were calculated by dividing the number of MPs in the replicate by the dried weight of the sample analysed. MP concentration L^{-1} of biosolid was calculated by dividing the number of MPs in the sample by the volume of sample analysed. Average MP concentrations and standard errors were calculated for the three replicates. Changes in MP distribution were calculated as the difference in MP soil concentrations at each soil depth between the baseline (before biosolid application) and date of sampling. MP accumulation was calculated as the sum of observed changes in MP distribution (positive and negative) over all soil depths, across the study period.

3. Results and discussion

3.1. Microplastics in biosolids

Microplastics were found in all biosolid samples (Fig. 2, Table 1). The highest dry and wet weight concentrations were found in biosolids supplied by Provider 1, applied to Field 1 (11,469 MP kg^{-1} or 686 MP l^{-1}) and Field 3 (14,407 MP kg^{-1} or 884 MP L^{-1}). The lowest concentrations were found in biosolids supplied by Provider 2, and applied to Field 2 (8678 MP kg-1 or 275 MP L^{-1}), and were significantly lower than those applied to Field 3 ($p < 0.01$). This range of concentrations is similar to those reported elsewhere (Primpke et al., 2018). Total numbers of microplastics applied to the fields ranged between 5.5×10^8 and 3.8×10^9 (Table 1).

The lower MP concentrations in biosolids from Provider 2 may be a result of several factors. First is the possibility of a difference in initial MP inputs to WWTPs; although treatment plants serve similar population sizes and have separate stormwater and sanitary systems. Second is the potential for differences in MP removal efficiency, i.e., the WWTP supplying Provider 2 may release more MPs in effluent and retain less in biosolids. High spatial and temporal variability in removal efficiency has been reported previously, e.g. between 54 and 91% MP removal efficiency was reported over 5 days in a Turkish WWTP (Gündoğdu et al., 2018) compared to a much more consistent 97–99% efficiency observed over a 13 day period in Canada (Gies et al., 2018). While this could partially explain the two-fold differences in biosolid MP concentrations measured in this study, short term variability in removal efficiency would likely have a minimal impact on biosolid MP concentrations, as biosolids are created from cumulative contributions from effluent flow over time. The third possibility is the difference in storage mechanisms; whereby Provider 2 used biosolids only after long-term storage and settling, and Provider 1 used materials directly from the WWTP. This settling process, in which the liquid fraction is syphoned off for re-treatment, equates to a form of density separation. As many plastic polymers are less dense than water (Nizzetto et al., 2016b), it is likely that MPs would be removed from biosolids during this process. The results indicate that long-term storage could be a possible mechanism for biosolid MP concentration reduction, and further research is therefore required to isolate the mechanisms causing variability in biosolids' MP concentrations between sources.

Several of the polymers identified in biosolids were found to be common between sources (Fig. 3, Table S2); polyethylene was found in similarly high concentrations in all samples from both providers, ranging from 4772 MP kg^{-1} (Provider 1) to 3926 MP kg^{-1} (Provider 2). Polypropylene, acrylics and polyesters were also found in high concentrations in all biosolids samples. Concentrations of other plastics common to all samples e.g. silicone, polyurethane, and ethyl-vinyl acetate were significantly lower in biosolids from Provider 2, at less than 30MP kg^{-1}, compared to up to 870MP kg^{-1} in biosolids from Provider 1. Furthermore, some plastic polymers found within Provider 1 biosolids samples at over 100MP kg^{-1} were entirely absent in biosolids from

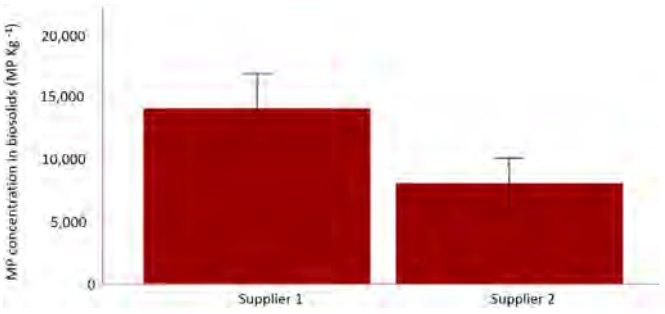


Fig. 2. MP concentrations in biosolids observed during 2017. Total samples analysed = 11. Error bars represent ± 1 Standard Error.

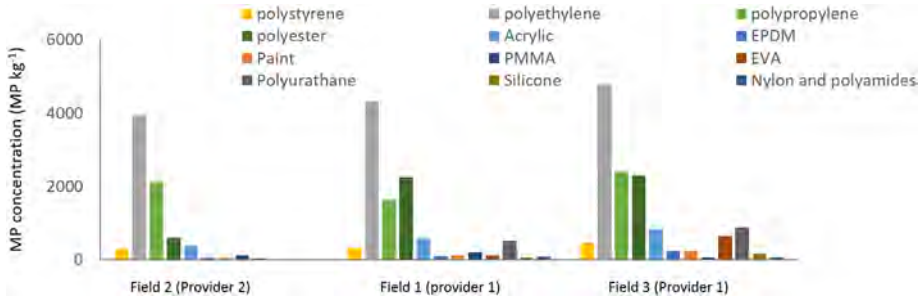


Fig. 3. Common types of plastics found in all biosolids from both providers applied to different fields.

Provider 2, including polycarbonate, polybutylene terephthalate, ethylene propylene rubber (EPR) and fluoroelastomers. These differences may again be due to the storage and density separation methods of Provider 2; since several of these polymers have a density less than or close to that of water, they are likely to have been preferentially removed during the settling process prior to application. Differences could also result from contrasting industrial inputs to the WWTPs, with Provider 1 receiving inputs from the automotive industry, and manufacturers of mining and railway equipment, steel fabrication and rubber products; and Provider 2 receiving inputs from manufacturers of motor vehicle parts, plastics, cement and concrete products.

All biosolids applied to Fields 1, 2 and 3 contained a similar dominance of fragments over fibers, with fragment content ranging from between 63% (Field 1) and 73% (Fields 2 and 3). This supports existing observations of preferential release of fibers in WWTP effluent waters (Sutton et al., 2016) and retention of fragments in biosolids (Weithmann et al., 2018).

3.2. Microplastics in soils

Soil MP concentrations prior to biosolid application were significantly different, both between depths and between sites (Fig. 4). Soils at Field 3 contained the highest number of MPs before application (average 541 MP kg^{-1}), with the control having the lowest (average 4 MP kg^{-1}). Biosolids were previously applied in 2013 and 2015 to Field 3, but only on one prior occasion on Fields 1 and 2; and there was no record of applications at the control site. High residual MP levels at Field 3, both in terms of MP numbers and MP mass (Table S3) may therefore represent accumulation of MPs from previous applications. Such accumulations have been hypothesized through laboratory experiments (Zubris and Richards, 2005) although not previously empirically observed in the environment.

Similar to the biosolids, high proportions and high concentrations of polypropylene, polyethylene, polyesters and acrylic were found in soils at all treated sites (Table S4). Soils also contained some of the polymers which were unique to individual biosolids providers. For example, poly butylene terephthalate (PBT) was found only in biosolids and soils from

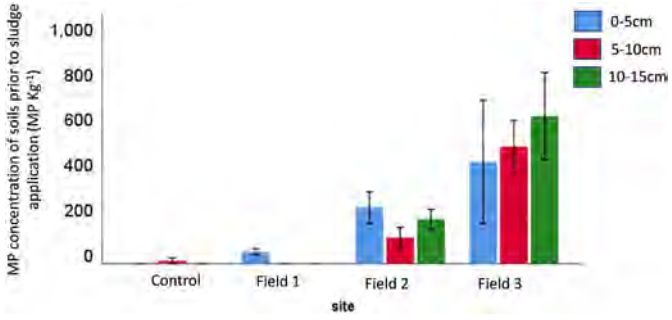


Fig. 4. Total MP concentrations in soils prior to 2017 biosolid application. Error Bars = ±1 standard error.

Provider 1, and polyvinyl chloride acetate (PVCA) was found only in biosolids and soils from Provider 2. The similarity in MP polymer types between individual biosolid sources and the soils to which they were applied indicates direct transfer and retention of plastic polymers between biosolids and agricultural soils. Much higher proportions of polyester MP fibers were found in soils (41–45%) (Fig. S1) than in original biosolid applications (8–21%). The higher dominance of polyester MP fibers in all soil sites, including the control, compared to biosolids, indicates that polyester MPs from an alternate source, e.g. atmospheric deposition, are preferentially retained in the soil profile.

Following biosolids applications, an immediate increase in soil MP concentration was observed at both Field 1 and Field 2 (Fig. 5), whereas no increase was seen in Field 3, despite the higher MP concentration and quantity of biosolids applied at this site. At Field 1, elevated soil MP concentrations persisted throughout the study period, amounting to a net increase of 41% compared to pre-treatment concentrations (Table 2); although after 2 months the majority of the increase was limited to the bottom 10–15 cm, in contrast to the upper soil layer (0–5 cm) that displayed a partial loss of MPs during this period. Biosolids were applied to this field via surface spreading on established crops, with no subsequent ploughing; and the initial MP accumulation in upper soil layers, followed by its decline and sustained accumulation in deeper layers is consistent with a downward movement of MPs. Unique polymers found both in the biosolids and soil profile indicate that MPs found in Field 1 originate from Provider 1 (Table S4).

In Field 2 biosolids applications were also surface spread without ploughing, subsequent to crop planting. Initial MP enrichment in upper soil layers was also observed here for seven weeks. Beyond this timeframe, a net loss of MPs compared to the pre-application phase was observed from the top layer. Unlike Field 1, however, this loss was not matched by concomitant MP increases in lower layers, suggesting limited MP infiltration, followed by removal during runoff events. Throughout the study period, a net loss of 30% MPs was observed throughout the soil profile at this site (Table 2). In Field 3 the sustained MP losses of 45%, and absence of unique MPs matching Provider 1 biosolids, suggests that the majority of MPs from biosolids were removed during early surface flushing events following application. Field 3 was the only field where biosolids were applied with ploughing and prior to crop establishment. High rainfall following biosolids application may account for the lack of MP accumulation during 2017. Considering the high historical MP accumulation in soils in Field 3, however, it appears that such flushing is not a common occurrence at this site.

As between 5.5×10^8 and 3.8×10^9 MPs were applied through biosolids to each site during the study period, this small net increase, and large net reductions in soil MP concentrations indicate that between 99% (Field 1) and >102% (Fields 2 and 3) of the MPs applied in biosolids were unaccounted for during soil sampling, and were likely ultimately exported from the soils, where >100% indicates that both biosolids and existing baseline MPs were removed. Surprisingly, net soil MP accumulation was lowest where the highest biosolid MP concentrations and volumes were applied (Field 3; Table 2), indicating that the response of soil MP concentrations to applications through biosolids is not solely

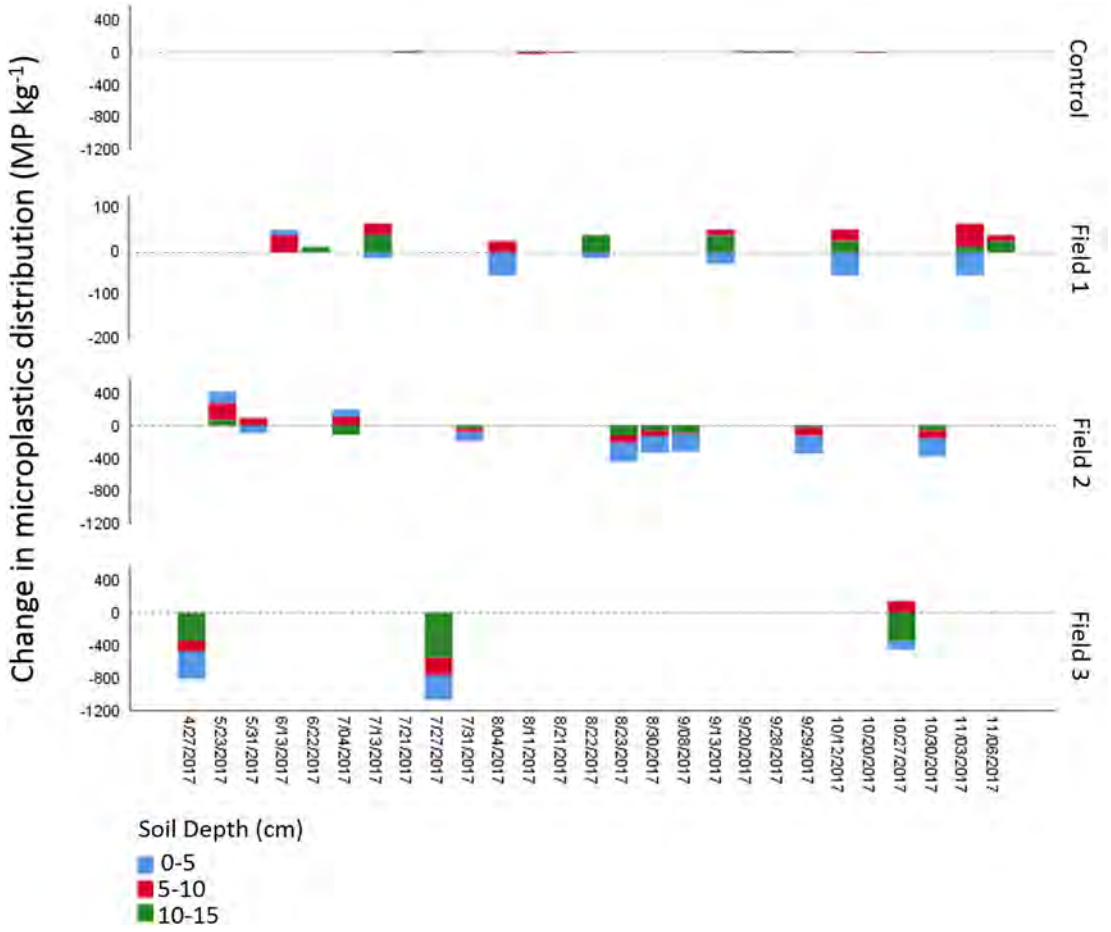


Fig. 5. Change in distribution of microplastics over time by soil depth. The change in distribution is calculated as MP numbers counted in soils prior to biosolids applications, subtracted from those identified after its application. Negative values indicate a reduction in MPs compared to the baseline; positive values indicate an increase. Note the larger scale axis for Field 1.

driven by the quantity of material used, but is influenced by a number of factors which affect subsequent MP mobilization within the soil. For instance, there is significant negative correlation between soil MP retention and soil wet density (Fig. 6). Fields 1 and 2 which retained MPs at deeper layers (Fig. 5), and which lost fewer MPs throughout the study period (Table 2) had significantly lower soil density than Field 3; which demonstrated no retention of MPs. The soil density is associated with its hydraulic properties. With higher density, and by association, fewer void spaces, MPs in Field 3 may have been subject to greater losses from surface runoff (Zemke et al., 2019) particularly during the unusually high rainfall events of 2017, with accumulation demonstrated in much drier years (Fig. 7). Applications of biosolids at Field 3 also occurred much earlier in the year (April) which likely increased the MPs exposure to these high rainfall amounts and saturated soils. Precipitation in April to June was more than double that in July; thus in Fields 1 and 2 where biosolids were applied later in the season, they were exposed to less rainfall, lower soil saturation, and were more easily able to move vertically through the soil profile. Pre-establishment of crops (Fields 1 and 2) could also facilitate vertical transport through bioturbation (Horton and Dixon, 2017) and preferential flow pathways enhanced by root growth; as it has been suggested that MP movement through soils could be impacted by soil macropores, strength of the soil matrix, accumulation within organic matter, and movement by soil biota (Rillig et al., 2017).

In all fields an increase in the proportion of MP fragments, a key characteristic of biosolids used, was noted either during or shortly following applications; although in Field 2 the increase was not observed until a full month after treatment (Fig. 8). Increases in fragments ranged

Table 2
Net change in average soil MP concentrations calculated between samples taken before and after spring applications of biosolids in 2017, including % relative error calculated across sample replicates and depth, measured as site average MP concentration divided by total range of MP concentrations.

Site	MP concentration (MP kg^{-1})		Net change	
	Before application	After	MP kg^{-1}	% increase
Field 1	18 ±22.2%	25 ±20.8%	7 ±43%	41 Min: 24% Max 59%
Field 2	187 ±53.1%	130 ±23.1%	−56 ±76%	−30 Min: −7% Max: −53%
Field 3	541 ±56.4%	298 ±39.1%	−244 ±95%	−45 Min: −2% Max: −88%

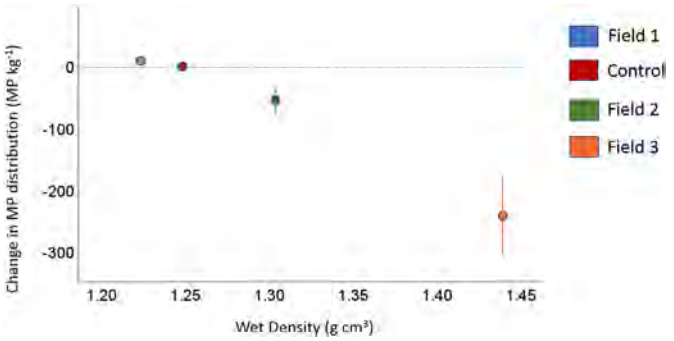


Fig. 6. Total change in microplastic distribution across all depths throughout the study period, by soil density. Error Bars = ±1 standard error.

from 4% (Fields 1 and 2) to 10% in Field 3. In Field 3 the increase was seen only during the application event itself, in comparison to Field 1 where the increase was sustained for several months. The eventual decline in proportion of fragments and increase in fibers in two of the three application sites might indicate that fragments from biosolids are preferentially transported out of the soil matrix, while fibers are retained. Previous studies on agricultural soils observed a high proportion of fibers, and suggested possible retention (e.g., Corradini et al., 2019; Zubris and Richards, 2005) due to entanglement within the matrix (Horton and Dixon, 2017).This study is the first empirical assessment of MP fragment and fiber transfer between biosolids and soils which is able to support this theory.

3.3. Wider implications

Total annual biosolid applications to agricultural land in Ontario, Canada (Central Lake Ontario Conservation Authority, 2007) have been estimated at 1.5×10^6 m^3. Using upper and lower biosolids MP concentrations from this study (Table 1), annual MP additions to agricultural soils in Ontario through biosolids use are between 4.1×10^{11} and 1.3×10^{12} particles (Fig. 9). Such high MP application rates, combined with the minimal capacity of soils to store MPs, as observed in this study, demonstrate the need for a targeted program for the protection of agricultural soils and the wider environment. For instance, results indicate that the long-term storage of biosolids and syphoning of supernatant liquid may be a relatively simple step which could reduce biosolid MP content and the quantities of MPs introduced to the environment.

4. Conclusion

This study reinforces the hypothesis that biosolids are a significant source of MPs to agrosystems, since up to 3.8×10^9 of MPs were applied to a single field in 2017. Different measures may need to be conceived to reduce MP inputs to agricultural soils treated with biosolids. Recently announced policies in many parts of the world, including Canada, to restrict single use plastics, along with existing regulations banning use of polymeric microbeads in cosmetics and personal care products will likely indirectly reduce the loads of MPs entering WWTPs, and thus reduce concentrations in sludge and biosolids. It is clear, however, that fibers, originating from laundry of synthetic clothes, will be unaffected by such legislation. In addition, revision of existing legislation surrounding biosolids management will be required to incorporate MP management, as results show that large numbers of MPs were lost from some sites following biosolid applications, despite adhering to all applicable regulations (e.g. use of Nutrient Management Plans). Meteorological conditions, soil characteristics, vegetative cover and timing of applications all impacted MP soil retention, and new legislation should be implemented to incorporate these factors and minimize transfer of MPs to watercourses.

Due to the current paucity of data on MP removal during different wastewater treatment steps and the near complete lack of MP measurements in agricultural soils, additional research is clearly needed to answer pressing questions. For instance, might heavy rainfall during spring alter agricultural soils from acting as an MP store, to an MP source? Can biosolid application subsequent to crop establishment reduce transmission of MPs into watercourses? What proportion of MPs are removed from biosolids through storage and filtering of surfactant

Fig. 7. A) total monthly precipitation (mm) at each field site during study period; arrows indicate locations and dates of biosolids application. B) Comparison of monthly precipitation amounts received at Site 3 between 2017 study period and average conditions over preceding 5 years (2012–2016) (ECCC, 2019).

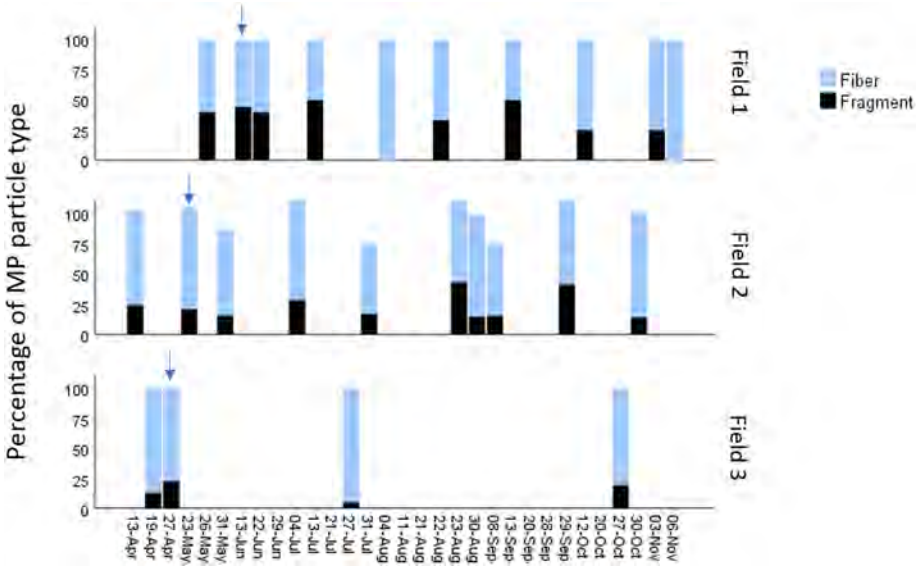


Fig. 8. Percentage of soil MP particles identified as fragments throughout the soil profile at active biosolid treatment sites (control site not included due to low numbers of particles). Arrows indicate dates of biosolid application.

liquids? Importantly, thresholds for ecological impact of MPs on soil biota have not yet been identified, meaning that currently an ecological risk assessment cannot be conducted on the results from this study. This study indicates that establishing a framework of estimating exposure to MPs in soil, a crucial step in any risk assessment, will require dealing with highly dynamic and complex processes. Additional research is therefore required as to whether the observed long-term accumulation of MP fibers in soils on plant growth and soil biota could pose a risk to

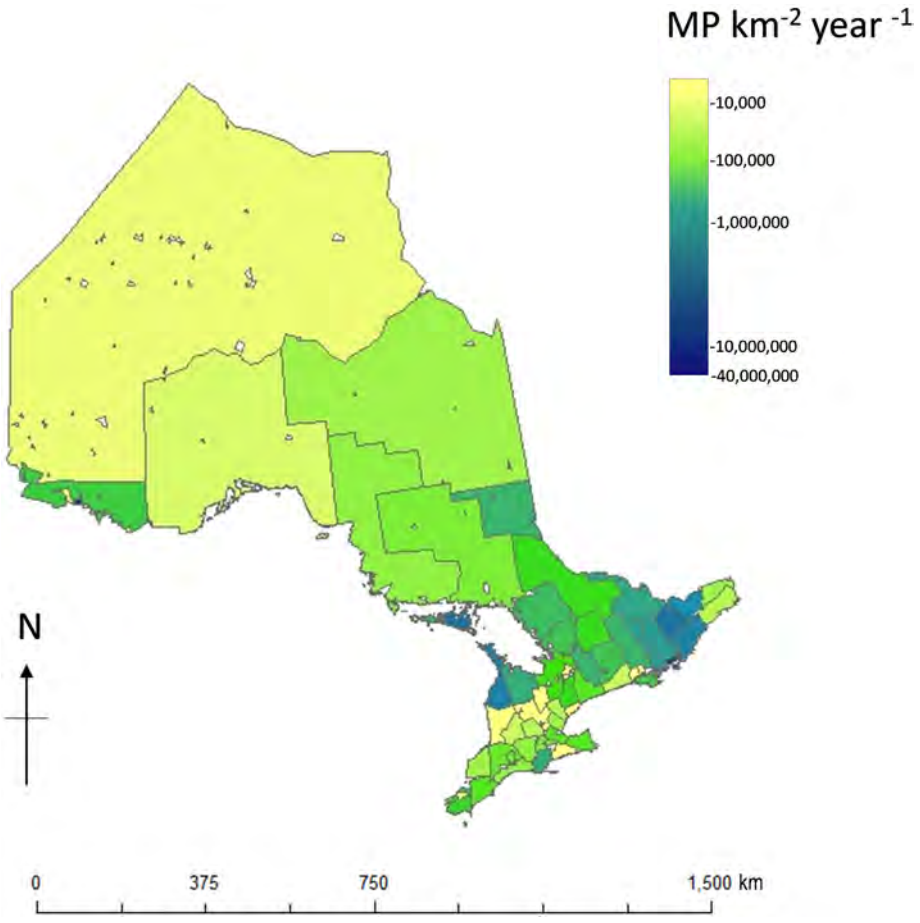


Fig. 9. Total number of microplastics applied to Ontario agricultural soils, calculated using annual biosolid application volumes (Central Lake Ontario Conservation Authority, 2007), farmland area (Ontario Ministry of Natural Resources, 2002) and observed average biosolid MP concentrations as quantified within this study.

agricultural sustainability. Researchers urgently need to address these uncertainties in order to enable effective management of terrestrial and aquatic MP pollution.

CRediT authorship contribution statement

Jill Crossman: Conceptualization, Funding acquisition, Methodology, Investigation, Formal analysis, Data curation, Visualization, Writing – original draft. **Rachel R. Hurley:** Methodology, Formal analysis, Data curation, Writing – original draft. **Martyn Futter:** Conceptualization, Funding acquisition, Investigation, Writing – original draft. **Luca Nizzetto:** Conceptualization, Funding acquisition, Methodology, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The study was funded under the frame of the collaborative international consortium (IMPASSE), financed under the ERA-NET WaterWorks 2015 co-funded call. The authors would like to thank the Canadian Research Council NSERC (WTWPJ506070-2016) the Swedish Research Council FORMAS (2017-00029) and the Research Council of Norway (271825) for funding parts of this study. ERA-NET is part of the Water Challenges for a Changing World Joint Programme Initiative (Water JPI), 2016. We would also like to thank field technician Mitch Hall for assistance with sample collection, and are extremely grateful to the anonymous stakeholders, landowners, WWTP managers and biosolids providers, who made this study possible. Thanks also to Dr. Jennifer Winter of the Ministry of Environment, Conservation and Parks for her initial stakeholder outreach help, and to Dr. Paul Helm for his valuable insights into methods of environmental microplastics sampling.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.138334.

References

Albert, M., 2013. City of Barrie secondary plan, background studies and infrastructure master plans–intensification and annexed lands. Final report. The City of Barrie. Available online at. https://www.barrie.ca/City%20Hall/Planning-and-Development/Engineering-Resources/Documents/Annexation%20PIC%203%20-%20Biosolids%20Management%20Class%20EA%20Report%20-%20Final.pdf.pdf.

Brodhagen, M., Goldberger, J.R., Hayes, D.G., Inglis, D.A., Marsh, T.L., Miles, C., 2017. Policy considerations for limiting unintended residual plastic in agricultural soils. Environ Sci Policy 69, 81–84.

Carr, S.A., Liu, J., Tesoro, A.G., 2016. Transport and fate of microplastic particles in wastewater treatment plants. Water Res. 91, 174–182.

Central Lake Ontario Conservation Authority, 2007. Source water protection plan program for the CTC CWP region. Available at. https://www.ctcswp.ca/app/uploads/2017/05/RPT_200703_WC_FNL.pdf.

Corradini, F., Mez, P., Equiliuz, R., Casado, F., Huerta-Lwanga, E., Geissen, V., 2019. Evidence of microplastics accumulation in agricultural soils from sewage sludge disposal. Sci. Total Environ. 671, 411–420.

de Souza Machado, A.A., Kloas, W., Zarfl, C., Hempel, S., Rillig, M.C., 2018. Microplastics as an emerging threat to terrestrial ecosystems. Glob. Chang. Biol. 24 (4), 1405–1416.

Environment and Climate Change Canada. 2019. Past Weather and Climate; Historical Data. Available at http://climate.weather.gc.ca/historical_data/search_historic_data_e.html Last Accessed August 2019.

Eriksen, M., Mason, S., Wilson, S., Box, C., Zellers, A., Edwards, W., Farley, H., Amato, S., 2013. Microplastic pollution in the surface waters of the Laurentian Great Lakes. Mar. Pollut. Bull. 77 (1–2), 177–182.

Galafassi, S., Nizzetto, L., Volta, P., 2019. Plastic sources: a survey across scientific and grey literature for their inventory and relative contribution to microplastics pollution in natural environments, with an emphasis on surface water. Sci. Total Environ. 693, 133499.

Gies, E.A., LeNoble, J.L., Noel, M., Etemadifar, A., Bishay, F., Hall, E.R., Ross, P.S., 2018. Retention of microplastics in a major secondary wastewater treatment plant in Vancouver, Canada. Mar. Pollut. Bull. 133, 553–561.

Gündoğdu, S., Çevik, C., Güzel, E., Kilercioğlu, S., 2018. Microplastics in municipal wastewater treatment plants in Turkey: a comparison of the influent and secondary effluent concentrations. Environ. Monit. Assess. 190, 626.

Horton, A.A., Dixon, S.J., 2017. Microplastics: an introduction to environmental transport processes. WIREs Water 5, e1268.

Hurley, R., Lusher, A.L., Olsen, M., Nizzetto, L., 2018. Validation of a method for extracting microplastics from complex, organic-rich, environmental matrices. Environ. Sci. Technol. 52 (13), 7409–7417.

Ng, E.L., Lwanga, E.H., Eldridge, S.M., Johnston, P., Hu, H.W., Geissen, V., Chen, D., 2018. An overview of microplastic and nanoplastic pollution in agroecosystems. Sci. Total Environ. 627, 1377–1388.

Nizzetto, L., Futter, M., Langaas, S., 2016a. Are agricultural soils dumps for microplastics of urban origin? Environ. Sci. Technol. 50, 10777–10779.

Nizzetto, L., Bussi, G., Futter, M.N., Butterfield, D., Whitehead, P.G., 2016b. A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments. Environ. Sci.: Processes Impacts 18 (8), 1050–1059.

Ontario Ministry of Natural Resources, 2002. Ontario Land Cover Data Base. Second Edtion, 2000. -27 classes. PLC 2000. Reference date - revision: 2002-08-31 https://www.ontario.ca/page/open-government-licence-ontario.

Ontario Nutrient Management Act, 2002. Ontario regulation 267/03 S.O. 2002, c.4. Available at. https://www.ontario.ca/laws/regulation/030267#BK17.

Primpke, S., Wirth, M., Lorenz, C., Gerdts, G., 2018. Reference database design for the automated analysis of microplastic samples based on Fourier transform infrared (FTIR) spectroscopy. Anal. Bioanal. Chem. 410 (21), 5131–5141.

Rillig, M.C., 2012. Microplastic in terrestrial ecosystems and the soil. Environ. Sci. Technol. 6453–6454.

Rillig, M.C., Ingraffia, R., de Souza Machad, A.A., 2017. Microplastic incorporation into soil agroecosystems. Front. Plant Sci. 8, 1805.

Rocha-Santos, T., Duarte, A.C., 2015. A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment. Trends Anal. Chem. 65, 47–53.

Rochman, C.M., Kross, S.M., Armstrong, J.B., Bogan, M.T., Darling, E.S., Green, S.J., Smyth, A.R., Veríssimo, D., 2015. Scientific evidence supports a ban on microbeads. Environ. Sci. Technol. 49 (18), 10759.

Soil Landscapes of Canada Working Group, 2010. Soil Landscapes of Canada Version 3.2. Agriculture and Agri-Food Canada (Digital Map and Database at 1:1 Million Scale).

Sutton, R., Mason, S.A., Stanek, S.K., Willis-Norton, E., Wren, I.F., Box, C., 2016. Microplastic contamination in the San Francisco Bay. California. Marine Pollution Bulletin 109 (1), 230–235.

Weithmann, N., Moller, J.N., Loder, M.G., Piehl, S., Laforsch, C., Freitag, R., 2018. Organic fertilizer as a vehicle for the entry of microplastic into the environment. Sci. Adv. 4 (4), eaap8060.

Xanthos, D., Walker, T.R., 2017. International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): a review. Mar. Pollut. Bull. 118 (1–2), 17–26.

Zemke, J.J., Enderling, M., Klein, A., Skubski, M., 2019. The influence of soil compaction on runoff formation. A case study focusing on skid trails at forested andosol sites. Geosciences 9 (204), 1–14.

Zubris, K.A.V., Richards, B.K., 2005. Synthetic fibers as an indicators of land application of sludge. Environ. Pollut. 138, 201–211.

EXHIBIT K

United States
Environmental Protection Agency

Office of Water
Office of Science and Technology
4304T

EPA-822R22007
December 2022

Biennial Review of 40 CFR part 503

To Fulfill Clean Water Act Section 405(d)(2)(C)

Biosolids Biennial Report No.9
(Reporting Period 2020–2021)

Biennial Review of 40 CFR part 503

To Fulfill Clean Water Act Section 405(d)(2)(C)

Biosolids Biennial Report No.9 (Reporting Period 2020–2021)

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, DC

December 2022

EPA-822R22007

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency (EPA) policy and approved for publication. The report was prepared with the support of Tetra Tech, Inc. under the direction and review of the Office of Water - Office of Science and Technology.

This document is not a regulation, nor does it change or substitute for any statutory provisions or EPA regulations. Thus, it imposes no legally binding requirements on EPA, states, tribes, or the regulated community. While EPA has made every effort to ensure the accuracy of the content of this document, obligations of the regulated community continue to be determined by statutes, regulations, or other legally binding requirements. In the event of a conflict between the discussion in this document and any statute or regulation, this document would not be controlling. Mention of trade names or commercial products does not constitute endorsement or recommendation for their use.

This document can be downloaded from EPA's website at http://www.epa.gov/biosolids.

Definition of Biosolids

The terms "biosolids" and "sewage sludge" are often used interchangeably; however, biosolids typically means sewage sludge treated to meet the requirements in Title 40 of the *Code of Federal Regulations* (CFR) part 503 and intended to be applied to land as a soil amendment or fertilizer. For the purposes of this biennial report, "biosolids" means "sewage sludge."

Sewage sludge, as defined in 40 CFR part 503, means:

Sewage sludge is solid, semi-solid, or liquid residue generated during the treatment of *domestic sewage* in a *treatment works*. Sewage sludge includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and a material derived from sewage sludge. Sewage sludge does not include ash generated during the firing of sewage sludge in a sewage sludge incinerator or grit and screenings generated during preliminary treatment of domestic sewage in a treatment works (40 CFR 503.9(w)). Terms in italics are defined as follows:

- ***Domestic sewage*** is waste and wastewater from humans or household operations that is discharged to or otherwise enters a treatment works (40 CFR 503.9(g)).
- ***Treatment works*** is either a federally owned, publicly owned, or privately owned device or system used to treat (including recycle and reclaim) either domestic sewage or a combination of domestic sewage and industrial waste of a liquid nature (40 CFR 503.9(aa)).
- ***Industrial wastewater*** is wastewater generated in a commercial or industrial process (40 CFR 503.9(n)).

Taken together, these definitions mean that biosolids, or sewage sludge, for the purposes of 40 CFR part 503, are the residues from treatment of domestic sewage, whether the industrial wastewater has been treated at the domestic treatment works alongside domestic sewage or not. It does not include sludge originating from treatment of industrial wastes in the absence of domestic sewage or at an industrial treatment works.

Executive Summary

During the 2020–2021 biennial review process, the U.S. Environmental Protection Agency (EPA) collected and searched publicly available peer-reviewed academic publications on pollutants found in biosolids that: (1) were identified in three previous EPA national sewage sludge surveys and in eight previous biennial reviews; and (2) were newly identified during the literature search timeframe (2020–2021). Information was collected on the occurrence, fate, and transport of these pollutants in the environment and their effects on human health and ecological receptors.

Since Biosolids Biennial Report (BR) No.8 was published in 2021, EPA undertook an effort to curate a complete list of chemicals found in biosolids based on the three previous national sewage sludge surveys and eight biennial review reports (Richman et al. 2022). Through that curation, EPA determined that 259 chemicals had been previously reported as detected in biosolids but had not been included in the data collection phase of previous biennial reviews. Also, EPA made corrections to the Chemical Abstracts Service (CAS) numbers of 22 chemicals that had been reported in previous biennial reviews. EPA included these 281 chemicals in the biennial review process for BR No.9.

EPA found 16 new articles that provide relevant data on chemical pollutants that have been found in biosolids in the U.S., two papers had information on both chemical and microbial pollutants. The articles identified 13 new chemicals found in biosolids: nine drugs, three per- and polyfluoroalkyl substances (PFAS), and one element. The articles also identified new data for three chemicals identified during the curation process and 30 chemicals that were previously identified in biosolids. Concentration data in biosolids were found for the 13 new chemicals, three chemicals identified during the curation process, and 30 chemicals identified in previous biennial reviews.

Human health toxicity values were found for 70 chemicals identified during the curation process, and 64 previously identified chemicals. ECOTOXicology records were found for five of the newly identified chemicals, 157 chemicals identified during the curation process, and 116 previously identified chemicals. Additional ecological toxicity data were identified for 20 chemicals identified in the curation process, and 32 previously identified chemicals. Uptake and transfer data, including bioconcentration or bioaccumulation factors, were identified for the 13 new chemicals, 276 chemicals identified during the curation process, and three previously identified chemicals.

In addition, five of the new articles provided relevant data for microbial pollutants that have been found in biosolids. Review of these articles identified one new microbial pollutant in biosolids and data for two previously identified microbial pollutants.

The list of all chemicals found in biosolids based on biennial reviews and sewage sludge surveys is publicly hosted on the EPA CompTox Chemicals Dashboard. The “Biosolids List” allows EPA to take advantage of the functionality of the Dashboard and its integrated data and make the list readily available to the public and connect chemicals found in biosolids with data that is needed for risk assessment. A total of 739 chemicals have been identified in biosolids to date; about 250 of these are dioxins, furans, and PCBs. The list is available here: https://comptox.epa.gov/dashboard/chemical-lists/BIOSOLIDS2022.

Contents

Figures

Tables

1 Introduction

Section 405(d) of the Clean Water Act (CWA) requires the U.S. Environmental Protection Agency (EPA) to review sewage sludge regulations every two years to identify any additional pollutants that might occur in biosolids and to set regulations for those pollutants if sufficient scientific evidence shows they could harm, or present a risk to, human health or the environment.

EPA's biennial review process is intended to help fulfill that CWA requirement. The data gleaned from the process may be used to assess risk from chemicals found in biosolids. EPA has published eight biosolids biennial reports (BRs) each covering a two-year timeframe: BR No.1 (2004–2005), BR No.2 (2006–2007), BR No.3 (2008–2009), BR No.4 (2010–2011), BR No.5 (2012–2013), BR No.6 (2014–2015), BR No.7 (2016–2017), and BR No.8 (2018–2019).

Once pollutants found in biosolids are identified, EPA must assess if there is sufficient information about the pollutants to determine whether they pose a risk to human health or the environment. EPA is currently developing a prioritization and risk screening process to evaluate pollutants found in biosolids. The screening results will be used to make informed decisions about priorities for risk assessments or to address data gaps or uncertainties.

Addressing the uncertainty around risks from pollutants identified in biosolids is the top priority for EPA's Biosolids Program. EPA continues to make significant progress in building capacity to assess pollutants by developing tools and data. EPA expects to begin risk evaluations once review of its screening process has been completed.

This report provides the approach used and the results of EPA's Biosolids BR No.9, covering 2020–2021.

2 Approach for the 2020–2021 Biennial Review

Every two years, EPA collects and reviews publicly available information about pollutants that have been found in biosolids in the U.S. since the last biennial review. The review focuses on pollutant occurrence and concentration, effects on human health and ecological receptors, and fate and transport in the environment. The four categories of information collected and presented here are needed to conduct risk assessments.

1. **Occurrence and Concentration**. Both the ability to detect a given pollutant in biosolids and the determination of the concentration at which that pollutant is present are highly dependent on the existence of analytical methods for the pollutant in the biosolids matrix.
2. **Toxicity to Human Health**. These data include values such as reference doses (RfDs), reference concentrations (RfCs), cancer slope factors (CSFs), and inhalation unit risks (IURs).
3. **Toxicity to Ecological Receptors**. These data include values such as lethal dose, lethal concentration, and chronic endpoints related to survival, growth, and reproduction.
4. **Environmental Fate and Transport**. These data are necessary for assessing exposure and include various physical-chemical properties as well as bioconcentration or bioaccumulation factors (BCFs and BAFs, respectively), which describe the tendency of a chemical to move from one medium (e.g., soil) to another (e.g., plant matter).

2.1 Two-Phase Literature Search and Review

The 2020–2021 biennial review process consisted of a series of steps designed to effectively search for and review data on chemical and microbial pollutants and divided into the following phases (Figure 1):

- **Phase 1. Search for Pollutant Occurrence**. EPA conducted a search of open literature published from January 1, 2020 through December 31, 2021 for papers that provided evidence of the occurrence of unregulated chemical or microbial pollutants in biosolids in the U.S. and Canada. EPA reported available concentration data for both newly found and previously found chemicals in biosolids.
- **Phase 2. Searches for Data Collection**. For newly identified chemicals found in biosolids, EPA conducted additional searches not limited to 2020–2021 and collected data on environmental fate and transport, human health, and ecological effects. For chemicals previously found to occur in biosolids, EPA collected environmental fate and transport data, human health toxicity data, and ecological toxicity data if data published since January 2020 were available. No additional literature searches were conducted for microbial pollutants.

Since BR No.8 was published in 2021, EPA undertook an effort to curate a complete list of chemicals found in biosolids based on the three previous national sewage sludge surveys and eight biennial review reports (Richman et al. 2022). Through that curation EPA determined that 259 chemicals had been previously detected in biosolids but had not been included in the data collection phase of previous biennial reviews. Also, EPA made corrections to the Chemical Abstracts Service (CAS) numbers of 22 chemicals that had been reported in previous biennial reviews. Therefore, EPA treated these 281 chemicals, as well as those identified from in this biennial review (2020–2021), as if they were newly identified in biosolids and did not limit the search dates for environmental fate and transport data, human health toxicity data, or ecological toxicity data.

The list of all chemicals found in biosolids based on biennial reviews and sewage sludge surveys is publicly hosted on the EPA CompTox Chemicals Dashboard. The Biosolids List allows EPA to take advantage of the functionality of the Dashboard and its integrated data and make the list readily available to the public and connect chemicals found in biosolids with data that is needed for risk assessment. A total of 739 chemicals have been identified in biosolids to date; about 250 of these are dioxins, furans, and PCBs. The list is available here: https://comptox.epa.gov/dashboard/chemical-lists/BIOSOLIDS2022.

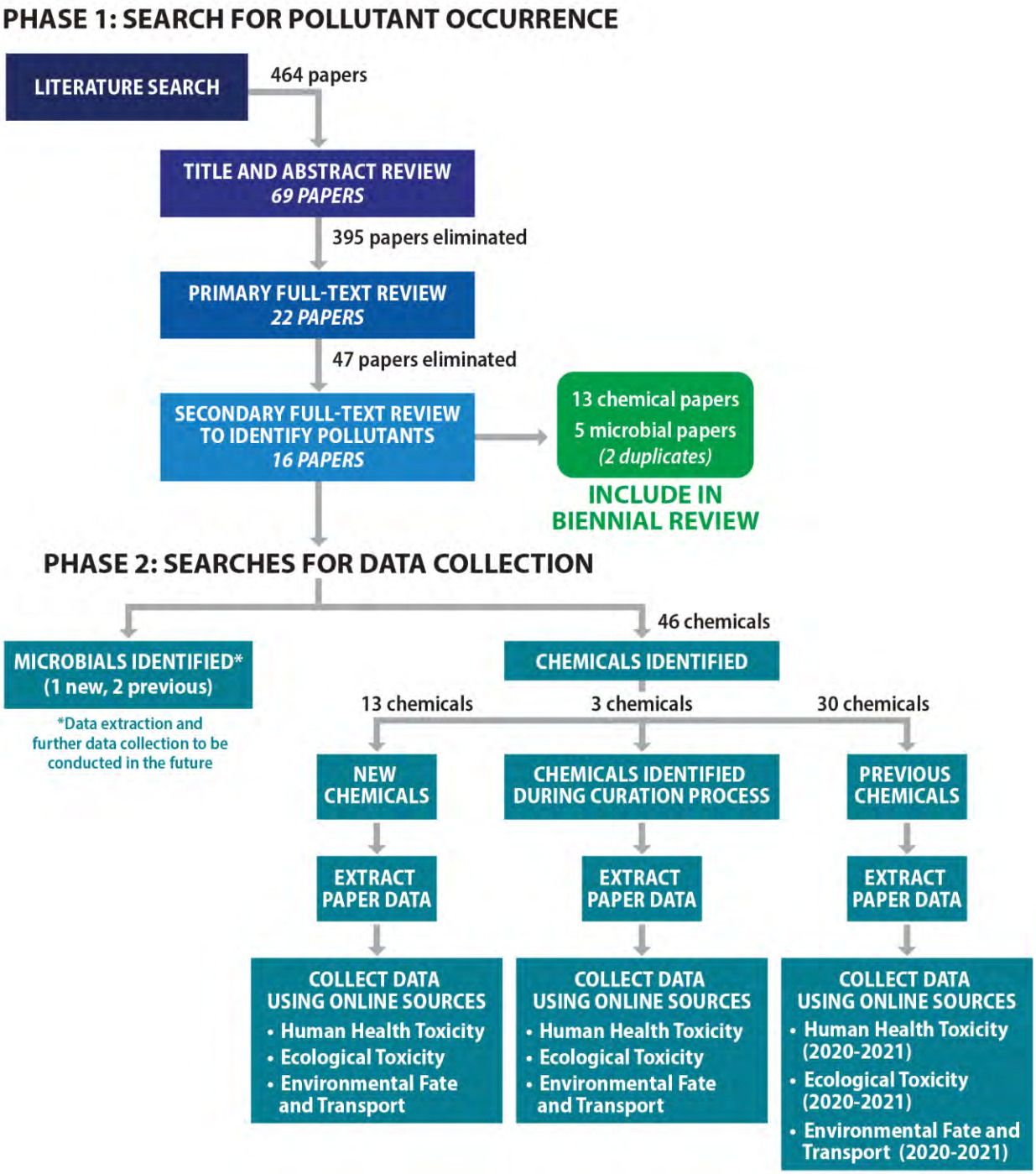


Figure 1. Overview of the 2020–2021 Biennial Review Process.

2.2 Literature Identification and Review

2.2.1 Literature Search for Pollutant Occurrence

EPA conducted a literature search for articles published in peer-reviewed, English language-based journals. The search, conducted for the period of January 1, 2020 through December 31, 2021, focused on identifying data published in ePuB or print since the previous biennial review search period ended in December 2019. The bibliographic databases searched for the current review included: ProQuest, PubMed, and Web of Science. Conference abstracts, reports, comments, letters, and editorials were excluded.

For chemical pollutants, health-related keywords were combined with chemical-related keywords and land application keywords. Geographical search terms were used to restrict the searches to studies conducted in the U.S. and Canada. Asterisks at the end of a search term broadened the search by returning results of that term with any relevant ending. Specifically, to be identified as a candidate, a paper had to have at least one biosolids-related keyword, one chemical keyword, one land application keyword, one health-related keyword, and one geographic keyword, based on the following search strings:

- ***Biosolids-related keywords***: sewage sludge OR biosolids OR treated sewage OR sludge treatment OR sewage treatment

  AND

- ***Land application-related keywords***: land application OR farm OR agriculture OR soil

  AND

- ***Chemical-related keywords***: pollutant* OR toxic* OR chemical OR constituent OR contaminant* OR metal* OR dioxin* OR inorganic* OR organic* OR flame retardant* OR pharmaceutical* OR steroid* OR hormone* OR antibiotic* OR personal care product*

  AND

- ***Health-related keywords***: occurrence OR concentration OR effect* OR propert* OR fate OR transport OR health

  AND

- ***Geographical keywords***: United States OR Canada OR USA OR U.S.A. OR U.S. OR US

For microbial pollutants, health-related keywords were combined with microbial pollutant-related keywords and land application keywords. Land application keywords were retained because 40 CFR part 503.32(b)(5) includes site restrictions specific to land application of Class B biosolids, which allow time for environmental conditions to further reduce pathogen levels. Geographical search terms were used to restrict the searches to studies conducted in the U.S. and Canada. Specifically, to be identified as a candidate, a paper had to have at least one biosolids-related keyword, one land application-related keyword, one microbial pollutant-related keyword, one health-related keyword, and one geographic keyword, based on the following search strings:

- ***Biosolids-related keywords***: sewage sludge OR biosolids OR treated sewage OR sludge treatment OR sewage treatment

  AND

- ***Land application-related keywords***: land application OR farm OR agriculture OR soil

  AND

- ***Microbial pollutant-related keywords***: pathogen* OR Salmonella OR microb*

  AND

- ***Health-related keywords***: occurrence OR concentration OR effect* OR propert* OR fate OR transport OR health

  AND

- ***Geographical keywords***: United States OR Canada OR USA OR U.S.A. OR U.S. OR US

2.2.2 Occurrence Literature Selection and Review

For the papers identified in the chemical and microbial literature searches for the occurrence of pollutants in biosolids, EPA first screened the citation titles and eliminated papers based on their titles if it was possible to determine the papers did not provide relevant data for pollutants that might occur in U.S. biosolids. Studies not related to biosolids or not conducted in the U.S. or Canada were eliminated from further evaluation.

For the remaining papers, EPA reviewed their abstracts and eliminated papers based on the following:

- Endpoints are not pollutant-specific (i.e., overall effects of biosolids on plant growth, crop yield, soil microbe community, or soil nutrients).
- The medium evaluated is:
  - influent and effluent wastewater;
  - industrial sludge (e.g., pulp and paper mill residuals);
  - activated carbon;
  - activated sludge;
  - biochar; and
  - biosolids compost.
- Only an analytical method or effectiveness-of-treatment method is described, and no data are provided on pollutant concentration in biosolids.
- The study was done outside of U.S. or Canada.

EPA reviewed the full text of papers not eliminated during the abstract review. During this review, additional papers were eliminated based on the exclusion criteria for abstracts, as sometimes a paper could not be fully evaluated using the abstract alone. Papers were also eliminated based on the following:

- Only spiked concentration data were reported.
- There was no evidence of the occurrence of new pollutants in biosolids AND no new data were reported for previously identified chemicals.
- The only reported data were for chemicals in biosolids that are already regulated under 40 CFR part 503 (i.e., arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc). EPA did not search the open literature for these chemicals but they were included in the chemical data collection phase of the review.

Appendix A provides 16 abstracts of the papers retained after full-text review for chemical pollutants (13 papers) and microbial pollutants (five[1] papers).

2.3 Chemical Data Collection

Information was collected on pollutants in biosolids, including their occurrence, concentration, fate and transport of chemicals in the environment, and their effects on human and ecological health. This section provides detailed information. Table B-1 in Appendix B provides a complete list of pollutants found in biosolids that are new, previously identified, and identified during the curation process.

EPA categorized chemicals found in biosolids using a hybridized approach accounting for both functional use and structure-based classification. An attempt was made to categorize the individual chemicals in terms of their primary membership in a single class, though many chemicals could naturally fit into multiple categories. Chemicals identified in biosolids were compared to chemical lists on the EPA CompTox Chemicals Dashboard to flag chemicals into specific list-category collections and, in some cases, expert judgement was used. EPA followed the same categorization approach in the curation effort described previously (Richman et al. 2022). Information is provided in Table B-2. Categories for microbes are provided in Table B-3.

2.3.1 Human Health Toxicity Value Sources and Selection

EPA uses human health effects information to assess the risk from pollutants that occur in biosolids. Specifically, EPA uses RfD and RfC values to evaluate noncancer risk associated with oral and inhalation exposures, respectively. Oral CSF and IUR values are used to evaluate risk from carcinogens associated with oral and inhalation exposures, respectively. These four values were searched for and obtained for newly identified chemicals and chemicals identified during the curation process without limiting the search period. For chemicals previously identified in biosolids, EPA limited the data search to the period from January 2020 through December 2021.

EPA's Integrated Risk Information System (IRIS) is considered an excellent source for human health toxicity values for EPA risk assessments; IRIS was the primary source of toxicity values for this review (U.S. EPA 2022a). However, IRIS does not contain toxicity values for all chemicals, and some chemicals with a toxicity value in IRIS do not necessarily have all four of the values EPA uses for risk assessments: RfD, RfC, CSF, and IUR. For the 2020–2021 biennial review, EPA conducted a search of peer-reviewed, publicly available sources to obtain the oral toxicity value (RfD or CSF) and the inhalation toxicity value (RfC or IUR) for potential use in biosolids risk assessments. EPA also searched for toxicological assessments from selected EPA program offices, other national and international programs, and state programs. EPA searched the following data sources:

- **Human Health Benchmarks for Pesticides (HHBPs)**: Data include EPA Office of Pesticide Program's risk assessments for pesticides using health effects data submitted during the pesticide registration process (U.S. EPA 2022b).
- **Provisional Peer-Reviewed Toxicity Values (PPRTVs)**: The Center for Public Health and Environmental Assessment (CPHEA), formerly the National Center for Environmental Assessment, and the Human Health Risk Assessment (HHRA) National Research Program develop PPRTVs (U.S. EPA 2022c). Both CPHEA and HHRA are within EPA's Office of Research and Development.

[1] Two of these papers contained occurrence data for chemical as well as microbial parameters.

- **Health Effects Support Documents (HESDs)**: EPA's Office of Science and Technology (within EPA's Office of Water) develops toxicity values for chemicals in drinking water in these peer-reviewed documents (U.S. EPA 2022e).
- **Agency for Toxic Substances and Disease Registry (ATSDR)**: ATSDR develops oral and inhalation minimum risk levels (MRLs), which are oral noncancer toxicity values equivalent to RfDs and RfCs, respectively (ATSDR 2022).
- **California Environmental Protection Agency (CalEPA)**: CalEPA develops reference exposure levels, which are noncancer toxicity values equivalent to RfDs or RfCs, and cancer potency factors, which are cancer toxicity values equivalent to CSFs or IURs (CalEPA 2021).
- **Health Canada**: Health Canada develops guidelines and technical documents with tolerable daily in-take values, which are noncancer toxicity values used in risk evaluation (Health Canada 2021).

For the 2020-2021 biennial review, EPA reviewed several sources not previously included in biennial reviews. EPA searched these databases for all chemicals found in biosolids and the data search time frame was not limited to any period. EPA searched the following data sources:

- **National Primary Drinking Water Regulations (NPDWR):** EPA's Office of Water develops legally enforceable primary standards limiting the levels of contaminants in drinking water (U.S. EPA 2022g).
- **National Recommended Water Quality Criteria – Human Health Criteria (NRWQC-HHC):** EPA's Office of Science and Technology (within EPA's Office of Water) develops human health ambient water quality criteria for states and authorized tribes to consider when adopting criteria into their water quality criteria. EPA provides recommendations for "water + organism" and "organism only" (U.S. EPA 2022i).

EPA searched for toxicity data using CAS numbers which are unique numeric identifiers assigned to chemical substances. In some cases, toxicity data associated with a CAS number may be applicable to other related chemicals. In the case of polychlorinated biphenyls (PCBs) there is some toxicity data available for the category PCBs which is actually a family of several hundred chemical structures. While EPA has noted that there is not toxicity data available for some of the individual PCB congeners in the category, it may be possible to utilize the toxicity data for the category PCBs when evaluating individual chemical structures. Further, the chemicals may be evaluated as a group using toxicity equivalency factors. A full hazard assessment of PCBs is outside of the scope of this document.

2.3.2 Ecological Toxicity Value Sources and Selection

To evaluate the potential for ecological risks from biosolids, EPA assesses direct contact and ingestion pathways for aquatic and terrestrial species. For the direct contact exposure pathway, species assemblages (or communities) are assessed in soil, sediment, and surface water where they are assumed to be exposed through direct contact with the contaminated medium. For the ingestion pathway, species are assumed to ingest contaminated food and prey from biosolids-treated agricultural fields and from farm ponds that receive runoff from biosolids-treated fields. The ecological toxicity values are expressed in terms of media concentration (e.g., milligrams [mg] per liter [L] for surface water and mg/kilograms [kg] for soil) for the direct contact pathway and in terms of dose (mg/kg/day) for the ingestion pathway.

ECOTOXicology Knowledgebase

EPA does not have a single repository for approved ecological toxicity values directly comparable to IRIS for human toxicity values; however, EPA searched ECOTOX (U.S. EPA 2022d) for all newly identified and existing chemicals to find the number of papers and species, if any, that were available. For previously identified chemicals, the search was limited to data added to ECOTOX from studies published in 2020–2021. For newly identified chemicals in biosolids (including the 281 previously identified chemicals described earlier), the search was not limited to studies published during the 2020–2021 period.

ECOTOX is a comprehensive, publicly available knowledgebase providing single-chemical environmental toxicity data on aquatic life, terrestrial plants, and wildlife. To be included in ECOTOX, studies must meet the following minimum criteria based on the ECOTOX applicability criteria:

- The toxic effects are related to single-chemical exposure.
- A biological effect on live, whole organisms is reported.
- Chemical test concentrations are reported.
- There is an explicit duration of exposure.
- Toxicology information is reported for the chemical of concern.
- The paper is published in the English language.
- The paper is available as a full article (not an abstract).
- The paper is publicly available.
- The paper is the primary source of the data.
- A calculated endpoint is reported or can be calculated using reported or available information.
- Treatment(s) are compared to an acceptable control.
- The location of the study (e.g., laboratory versus field) is reported.
- The tested species is reported (with recognized nomenclature).

EPA considered the studies from the open literature papers that passed the ECOTOX screen of applicability to be potentially relevant for inclusion in its risk assessments.

EPA also publishes aquatic life criteria and benchmarks. For the 2020-2021 biennial review, EPA reviewed these sources not previously included in biennial reviews. EPA searched these databases for all chemicals found in biosolids and the data search time frame was not limited to any period. EPA searched the following data sources:

- **National Recommended Water Quality Criteria – Aquatic Life Criteria (NRWQC-ALC):** EPA's Office of Science Technology (with EPA's Office of Water) develop Aquatic Life Criteria for chemicals representing the highest concentration of a specific pollutant that is not expected to pose a significant risk to the majority of species in a given environment or a narrative description of the desired conditions of a water body being "free from" certain negative conditions (U.S. EPA 2022h).
- **Office of Pesticide Programs Aquatic Life Benchmarks for Registered Pesticides (OPP-ALB):** EPA worked with the U.S. Geological Survey to identify aquatic ecotoxicity benchmark values from risk assessments developed by EPA for individual pesticides during previous re-registration programs. The toxicity data used to develop Aquatic Life Benchmarks are extracted from the most recent publicly available OPP risk assessment for the individual pesticide and are typically based on the most sensitive value for each taxon (U.S. EPA 2022f).

2.3.3 Environmental Fate and Transport Data

EPA uses risk assessment models that require physical-chemical properties and transfer factors to estimate the potential for chemical transport and uptake from agricultural lands that were amended with biosolids.

Physical-Chemical Properties

Because the list of chemicals identified in biosolids is now integrated into the EPA Comptox Chemicals Dashboard, and the Dashboard contains measured and predicted values for physical-chemical properties, there was no need to collect and report physical-chemical values for these properties for newly identified or previously identified chemicals.

Uptake and Transfer Factors

For many organic chemicals, the plant and animal product uptake and transfer factors can be estimated using empirical relationships between the transfer factor and the octanol/water partition coefficient, or log K_{ow}. BCFs are preferred if available. If adequate physical-chemical property data were available, EPA estimated fish BCFs and BAFs using EPI Suite, and EPA searched for and extracted the following data during this biennial review:

- Log BCF (regression-based estimate)
- Log BCF and BAF (Arnot-Gobas upper, mid, and lower trophic)

During this biennial review, EPA also searched for and extracted species-specific, field-measured BAFs and laboratory-measured BCFs from two peer-reviewed, publicly available databases—Arnot and Gobas (2006) and Environment and Climate Change Canada (2006)—as well as bioaccumulation values published by the Oak Ridge National Laboratory (ORNL) (2022). EPA uses these sources in risk-based assessments. These data included the following:

- Log BCF or BAF
- Organism scientific name
- Organism common name

The ORNL Risk Assessment Information System (RAIS) database (ORNL 2022) contains additional uptake and transfer data, which EPA also searched for and extracted during this biennial review. These include:

- Diffusivities in air and water
- Soil-to-dry plant uptake
- Soil-to-wet plant uptake
- Beef transfer coefficient
- Milk transfer coefficient
- Soil-water partition coefficient (K_d)
- Organic carbon partition coefficient (F_{oc})

3 Results from the 2020–2021 Biosolids Biennial Review

During the 2020–2021 biennial review, EPA identified 13 articles that met the eligibility criteria for chemicals. Review of these 13 articles identified 13 new chemicals that occur in biosolids (Table 1): nine drugs, three per- and polyfluoroalkyl substances (PFAS), and one element. The 13 new articles also provided concentration data for three of the chemicals identified during the curation process (see

chemicals marked with 'A' in the column 'Concentration Data' in Table 2) and 30 previously identified chemicals (see chemicals marked with 'A' in the column 'Concentration Data' in Table 3).

Of the 13 papers, four identified or provided data on new chemicals and 11 provided data on previously identified chemicals. Abstracts for all 13 articles are provided in Appendix A-1. EPA identified several papers during the literature review that met the search criteria but were excluded from the biennial review. For example, EPA excluded studies that provided information on plastic-related compounds or nutrients, or studies that provided information on chemicals without providing concentration data. Abstracts for these articles that were reviewed but not included in the biennial review are provided in Appendix A-2.

Data identified for all the sources that EPA reviewed included:

- Concentration data for 13 newly identified chemicals, three chemicals identified during the curation process, and 30 previously identified chemicals (see Appendix C).
- Human health toxicity data for 70 chemicals identified during the curation process, and 64 previously identified chemicals (see Appendix D).
- ECOTOX records for five newly identified chemicals, 157 chemicals identified during the curation process, and 116 previously identified chemicals (see Appendix E).
- Environmental fate and transport data for 13 newly identified chemicals, 276 chemicals identified during the curation process, and three previously identified chemical (see Appendix F).

3.1 Chemicals Newly Identified in the 2020–2021 Biennial Review

Table 1 lists the 13 chemicals that were newly identified as occurring in biosolids in the 2020–2021 biennial review. The letters in the table legend indicate where further information can be found in the appendices. As stated previously for these chemicals, EPA collected data required to inform risk assessments from preferred sources not limited to the 2020–2021 reporting period (see sections 2.3.1, 2.3.2, and 2.3.3 in this report).

EPA extracted concentration data for the 13 newly identified chemicals from the public literature reviewed. These data are provided in Appendix C.

No human health toxicity values were found for any of the newly identified chemicals.

EPA found papers for five newly identified chemicals in ECOTOX (U.S. EPA 2022d). The results are presented in Appendix E, Table E-1. These papers will require further evaluation for relevance for inclusion in risk assessments.

Environmental fate and transport data were available from the papers reviewed for 13 of the newly identified chemicals (see Appendix F). BAFs and BCFs were reported by trophic level for 12 of the newly identified chemicals in EPI Suite, but the values are not species-specific (see Appendix F, Table F-2). Additionally, EPA found species-specific, field-measured BAFs and laboratory-measured BCFs in the peer-reviewed database published by ORNL (2022) for one of the newly identified chemicals (see Appendix F, Table F-3).

Additional uptake and transfer data were available for two newly identified chemicals from the ONRL RASI database (ORNL 2022) (see Appendix F, Table F-4).

Additional physical/chemical properties were not collected for this biennial review because the data are now available in EPA's Comptox Chemicals Dashboard here: https://comptox.epa.gov/dashboard/chemical-lists/BIOSOLIDS2022.

Table 1. Chemicals Newly Identified in Biosolids in the 2020–2021 Reporting Period and Types of Data Available

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
New Chemicals Identified in the 2021–2022 Literature Review					
2-(N-Ethylperfluorooctanesulfonamido)acetic acid	2991-50-6	A	X	I	J
2-(N-Methylperfluorooctanesulfonamido)acetic acid	2355-31-9	A	X	X	J, M
alpha-Solanine	20562-02-1	A	X	X	J
Berberine	2086-83-1	A	X	X	J
Bromide	24959-67-9	A	X	X	J
Doxepin	1668-19-5	A	X	X	J
Fentanyl	437-38-7	A	X	I	J
Hydromorphone	466-99-9	A	X	X	J
Hydroxychloroquine	118-42-3	A	X	X	J
Levorphanol	77-07-6	A	X	X	J
Losartan	114798-26-4	A	X	I	J
Methadone	76-99-3	A	X	I	J
Perfluorohexadecanoic acid	67905-19-5	A	X	I	J, M

Notes:

X = No data were found
A = Concentration data (Table C-1)
I = ECOTOX (Table E-1)
J = EPI Suite (Table F-2)
M = ORNL RAIS (Tables F-3 and F-4)

3.2 Chemicals Identified in the Curation Process

Table 2 lists the 281 chemicals that EPA identified through the curation process described previously. The letters in the table legend indicate where further information can be found in the appendices. As stated previously for these chemicals, EPA collected data required to inform risk assessments from preferred sources not limited to the 2020–2021 reporting period (see sections 2.3.1, 2.3.2, and 2.3.3 in this report).

Concentration data for three chemicals identified in the curation process were extracted from the reviewed literature. These data are provided in Appendix C.

Human health toxicity values were found for 70 chemicals identified in the curation process. Data were found in eight different sources (IRIS, HHBP, PPRTV, ATSDR, CalEPA, Health Canada, NRWQC-HHC, and NPDWR). These values are reported in Appendix D.

Papers for 157 chemicals identified in the curation process were found in ECOTOX (U.S. EPA 2022d). The results are presented in Appendix E, Table E-2. These papers will require further evaluation for relevance for inclusion in risk assessments. Ecotoxicity data were available for 11 chemicals identified in the curation process from the National Recommended Water Quality Criteria – Aquatic Life Criteria (see Appendix E, Table E-4). Additional ecotoxicity data were available for 14 chemicals identified in the curation process from EPA's Office of Pesticide Programs – Aquatic Life Benchmarks for pesticides (See Appendix E, Table E-5).

Environmental fate and transport data were available from the papers reviewed for 276 of the chemicals identified in the curation process. These values are provided in Appendix F. BAFs and BCFs were reported by trophic level for 275 of the chemicals identified in the curation process in EPISuite, but the values are not species-specific (see Appendix F, Table F-2). Additionally, species-specific, field-measured BAFs and laboratory-measured BCFs were found in peer-reviewed databases published by Arnot and Gobas (2006), Environment and Climate Change Canada (2006), and ORNL (2022) for 114 of the chemicals identified in the curation process; these data are provided in Tables F-1 and F-3.

Additional uptake and transfer data were available for 86 chemicals identified in the curation process from the ONRL RASI database (ORNL 2022) (see Appendix F, Table F-4).

Additional physical/chemical properties were not collected for this biennial review because the data are now available in EPA's Comptox Chemicals Dashboard.

Table 2. Chemicals Identified in the Curation Process and Types of Data Available

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
(E)-1,2-Dichloroethylene	156-60-5	X	B, D, F, P, Q	I	J, M
1,1,1-Trichloroethane	71-55-6	X	B, F, G, P, Q	I	K, L, M
1,2,3,4,6,7,8-Heptachlorodibenzo[b,d]furan	67562-39-4	X	G	I	J, M
1,2,3,7,8,9-Hexachlorodibenzo[b,d]furan	72918-21-9	X	G	I	J, M
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321-76-4	X	G	I	J, M
1,2,3-Trichlorobenzene	87-61-6	X	D, H	I	L, M
1,2,4-Trichlorobenzene	120-82-1	X	B, F, G, H, P, Q	I	K, L, M
1,2-Dichlorobenzene	95-50-1	X	B, F, H, P, Q	I	K, L, M
1,2-Dichloropropane	78-87-5	X	B, D, F, G, P, Q	I	K, M
1,4-Dinitrobenzene	100-25-4	X	D	I	K, M
1,4-Dioxane	123-91-1	X	B, F, G, Q	I	K, M
1-Methyl phenanthrene	832-69-9	X	X	I	J, M
2-(2,4,5-Trichlorophenoxy)propionic acid	93-72-1	X	B, P, Q	I	J, M

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
2-(Methylthio)benzothiazole	615-22-5	X	X	X	J
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	40186-72-9	X	X	I	L
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	35694-08-7	X	X	I	L
2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl	52663-79-3	X	X	X	J
2,2',3,3',4,4',5,6-Octachlorobiphenyl	52663-78-2	X	X	I	L
2,2',3,3',4,4',6,6'-Octachlorobiphenyl	33091-17-7	X	X	X	J
2,2',3,3',4,4',6-Heptachlorobiphenyl	52663-71-5	X	X	I	J
2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl	52663-77-1	X	X	X	J
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	52663-75-9	X	X	X	L
2,2',3,3',4,5,5',6-Octachlorobiphenyl	68194-17-2	X	X	I	J
2,2',3,3',4,5,5'-Heptachlorobiphenyl	52663-74-8	X	X	X	J
2,2',3,3',4,5,6,6'-Octachlorobiphenyl	52663-73-7	X	X	X	J
2,2',3,3',4,5,6'-Heptachlorobiphenyl	38411-25-5	X	X	X	L
2,2',3,3',4,5,6-Heptachlorobiphenyl	68194-16-1	X	X	I	J
2,2',3,3',4,5',6'-Heptachlorobiphenyl	52663-70-4	X	X	X	L
2,2',3,3',4,5',6-Heptachlorobiphenyl	40186-70-7	X	X	X	J
2,2',3,3',4,5'-Hexachlorobiphenyl	52663-66-8	X	X	I	J
2,2',3,3',4,6,6'-Heptachlorobiphenyl	52663-65-7	X	X	X	J
2,2',3,3',4,6'-Hexachlorobiphenyl	38380-05-1	X	X	X	L
2,2',3,3',4-Pentachlorobiphenyl	52663-62-4	X	X	X	L
2,2',3,3',5,5',6,6'-Octachlorobiphenyl	2136-99-4	X	X	I	J
2,2',3,3',5,5'-Hexachlorobiphenyl	35694-04-3	X	X	I	J
2,2',3,3',5,6,6'-Heptachlorobiphenyl	52663-64-6	X	X	X	J
2,2',3,3',5,6'-Hexachlorobiphenyl	52744-13-5	X	X	X	J
2,2',3,3',5,6-Hexachlorobiphenyl	52704-70-8	X	X	X	J
2,2',3,3',5-Pentachlorobiphenyl	60145-20-2	X	X	X	J
2,2',3,3',6-Pentachlorobiphenyl	52663-60-2	X	X	X	L
2,2',3,3'-Tetrachlorobiphenyl	38444-93-8	X	X	X	L
2,2',3,4,4',5,6,6'-Octachlorobiphenyl	74472-52-9	X	X	X	J
2,2',3,4,4',5,6'-Heptachlorobiphenyl	60145-23-5	X	X	X	J
2,2',3,4,4',5,6-Heptachlorobiphenyl	74472-47-2	X	X	X	J
2,2',3,4,4',5',6-Heptachlorobiphenyl	52663-69-1	X	X	I	L
2,2',3,4,4',5-Hexachlorobiphenyl	35694-06-5	X	X	X	J
2,2',3,4,4',5'-Hexabromodiphenyl ether	182677-30-1	X	X	X	J
2,2',3,4,4',6,6'-Heptachlorobiphenyl	74472-48-3	X	X	I	J

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
2,2',3,4,4',6'-Hexachlorobiphenyl	59291-64-4	X	X	X	J
2,2',3,4,4',6-Hexachlorobiphenyl	56030-56-9	X	X	X	J
2,2',3,4',5,5',6-Heptachloro-1,1'-biphenyl	52663-68-0	X	X	X	L
2,2',3,4,5,5',6-Heptachlorobiphenyl	52712-05-7	X	X	I	J
2,2',3,4,5,5'-Hexachlorobiphenyl	52712-04-6	X	X	I	L
2,2',3,4',5,5'-Hexachlorobiphenyl	51908-16-8	X	X	X	L
2,2',3,4,5,6,6'-Heptachlorobiphenyl	74472-49-4	X	X	X	J
2,2',3,4',5,6,6'-Heptachlorobiphenyl	74487-85-7	X	X	I	J
2,2',3,4,5,6'-Hexachlorobiphenyl	68194-15-0	X	X	I	J
2,2',3,4,5',6-Hexachlorobiphenyl	68194-14-9	X	X	X	J
2,2',3,4',5,6'-Hexachlorobiphenyl	74472-41-6	X	X	X	J
2,2',3,4',5,6-Hexachlorobiphenyl	68194-13-8	X	X	X	J
2,2',3,4',5',6-Hexachlorobiphenyl	38380-04-0	X	X	X	J
2,2',3,4,5-Pentachlorobiphenyl	55312-69-1	X	X	X	J
2,2',3,4',5'-Pentachlorobiphenyl	41464-51-1	X	X	I	L
2,2',3,4',5-Pentachlorobiphenyl	68194-07-0	X	X	X	J
2,2',3,4,6,6'-Hexachlorobiphenyl	74472-40-5	X	X	X	J
2,2',3,4',6,6'-Hexachlorobiphenyl	68194-08-1	X	X	X	J
2,2',3,4,6'-Pentachlorobiphenyl	73575-57-2	X	X	X	J
2,2',3,4,6-Pentachlorobiphenyl	55215-17-3	X	X	X	J
2,2',3,4',6'-Pentachlorobiphenyl	60233-25-2	X	X	X	J
2,2',3,4',6-Pentachlorobiphenyl	68194-05-8	X	X	X	L
2,2',3,4'-Tetrachloro-1,1'-biphenyl	36559-22-5	X	X	X	L
2,2',3,4-Tetrachlorobiphenyl	52663-59-9	X	X	X	J
2,2',3,5,5',6-Hexachlorobiphenyl	52663-63-5	X	X	I	L
2,2',3,5,5'-Pentachlorobiphenyl	52663-61-3	X	X	X	L
2,2',3,5,6,6'-Hexachlorobiphenyl	68194-09-2	X	X	X	J
2,2',3,5,6'-Pentachlorobiphenyl	73575-55-0	X	X	X	J
2,2',3,5,6-Pentachlorobiphenyl	73575-56-1	X	X	X	J
2,2',3,5'-tetrachlorobiphenyl	41464-39-5	X	X	I	L
2,2',3,6,6'-Pentachlorobiphenyl	73575-54-9	X	X	X	J
2,2',3,6'-Tetrachlorobiphenyl	41464-47-5	X	X	X	J
2,2',3-Trichlorobiphenyl	38444-78-9	X	X	X	L
2,2',4,4',5,6'-Hexachlorobiphenyl	60145-22-4	X	X	X	J
2,2',4,4',5-Pentachlorobiphenyl	38380-01-7	X	X	X	L

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
2,2',4,4',6,6'-Hexachlorobiphenyl	33979-03-2	X	X	I	J
2,2',4,4',6-Pentachlorobiphenyl	39485-83-1	X	X	I	L
2,2',4,4',6-Pentabromodiphenyl ether	189084-64-8	X	X	I	J
2,2',4,5,6'-Pentachlorobiphenyl	68194-06-9	X	X	X	J
2,2',4,5',6-Pentachlorobiphenyl	60145-21-3	X	X	X	J
2,2',4,6,6'-Pentachlorobiphenyl	56558-16-8	X	X	I	J
2,2',4,6-Tetrachlorobiphenyl	62796-65-0	X	X	I	L
2,2',4-Trichlorobiphenyl	37680-66-3	X	X	X	L
2,2',5,6'-Tetrachlorobiphenyl	41464-41-9	X	X	X	L
2,2',5-Trichlorobiphenyl	37680-65-2	X	X	I	L
2,2',6,6'-Tetrachlorobiphenyl	15968-05-5	X	X	I	J
2,2'-Bioxirane	1464-53-5	X	X	I	J, M
2,3,3',4,4',5,5',6-Octachlorobiphenyl	74472-53-0	X	X	X	L
2,3,3',4,4',5',6-Heptachlorobiphenyl	74472-50-7	X	X	X	J
2,3,3',4,5,5',6-Heptachlorobiphenyl	74472-51-8	X	X	X	J
2,3,3',4',5,5',6-Heptachlorobiphenyl	69782-91-8	X	X	X	J
2,3,3',4,5,5'-Hexachlorobiphenyl	39635-35-3	X	X	X	J
2,3,3',4',5,5'-Hexachlorobiphenyl	39635-34-2	X	X	X	J
2,3,3',4,5,6-Hexachlorobiphenyl	41411-62-5	X	X	X	J
2,3,3',4,5',6-Hexachlorobiphenyl	74472-43-8	X	X	X	J
2,3,3',4',5',6-Hexachlorobiphenyl	74472-45-0	X	X	X	J
2,3,3',4,5'-Pentachlorobiphenyl	70362-41-3	X	X	X	J
2,3,3',4',5'-Pentachlorobiphenyl	76842-07-4	X	X	X	J
2,3,3',4',5-Pentachlorobiphenyl	70424-68-9	X	X	X	J
2,3,3',4,6-Pentachlorobiphenyl	74472-35-8	X	X	X	J
2,3,3',4',6-Pentachlorobiphenyl	38380-03-9	X	X	I	L
2,3,3',4'-Tetrachlorobiphenyl	41464-43-1	X	X	X	L
2,3,3',4-Tetrachlorobiphenyl	74338-24-2	X	X	X	J
2,3,3',5,5',6-Hexachlorobiphenyl	74472-46-1	X	X	X	J
2,3,3',5,5'-Pentachlorobiphenyl	39635-32-0	X	X	X	J
2,3,3',5',6-Pentachlorobiphenyl	68194-10-5	X	X	X	J
2,3,3',5'-Tetrachlorobiphenyl	41464-49-7	X	X	I	J
2,3,3',5-Tetrachlorobiphenyl	70424-67-8	X	X	X	J
2,3,3',6-Tetrachlorobiphenyl	74472-33-6	X	X	X	J
2,3,3'-Trichlorobiphenyl	38444-84-7	X	X	I	J

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
2,3,4,4',5,6-Hexachlorobiphenyl	41411-63-6	X	X	X	J
2,3',4,4',5',6-Hexachlorobiphenyl	59291-65-5	X	X	X	J
2,3,4,4',6-Pentachlorobiphenyl	74472-38-1	X	X	X	J
2,3',4,4',6-Pentachlorobiphenyl	56558-17-9	X	X	I	J
2,3',4,4'-Tetrabromodiphenyl ether	189084-61-5	X	X	X	J
2,3,4,4'-Tetrachlorobiphenyl	33025-41-1	X	X	I	L
2,3',4,5,5'-Pentachlorobiphenyl	68194-12-7	X	X	X	J
2,3',4',5,5'-Pentachlorobiphenyl	70424-70-3	X	X	X	J
2,3,4,5,6-Pentachlorobiphenyl	18259-05-7	X	X	I	J
2,3,4',5,6-Pentachlorobiphenyl	68194-11-6	X	X	X	J
2,3',4,5',6-Pentachlorobiphenyl	56558-18-0	X	X	X	J
2,3',4',5',6-Pentachlorobiphenyl	74472-39-2	X	X	X	J
2,3,4,5-Tetrachlorobiphenyl	33284-53-6	X	X	I	J
2,3,4',5-Tetrachlorobiphenyl	74472-34-7	X	X	X	J
2,3',4,5'-Tetrachlorobiphenyl	73575-52-7	X	X	X	J
2,3',4,5-Tetrachlorobiphenyl	73575-53-8	X	X	X	J
2,3',4',5'-Tetrachlorobiphenyl	70362-48-0	X	X	X	J
2,3',4',5-Tetrachlorobiphenyl	32598-11-1	X	X	I	L
2,3,4,6-Tetrachlorobiphenyl	54230-22-7	X	X	X	J
2,3,4',6-Tetrachlorobiphenyl	52663-58-8	X	X	X	L
2,3',4,6-Tetrachlorobiphenyl	60233-24-1	X	X	X	J
2,3',4',6-Tetrachlorobiphenyl	41464-46-4	X	X	X	J
2,3,4-Trichlorobiphenyl	55702-46-0	X	X	X	J
2,3',4-Trichlorobiphenyl	55712-37-3	X	X	X	J
2',3,4-Trichlorobiphenyl	38444-86-9	X	X	X	L
2,3',5,5'-Tetrachlorobiphenyl	41464-42-0	X	X	X	J
2,3,5,6-Tetrachlorobiphenyl	33284-54-7	X	X	I	J
2,3',5',6-Tetrachlorobiphenyl	74338-23-1	X	X	X	J
2,3,5-Trichlorobiphenyl	55720-44-0	X	X	X	J
2,3',5'-Trichlorobiphenyl	37680-68-5	X	X	X	J
2,3'-Dichlorobiphenyl	25569-80-6	X	X	X	J
2,4,4',5-Tetrachlorobiphenyl	32690-93-0	X	X	X	L
2,4,4',6-Tetrachlorobiphenyl	32598-12-2	X	X	I	J
2,4,4'-Tribromodiphenyl ether	41318-75-6	X	X	I	J
2,4,4'-Trichlorobiphenyl	7012-37-5	X	X	I	L

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
2,4,5-Trichlorobiphenyl	15862-07-4	X	X	I	J
2,4,5-Trichlorophenoxyacetic acid	93-76-5	X	B, Q	I	J, M
2,4,5-Trimethylaniline	137-17-7	X	X	I	J
2,4,6-Trichlorobiphenyl	35693-92-6	X	X	I	J
2,4',6-Trichlorobiphenyl	38444-77-8	X	X	X	J, L
2,4-Dichlorobiphenyl	33284-50-3	X	X	I	X
2,5-Dichlorobiphenyl	34883-39-1	X	X	I	X
2,6-Dinitrotoluene	606-20-2	X	D, F, Q	I	K, M
2-Chloro-4-phenylphenol	92-04-6	X	X	I	J
2-Hexanone	591-78-6	X	B, F	I	J, M
2-Methyl-1-propanol	78-83-1	X	B	I	J, M
2-Methylpyridine	109-06-8	X	X	I	J, M
3,3',4,5,5'-Pentachlorobiphenyl	39635-33-1	X	X	X	J
3,3',4,5'-Tetrachlorobiphenyl	41464-48-6	X	X	X	J
3,3',4,5-Tetrachlorobiphenyl	70362-49-1	X	X	X	J
3,3',4-Trichlorobiphenyl	37680-69-6	X	X	X	J
3,3',5,5'-Tetrachlorobiphenyl	33284-52-5	X	X	I	J
3,3',5-Trichlorobiphenyl	38444-87-0	X	X	X	J
3,3'-Dichloro-1,1'-biphenyl	2050-67-1	X	X	X	J
3,4,5-Trichlorobiphenyl	53555-66-1	X	X	X	J
3,4',5-Trichlorobiphenyl	38444-88-1	X	X	X	J
3,4'-Dichlorobiphenyl	2974-90-5	X	X	X	J
3,4-Dichlorobiphenyl	2974-92-7	X	X	I	J
3,5-Dichlorobiphenyl	34883-41-5	X	X	I	J
3,6-Dimethylphenanthrene	1576-67-6	X	X	I	J, M
3-Chlorobiphenyl	2051-61-8	X	X	I	J
4,4'-Dichlorobiphenyl	2050-68-2	X	X	I	J
4-Androstene-3,17-dione	63-05-8	X	X	I	J
4-Chloro-3-methylphenol	59-50-7	X	P	I	K, L, M
4-Methyl-2-pentanone	108-10-1	X	B	I	J, M
Acenaphthene	83-32-9	X	B, D, F, P, Q	I	K, M
Aldrin	309-00-2	X	B, D, F, G, H, P, Q	I, N	L, M
Allyl alcohol	107-18-6	X	B, D	I	J, M

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
Allyl chloride	107-05-1	X	B, G	I	K, M
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	319-84-6	X	B, F, P	I	L, M
alpha-Terpineol	98-55-5	X	X	I	J
Anhydrochlortetracycline	4497-08-9	X	X	X	X
Aroclor 1248	12672-29-6	X	F	I	J, M
Aroclor 1254	11097-69-1	X	B, F	I	J, M
Aroclor 1260	11096-82-5	X	X	I	J, M
Azinphos-methyl	86-50-0	X	B, C, F	I, N, O	J, M
Bensulide	741-58-2	X	C	I, O	J, M
Benzene	71-43-2	X	B, D, F, G, P, Q	I	K, L, M
Benzenethiol	108-98-5	X	D	I	M
Benzo(g,h,i)perylene	191-24-2	X	Q	I	J, M
Benzyl alcohol	100-51-6	X	D	I	J, M
Benzyl butyl phthalate	85-68-7	X	B, D, P, Q	I	K, L, M
beta-Hexachlorocyclohexane	319-85-7	X	B, F, P	I	J, M
Biphenyl	92-52-4	X	B, D	I	K, L, M
Bisphenol A	80-05-7	A	B	I	K, L, M
Caffeine	58-08-2	X	X	I	J
Captan	133-06-2	X	B, C, G	I, O	K, M
Carbon disulfide	75-15-0	X	B, F, G	I, O	L, M
Carbadox	6804-07-5	X	X	I	J
Carbophenothion	786-19-6	X	X	I	J, M
Chlorobenzene	108-90-7	X	B, D, F, G, H, P, Q	I	K, L, M
Chlorobenzilate	510-15-6	X	B, G	I	J, M
Chloroethane	75-00-3	X	B, D, F, G	I	J, M
Chloromethane	74-87-3	X	B, D, F, Q	I	J, M
Chlorpyrifos	2921-88-2	X	F, Q	I, N, O	K, L, M
Clomazone	81777-89-1	X	C	I, O	J, M
Crotonaldehyde	4170-30-3	X	X	I	J, M
Crotoxyphos	7700-17-6	X	X	I	J
Cyanide	57-12-5	X	B, P, Q	I, N	J, M
Decane	124-18-5	X	X	I	J, M
delta-Hexachlorocyclohexane	319-86-8	X	X	I	J, M

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
Diallate	2303-16-4	X	X	I	J, M
Diazinon	333-41-5	X	F, P, Q	I, N	K, L, M
Dibenzofuran	132-64-9	X	D	I	K, M
Dibenzothiophene	132-65-0	X	X	I	K, L, M
Dichlorodiphenyltrichloroethane	50-29-3	X	B, F, G, H, P	I, N	L, M
Dichloromethane	75-09-2	X	B, F, G, H, P, Q	I	K, L, M
Dicrotophos	141-66-2	X	C	I, O	J, M
Dieldrin	60-57-1	X	B, F, G, H, P, Q	I, N	L, M
Dimethyl sulfone	67-71-0	X	X	X	J
Diphenyl oxide	101-84-8	X	X	I	K, M
Diphenylamine	122-39-4	X	C	I	K
dl-Norgestrel	6533-00-2	X	X	X	J
Docosane	629-97-0	X	X	I	J
Dodecane	112-40-3	X	X	I	K, L
Eicosane	112-95-8	X	X	I	J
Endrin	72-20-8	X	B, F, P, Q	I, N	L, M
EPN	2104-64-5	X	B	I, O	J, M
Heptachlor	76-44-8	X	B, F, G, P, Q	I, N	L, M
Hexabromocyclododecane	25637-99-4	X	X	I	J
Hexacosane	630-01-3	X	X	X	J
Hexadecane	544-76-3	X	X	I	L
Iodine	7553-56-2	X	F	I	J, M
Leptophos	21609-90-5	X	X	I	J
Lindane	58-89-9	X	B, G, P, Q	I, N, O	K, L, M
Methacrylonitrile	126-98-7	X	B, D	I	X
Methyl ethyl ketone	78-93-3	X	B, F, G, Q	I	J, M
Methyl triclosan	4640-01-1	X	X	I	X
Mevinphos	7786-34-7	X	C	I, O	J, M
Naled	300-76-5	X	B, C	I, O	J, M
Nitrobenzene	98-95-3	X	B, P	I	K, L, M
Nonylphenol and Nonylphenol Ethoxylates (NP/NPEs)	NOCAS_872428	X	X	X	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
o-Cresol	95-48-7	X	B, D	I	K, M
Octacosane	630-02-4	X	X	I	J
Octadecane	593-45-3	X	X	I	J
p,p'-DDD	72-54-8	X	B, F, G, P	I	L, M
p,p'-DDE	72-55-9	X	B, D, F, G, P	I	L, M
PCB 026	38444-81-4	X	X	X	J
p-Cymene	99-87-6	X	X	I	J, M
Penicillin V	87-08-1	X	X	X	J
Pentachlorophenol	87-86-5	X	B, F, G, P, Q	I, N, O	K, L, M
Perfluorodecanesulfonic acid	335-77-3	A	X	X	J, M
Perylene	198-55-0	X	X	I	J, M
Phenanthrene	85-01-8	X	Q	I	K, L, M
Phosphamidon	13171-21-6	X	X	I	J, M
Potassium	7440-09-7	A	X	I	J, M
Propionitrile	107-12-0	X	X	I	J, M
Quinine	130-95-0	X	X	I	J
Silicon	7440-21-3	X	X	I	J, M
Squalene	7683-64-9	X	X	X	J
Strontium	7440-24-6	X	B, F, Q	I	J, M
Tenofovir	147127-20-6	X	X	X	J
Tetracosane	646-31-1	X	x	X	J
Tetradecane	629-59-4	X	X	I	J
Tetraethyl pyrophosphate	107-49-3	X	X	I	J
Thioxanthen-9-one	492-22-8	X	X	I	J
Triacontane	638-68-6	X	X	X	J
Trichloroethylene	79-01-6	X	B, F, G, H, P, Q	I	K, L, M
Trichlorofluoromethane	75-69-4	X	B, D, Q	X	J, M
Trifluralin	1582-09-8	X	B, Q	I, O	K, M
Tri-o-cresyl phosphate	78-30-8	X	X	I	K, L
Triphenylene	217-59-4	X	X	I	J
Valproic acid	99-66-1	X	X	I	J

Notes:

X = No data were found
A = Concentration data (Tables C-1)
B = IRIS (Table D-1)
C = HHBP (Table D-2)
D = PPRTV (Table D-3)
E = HESD (No data available)
F = ATSDR (Table D-5)
G = CalEPA (Table D-5)
H = Health Canada (Table D-6)
I = ECOTOX (Table E-2)
J = EPI Suite (Table F-2)
K = Environment and Climate Change Canada (BCF/BAF only) (Table F-1)
L = Arnot and Gobas (BCF/BAF only) (Table F-1)
M = ORNL RAIS (Tables F-3 and F-4)
N = NRWQC-ALC (Table E-4)
O = OPP-ALB (Table E-5)
P = NRWQC-HHC (Table D-7)
Q = NPDWR (Table D-8)

3.3 Chemicals Identified in Previous Biennial Reviews

In addition to reporting newly identified chemicals in biosolids, EPA reviewed the literature for new (i.e., published after the previous biennial review period) concentration data, physical-chemical properties, human health and ecological toxicity data, and environmental fate and transport data for chemical pollutants previously identified in biosolids. Table 3 shows the 445 previously identified chemicals for which new data were found, along with the types of data available for the chemicals. The letters in the table legend indicate where further information can be found in the appendices).

Concentration data for 30 previously identified chemicals were available in the reviewed literature. These data are provided in Appendix C.

Six sources EPA reviewed (HHBP, ATSDR, CalEPA, Health Canada, NRWQC-HHC, and NPDWR) contained one or more human health toxicity values for 64 previously identified chemicals. These values are reported in Appendix D.

EPA found papers published in ECOTOX (U.S. EPA 2022d) from 2020 to 2021 for 116 previously identified chemicals. The results are presented in Appendix E, Table E-3. These papers will require further evaluation for relevance for inclusion in risk assessments. Ecotoxicity data were available for 19 previously identified from the National Recommended Water Quality Criteria – Aquatic Life Criteria (see Appendix E, Table E-4). Additional ecological toxicity data were available for 14 previously identified chemicals from EPA's Office of Pesticide Programs – Aquatic Life Benchmarks for pesticides (See Appendix E, Table E-5).

There were no new data available since the last reporting period (i.e., after 2019) from EPI Suite (U.S. EPA 2017), Arnot and Gobas (2006), and Environment and Climate Change Canada (2006). ORNL (2022) had BAF/BCF data and additional uptake and transfer data for one previously identified chemical (see Appendix F, Table F-4).

Table 3. Previously Identified Chemicals with Data Found in the 2020–2021 Reporting Period and Types of Data Available

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
(+)-Diltiazem	42399-41-7	X	X	I	X
(+/-)-Verapamil	52-53-9	X	X	I	X
(3alpha,5beta)-Cholestan-3-ol	516-92-7	X	X	X	X
1-(p-Chlorobenzoyl)-5-methoxy-2-methyl-Indole-3-acetic acid	53-86-1	X	X	I	X
1,1'-Ethane-1,2-diylbis(pentabromobenzene)	84852-53-9	X	X	I	X
1,1'-Oxybis[2,3,4,5,6-pentabromobenzene]	1163-19-5	X	X	I	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
1,2,3,4,5-Pentabromo-6-(2,3,4,5-tetrabromophenoxy)benzene	63387-28-0	X	X	X	X
1,2,3,4,6,7,8,9,10,10,11,11-dodecachloro-1,4,4a,5a,6,9,9a,9b-octahydro-1,4:6,9-dimethanodibenzofuran	31107-44-5	X	X	X	X
1,2,3,4,6,7,8-Heptabromodibenzofuran	107555-95-3	X	X	X	X
1,2,3,4,6,7,8-Heptabromodibenzo-p-dioxin	110999-47-8	X	X	X	X
1,2,3,4,6,7,8-Heptachlorodibenzodioxin	35822-46-9	X	X	X	X
1,2,3,4,7,8,9-Heptabromodibenzo[b,d]furan	161880-51-9	X	X	X	X
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673-89-7	X	X	X	X
1,2,3,4,7,8-Hexabromodibenzofuran	129880-08-6	X	X	X	X
1,2,3,4,7,8-Hexabromodibenzo-p-dioxin	110999-44-5	X	X	X	X
1,2,3,4,7,8-Hexachlorodibenzodioxin	39227-28-6	X	X	X	X
1,2,3,4,7,8-Hexachlorodibenzofuran	70648-26-9	X	X	X	X
1,2,3,5-Tetrabromo-4-(3,4,5-tribromophenoxy)benzene	446255-30-7	X	X	X	X
1,2,3,6,7,8-Hexabromodibenzofuran	107555-94-2	X	X	X	X
1,2,3,6,7,8-Hexabromodibenzo-p-dioxin	110999-45-6	X	X	X	X
1,2,3,6,7,8-Hexachlorodibenzofuran	57117-44-9	X	X	X	X
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	57653-85-7	X	X	X	X
1,2,3,7,8,9-Hexabromodibenzo[b,d]furan	161880-49-5	X	X	X	X
1,2,3,7,8,9-Hexabromodibenzo-p-dioxin	110999-46-7	X	X	X	X
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	19408-74-3	X	X	X	X
1,2,3,7,8-Pentabromodibenzo[b,d]furan	107555-93-1	X	X	X	X
1,2,3,7,8-Pentabromodibenzo-p-dioxin	109333-34-8	X	X	X	X
1,2,3,7,8-Pentachlorodibenzofuran	57117-41-6	X	X	X	X
1,2-Bis(2,4,6-tribromophenoxy)ethane	37853-59-1	X	X	X	X
1,3,5-Triazin-2(1H)-one, 4,6-diamino-	645-92-1	X	X	X	X
1,3,5-Trichlorobenzene	108-70-3	X	Q	X	X
1,3-Dichlorobenzene	541-73-1	X	P, Q	X	X
1,4:5,8:9,10-Trimethanoanthracene, 1,2,3,4,5,6,7,8,12,12,13,13-dodecachloro-1,4,4a,5,8,8a,9,9a,10,10a-decahydro-	13560-92-4	X	X	X	X
1,4-Dichlorobenzene	106-46-7	X	H, P, Q	X	X
1,7-Dimethylxanthine	611-59-6	X	X	X	X
10-Hydroxyamitriptyline	1159-82-6	X	X	X	X
17alpha-Estradiol	57-91-0	X	X	X	X
17alpha-Ethinylestradiol	57-63-6	X	X	I	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
17beta-Estradiol	50-28-2	X	X	I	X
2,2',3,3',4,4',5,6'-Octachlorobiphenyl	42740-50-1	X	X	X	X
2,2',3,3',4,4',5-Heptachlorobiphenyl	35065-30-6	X	X	X	X
2,2',3,3',4,4'-Hexachlorobiphenyl	38380-07-3	X	X	X	X
2,2',3,3',4,5',6,6'-Octachlorobiphenyl	40186-71-8	X	X	X	X
2,2',3,3',4,5-Hexachlorobiphenyl	55215-18-4	X	X	X	X
2,2',3,3',5,5',6-Heptachlorobiphenyl	52663-67-9	X	X	X	X
2,2',3,3',6,6'-Hexachlorobiphenyl	38411-22-2	X	X	X	X
2,2',3,4,4',5,5',6-Octachlorobiphenyl	52663-76-0	X	X	X	X
2,2',3,4,4',5,5'-Heptachlorobiphenyl	35065-29-3	X	X	X	X
2,2',3,4,4',5',6-Heptabromodiphenyl ether	207122-16-5	X	X	X	X
2,2',3,4,4',5'-Hexachlorobiphenyl	35065-28-2	X	X	X	X
2,2',3,4,4'-Pentabromodiphenyl ether	182346-21-0	X	X	X	X
2,2',3,4,4'-Pentachlorobiphenyl	65510-45-4	X	X	X	X
2,2',3,4,5'-Pentachlorobiphenyl	38380-02-8	X	X	X	X
2,2',3,5',6-Pentachlorobiphenyl	38379-99-6	X	X	X	X
2,2',3,5-Tetrachlorobiphenyl	70362-46-8	X	X	X	X
2,2',4,4',5,5'-Hexabromobiphenyl	59080-40-9	X	X	X	X
2,2',4,4',5,5'-Hexabromodiphenyl ether	68631-49-2	X	X	X	X
2,2',4,4',5,5'-Hexachlorobiphenyl	35065-27-1	X	X	I	X
2,2',4,4',5,6'-Hexabromodiphenyl ether	207122-15-4	X	X	X	X
2,2',4,4',5-Pentabromodiphenyl ether	60348-60-9	X	X	X	X
2,2',4,4'-Tetrabromodiphenyl ether	5436-43-1	X	X	I	X
2,2',4,4'-Tetrachlorobiphenyl	2437-79-8	X	X	X	X
2,2',4,5,5'-Pentachlorobiphenyl	37680-73-2	X	X	X	X
2,2',4,5'-Tetrachlorobiphenyl	41464-40-8	X	X	X	X
2,2',4,5-Tetrachlorobiphenyl	70362-47-9	X	X	X	X
2,2',4,6'-Tetrachlorobiphenyl	68194-04-7	X	X	X	X
2,2',4-Tribromodiphenyl ether	147217-75-2	X	X	X	X
2,2',5,5'-Tetrachlorobiphenyl	35693-99-3	X	X	X	X
2,2',6-Trichlorobiphenyl	38444-73-4	X	X	X	X
2,2'-Dichlorobiphenyl	13029-08-8	X	X	X	X
2,3,3',4,4',5,5'-Heptachlorobiphenyl	39635-31-9	X	X	X	X
2,3,3',4,4',5,6-Heptachlorobiphenyl	41411-64-7	X	X	X	X
2,3,3',4,4',5'-Hexachlorobiphenyl	69782-90-7	X	X	X	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
2,3,3',4,4',5-Hexachlorobiphenyl	38380-08-4	X	X	X	X
2,3,3',4,4',6-Hexachlorobiphenyl	74472-42-7	X	X	X	X
2,3,3',4,4'-Pentachlorobiphenyl	32598-14-4	X	X	X	X
2,3,3',4',5,6-Hexachlorobiphenyl	74472-44-9	X	X	X	X
2,3',4,4',5,5'-Hexachlorobiphenyl	52663-72-6	X	X	X	X
2,3,4,4',5-Pentachlorobiphenyl	74472-37-0	X	X	X	X
2,3',4,4',5-Pentachlorobiphenyl	31508-00-6	X	X	X	X
2',3,4,4',5-Pentachlorobiphenyl	65510-44-3	X	X	X	X
2,3',4,4'-Tetrachlorobiphenyl	32598-10-0	X	X	X	X
2,3,4,5,6-Pentabromoethylbenzene	85-22-3	X	X	X	X
2,3,4,6,7,8-Hexabromodibenzo[b,d]furan	161880-50-8	X	X	X	X
2,3,4,6,7,8-Hexachlorodibenzo[b,d]furan	60851-34-5	X	X	X	X
2,3,4,7,8-Pentabromodibenzofuran	131166-92-2	X	X	X	X
2,3,4,7,8-Pentachlorodibenzofuran	57117-31-4	X	X	X	X
2,3,4'-Trichlorobiphenyl	38444-85-8	X	X	X	X
2,3,6-Trichlorobiphenyl	55702-45-9	X	X	X	X
2,3',6-Trichlorobiphenyl	38444-76-7	X	X	X	X
2,3,7,8-Tetrabromodibenzofuran	67733-57-7	X	X	X	X
2,3,7,8-Tetrabromodibenzo-p-dioxin	50585-41-6	X	X	X	X
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9	X	X	X	X
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	X	P, Q	I	X
2,3-Dichlorobiphenyl	16605-91-7	X	X	X	X
2,4',5-Trichlorobiphenyl	16606-02-3	X	X	X	X
2,4,5-Trichlorophenol	95-95-4	X	P	X	X
2,4,6-Trinitro-1,3-dimethyl-5-tert-butylbenzene	81-15-2	X	X	X	X
2,4,6-Tris(tert-butyl)phenol	732-26-3	X	X	X	X
2,4'-Dichlorobiphenyl	34883-43-7	X	X	X	X
2,4-Dichlorophenol	120-83-2	X	P, Q	I	X
2,4-Dichlorophenoxyacetic acid	94-75-7	X	P, Q	I, O	X
2,4-Di-tert-butylphenol	96-76-4	X	X	X	X
2,4-Di-tert-pentylphenol	120-95-6	X	X	X	X
2,6-Dichlorobiphenyl	33146-45-1	X	X	X	X
2,6-Di-tert-butylphenol	128-39-2	X	X	X	X
2-Chlorobiphenyl	2051-60-7	X	X	X	X
2-Chloronaphthalene	91-58-7	X	P	X	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
2-Ethylhexyl diphenyl phosphate	1241-94-7	X	X	X	X
2H,2H,3H,3H-Perfluorooctanoic acid	914637-49-3	X	X	I	X
2-Methylnaphthalene	91-57-6	X	X	X	X
3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-Henicosafluorododecyl 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl hydrogen phosphate	1158182-60-5	X	X	X	X
3,3',4,4',5,5'-Hexachlorobiphenyl	32774-16-6	X	X	X	X
3,3',4,4',5-Pentachlorobiphenyl	57465-28-8	X	X	I	X
3,3',4,4'-Tetrachlorobiphenyl	32598-13-3	X	X	X	X
3,3',5,5'-Tetrabromobisphenol A	79-94-7	X	X	I	X
3,4,4',5-Tetrachlorobiphenyl	70362-50-4	X	X	X	X
3,4,4'-Trichlorobiphenyl	38444-90-5	X	X	X	X
3,4-Dihydroxybenzoic acid	99-50-3	X	X	X	X
3-Methylindole	83-34-1	X	X	X	X
4-(1,1,3,3-Tetramethylbutyl)phenol	140-66-9	X	X	X	X
4-(Butan-2-yl)-2,6-di-tert-butylphenol	17540-75-9	X	X	X	X
4,4'-Dichlorocarbanilide	1219-99-4	X	X	X	X
4,4'-Methylenebis(2,6-di-t-butylphenol)	118-82-1	X	X	X	X
4,4'-Thiobis(6-tert-butyl-m-cresol)	96-69-5	X	X	X	X
4-Chloroaniline	106-47-8	X	X	X	X
4-Chlorobiphenyl	2051-62-9	X	X	X	X
4-Dimethylaminoantipyrine	58-15-1	X	X	X	X
4-Epianhydrotetracycline	7518-17-4	X	X	X	X
4-Epichlortetracycline	14297-93-9	X	X	X	X
4-epi-Oxytetracycline	14206-58-7	X	X	X	X
4-Hydroxybenzoic acid	99-96-7	X	X	X	X
4-Nitrophenol	100-02-7	X	Q	X	X
4-Nonylphenol	104-40-5	X	X	X	X
4-Nonylphenol, branched	84852-15-3	X	X	I, N	X
5-Aminosalicylic acid	89-57-6	X	X	X	X
6:2 Fluorotelomer phosphate diester	57677-95-9	X	X	I	X
6:2 Fluorotelomer sulfonic acid	27619-97-2	X	X	I	X
6:2/8:2 Fluorotelomer phosphate diester	943913-15-3	X	X	X	X
7-Acetyl-1,1,3,4,4,6-hexamethyltetraline	21145-77-7	X	X	I	X
8:2 Fluorotelomer phosphate diester	678-41-1	X	X	I	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
8:2 Fluorotelomer sulfonic acid	39108-34-4	X	X	I	X
Acetaminophen	103-90-2	X	X	I, O	X
Acetone	67-64-1	X	F	I	X
Acetophenone	98-86-2	X	X	X	X
Albuterol	18559-94-9	X	X	X	X
Alprazolam	28981-97-7	X	X	X	X
Aluminum	7429-90-5	X	X	N	X
Amitriptyline	50-48-6	X	X	X	X
Amlodipine	88150-42-9	X	X	X	X
Ammelide	645-93-2	X	X	X	X
Amoxicillin	26787-78-0	X	X	I	X
Amphetamine	300-62-9	X	X	X	X
Ampicillin	69-53-4	X	X	I	X
Androsterone	53-41-8	X	X	X	X
Anhydrotetracycline	1665-56-1	X	X	X	X
Anthracene	120-12-7	X	P, Q	X	X
Antimony	7440-36-0	X	P, Q	X	X
Arsenic	7440-38-2	X	P, Q	I, N	X
Aspirin	50-78-2	X	X	I	X
Atenolol	29122-68-7	X	X	I	X
Atorvastatin	134523-00-5	X	X	I	X
Azithromycin	83905-01-5	A	X	I	X
Barium	7440-39-3	X	P, Q	X	X
BDE-196	446255-39-6	X	X	X	X
BDE-197	117964-21-3	X	X	X	X
BDE-207	437701-79-6	X	X	X	X
Benz(a)anthracene	56-55-3	X	P, Q	X	X
Benzene, 1,2,3,5-tetrabromo-4-(2,4,6-tribromophenoxy)-	117948-63-7	X	X	X	X
Benzo(a)pyrene	50-32-8	X	H, P, Q	I	X
Benzo(b)fluoranthene	205-99-2	X	P, Q	I	X
Benzo(k)fluoranthene	207-08-9	X	P, Q	X	X
Benzoic acid	65-85-0	X	X	I, O	X
Benzoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, 2,4-bis(1,1-dimethylethyl)phenyl ester	4221-80-1	X	X	X	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
Benzoylecgonine	519-09-5	X	X	X	X
Benztropine	86-13-5	X	X	X	X
Benzyl 4-hydroxybenzoate	94-18-8	X	X	X	X
Beryllium	7440-41-7	X	H, Q	X	X
beta-Sitosterol	83-46-5	X	X	X	X
Bezafibrate	41859-67-0	X	X	X	X
Bis(1,3-dichloropropan-2-yl) hydrogen phosphate	72236-72-7	X	X	I	X
bis(1-Chloropropan-2-yl) hydrogen phosphate	789440-10-4	X	X	X	X
Bis(2-chloroethyl) phosphate	3040-56-0	X	X	I	X
Bis(2-ethylhexyl) phosphate	298-07-7	X	X	X	X
Bis(2-methylphenyl) hydrogen phosphate	35787-74-7	X	X	X	X
Boron	7440-42-8	X	Q	N	X
Butylated hydroxyanisole	25013-16-5	X	X	X	X
Butylated hydroxytoluene	128-37-0	X	X	X	X
Butylparaben	94-26-8	X	X	I	X
Cadmium	7440-43-9	X	H, P, Q	N	M
Calcium	7440-70-2	X	X	X	X
Campesterol	474-62-4	X	X	X	X
Carbamazepine	298-46-4	A	X	I	X
Carbon tetrachloride	56-23-5	X	H, P, Q	X	X
Cerium	7440-45-1	X	X	X	X
Cesium	7440-46-2	X	X	X	X
Chloroform	67-66-3	X	P, Q	I	X
Chlortetracycline	57-62-5	X	X	X	X
Cholestan-3-ol, (3.beta.,5.alpha.)-	80-97-7	X	X	X	X
Cholesterol	57-88-5	X	X	X	X
Chromium	7440-47-3	X	P, Q	N	X
Chrysene	218-01-9	X	P, Q	X	X
Cimetidine	51481-61-9	X	X	I	X
Ciprofloxacin	85721-33-1	A	X	I	X
Clarithromycin	81103-11-9	X	X	X	X
Clindamycin	18323-44-9	X	X	X	X
Clofibric acid	882-09-7	X	X	I	X
Clorophene	120-32-1	X	X	I	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
Clotrimazole	23593-75-1	X	X	X	X
Cobalt	7440-48-4	X	X	X	X
Cocaine	50-36-2	A	X	I	X
Codeine	76-57-3	A	X	X	X
Copper	7440-50-8	X	H, P, Q	N, O	X
Coprosterol	360-68-9	X	X	X	X
Cotinine	486-56-6	X	X	X	X
Cresyl diphenyl phosphate	26444-49-5	X	X	X	X
Cyanuric acid	108-80-5	X	X	X	X
Cyclopenta[g]-2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethyl-	1222-05-5	X	X	I	X
Cyclophosphamide	50-18-0	X	X	X	X
Decachlorobiphenyl	2051-24-3	X	X	X	X
Decamethylcyclopentasiloxane	541-02-6	X	X	X	X
Dechlorane Plus	13560-89-9	X	X	X	X
DEET	134-62-3	X	X	O	X
Demeclocycline	127-33-3	X	X	X	X
Desmosterol	313-04-2	X	X	X	X
Di(2-ethylhexyl) phthalate	117-81-7	X	F, P, Q	I	X
Diazepam	439-14-5	X	X	I	X
Dibenzofuran, 1,2,3,4,6,7,8,9-octabromo-	103582-29-2	X	X	X	X
Dibutyl phthalate	84-74-2	X	P, Q	I	X
Dichlorobiphenyl	25512-42-9	X	X	X	X
Dichlorophen	97-23-4	X	X	X	X
Diclofenac	15307-86-5	X	X	I	X
Diethyl hydrogen phosphate	598-02-7	X	X	X	X
Digoxin	20830-75-5	X	X	X	X
Diisobutyl hydrogen phosphate	6303-30-6	X	X	X	X
Dimethoate	60-51-5	X	X	I, O	X
Dimethyl 2,6-dimethyl-4-(2-nitrophenyl)-3,5-pyridinedicarboxylate	67035-22-7	X	X	X	X
Dimethyl phthalate	131-11-3	X	P, Q	I	X
Di-n-octyl phthalate	117-84-0	X	X	I	X
Diphenhydramine	58-73-1	X	X	X	X
Diphehyl phosphate	838-85-7	X	X	I	X
D-Limonene	5989-27-5	X	X	O	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
Doxycycline	564-25-0	X	X	I	X
Endosulfan I	959-98-8	X	P	I, N	X
Endosulfan II	33213-65-9	X	P	I, N	X
Enrofloxacin	93106-60-6	X	X	I	X
Epitetracycline	79-85-6	X	X	X	X
Equilenin	517-09-9	X	X	X	X
Equilin	474-86-2	X	X	X	X
ERGOSTEROL	57-87-4	X	X	X	X
Erythromycin	114-07-8	X	X	X	X
Estradiol benzoate	50-50-0	X	X	X	X
Estriol	50-27-1	X	X	X	X
Estrone	53-16-7	X	X	X	X
Ethanaminium, 2-hydroxy-N-(2-hydroxyethyl)-N,N-dimethyl-, esters with C16-18 and C18-unsatd. Fatty acids, chlorides	1079184-43-2	X	X	X	X
Ethanol, 2-butoxy-, hydrogen phosphate	14260-97-0	X	X	X	X
Ethylbenzene	100-41-4	X	H, P, Q	X	X
Ethylene glycol nonylphenyl ether	27986-36-3	X	X	X	X
Ethylparaben	120-47-8	X	X	I	X
Fenofibric acid	42017-89-0	X	X	I	X
Fenthion	55-38-9	X	X	I, O	X
Fipronil	120068-37-3	X	C	I, O	X
Fipronil amide	205650-69-7	X	X	X	X
Fipronil sulfide	120067-83-6	X	X	X	X
Fipronil Sulfone	120068-36-2	X	X	X	X
Fipronil-desulfinyl	205650-65-3	X	X	X	X
Floxacillin	5250-39-5	X	X	X	X
Fluoranthene	206-44-0	X	P	I	X
Fluoride	16984-48-8	X	Q	X	X
Fluoxetine	54910-89-3	X	X	I	X
Furosemide	54-31-9	X	X	I	X
Gemfibrozil	25812-30-0	A	X	I	X
Glybenclamide	10238-21-8	X	X	X	X
Heptachlor epoxide B	1024-57-3	X	P, Q	N	X
Heptachlorobiphenyl	28655-71-2	X	X	X	X
Hexabromobenzene	87-82-1	X	X	I	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
Hexachlorobiphenyl	26601-64-9	X	X	X	X
Hexanoic acid	142-62-1	X	X	X	X
Hydrocodone	125-29-1	X	X	X	X
Ibuprofen	15687-27-1	A	X	I	X
Indole	120-72-9	X	X	X	X
Iron	7439-89-6	A	X	N	X
Isochlortetracycline	514-53-4	X	X	X	X
Isodecyl diphenyl phosphate	29761-21-5	X	X	X	X
Ketoprofen	22071-15-4	X	X	I	X
Lead	7439-92-1	X	H, Q	N	X
Lincomycin	154-21-2	X	X	X	X
Lomefloxacin	98079-51-7	X	X	X	X
Magnesium	7439-95-4	A	X	X	X
Manganese	7439-96-5	A	H, P, Q	X	M
MDMA	42542-10-9	X	X	X	X
Mefenamic acid	61-68-7	X	X	X	X
Melamine	108-78-1	X	X	O	X
Mercury	7439-97-6	X	Q	X	N
Mestranol	72-33-3	X	X	X	X
Metformin	657-24-9	X	X	X	X
Methamphetamine	537-46-2	X	X	I	X
Methyl 3,4-dihydroxybenzoate	2150-43-8	X	X	X	X
Methylparaben	99-76-3	X	X	I	X
Metoprolol	51384-51-1	X	X	I	X
Miconazole	22916-47-8	A	X	X	X
Minocycline	10118-90-8	X	X	X	X
Molybdenum	7439-98-7	X	F, Q	X	X
Monochlorobiphenyl	27323-18-8	X	X	X	X
Monuron	150-68-5	X	X	I	X
Musk ketone	81-14-1	X	X	X	X
m-Xylene	108-38-3	X	X	X	X
Nadolol	42200-33-9	X	X	X	X
Nalidixic acid	389-08-2	X	X	X	X
Naphthalene	91-20-3	X	H, Q	I	X
Naproxen	22204-53-1	A	X	I	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
N-Desmethyldiltiazem	86408-45-9	X	X	X	X
Nickel	7440-02-0	X	P, Q	N	X
Nitrofen	1836-75-5	X	X	I	X
N-Nitrosodibutylamine	924-16-3	X	P	X	X
N-Nitrosodiethylamine	55-18-5	X	P	X	X
N-Nitrosodimethylamine	62-75-9	X	P	X	X
N-Nitrosodi-n-propylamine	621-64-7	X	P	X	X
N-Nitrosodiphenylamine	86-30-6	X	P	X	X
N-Nitrosopiperidine	100-75-4	X	X	X	X
N-Nitrosopyrrolidine	930-55-2	X	P	X	X
n-Nonylphenol	25154-52-3	X	X	X	X
n-Octylphenol	67554-50-1	X	X	X	X
Nonachlorobiphenyl	53742-07-7	X	X	X	X
Norethindrone	68-22-4	X	X	I	X
Norfloxacin	70458-96-7	X	X	X	X
Norfluoxetine	83891-03-6	X	X	I	X
Norverapamil	67018-85-3	X	X	X	X
Octabromodibenzo-p-dioxin	2170-45-8	X	X	X	X
Octachlorobiphenyl	55722-26-4	X	X	X	X
Octachlorodibenzofuran	39001-02-0	X	X	X	X
Octachlorodibenzo-p-dioxin	3268-87-9	X	X	X	X
Ofloxacin	82419-36-1	A	X	X	X
Ormetoprim	6981-18-6	X	X	X	X
Oxolinic acid	14698-29-4	X	X	X	X
Oxycodone	76-42-6	A	X	X	X
o-Xylene	95-47-6	X	X	X	X
Oxytetracycline	79-57-2	X	C	I, O	X
Paroxetine	61869-08-7	X	X	X	X
PCB 045	70362-45-7	X	X	X	X
PCB 131	61798-70-7	X	X	X	X
p-Cresol	106-44-5	X	X	X	X
Pentabromodiphenyl ether	32534-81-9	X	X	X	X
Pentachloro-1,1'-biphenyl	25429-29-2	X	X	X	X
Pentachloronitrobenzene	82-68-8	X	X	I, O	X
Perfluorobutanesulfonic acid	375-73-5	A	X	I	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
Perfluorobutanoic acid	375-22-4	A	X	I	X
Perfluorodecanoic acid	335-76-2	A	X	I	X
Perfluorododecanoic acid	307-55-1	A	X	I	X
Perfluoroheptanoic acid	375-85-9	A	X	I	X
Perfluorohexanesulfonic acid	355-46-4	A	F	I	X
Perfluorohexanoic acid	307-24-4	A	X	I	X
Perfluorononanoic acid	375-95-1	A	X	I	X
Perfluorooctanesulfonamide	754-91-6	X	X	I	X
Perfluorooctanesulfonic acid	1763-23-1	A	H, Q	I, N	X
Perfluorooctanoic acid	335-67-1	A	H, Q	I, N	X
Perfluoropentanoic acid	2706-90-3	X	X	I	X
Perfluorotetradecanoic acid	376-06-7	A	X	X	X
Perfluorotridecanoic acid	72629-94-8	A	X	I	X
Perfluoroundecanoic acid	2058-94-8	A	X	I	X
Phenazone	60-80-0	X	X	X	X
Phenol	108-95-2	X	P, Q	I	X
Phenol, 2,5-bis(1,1-dimethylethyl)-	5875-45-6	X	X	X	X
Phenol, 4,4',4"-(1-methyl-1-propanyl-3-ylidene)tris 2-(1,1-dimethylethyl)-5-methyl-	1843-03-4	X	X	X	X
Phosphoric acid, 2,2-bis(chloromethyl)-1,3-propanediyl tetrakis(2-chloroethyl) ester	38051-10-4	X	X	X	X
Phosphoric acid, dibutyl ester	107-66-4	X	X	X	X
Phosphoric acid, dipropyl ester	1804-93-9	X	X	X	X
Phosphoric acid, P,P'-[(1-methylethylidene)di-4,1-phenylene] P,P,P',P'-tetraphenyl ester	5945-33-5	X	X	X	X
Polycarbonates	25766-59-0	X	X	X	X
Polychlorinated biphenyls	1336-36-3	X	P, Q	X	M
Polyethylene glycol	25322-68-3	X	X	X	X
Polyethylene terephthalate	25038-59-9	X	X	X	X
Progesterone	57-83-0	X	X	X	X
Promethazine	60-87-7	X	X	X	X
Propoxyphene	469-62-5	X	X	X	X
Propranolol	525-66-6	X	X	I	X
Propylparaben	94-13-3	X	X	I	X
p-Xylene	106-42-3	X	X	X	X
Pyrene	129-00-0	X	P, Q	X	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
Ranitidine	66357-35-5	X	X	X	X
Roxithromycin	80214-83-1	X	X	I	X
Rubidium	7440-17-7	X	X	X	X
Salicylic acid	69-72-7	X	X	X	X
Sarafloxacin	98105-99-8	X	X	X	X
Selenium	7782-49-2	X	H, P, Q	N	X
Sertraline	79617-96-2	X	X	I	X
Silver	7440-22-4	A	Q	I, N	X
Sodium	7440-23-5	X	X	X	X
Stigmastan-3beta-ol	19466-47-8	X	X	X	X
Stigmastanol	138126-65-5	X	X	X	X
Stigmasterol	83-48-7	X	X	X	X
STK368415	5136-34-5	X	X	X	X
Styrene	100-42-5	X	Q	X	X
Sulfachloropyridazine	80-32-0	X	X	X	X
Sulfadiazine	68-35-9	X	X	I	X
Sulfadimethoxine	122-11-2	X	X	X	X
Sulfamerazine	127-79-7	X	X	X	X
Sulfamethazine	57-68-1	X	X	I	X
Sulfamethoxazole	723-46-6	X	X	I	X
Sulfanilamide	63-74-1	X	X	X	X
Sulfasalazine	599-79-1	X	X	X	X
Sulfate	14808-79-8	X	X	X	X
Sulfathiazole	72-14-0	X	X	X	X
Sulfur	7704-34-9	X	X	I	X
Terephthalic acid	100-21-0	X	X	X	X
tert-Butylphenyl diphenyl phosphate	56803-37-3	X	X	X	X
Testosterone	58-22-0	X	X	X	X
Tetrabutyl ethylidenebisphenol	35958-30-6	X	X	X	X
Tetrachlorobiphenyl	26914-33-0	X	X	X	X
Tetrachloroethylene	127-18-4	X	F, H, P, Q	X	X
Tetracycline	60-54-8	X	X	I	X
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	X	X	X	X
Thallium	7440-28-0	X	P, Q	X	X
Thiabendazole	148-79-8	X	C	I, O	X

Chemical	CAS number	Concentration data	Human health toxicity data	Ecological toxicity data	Environmental fate and transport data
Tin	7440-31-5	X	X	X	X
Titanium	7440-32-6	X	X	X	X
Toluene	108-88-3	X	G, P, Q	X	X
Triamterene	396-01-0	X	X	X	X
Tributyl phosphate	126-73-8	X	X	X	X
Trichlorfon	52-68-6	X	C	O	X
Trichlorobiphenyl	25323-68-6	X	X	X	X
Triclocarban	101-20-2	A	X	I	X
Triclosan	3380-34-5	A	X	I	X
Triethyl phosphate	78-40-0	X	X	X	X
Triethylene glycol bis(3-tert-butyl-4-hydroxy-5-methylphenyl)propionate	36443-68-2	X	X	X	X
Triisobutyl phosphate	126-71-6	X	X	X	X
Trimethoprim	738-70-5	X	X	X	X
Trimethyl phosphate	512-56-1	X	X	X	X
Trimethylsilanol	1066-40-6	X	X	X	X
Triphenyl phosphate	115-86-6	X	X	I	X
Tripropyl phosphate	513-08-6	X	X	X	X
Tris(1,3-dichloro-2-propyl) phosphate	13674-87-8	X	X	I	X
Tris(2-butoxyethyl) phosphate	78-51-3	X	X	X	X
Tris(2-chloroethyl) phosphate	115-96-8	X	X	I	X
Tris(2-chloroisopropyl)phosphate	13674-84-5	X	X	X	X
Tris(2-ethylhexyl) phosphate	78-42-2	X	X	I	X
Tris(4-tert-butylphenyl) phosphate	78-33-1	X	X	X	X
Tris(methylphenyl) phosphate	1330-78-5	X	X	X	X
Tylosin	1401-69-0	X	X	X	X
Valsartan	137862-53-4	X	X	I	X
Vanadium	7440-62-2	X	X	X	X
Virginiamycin	11006-76-1	X	X	X	X
Yttrium	7440-65-5	X	X	I	X
Zinc	7440-66-6	X	H, P, Q	X, N	X
α-Dihydroequilin	651-55-8	X	X	X	X

Notes:

X = No data were found
A = Concentration data (Table C-1)
B = IRIS (Table D-1)
C = HHBP (Table D-2)
D = PPRTV (Table D-3)
E = HESD (No available data)
F = ATSDR (Table D-4)
G = CalEPA (Table D-5)
H = Health Canada (Table D-6)
I = ECOTOX (Table E-3)
M = ORNL (Tables F-3 and F-4)
N = NRWQC-ALC (Table E-4)
O = OPP-ALB (Table E-5)
P = NRWQC-HHC (Table D-7)
Q = NPDWR (Table D-8)

3.4 Microbial Pollutants Identified in the 2020–2021 Biennial Review

EPA identified five articles that met the eligibility criteria for microbial pollutants (abstracts of the articles are provided in Appendix A-1). Review of the articles found one newly identified microbial pollutant in biosolids and provided potentially useful data on two previously identified microbial pollutants. Table 4 lists these microbial pollutants.

Table 4. Microbial Pollutants Identified During the Biosolids Biennial Review for the 2020–2021 Reporting Period

Name	Category	New or previous	Reference[1]
Antibiotic Resistant Bacteria[2]	Bacteria	Previous	Mays et al. 2021
Escherichia coli	Bacteria	Previous	Archer et al. 2020; Navab-Daneshmand et al. 2021
SARS-CoV2	Virus	New	Nason et al. 2021; Peccia et al. 2020

Notes:

[1]These references are described in Appendix A-1, Abstracts for Papers Reviewed for the 2020–2021 Biennial Review.
[2]Antibiotic resistant *E. coli* and *Enterococcus* were identified in this paper.

4 Conclusions

Every two years, EPA develops biennial reports by collecting and reviewing publicly available information on the occurrence, human health and ecological effects, and fate and transport in the environment of pollutants that have been found in biosolids in the previous two years. The types of information collected and presented in Biennial Report No.9 (Reporting Period 2020–2021) are needed to conduct risk assessments.

EPA identified 13 new articles that provide relevant data for chemical pollutants that may occur in biosolids. Review of the 13 articles identified 13 new chemicals in biosolids: nine drugs, three PFAS, and one element. These articles also identified new data for three chemicals identified during the curation process and 30 chemicals that were previously identified in biosolids. EPA found concentration data in biosolids for 13 new chemicals, three chemicals identified during the curation process, and 30 chemicals identified in a previous biennial review. EPA found human health toxicity values for 70 of the chemicals identified during the curation process, and 64 previously identified chemicals. EPA found ECOTOX (U.S. EPA 2022d) records for five newly identified chemicals, 157 chemicals identified during the curation process, and 116 previously identified chemicals. EPA identified additional ecological toxicity data for 20 chemicals identified in the curation process, and 32 previously identified chemicals.

EPA identified environmental fate and transport data in EPI Suite (U.S. EPA 2017), Arnot and Gobas (2006), Environment and Climate Change Canada (2006), or ORNL (2022) for 13 newly identified

chemicals, 276 chemicals identified during the curation process, and three previously identified chemicals.

EPA identified five new articles that provide relevant data for microbial pollutants that may occur in biosolids. Within these articles, one new microbial pollutant in biosolids was identified, and potentially useful data on two previously identified microbial pollutants were found.

Addressing the uncertainty around potential risk for pollutants identified in biosolids is the top priority for EPA's Biosolids Program. EPA has made significant progress in developing the necessary tools and data needed to build capacity to assess pollutants found in biosolids.

For additional information about EPA's Biosolids Program, please visit the website at: http://epa.gov/biosolids.

5 References

Arnot, J.A., and A.P.C. Gobas. 2006. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environmental Reviews* 14(4):257–297.

ATSDR (Agency for Toxic Substances and Disease Registry). 2022. *Minimal Risk Levels (MRLs) for Hazardous Substances*. Accessed February 2022. https://www.atsdr.cdc.gov/.

CalEPA (California Environmental Protection Agency). 2021. *OEHHA Chemical Database.* California Environmental Protection Agency, California Office of Environmental Health Hazard Assessment. Accessed February 2022. https://oehha.ca.gov/chemicals.

Environment and Climate Change Canada. 2006. Bioaccumulation Canada. In *The OECD QSAR Toolbox, Version 3.3.2.* An online database. Retrieved January 5, 2015. Organisation for Economic Co-operation and Development, Paris, France. http://www.oecd.org/env/ehs/risk-assessment/oecd-qsar-toolbox.htm.

Health Canada. 2021. *Federal Contaminated Site Risk Assessment in Canada: Toxicological Reference Values, Version 3.0*. Health Canada. Ottawa, Canada. Accessed April 2022. https://publications.gc.ca/collections/collection_2021/sc-hc/H129-108-2021-eng.pdf.

ORNL (Oak Ridge National Laboratory). 2022. The Risk Assessment Information System (RAIS). *RAIS Toxicity Values and Physical Parameters Search*. Accessed February 2022. https://rais.ornl.gov/.

Richman, T., E. Arnold, and A.J. Williams. 2022. Curation of a list of chemicals in biosolids from EPA National Sewage Sludge Surveys & Biennial Review Reports. *Sci Data* 9:180. https://doi.org/10.1038/s41597-022-01267-9.

U.S. EPA (U.S. Environmental Protection Agency). 2009. *Targeted National Sewage Sludge Survey Statistical Analysis Report*. EPA-822-R-08-018. U.S. EPA, Office of Water, Washington, DC. Accessed June 2020. https://www.epa.gov/biosolids/sewage-sludge-surveys.

U.S. EPA (U.S. Environmental Protection Agency). 2017. *Estimation Programs Interface Suite™ for Microsoft® Windows, v 4.11*. Updated July 19, 2017. U.S. EPA, Washington, DC. Accessed January 2022. https://www.epa.gov/tsca-screening-tools/download-epi-suitetm-estimation-program-interface-v411.

U.S. EPA (U.S. Environmental Protection Agency). 2022a. *Integrated Risk Information System (IRIS)*. U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Washington, DC. Accessed February 2022. http://www.epa.gov/iris/.

U.S. EPA (U.S. Environmental Protection Agency). 2022b. *Human Health Benchmarks for Pesticides*. U.S. EPA, Office of Pesticide Programs, Washington, DC. Accessed February 2022. https://iaspub.epa.gov/apex/pesticides/f?p=CHEMICALSEARCH:1:0::NO:1.

U.S. EPA (U.S. Environmental Protection Agency). 2022c. *Superfund Provisional Peer-Reviewed Toxicity Values*. U.S. EPA, Washington, DC. Accessed February 2022. https://www.epa.gov/pprtv/provisional-peer-reviewed-toxicity-values-pprtvs-assessments.

U.S. EPA (U.S. Environmental Protection Agency). 2022d. *ECOTOXicology Knowledgebase (ECOTOX)*. U.S. EPA, Washington, DC. Accessed May 2022. https://cfpub.epa.gov/ecotox/.

U.S. EPA (U.S. Environmental Protection Agency). 2022e. *Health Effects Support Documents*. U.S. EPA, Office of Water, Office of Science and Technology, Washington, DC. Accessed March 2022. https://www.epa.gov/sdwa/drinking-water-contaminant-human-health-effects-information#regulatory.

U.S. EPA (U.S. Environmental Protection Agency). 2022f. *Aquatic Life Benchmarks and Ecological Risk Assessments for Registered Pesticides*. U.S. EPA, Office of Water, Washington, DC. Last updated September 29, 2022; Accessed November 2022. https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/aquatic-life-benchmarks-and-ecological-risk.

U.S. EPA (U.S. Environmental Protection Agency). 2022g. *National Primary Drinking Water Regulations*. U.S. EPA, Office of Water, Washington, DC. Last updated January 26, 2022; Accessed November 2022. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

U.S. EPA (U.S. Environmental Protection Agency). 2022h. *National Recommended Water Quality Criteria - Aquatic Life Criteria Table*. U.S. EPA, Office of Water, Washington, DC. Last updated September 15, 2022; Accessed November 2022. https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table.

U.S. EPA (U.S. Environmental Protection Agency). 2022i. *National Recommended Water Quality Criteria - Human Health Criteria Table*. U.S. EPA, Office of Water, Washington, DC. Last updated September 15, 2022; Accessed November 2022. https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table.

Appendix A-1: Abstracts for Papers Reviewed for the 2020–2021 Biennial Review

Abbott, T., and C. Eskicioglu. 2020. Comparison of anaerobic, cycling aerobic/anoxic, and sequential anaerobic/aerobic/anoxic digestion to remove triclosan and triclosan metabolites from municipal biosolids. *Science of the Total Environment* 745:140953.

The antimicrobial triclosan (TCS) is a pervasive and persistent environmental micropollutant which can contaminate land, biota, and water through the land application of biosolids. Many existing sludge management techniques have limited effectiveness against TCS and TCS metabolites including triclosan-sulfate (TCS-SO_4). The objective of this study was to evaluate the impacts of different digestion types (anaerobic, aerobic/anoxic, and sequential anaerobic + aerobic/anoxic), temperatures, and digester sludge retention times (SRTs) on the destruction of organic matter, and on TCS/TCS metabolites. Conventional mesophilic anaerobic digesters (AD), room temperature cycling aerobic/anoxic digesters (AERO/ANOX), and sequential AD + AERO/ANOX digesters were all effective in removing organic matter. The optimum single-stage AD, and AERO/ANOX scenarios were both 20-day SRTs which had 52.3 ± 1.4 and 47.1 ± 3.7% chemical oxygen demand (COD) removals, respectively. Sequential AD + AERO/ANOX digesters improved organic matter destruction, removing up to 68.2 ± 2.1% of COD at an 8-day AD + 12-day AERO/ANOX second-stage (mesophilic) SRTs. While AD showed modest levels of TCS removals (all <40%), TCS was substantially more degradable aerobically with AERO/ANOX removing up to 80.3 ± 2.5% of TCS and nearly all TCS-SO_4 entering the digester at a 20-day SRT. Sequential AD + AERO/ANOX removed virtually all TCS-SO_4 entering the system and improved TCS removals from first stage ADs. However, they were less effective than a single-stage AERO/ANOX digester operating at the same overall SRT. These results demonstrate that AERO/ANOX and sequential AD + AERO/ANOX processes could be used to reduce the amount of TCS, TCS-SO_4 and TCS-related compounds in digested sludge, minimizing the environmental burden of the land application of biosolids.

Adesanya, T., F. Zvomuya, T. Sultana, C. Metcalfe, and A. Farenhorst. 2021. Dissipation of sulfamethoxazole and trimethoprim during temporary storage of biosolids: a microcosm study. *Chemosphere* 269:128729.

Little is known about the dissipation rate of microcontaminants in biosolids during storage and stabilization in stockpiles (unsaturated) or storage lagoons/tanks (saturated). The objective of this study was to characterize the dissipation in biosolids of two antibiotics, sulfamethoxazole (SMX) and trimethoprim (TMP), in microcosms under saturated and unsaturated conditions that simulate biosolids that are stockpiled on land or deposited in lagoons/tanks, respectively. The laboratory experiment was conducted at 22 °C using biosolids spiked at an initial nominal concentration of 10 mg kg^{-1} for both antibiotics. Biosolids were sampled in triplicate at seven sampling times over a 42-d period. Concentrations of SMX and TMP in extracts prepared from biosolids were quantified using liquid chromatography with tandem mass spectrometry. Dissipation data fitted to a first-order kinetic model indicated that the time to 50% dissipation (DT_{50}) for SMX was significantly shorter in the unsaturated microcosms (2.8 d) than the saturated microcosms (4.4 d), while the DT50 for TMP was significantly shorter in microcosms under saturated conditions (10 d) relative to unsaturated conditions (116 d). These results indicate that the reducing conditions that develop in biosolids deposited in lagoons or placed in storage tanks might be effective for enhancing the microbial degradation of antibiotics that are otherwise persistent under aerobic conditions (i.e., TMP), while also being effective for removing other antibiotics including those that dissipate relatively readily under aerobic conditions (i.e., SMX).

Archer, G., C. Jin, and W. Parker. 2020. Benchmarking the sustainability of sludge handling systems in small wastewater treatment plants. *Journal of Environmental Management* 256:109893.

A benchmarking strategy was developed to assess all aspects of sludge handling in small wastewater treatment plants and tested on a cross-section of Ontario facilities. Using operational data and on-site measurements, sustainability metrics that addressed energy consumption, chemical use, biosolids quality and disposition, and greenhouse gas (GHG) emissions were estimated. Electricity consumption for sludge handling ranged from 0.9 to 3.9 kW-hours per dry kilogram of raw sludge (kWh/dry kg) with thermo-alkali hydrolysis and auto-thermal thermophilic aerobic digestion (ATAD) processes consuming the least and most electricity for stabilization, respectively. Mechanical dewatering processes consumed between 2 and 5% of total sludge handling electricity, however, associated polymer dosages were higher than literature values in some cases. Disposition fuel requirements for plants with dewatering were up to 85% lower than facilities without dewatering. Biosolids contaminant (pathogen/metals) contents were observed to be substantially below Non-Agricultural Source Material (NASM) requirements. The copper content of the hauled biosolids exhibited the highest concentration relative to the NASM limit among all plants studied, ranging from 14 to 37% among facilities practicing land application of biosolids. Four biosolid products met Class A requirements for *E. coli* content, including one product generated via long-term storage. Carbon emissions ranged from −119 to 299 kg CO_2 equivalents per dry tonne of raw sludge (g CO_2 eq./kg). Six facilities that practiced land application exhibited net-negative GHG emissions; the carbon credits gained from fertilizer production avoidance outweighed emissions associated with sludge processing and transportation. The results provide evidence that this practice is sustainable from a GHG emissions standpoint. The benchmarking approach developed and information gathered is beneficial to plant owners and operators seeking to better understand how their utility is performing relative to peers, identify areas of need and further investigation, and improve the sustainability of their operations.

Gewurtz, S.B., G. Tardif, M. Power, S.M. Backus, A. Dove, K. Dubé-Roberge, C. Garron, M. King, B. Lalonde, R.J. Letcher, P.A. Martin, T.V. McDaniel, D.J. McGoldrick, M. Pelletier, J. Small, S.A. Smyth, S. Teslic, and J. Tessier. 2021. Bisphenol A in the Canadian environment: a multimedia analysis. *Science of the Total Environment* 755:142472.

Bisphenol A (BPA) is an industrial chemical that has been identified by some jurisdictions as an environmental concern. In 2010, Canada concluded that this substance posed a risk to the environment and human health, and implemented actions to reduce its concentrations in the environment. To support these activities, a multimedia analysis of BPA in the Canadian environment was conducted to evaluate spatial and temporal trends, and to infer mechanisms influencing the patterns. BPA was consistently detected in wastewater and biosolids across Canadian wastewater treatment plants (WWTPs) and in landfill leachate. In addition, BPA concentrations were significantly higher in surface water downstream compared to upstream of WWTPs in three of five urban areas evaluated. However, application of biosolids to Canadian agricultural fields did not contribute to elevated BPA concentrations in soil, earthworms, and European Starling (*Sturnus vulgaris*) plasma one and two years post-treatment. Spatial trends of BPA concentrations in surface water and sediment are influenced by human activity, with higher concentrations typically found downstream of industrial sources and WWTPs in urban areas. BPA was detected in bird plasma at locations impacted by WWTPs and landfills. However, spatial trends in birds were less clear and may have been confounded by metabolic biotransformation. In terms of temporal trends, BPA concentrations in surface water decreased significantly at 10 of 16 monitoring sites evaluated between 2008 and 2018. In contrast, recent temporal trends of BPA in six sediment cores were

variable, which may be a result of biotransformation of the flame retardant tetrabromobisphenol A to BPA. Overall, our study provides evidence that Government of Canada actions have been generally successful in reducing BPA concentrations in the Canadian environment. Our results indicate that long-term monitoring programs using surface water are more effective than other media for tracking and understanding future environmental trends of BPA.

Kor-Bicakci, G., T. Abbott, E. Ubay-Cokgor, and C. Eskicioglu. 2020. Occurrence of the persistent antimicrobial triclosan in microwave pretreated and anaerobically digested municipal sludges under various process conditions. *Molecules* 25(2):310.

Treatment of emerging contaminants, such as antimicrobials, has become a priority topic for environmental protection. As a persistent, toxic, and bioaccumulative antimicrobial, the accumulation of triclosan (TCS) in wastewater sludge is creating a potential risk to human and ecosystem health via the agricultural use of biosolids. The impact of microwave (MW) pretreatment on TCS levels in municipal sludge is unknown. This study, for the first time, evaluated how MW pretreatment (80 and 160 °C) itself and together with anaerobic digestion (AD) under various sludge retention times (SRTs: 20, 12, and 6 days) and temperatures (35 and 55 °C) can affect the levels of TCS in municipal sludge. TCS and its potential transformation products were analyzed with ultra-high-performance liquid chromatography and tandem mass spectrometry. Significantly higher TCS concentrations were detected in sludge sampled from the plant in colder compared to those in warmer temperatures. MW temperature did not have a discernible impact on TCS reduction from undigested sludge. However, AD studies indicated that compared to controls (no pretreatment), MW irradiation could make TCS more amenable to biodegradation (up to 46%), especially at the elevated pretreatment and digester temperatures. At different SRTs studied, TCS levels in the thermophilic digesters were considerably lower than that of in the mesophilic digesters.

Lazcano, R.K., Y.J. Choi, M.L. Mashtare, and L.S. Lee. Characterizing and comparing per- and polyfluoroalkyl substances in commercially available biosolid and organic non-biosolid-based products. *Environmental Science and Technology* 54(14):8640–8648.

There is increasing concern over the presence of per- and polyfluoroalkyl substances (PFAS) in biosolids, while sales in commercially available biosolid-based products used as soil amendments are also increasing. Here, the occurrence of 17 perfluoroalkyl acids (PFAAs) present in 13 commercially available biosolid-based products, six organic composts (manure, mushroom, peat, and untreated wood), and one food and yard waste compost were studied. The PFAA concentration ranges observed are as follows: biosolid based products (9.0−199 μg/kg) > food and yard waste (18.5 μg/kg) > other organic products (0.1−1.1 μg/kg). Analysis of 2014, 2016, and 2018 bags produced from one product line showed a temporal decrease in the total PFAAs (181, 101, and 74 μg/kg, respectively). The total oxidizable precursor (TOP) assay revealed the presence of PFAA precursors in the biosolid-based products at much higher levels, when the soluble carbon was removed by the ENVI-Carb clean-up prior to the TOP assay. Time-of-flight mass spectrometry confirmed the presence of three sulfonamides, two fluorotelomer sulfonates, and several polyfluoroalkyl phosphate diesters. Pore-water concentrations of water-saturated products were primarily of short-chain PFAAs and increased with increasing PFAA concentrations in the products. A strong positive log-linear correlation between organic carbon (OC)-normalized PFAA partition coefficients and the number of CFn units indicates that OC is a good predictor of PFAA release concentrations.

Li, J., L. Sabourin, J. Renaud, S. Halloran, A. Singh, M. Sumarah, M. Dagnew, and M.B. Ray. 2021. Simultaneous quantification of five pharmaceuticals and personal care products in biosolids and their fate in thermo-alkaline treatment. *Journal of Environmental Management* 278:111404.

The presence of pharmaceuticals and personal care products (PPCPs) in biosolids applied to farmland is of concern due to their potential accumulation in the environment and the subsequent effects on humans. Thermo-alkaline hydrolysis (TAH) is a method used for greater stabilization of biosolids after anaerobic digestion. In this work, the effect of TAH on five selected PPCPs including fluoroquinolone antibiotics, ciprofloxacin (CIP), and ofloxacin (OFLX), and three commonly used antimicrobial agents, miconazole (MIC), triclosan (TCS) and triclocarban (TCC) was evaluated. At the onset, extraction and analytical methods were optimized for maximum simultaneous recovery and LC-MS quantification of the target PPCPs from both water and biosolids for improved accuracy. The compounds were detected in the range of 54 ± 3 to 6166 ± 532 ng/g in raw biosolids collected from a local WWTP. Next, batch control adsorption experiments of the selected PPCPs were conducted in various sludges, which indicated about 89%–98% sorption of the PPCPs onto solid phase due to their high octanol-water coefficients. Subsequently, thermo-alkaline (pH 9.5, 75 °C, 45 min) hydrolysis (TAH) was conducted to determine the extent of degradation of these compounds in deionized (DI) water and biosolids due to treatment. The degradation of these compounds due to TAH ranged from 42% to 99% and 37%–41% in pure water and biosolids, respectively, potentially lowering their risk in the environment due to land application. A list of compounds for which the optimized analytical method potentially can be used for detection and quantification in environmental samples is provided in the supporting document.

Liu, Y., C.J. Ptacek, S. Beauchemin, T. MacKinnon, and D.W. Blowes. 2021. Effect of composting and amendment with biochar and woodchips on the fate and leachability of pharmaceuticals in biosolids destined for land application. *Science of the Total Environment* 810:151193.

Land application of biosolids can improve soil fertility and enhance crop production. However, the occurrence and persistence of pharmaceutical compounds in the biosolids may result in leaching of these contaminants to surface water and groundwater, causing environmental contamination. This study evaluated the effectiveness of two organic amendments [biochar (BC) and woodchips (WC)] for reducing the concentration and leachability (mobility) of four pharmaceuticals in biosolids derived from wastewater treatment plants in southern Ontario, Canada. The effect of 360-d composting on fate and leachabilities of target pharmaceuticals in biosolid mixtures was also investigated. Composting decreased total and leachable concentrations of pharmaceuticals in unamended and BC- and WC-amended biosolids to various degrees, from 10% up to 99% depending on the compound. Blending BC or WC into the biosolids greatly increased the removal rates of the target pharmaceuticals, while simultaneously decreasing their half-lives ($t_{0.5}$), compared to unamended biosolids. The $t_{0.5}$ of contaminants in this study followed the order: carbamazepine (304–3053 d) > gemfibrozil (42.3–92.4 d) > naproxen (15.3–104 d) > ibuprofen (12.5–19.0 d). Amendment with BC and(or) WC significantly reduced the leachability of carbamazepine, ibuprofen, and gemfibrozil to variable extents, but significantly enhanced the leachability of naproxen, compared to unamended biosolids ($P < 0.05$). Biochar and WC exhibited different (positive or negative) effects on the leachability of individual pharmaceuticals. Significantly lower concentrations of total and(or) leachable (mobile) pharmaceuticals were observed in amended biosolids than unamended biosolids ($P < 0.05$). Biochar and WC are effective amendments that can reduce the environmental impact of biosolid land applications with respect to pharmaceutical contamination.

Mays, C., G.L. Garza, J. Waite-Cusic, T.S. Radniecki, and T. Navab-Daneshmand. 2021. Impact of biosolids amendment and wastewater effluent irrigation on enteric antibiotic-resistant bacteria – a greenhouse study. *Water Research X* 13:100119.

Reuse of wastewater effluent and biosolids in agriculture is essential to sustainable water and nutrient resource management practices. Wastewater and biosolids, however, are reportedly the recipients, reservoirs, and sources of antibiotic-resistant enteric pathogens. While decay rates of fecal bacterial indicators in soil are frequently studied, very few studies have reported on the persistence of the antibiotic-resistant sub-populations. Little is known about how multi-drug resistance phenotypes of enteric bacteria in agricultural soil change over time. In this study, germinated carrot seeds were planted in soil that received biosolids amendment and/or wastewater effluent irrigation in a greenhouse setting. We quantified total and antibiotic-resistant fecal bacterial indicators (E*scherichia coli* and enterococci) weekly in soil and total *E. coli* at harvest (day 77) on carrots. Antibiotic susceptibility of 121 *E. coli* and 110 enterococci collected isolates were determined. E. coli or enterococci were not recovered from the soil without biosolids amendment regardless of the irrigation water source. After biosolids amendment, soil *E. coli* and enterococci concentrations increased more than 3 $\log_{10}$ CFU/g-TS within the first week, declined slowly over time, but stayed above the detection limit (0.39 CFU/g-TS) over the entirety of the study. No statistical difference was found between effluent wastewater or water irrigation in soil total and antibiotic-resistant *E. coli* and enterococci concentrations or carrots *E. coli* levels. Soil antibiotic-resistant *E. coli* and enterococci decayed significantly faster than total *E. coli* and enterococci. Moreover, the prevalence of multi drug resistant (resistance to three or more antibiotics) *E. coli* declined significantly over time, while almost all collected enterococci isolates showed multi-drug resistance phenotypes. At harvest, *E. coli* were present on carrots; the majority of which were resistant to ampicillin. The survival of antibiotic-resistant enteric bacteria in soil and on harvested carrots indicates there are transmission risks associated with biosolids amendment use in root crops.

Nason, S.L., E. Lin, K.J.G. Pollitt, and J. Peccia. 2021. Changes in sewage sludge chemical signatures during a COVID-19 community lockdown, part 2: nontargeted analysis of sludge and evaluation with COVID-19 metrics. *Environmental Toxicology and Chemistry* 41(5):1193–1201.

Sewage sludge and wastewater include urine and feces from an entire community, and it is highly likely that this mixture contains chemicals whose presence is dependent on levels of SARS-CoV-2 in the community. We analyzed primary sewage sludge samples collected in New Haven, Connecticut, USA, during the initial wave of the COVID-19 pandemic using liquid chromatography coupled with high-resolution mass spectrometry and performed an exploratory investigation of correlations between chemical features and COVID-19 metrics including concentrations of severe acute respiratory syndrome–coronavirus 2 (SARS-CoV-2) RNA in the sludge and local COVID-19 case numbers and hospital admissions. Inclusion of all chemical features in this analysis is key for discovering potential indicator compounds for COVID-19, whose structures may not be known. We found correlations with COVID-19 metrics for several identified chemicals as well as many unidentified features in the data, including three potential indicator molecules that are recommended for prioritization in future studies on COVID-19 in wastewater and sludge. These features have molecular weights of 108.0935, 318.1214, and 331.1374. While it is not possible to achieve prediction of COVID-19 epidemiological metrics from the one data set used in the present study, advances in this research area are important to share as scientists worldwide work on discovering efficient methods for tracking SARS-CoV-2 in wastewater and the environment.

Navab-Daneshmand, T., B. Guo, R. Gehr, and D. Frigon. 2022. Impact of pH and removed filtrate on *E. coli* regrowth and microbial community during storage of electro-dewatered biosolids. *Science of the Total Environment* 814:152544.

Residual biosolids can be land applied if they meet microbiological requirements at the time of application. Electro-dewatering technology is shown to reduce biosolids bacterial counts to detection limits with little potential for bacterial regrowth during incubations. Here, we investigated the impacts on *Escherichia coli* regrowth and microbial communities of biosolids pH, removed nutrients via the filtrate, and inhibitory compounds produced in electro-dewatered biosolids. Findings suggest pH as the primary mechanism impacting *E. coli* regrowth in electro-dewatered biosolids. Propidium monoazide treatments were effective at removing DNA from dead cells, based on the removal of obligate anaerobes observed after anaerobic incubation. Analyses of high throughput sequenced data showed lower alpha-diversities associated with electro-dewatering treatment and incubation time. Moreover, biosolids pH and incubation period were the main factors contributing to the variations in microbial community compositions after incubation. Results highlight the role of electro-dewatered biosolids' low pH on inhibiting the regrowth of culturable bacteria as well as reducing the microbial community variance.

Onchoke, K.K., C.M. Franclemont, and P.W. Weatherford. 2018. Structural characterization and evaluation of municipal wastewater sludge (biosolids) from two rural wastewater treatment plants in East Texas, USA. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* 204:514–524.

Wastewater sludge (or) biosolids collected from two rural wastewater treatment plants (NWWTP, LWWTP) in East Texas, USA were characterized and evaluated via inductively coupled plasma optical emission spectrometry, scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), thermogravimetric analysis, X-ray diffraction, Fourier transform infrared spectroscopy (FTIR), and ion chromatography. The proximate organic and inorganic compositions and spectroscopic characteristics of sewage sludge were determined. The results show that the concentrations of toxic metals Cd, Cr, Cu, Mo, Ni, Pb, Hg, and Zn meet USEPA guideline recommendations for land applications. Notably, metals concentrations in biosolids from NWWTP (Mn (700 ± 83) > Zn (422.5 ± 35.4 ppm) > Ba (319.5 ± 87 ppm) > Cu (240 ± 27 ppm) > B (107 ± 14 ppm) > V (24 ± 3.3 ppm) > Cr (20 ± 3.3 ppm) > Ni (16.7 ± 2.0 ppm) > Pb (16.8 ± 1.1 ppm) > As (11.99 ± 1.27 ppm) > Co (7.6 ± 0.7 ppm) > Mo (6.4 ± 1.4 ppm) > Hg (0.55 ± 0.24 ppm) > Cd (0.130 ± 0.109 ppm)) and LWWTP follow similar trends. Macro-elements concentrations in LWWTP follow the trend P (19,648 ± 169) > Fe (22,688 ± 2110) > Ca (9372 ± 163) > S (9010 ± 1009) > Al (12,538 ± 2116) > K (3514 ± 550) > Mg (33,370 ± 502) > Na (1511 ± 472). The Br^-, NO_3^-, NO_2^-, F^-, Cl^-, and SO_4^{2-} concentrations meet USEPA guidelines. Whereas biosolid particle sizes were in the range ~20 μm to 500 μm, mineralogical results show quartz and vermiculite to be major constituents with abundancies 12.94%, and 10.87% w/wt, respectively.

Peccia, J., A. Zulli, D.E. Brackney, N.D. Grubaugh, E.H. Kaplan, A. Casanovas-Massana, A.I. Ko, A.A. Malik, D. Wang, M. Wang, J.L. Warren, D.M. Weinberger, W. Arnold, and S.B. Omer. 2020. Measurement of SARS-CoV-2 RNA in wastewater tracks community infection dynamics. *Nature Biotechnology* 38:1164–1167.

We measured severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) RNA concentrations in primary sewage sludge in the New Haven, Connecticut, USA, metropolitan area during the Coronavirus Disease 2019 (COVID-19) outbreak in Spring 2020. SARS-CoV-2 RNA was detected throughout the more than 10-week study and, when adjusted for time lags, tracked the rise and fall of cases seen in SARS-CoV-2 clinical test results and local COVID-19 hospital admissions. Relative to

these indicators, SARS-CoV-2 RNA concentrations in sludge were 0–2 d ahead of SARS-CoV-2 positive test results by date of specimen collection, 0–2 d ahead of the percentage of positive tests by date of specimen collection, 1–4 d ahead of local hospital admissions and 6–8 d ahead of SARS-CoV-2 positive test results by reporting date. Our data show the utility of viral RNA monitoring in municipal wastewater for SARS-CoV-2 infection surveillance at a population-wide level. In communities facing a delay between specimen collection and the reporting of test results, immediate wastewater results can provide considerable advance notice of infection dynamics.

Pepper, I.L., M.L. Brusseau, F.J. Prevatt, and B.A. Escobar. 2021. Incidence of Pfas in soil following long-term application of class B biosolids. *Science of the Total Environment* 793:148449.

This field study investigated the impact of long-term land application of biosolids on PFAS presence in soils that received annual repetitive land application of Class B biosolids from 1984 to 2019. Soil samples were collected from three depths of 30.5, 91 and 183 cm below land surface. Biosolid and groundwater samples used for irrigation were also collected. Concentrations measured for 18 PFAS compounds were evaluated to assess incidence rates and potential impact on groundwater. No PFAS analytes were detected at the three sampling depths for soil samples collected from undisturbed sites with no history of agriculture, irrigation, or biosolids application (background control sites). Relatively low mean concentrations of PFAS ranging from non-detect to 1.9 µg/kg were measured in soil samples collected from sites that were used for agriculture and that received irrigation with groundwater, but never received biosolids. PFAS concentrations in soils amended with biosolids were similarly low, ranging from non-detect to a mean concentration of 4.1 µg/kg. PFOS was observed at the highest concentrations, followed by PFOA for all locations. PFAS detected in the irrigation water were also present in the soil. These results indicate that biosolids and irrigation water are both important sources of PFAS present in the soils for all of the study sites. Not all PFAS detected in the biosolids were detected in the soil. Very long chain PFAS present in the biosolids were not detected or were detected at very low levels for soil, suggesting potential preferential retention within the biosolids. The precursor NMeFOSAA was present at the second highest concentrations in the biosolids but not detected in soil, indicating possible occurrence of transformation reactions. The total PFAS soil concentrations exhibited significant attenuation with depth, with a mean attenuation of 73% at the 183 cm depth. Monotonically decreasing concentrations with depth were observed for the longer-chain PFAS.

Sidhu, H., H.S. Bae, A. Ogram, G. O'Connor, and F. Yu. 2021. Azithromycin and Ciprofloxacin can promote antibiotic resistance in biosolids and biosolids-amended soils. *Applied and Environmental Microbiology* 87(16):e00373-21.

Spread of biosolids-borne antibiotic resistance is a growing public and environmental health concern. Herein, we conducted incubation experiments involving biosolids, which are byproducts of sewage treatment processes, and biosolids-amended soil. Quantitative reverse transcription-PCR (RT-qPCR) was employed to assess responses of select antibiotic resistance genes (ARGs) and mobile elements to environmentally relevant concentrations of two biosolids-borne antibiotics, azithromycin (AZ) and ciprofloxacin (CIP). Additionally, we examined sequence distribution of *gyrA* (encoding DNA gyrase; site of action of CIP) to assess potential shifts in genotype. Increasing antibiotic concentrations generally increased the transcriptional activities of *qnrS* (encoding CIP resistance) and *ermB* and *mefE* (encoding AZ resistance). The transcriptional activity of *intl1*, a marker of class 1 integrons, was unaffected by CIP or AZ concentrations, but biosolids amendment increased *intl1* activity in the soil by 4 to 5 times, which persisted throughout incubation. While the dominant *gyrA* sequences found herein were unrelated to known CIP-resistant genotypes, the increasing CIP concentrations significantly decreased the diversity of genes encoding the DNA gyrase A subunit,

suggesting changes in microbial community structures. This study suggests that biosolids harbor transcriptionally active ARGs and mobile elements that could survive and spread in biosolids-amended soils. However, more research is warranted to investigate these trends under field conditions.

Taylor, S.E., C.I. Pearce, I. Chowdhury, L. Kovarik, I. Leavy, S. Baum, A.I. Bary, and M. Flury. 2020. Long-term accumulation, depth distribution, and speciation of silver nanoparticles in biosolids-amended soils. *Journal of Environmental Quality* 49(6):1679–1689.

Biosolids can be a source of metals and metal nanoparticles. The objective of this study was to quantify and characterize the accumulation and transport of silver (Ag) in a natural soil that has received agronomically recommended rates of biosolids as fertilizer from 1994 to 2017. Total Ag concentrations were measured in biosolids and soil samples collected from 0 to 10 cm between 1996 and 2017. The depth distribution of Ag in soil to 60-cm depth was measured in 2017. Electron microscopy, in combination with X-ray spectroscopy, and X-ray absorption spectroscopy were used to characterize the Ag. The Ag concentrations in the biosolids-amended soil increased steadily from 1996 until 2007, after which the concentrations leveled off at about 1.25 mg Ag kg^{-1} soil. This corresponded with a decrease of Ag concentrations in biosolids over time. The majority of the Ag (82%) was confined to the top 10 cm of the soil, small amounts (14%) were detected at 10-to-20-cm depth, and trace amounts (4%) were detected at 30-to-40-cm depth. The Ag in the biosolids was identified as S-containing nanoparticles (Ag_2S) with a diameter of 10–12 nm; however, in soil, the Ag concentrations were too low to allow identification of Ag speciation. This study shows that in a real-world field scenario, biosolids applied at agronomic rates represent a long-term, economically viable source of crop nutrients without increasing the concentration of total Ag in soil above a maximum of 1.5 mg Ag kg^{-1}. This concentration is below estimated ecotoxicity limits for Ag_2S in soil.

Appendix A-2: Abstracts of Papers Containing Microplastics, Nutrients, or Chemicals Without Concentration Data (Excluded from the 2020–2021 Biennial Review)

Buchanan, C.M., and J.A. Ippolito. 2021. Long-term biosolids applications to overgrazed rangelands improve soil health. *Agronomy* 11(7):1339.

Overgrazed rangelands can lead to soil degradation, yet long-term land application of organic amendments (i.e., biosolids) may play a pivotal role in improving degraded rangelands in terms of soil health. However, the long-term effects on soil health properties in response to single or repeated, low to excessive biosolids applications, on semi-arid, overgrazed grasslands have not been quantified. Using the Soil Management Assessment Framework (SMAF), soil physical, biological, chemical, nutrient, and overall soil health indices between biosolids applications (0, 2.5, 5, 10, 21, or 30 Mg ha^{-1}) and application time (single: 1991, repeated: 2002) were determined. Results showed no significant changes in soil physical and nutrient health indices. However, the chemical soil health index was greater when biosolids were applied at rates <30 Mg ha^{-1} and within the single compared to repeated applications. The biological soil health index was positively affected by increasing biosolids application rates, was overall greater in the repeated as compared to the single application, and was maximized at 30 Mg ha^{-1}. The overall soil health index was maximized at rates <30 Mg ha^{-1}. When all indices were combined, and considering past plant community findings at this site, overall soil health appeared optimized at a biosolids application rate of ~10 Mg ha^{-1}. The use of soil health tools can help determine a targeted organic amendment application rate to overgrazed rangelands so the material provides maximum benefits to soils, plants, animals, and the environment.

Crossman, J., R.R. Hurley, M. Futter, and L. Nizzetto. 2020. Transfer and transport of microplastics from biosolids to agricultural soils and the wider environment. *Science of the Total Environment* 724:138334.

Between April to November of 2017, microplastics (MPs) were analysed in biosolids from two separate suppliers, and in the soils of three agricultural fields to which they were applied, in Ontario, Canada. Soils of a control site with no history of biosolid application were also examined. High MP concentrations of between 8.7×10^3 MP kg^{-1} and 1.4×10^4 MP kg^{-1} were found in biosolids samples. Lower MP concentrations observed in Provider 2 biosolids may be due to storage, settling and supernatant removal prior to applications. Annual MP additions to agricultural soils across Ontario were estimated at between 4.1×10^{11} and 1.3×10^{12} particles. All fields receiving biosolids had higher soil pre-treatment MP concentrations than the control. The field with the greatest number of previous biosolid treatments had the highest pre-treatment soil MP concentrations; suggesting some MP retention in soils between applications. Immediately following biosolids applications, two fields demonstrated significant increases in soil MP concentrations, with preferential retention of MP fibers over fragments observed, while a reduction in soil MP concentrations were observed in the third. Surprisingly, only one field demonstrated a net gain in soil MPs over the course of the study. At all three fields, >99% of MPs applied in biosolids in 2017 were unaccounted for. The study suggests that despite adhering to applicable legislation, biosolids applications at all sites likely result in high rates of MP export. This study is the first to track MP transport through soils following their application in biosolids, and contributes to filling current knowledge gaps regarding export of MPs to aquatic systems from the terrestrial environment.

Gravesen, C., and J.D. Judy. 2020. Effect of biosolids characteristics on retention and release behavior azithromycin and ciprofloxacin. *Environmental Research* 184:109333.

Azithromycin (AZ) and ciprofloxacin (CIP) are commonly prescribed antibiotics frequently detected in municipal biosolids and identified by the USEPA as contaminants of emerging concern. The land application of municipal biosolids is an agronomically beneficial practice but is also a potential pathway of CIP and AZ release into the environment. Understanding retention-release behavior is crucial for assessing the environmental fate of and risks from land-applied biosolids-borne target antibiotics. Here, we used batch equilibrations to assess retention and release of environmentally relevant concentrations of CIP and AZ in ten different biosolids. The biosolids included Class A and Class B materials with a range of physiochemical characteristics (e.g. pH, cation exchange capacity (CEC), organic matter content (OM), and iron (Fe) and aluminum (Al)) expected to influence retention and release of AZ and CIP. Retention was linear ($R^2 > 0.99$ for AZ and >0.96 for CIP) and sorption coefficients (K_d) ranged from 52 to 370 L kg^{-1} for AZ and 430–2300 L kg^{-1} for CIP. Desorption also varied but was highly hysteretic, with hysteresis coefficients (H) ranging 0.01 to 0.15 for AZ and ≤0.01 for CIP, suggesting limited bioaccessibility. The penalized and shrinkage method least absolute shrinkage and selection operator (LASSO) was used to produce models describing AZ and CIP sorption behavior based on any given biosolids physiochemical characteristics. Multiple linear regression analysis linked AZ sorption behavior to total Fe content, likely due to a predisposition of AZ to participate in reactions with in situ Fe species. CIP sorption behavior was linked to oxalate extractable Al and total phosphorus (P) content, suggesting CIP bonding with amorphous forms of Al and a potential relationship between CIP sorption to biosolids and biosolids production processes, as manifested by correlation of CIP sorption with total P content.

Ippolito, J.A., T.F. Ducey, K. Diaz, and K.A. Barbarick. 2021. Long-term biosolids land application influences soil health. *Science of the Total Environment* 791:148344.

Soil health assessments associated with organic amendment applications have primarily focused attention on manure or composts. Yet, quantifying specific changes in soil health associated with biosolids land applications has yet to be determined. Our objectives were to evaluate the changes in various soil indicators, and utilizing the Soil Management Assessment Framework (SMAF), quantify changes in soil indicator scores and soil health indices as affected by either increasing inorganic N fertilizer (0 up to 112 kg N ha^{-1}) or biosolids (0 up to 11.2 dry Mg ha^{-1}) applied every other year over 22 years. Soils were sampled (0 to 20 cm depth) following 22 years of N fertilizer or biosolids inputs to a dryland wheat-fallow (*Triticum aestivum* L.) rotation, 11 soil health indicators were monitored under SMAF guidelines, and indicators, indicator scores, and soil health indices were analyzed statistically. In general, increasing N fertilizer application rates had little effect on soil indicators, SMAF indicator scores or soil health indices. Increasing biosolids application rates increased soil organic C (SOC) and potentially mineralizable N (PMN). The SMAF indicator scores showed upward trends for soil pH, SOC, PMN, and microbial biomass C (MBC) associated with increasing biosolids application rates; discussing trends are important as these indicator scores are combined to provide soil health indices. Indeed, increasing biosolids application rates increased soil chemical and biological health indices, leading to an improvement in the overall soil health index. When comparing the overall N fertilizer to biosolids effect, biosolids applications significantly improved the soil biological health index. Results indicate that long-term biosolids land application to semi-arid, dryland wheat fallow rotations, similar to those studied, improve various aspects of soil health. These findings suggest that biosolids may play a pivotal role in dryland agroecosystem sustainability**.**

Lu, Y., M.L. Silveira, G.A. O'Connor, J.M.B. Vendramini, J.E. Erickson, Y.C. Li, and M. Cavigelli. 2020. Biochar impacts on nutrient dynamics in a subtropical grassland soil – part I. N and P leaching. *Journal of Environmental Quality* 49(5):1408–1420.

Despite the numerous benefits of biosolids, concerns over nutrient losses restrict the extent to which biosolids can be beneficially reused. We evaluated the effectiveness of biochar in controlling the lability of nutrients in agricultural land. This study was designed to investigate the potential impacts of co-applying biochar with biosolids or inorganic fertilizer on N and P leaching losses. A companion paper focuses on greenhouse gas responses. Nutrients were surface applied as biosolids (aerobically digested Class B) and inorganic fertilizer (ammonium nitrate and triple superphosphate) to an established perennial pasture at equivalent annual rates typical of field practices. Biochar was applied at an annual rate of 20 Mg ha^{-1}. Leachate N and P were monitored using passive capillary drainage lysimeters. Results demonstrated significant temporal variability in leachate N and P, with larger pulses generally occurring during periods of high water table levels or after intensive rainfall. Inorganic fertilizer generally resulted in greater leachate N and P losses than biosolids. No differences in leachate N and P losses between biosolids and control were observed. Approximately 1% of applied N was lost via leaching from biosolids treatments vs. 16% for inorganic fertilizer. Regardless of the P source, negligible (0.1–0.2% of applied P), cumulative P leaching occurred during the 3-yr study. Biochar had no effect on P leaching but reduced N leaching from treatments receiving inorganic fertilizer by 60%. Prudent nutrient management is possible even on biosolids-amended Spodosols with high water tables.

White, J.G., R. Dodd, and R. Walters. 2020. Can an amino sugar test estimate potentially available nitrogen from biosolids? *Soil Science Society of America Journal* 84(1):274–286.

Biosolids land application is governed by N content and estimates of potentially available N (PAN). Amino sugar test N (AST-N) has been used with varying success to estimate soil responsiveness to N and optimum N rates. We investigated the utility of an amino sugar test (AST) in estimating PAN and hypothesized that this would depend on biosolids type, rate, and receiving soil. In vitro, we applied three dissimilar biosolids at five rates to four representative southeastern US soils, measured AST-N, and estimated recovery of biosolids AST-N. Target PAN rates were zero to two times a realistic yield expectation rate (127 kg N ha−1) for a common biosolids-receiving grass. Rates were based on biosolids type, total N, and book-value availability coefficients. Biosolids AST-N varied from 263 to 9790 mg kg−1 (3.8–20.1% of total N). Soil AST-N was 66–93 mg kg−1 and differed among soils. Treatment interactions indicated that AST-N of the biosolids–soil mixtures differed from what might be predicted from biosolids and soil AST-N and rate. Rate response was linear; thus, the AST did not saturate at the rates tested. Biosolids AST-N recovery ranged from −303 to 152% depending on biosolids, rate, soil, and their interactions. The AST-N was related linearly to total N from anaerobic incubation (R2 = 0.10–0.67), depending on biosolids. The weakness of these relationships; the biosolids, rate, and soil interactions; and the potential confounding effects of biosolids and soil NH4–N suggest that AST-N would not be a good estimator of PAN.

Appendix B: Pollutants Identified in Biosolids

The list of all chemicals that have been identified in biosolids is provided in Table B-1. The list of all microbials that have been identified in biosolids is provided in Table B-3. The categories for all of the chemicals that have been identified in biosolids are shown in Table B-2. An explanation for how the categories are determined is included below.

The dashboard lists and queries (represented as Dashboard URLs) used for the categorization and classification of chemicals are listed below. Each list can be viewed on the dashboard by adding the appropriate URL prefix:
https://comptox.epa.gov/dashboard/chemical_lists/CHEMICAL_LIST_NAME.

A. Drugs/Metabolites

Chemicals are compared to 11 drug/metabolite lists in ChemDashboard. Despite their primary categorization (which could differ based on expert judgement), if they are present in any of these 11 lists they are considered Drugs/Metabolites and there is a Y in that column.

a. Drugs/Metabolites

ZINC15PHARMA
DRUGBANK
LUXPHARMA
NTUPHTW
ITNANTIBIOTIC
OPIOIDS
SWISSPHARMA
STATINS
UOATARGPHARMA
VETDRUGS
ANTIBIOTICS

b. Antimicrobials

ANTIMICROBIALS

c. Antibiotics

ANTIBIOTICS
ITNANTIBIOTIC

d. Steroids/Sterols

Inclusion in the Steroids/Sterols category is based on expert judgement.

B. Cosmetics

COSMOSDB

C. Polychlorinated biphenyls (PCBs)

PCBCHEMICALS

D. Pesticides/Metabolites

OPPIN
INERTNONFOOD
LUXPEST
SLUPESTTPS

SWISSPEST
PESTACTIVES
PESTINERTS
EPAPCS
NPINSECT
SWISSPEST19
PFASPACKAGING
PPDB

E. Dibenzofurans
https://comptox.epa.gov/dashboard/dsstoxdb/multiple_results?input_type=synonym_substring&inputs=dibenzofuran

F. Dioxins
https://comptox.epa.gov/dashboard/dsstoxdb/multiple_results?input_type=synonym_substring&inputs=p-dioxin

G. Elements
ELEMENTS

H. Perfluoro- and polyfluoroalkyl substances
PFASSTRUCT

I. Phosphate
https://comptox.epa.gov/dashboard/dsstoxdb/multiple_results?input_type=synonym_substring&inputs=phosphate

J. Polybrominated Diphenyl Ethers (PBDEs)
PBDEs

K. Polyaromatic hydrocarbons (PAHs)
PAHLIST

L. Flame retardants
FLAMERETARD

M. Surfactants
ALLSURFACTANTS

N. Extractables/ Leachables
ELSIE

O. Other Organics
This set of chemicals remains after the classification and categorization of the rest of the list.

P. Inorganic Anions

UVCB Chemicals
UVCB chemicals are generally recognized by the fact that they do not have explicit structures, so no InChIKeys in ChemDashboard. The chemicals are then manually checked.

Table B-1. Chemical Pollutants Identified in Biosolids

Chemical	CAS number	When identified
(+)-Diltiazem	42399-41-7	BR No.1 (2004–2005)
(+/-)-Verapamil	52-53-9	BR No.5 (2012–2013)
(3alpha,5beta)-Cholestan-3-ol	516-92-7	2006 TNSSS
(E)-1,2-Dichloroethylene	156-60-5	1988 NSSS
1-(p-Chlorobenzoyl)-5-methoxy-2-methyl-Indole-3-acetic acid	53-86-1	BR No.1 (2004–2005)
1,1,1-Trichloroethane	71-55-6	1988 NSSS
1,1'-Ethane-1,2-diylbis(pentabromobenzene)	84852-53-9	BR No.7 (2016–2017)
1,1'-Oxybis[2,3,4,5,6-pentabromobenzene]	1163-19-5	2006 TNSSS
1,2,3,4,5-Pentabromo-6-(2,3,4,5-tetrabromophenoxy)benzene	63387-28-0	BR No.7 (2016–2017)
1,2,3,4,6,7,8,9,10,10,11,11-dodecachloro-1,4,4a,5a,6,9,9a,9b-octahydro-1,4:6,9-dimethanodibenzofuran	31107-44-5	BR No.7 (2016–2017)
1,2,3,4,6,7,8-Heptabromodibenzofuran	107555-95-3	BR No.6 (2014–2015)
1,2,3,4,6,7,8-Heptabromodibenzo-p-dioxin	110999-47-8	BR No.6 (2014–2015)
1,2,3,4,6,7,8-Heptachlorodibenzo[b,d]furan	67562-39-4	1988 NSSS
1,2,3,4,6,7,8-Heptachlorodibenzodioxin	35822-46-9	1988 NSSS
1,2,3,4,7,8,9-Heptabromodibenzo[b,d]furan	161880-51-9	BR No.6 (2014–2015)
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673-89-7	1988 NSSS
1,2,3,4,7,8-Hexabromodibenzofuran	129880-08-6	BR No.6 (2014–2015)
1,2,3,4,7,8-Hexabromodibenzo-p-dioxin	110999-44-5	BR No.6 (2014–2015)
1,2,3,4,7,8-Hexachlorodibenzodioxin	39227-28-6	1988 NSSS
1,2,3,4,7,8-Hexachlorodibenzofuran	70648-26-9	1988 NSSS
1,2,3,5-Tetrabromo-4-(3,4,5-tribromophenoxy)benzene	446255-30-7	BR No.7 (2016–2017)
1,2,3,6,7,8-Hexabromodibenzofuran	107555-94-2	BR No.6 (2014–2015)
1,2,3,6,7,8-Hexabromodibenzo-p-dioxin	110999-45-6	BR No.6 (2014–2015)
1,2,3,6,7,8-Hexachlorodibenzofuran	57117-44-9	1988 NSSS
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	57653-85-7	1988 NSSS
1,2,3,7,8,9-Hexabromodibenzo[b,d]furan	161880-49-5	BR No.6 (2014–2015)
1,2,3,7,8,9-Hexabromodibenzo-p-dioxin	110999-46-7	BR No.6 (2014–2015)
1,2,3,7,8,9-Hexachlorodibenzo[b,d]furan	72918-21-9	1988 NSSS
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	19408-74-3	1988 NSSS
1,2,3,7,8-Pentabromodibenzo[b,d]furan	107555-93-1	BR No.6 (2014–2015)
1,2,3,7,8-Pentabromodibenzo-p-dioxin	109333-34-8	BR No.6 (2014–2015)
1,2,3,7,8-Pentachlorodibenzofuran	57117-41-6	1988 NSSS
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321-76-4	1988 NSSS
1,2,3-Trichlorobenzene	87-61-6	1988 NSSS
1,2,4-Trichlorobenzene	120-82-1	1988 NSSS
1,2-Bis(2,4,6-tribromophenoxy)ethane	37853-59-1	BR No.7 (2016–2017)
1,2-Dichlorobenzene	95-50-1	1988 NSSS

Chemical	CAS number	When identified
1,2-Dichloropropane	78-87-5	1988 NSSS
1,3,5-Triazin-2(1H)-one, 4,6-diamino-	645-92-1	BR No.8 (2018–2019)
1,3,5-Trichlorobenzene	108-70-3	BR No.1 (2004–2005)
1,3-Dichlorobenzene	541-73-1	1988 NSSS
1,4:5,8:9,10-Trimethanoanthracene, 1,2,3,4,5,6,7,8,12,12,13,13-dodecachloro-1,4,4a,5,8,8a,9,9a,10,10a-decahydro-	13560-92-4	BR No.7 (2016–2017)
1,4-Dichlorobenzene	106-46-7	1988 NSSS
1,4-Dinitrobenzene	100-25-4	1988 NSSS
1,4-Dioxane	123-91-1	1988 NSSS
1,7-Dimethylxanthine	611-59-6	BR No.1 (2004–2005)
10-Hydroxyamitriptyline	1159-82-6	BR No.5 (2012–2013)
17alpha-Estradiol	57-91-0	BR No.1 (2004–2005)
17alpha-Ethinylestradiol	57-63-6	BR No.1 (2004–2005)
17beta-Estradiol	50-28-2	BR No.1 (2004–2005)
1-Methyl phenanthrene	832-69-9	1988 NSSS
2-(2,4,5-Trichlorophenoxy)propionic acid	93-72-1	1988 NSSS
2-(Methylthio)benzothiazole	615-22-5	1988 NSSS
2-(N-Ethylperfluorooctanesulfonamido)acetic acid	2991-50-6	BR No.9 (2020–2021)
2-(N-Methylperfluorooctanesulfonamido)acetic acid	2355-31-9	BR No.9 (2020–2021)
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	40186-72-9	2001 NSSS
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	35694-08-7	2001 NSSS
2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl	52663-79-3	2001 NSSS
2,2',3,3',4,4',5,6'-Octachlorobiphenyl	42740-50-1	2001 NSSS
2,2',3,3',4,4',5,6-Octachlorobiphenyl	52663-78-2	2001 NSSS
2,2',3,3',4,4',5-Heptachlorobiphenyl	35065-30-6	2001 NSSS
2,2',3,3',4,4',6,6'-Octachlorobiphenyl	33091-17-7	2001 NSSS
2,2',3,3',4,4',6-Heptachlorobiphenyl	52663-71-5	2001 NSSS
2,2',3,3',4,4'-Hexachlorobiphenyl	38380-07-3	2001 NSSS
2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl	52663-77-1	2001 NSSS
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	52663-75-9	2001 NSSS
2,2',3,3',4,5,5',6-Octachlorobiphenyl	68194-17-2	2001 NSSS
2,2',3,3',4,5,5'-Heptachlorobiphenyl	52663-74-8	2001 NSSS
2,2',3,3',4,5,6,6'-Octachlorobiphenyl	52663-73-7	2001 NSSS
2,2',3,3',4,5',6,6'-Octachlorobiphenyl	40186-71-8	2001 NSSS
2,2',3,3',4,5,6'-Heptachlorobiphenyl	38411-25-5	2001 NSSS
2,2',3,3',4,5,6-Heptachlorobiphenyl	68194-16-1	2001 NSSS
2,2',3,3',4,5',6'-Heptachlorobiphenyl	52663-70-4	2001 NSSS
2,2',3,3',4,5',6-Heptachlorobiphenyl	40186-70-7	2001 NSSS
2,2',3,3',4,5'-Hexachlorobiphenyl	52663-66-8	2001 NSSS

Chemical	CAS number	When identified
2,2',3,3',4,5-Hexachlorobiphenyl	55215-18-4	2001 NSSS
2,2',3,3',4,6,6'-Heptachlorobiphenyl	52663-65-7	2001 NSSS
2,2',3,3',4,6'-Hexachlorobiphenyl	38380-05-1	2001 NSSS
2,2',3,3',4-Pentachlorobiphenyl	52663-62-4	2001 NSSS
2,2',3,3',5,5',6,6'-Octachlorobiphenyl	2136-99-4	2001 NSSS
2,2',3,3',5,5',6-Heptachlorobiphenyl	52663-67-9	2001 NSSS
2,2',3,3',5,5'-Hexachlorobiphenyl	35694-04-3	2001 NSSS
2,2',3,3',5,6,6'-Heptachlorobiphenyl	52663-64-6	2001 NSSS
2,2',3,3',5,6'-Hexachlorobiphenyl	52744-13-5	2001 NSSS
2,2',3,3',5,6-Hexachlorobiphenyl	52704-70-8	2001 NSSS
2,2',3,3',5-Pentachlorobiphenyl	60145-20-2	2001 NSSS
2,2',3,3',6,6'-Hexachlorobiphenyl	38411-22-2	2001 NSSS
2,2',3,3',6-Pentachlorobiphenyl	52663-60-2	2001 NSSS
2,2',3,3'-Tetrachlorobiphenyl	38444-93-8	2001 NSSS
2,2',3,4,4',5,5',6-Octachlorobiphenyl	52663-76-0	2001 NSSS
2,2',3,4,4',5,5'-Heptachlorobiphenyl	35065-29-3	2001 NSSS
2,2',3,4,4',5,6,6'-Octachlorobiphenyl	74472-52-9	2001 NSSS
2,2',3,4,4',5',6-Heptabromodiphenyl ether	207122-16-5	2006 TNSSS
2,2',3,4,4',5,6'-Heptachlorobiphenyl	60145-23-5	2001 NSSS
2,2',3,4,4',5,6-Heptachlorobiphenyl	74472-47-2	2001 NSSS
2,2',3,4,4',5',6-Heptachlorobiphenyl	52663-69-1	2001 NSSS
2,2',3,4,4',5'-Hexabromodiphenyl ether	182677-30-1	2006 TNSSS
2,2',3,4,4',5'-Hexachlorobiphenyl	35065-28-2	2001 NSSS
2,2',3,4,4',5-Hexachlorobiphenyl	35694-06-5	2001 NSSS
2,2',3,4,4',6,6'-Heptachlorobiphenyl	74472-48-3	2001 NSSS
2,2',3,4,4',6'-Hexachlorobiphenyl	59291-64-4	2001 NSSS
2,2',3,4,4',6-Hexachlorobiphenyl	56030-56-9	2001 NSSS
2,2',3,4,4'-Pentabromodiphenyl ether	182346-21-0	2006 TNSSS
2,2',3,4,4'-Pentachlorobiphenyl	65510-45-4	2001 NSSS
2,2',3,4',5,5',6-Heptachloro-1,1'-biphenyl	52663-68-0	2001 NSSS
2,2',3,4,5,5',6-Heptachlorobiphenyl	52712-05-7	2001 NSSS
2,2',3,4,5,5'-Hexachlorobiphenyl	52712-04-6	2001 NSSS
2,2',3,4',5,5'-Hexachlorobiphenyl	51908-16-8	2001 NSSS
2,2',3,4,5,6,6'-Heptachlorobiphenyl	74472-49-4	2001 NSSS
2,2',3,4',5,6,6'-Heptachlorobiphenyl	74487-85-7	2001 NSSS
2,2',3,4,5,6'-Hexachlorobiphenyl	68194-15-0	2001 NSSS
2,2',3,4,5',6-Hexachlorobiphenyl	68194-14-9	2001 NSSS
2,2',3,4',5,6'-Hexachlorobiphenyl	74472-41-6	2001 NSSS
2,2',3,4',5,6-Hexachlorobiphenyl	68194-13-8	2001 NSSS

Chemical	CAS number	When identified
2,2',3,4',5',6-Hexachlorobiphenyl	38380-04-0	2001 NSSS
2,2',3,4,5'-Pentachlorobiphenyl	38380-02-8	2001 NSSS
2,2',3,4,5-Pentachlorobiphenyl	55312-69-1	2001 NSSS
2,2',3,4',5'-Pentachlorobiphenyl	41464-51-1	2001 NSSS
2,2',3,4',5-Pentachlorobiphenyl	68194-07-0	2001 NSSS
2,2',3,4,6,6'-Hexachlorobiphenyl	74472-40-5	2001 NSSS
2,2',3,4',6,6'-Hexachlorobiphenyl	68194-08-1	2001 NSSS
2,2',3,4,6'-Pentachlorobiphenyl	73575-57-2	2001 NSSS
2,2',3,4,6-Pentachlorobiphenyl	55215-17-3	2001 NSSS
2,2',3,4',6'-Pentachlorobiphenyl	60233-25-2	2001 NSSS
2,2',3,4',6-Pentachlorobiphenyl	68194-05-8	2001 NSSS
2,2',3,4'-Tetrachloro-1,1'-biphenyl	36559-22-5	2001 NSSS
2,2',3,4-Tetrachlorobiphenyl	52663-59-9	2001 NSSS
2,2',3,5,5',6-Hexachlorobiphenyl	52663-63-5	2001 NSSS
2,2',3,5,5'-Pentachlorobiphenyl	52663-61-3	2001 NSSS
2,2',3,5,6,6'-Hexachlorobiphenyl	68194-09-2	2001 NSSS
2,2',3,5,6'-Pentachlorobiphenyl	73575-55-0	2001 NSSS
2,2',3,5,6-Pentachlorobiphenyl	73575-56-1	2001 NSSS
2,2',3,5',6-Pentachlorobiphenyl	38379-99-6	2001 NSSS
2,2',3,5'-Tetrachlorobiphenyl	41464-39-5	2001 NSSS
2,2',3,5-Tetrachlorobiphenyl	70362-46-8	2001 NSSS
2,2',3,6,6'-Pentachlorobiphenyl	73575-54-9	2001 NSSS
2,2',3,6'-Tetrachlorobiphenyl	41464-47-5	2001 NSSS
2,2',3-Trichlorobiphenyl	38444-78-9	2001 NSSS
2,2',4,4',5,5'-Hexabromobiphenyl	59080-40-9	BR No.1 (2004–2005)
2,2',4,4',5,5'-Hexabromodiphenyl ether	68631-49-2	2006 TNSSS
2,2',4,4',5,5'-Hexachlorobiphenyl	35065-27-1	2001 NSSS
2,2',4,4',5,6'-Hexabromodiphenyl ether	207122-15-4	2006 TNSSS
2,2',4,4',5,6'-Hexachlorobiphenyl	60145-22-4	2001 NSSS
2,2',4,4',5-Pentabromodiphenyl ether	60348-60-9	2006 TNSSS
2,2',4,4',5-Pentachlorobiphenyl	38380-01-7	2001 NSSS
2,2',4,4',6,6'-Hexachlorobiphenyl	33979-03-2	2001 NSSS
2,2',4,4',6-Pentabromodiphenyl ether	189084-64-8	2006 TNSSS
2,2',4,4',6-Pentachlorobiphenyl	39485-83-1	2001 TNSSS
2,2',4,4'-Tetrabromodiphenyl ether	5436-43-1	2006 TNSSS
2,2',4,4'-Tetrachlorobiphenyl	2437-79-8	2001 NSSS
2,2',4,5,5'-Pentachlorobiphenyl	37680-73-2	2001 NSSS
2,2',4,5,6'-Pentachlorobiphenyl	68194-06-9	2001 NSSS
2,2',4,5',6-Pentachlorobiphenyl	60145-21-3	2001 NSSS

Chemical	CAS number	When identified
2,2',4,5'-Tetrachlorobiphenyl	41464-40-8	2001 NSSS
2,2',4,5-Tetrachlorobiphenyl	70362-47-9	2001 NSSS
2,2',4,6,6'-Pentachlorobiphenyl	56558-16-8	2001 NSSS
2,2',4,6'-Tetrachlorobiphenyl	68194-04-7	2001 NSSS
2,2',4,6-Tetrachlorobiphenyl	62796-65-0	2001 NSSS
2,2',4-Tribromodiphenyl ether	147217-75-2	BR No.7 (2016–2017)
2,2',4-Trichlorobiphenyl	37680-66-3	2001 NSSS
2,2',5,5'-Tetrachlorobiphenyl	35693-99-3	2001 NSSS
2,2',5,6'-Tetrachlorobiphenyl	41464-41-9	2001 NSSS
2,2',5-Trichlorobiphenyl	37680-65-2	2001 NSSS
2,2',6,6'-Tetrachlorobiphenyl	15968-05-5	2001 NSSS
2,2',6-Trichlorobiphenyl	38444-73-4	2001 NSSS
2,2'-Bioxirane	1464-53-5	1988 NSSS
2,2'-Dichlorobiphenyl	13029-08-8	2001 NSSS
2,3,3',4,4',5,5',6-Octachlorobiphenyl	74472-53-0	2001 NSSS
2,3,3',4,4',5,5'-Heptachlorobiphenyl	39635-31-9	2001 NSSS
2,3,3',4,4',5,6-Heptachlorobiphenyl	41411-64-7	2001 NSSS
2,3,3',4,4',5',6-Heptachlorobiphenyl	74472-50-7	2001 NSSS
2,3,3',4,4',5'-Hexachlorobiphenyl	69782-90-7	2001 NSSS
2,3,3',4,4',5-Hexachlorobiphenyl	38380-08-4	2001 NSSS
2,3,3',4,4',6-Hexachlorobiphenyl	74472-42-7	2001 NSSS
2,3,3',4,4'-Pentachlorobiphenyl	32598-14-4	2001 NSSS
2,3,3',4,5,5',6-Heptachlorobiphenyl	74472-51-8	2001 NSSS
2,3,3',4',5,5',6-Heptachlorobiphenyl	69782-91-8	2001 NSSS
2,3,3',4,5,5'-Hexachlorobiphenyl	39635-35-3	2001 NSSS
2,3,3',4',5,5'-Hexachlorobiphenyl	39635-34-2	2001 NSSS
2,3,3',4,5,6-Hexachlorobiphenyl	41411-62-5	2001 NSSS
2,3,3',4,5',6-Hexachlorobiphenyl	74472-43-8	2001 NSSS
2,3,3',4',5,6-Hexachlorobiphenyl	74472-44-9	2001 NSSS
2,3,3',4',5',6-Hexachlorobiphenyl	74472-45-0	2001 NSSS
2,3,3',4,5'-Pentachlorobiphenyl	70362-41-3	2001 NSSS
2,3,3',4',5'-Pentachlorobiphenyl	76842-07-4	2001 NSSS
2,3,3',4',5-Pentachlorobiphenyl	70424-68-9	2001 NSSS
2,3,3',4,6-Pentachlorobiphenyl	74472-35-8	2001 NSSS
2,3,3',4',6-Pentachlorobiphenyl	38380-03-9	2001 NSSS
2,3,3',4'-Tetrachlorobiphenyl	41464-43-1	2001 NSSS
2,3,3',4-Tetrachlorobiphenyl	74338-24-2	2001 NSSS
2,3,3',5,5',6-Hexachlorobiphenyl	74472-46-1	2001 NSSS
2,3,3',5,5'-Pentachlorobiphenyl	39635-32-0	2001 NSSS

Chemical	CAS number	When identified
2,3,3',5',6-Pentachlorobiphenyl	68194-10-5	2001 NSSS
2,3,3',5'-Tetrachlorobiphenyl	41464-49-7	2001 NSSS
2,3,3',5-Tetrachlorobiphenyl	70424-67-8	2001 NSSS
2,3,3',6-Tetrachlorobiphenyl	74472-33-6	2001 NSSS
2,3,3'-Trichlorobiphenyl	38444-84-7	2001 NSSS
2,3',4,4',5,5'-Hexachlorobiphenyl	52663-72-6	2001 NSSS
2,3,4,4',5,6-Hexachlorobiphenyl	41411-63-6	2001 NSSS
2,3',4,4',5',6-Hexachlorobiphenyl	59291-65-5	2001 NSSS
2,3,4,4',5-Pentachlorobiphenyl	74472-37-0	2001 NSSS
2,3',4,4',5-Pentachlorobiphenyl	31508-00-6	2001 NSSS
2',3,4,4',5-Pentachlorobiphenyl	65510-44-3	2001 NSSS
2,3,4,4',6-Pentachlorobiphenyl	74472-38-1	2001 NSSS
2,3',4,4',6-Pentachlorobiphenyl	56558-17-9	2001 NSSS
2,3',4,4'-Tetrabromodiphenyl ether	189084-61-5	2006 TNSSS
2,3,4,4'-Tetrachlorobiphenyl	33025-41-1	2001 NSSS
2,3',4,4'-Tetrachlorobiphenyl	32598-10-0	2001 NSSS
2,3',4,5,5'-Pentachlorobiphenyl	68194-12-7	2001 NSSS
2,3',4',5,5'-Pentachlorobiphenyl	70424-70-3	2001 NSSS
2,3,4,5,6-Pentabromoethylbenzene	85-22-3	BR No.7 (2016–2017)
2,3,4,5,6-Pentachlorobiphenyl	18259-05-7	2001 NSSS
2,3,4',5,6-Pentachlorobiphenyl	68194-11-6	2001 NSSS
2,3',4,5',6-Pentachlorobiphenyl	56558-18-0	2001 NSSS
2,3',4',5',6-Pentachlorobiphenyl	74472-39-2	2001 NSSS
2,3,4,5-Tetrachlorobiphenyl	33284-53-6	2001 NSSS
2,3,4',5-Tetrachlorobiphenyl	74472-34-7	2001 NSSS
2,3',4,5'-Tetrachlorobiphenyl	73575-52-7	2001 NSSS
2,3',4,5-Tetrachlorobiphenyl	73575-53-8	2001 NSSS
2,3',4',5'-Tetrachlorobiphenyl	70362-48-0	2001 NSSS
2,3',4',5-Tetrachlorobiphenyl	32598-11-1	2001 NSSS
2,3,4,6,7,8-Hexabromodibenzo[b,d]furan	161880-50-8	BR No.6 (2014–2015)
2,3,4,6,7,8-Hexachlorodibenzo[b,d]furan	60851-34-5	1988 NSSS
2,3,4,6-Tetrachlorobiphenyl	54230-22-7	2001 NSSS
2,3,4',6-Tetrachlorobiphenyl	52663-58-8	2001 NSSS
2,3',4,6-Tetrachlorobiphenyl	60233-24-1	2001 NSSS
2,3',4',6-Tetrachlorobiphenyl	41464-46-4	2001 NSSS
2,3,4,7,8-Pentabromodibenzofuran	131166-92-2	BR No.6 (2014–2015)
2,3,4,7,8-Pentachlorodibenzofuran	57117-31-4	1988 NSSS
2,3,4'-Trichlorobiphenyl	38444-85-8	2001 NSSS
2,3,4-Trichlorobiphenyl	55702-46-0	2001 NSSS

Chemical	CAS number	When identified
2,3',4-Trichlorobiphenyl	55712-37-3	2001 NSSS
2',3,4-Trichlorobiphenyl	38444-86-9	2001 NSSS
2,3',5,5'-Tetrachlorobiphenyl	41464-42-0	2001 NSSS
2,3,5,6-Tetrachlorobiphenyl	33284-54-7	2001 NSSS
2,3',5',6-Tetrachlorobiphenyl	74338-23-1	2001 NSSS
2,3,5-Trichlorobiphenyl	55720-44-0	2001 NSSS
2,3',5'-Trichlorobiphenyl	37680-68-5	2001 NSSS
2,3,6-Trichlorobiphenyl	55702-45-9	2001 NSSS
2,3',6-Trichlorobiphenyl	38444-76-7	2001 NSSS
2,3,7,8-Tetrabromodibenzofuran	67733-57-7	BR No.6 (2014–2015)
2,3,7,8-Tetrabromodibenzo-p-dioxin	50585-41-6	BR No.6 (2014–2015)
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9	1988 NSSS1
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	1988 NSSS
2,3'-Dichlorobiphenyl	25569-80-6	2001 NSSS
2,3-Dichlorobiphenyl	16605-91-7	2001 NSSS
2,4,4',5-Tetrachlorobiphenyl	32690-93-0	2001 NSSS
2,4,4',6-Tetrachlorobiphenyl	32598-12-2	2001 NSSS
2,4,4'-Tribromodiphenyl ether	41318-75-6	2006 TNSSS
2,4,4'-Trichlorobiphenyl	7012-37-5	2001 NSSS
2,4,5-Trichlorobiphenyl	15862-07-4	2001 NSSS
2,4',5-Trichlorobiphenyl	16606-02-3	2001 NSSS
2,4,5-Trichlorophenol	95-95-4	BR No.6 (2014–2015)
2,4,5-Trichlorophenoxyacetic acid	93-76-5	1988 NSSS
2,4,5-Trimethylaniline	137-17-7	1988 NSSS
2,4,6-Trichlorobiphenyl	35693-92-6	2001 NSSS
2,4',6-Trichlorobiphenyl	38444-77-8	2001 NSSS
2,4,6-Trinitro-1,3-dimethyl-5-tert-butylbenzene	81-15-2	BR No.1 (2004–2005)
2,4,6-Tris(tert-butyl)phenol	732-26-3	BR No.8 (2018–2019)
2,4'-Dichlorobiphenyl	34883-43-7	2001 NSSS
2,4-Dichlorobiphenyl	33284-50-3	2001 NSSS
2,4-Dichlorophenol	120-83-2	BR No.7 (2016–2017)
2,4-Dichlorophenoxyacetic acid	94-75-7	1988 NSSS
2,4-Di-tert-butylphenol	96-76-4	BR No.8 (2018–2019)
2,4-Di-tert-pentylphenol	120-95-6	BR No.8 (2018–2019)
2,5-Dichlorobiphenyl	34883-39-1	2001 NSSS
2,6-Dichlorobiphenyl	33146-45-1	2001 NSSS
2,6-Dinitrotoluene	606-20-2	1988 NSSS
2,6-Di-tert-butylphenol	128-39-2	BR No.1 (2004–2005)
2-Chloro-4-phenylphenol	92-04-6	BR No.6 (2014–2015)

Chemical	CAS number	When identified
2-Chlorobiphenyl	2051-60-7	2001 NSSS
2-Chloronaphthalene	91-58-7	1988 NSSS
2-Ethylhexyl diphenyl phosphate	1241-94-7	BR No.8 (2018–2019)
2H,2H,3H,3H-Perfluorooctanoic acid	914637-49-3	BR No.8 (2018–2019)
2-Hexanone	591-78-6	1988 NSSS
2-Methyl-1-propanol	78-83-1	1988 NSSS
2-Methylnaphthalene	91-57-6	1988 NSSS
2-Methylpyridine	109-06-8	1988 NSSS
3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-Henicosafluorododecyl 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl hydrogen phosphate	1158182-60-5	BR No.8 (2018–2019)
3,3',4,4',5,5'-Hexachlorobiphenyl	32774-16-6	2001 NSSS
3,3',4,4',5-Pentachlorobiphenyl	57465-28-8	2001 NSSS
3,3',4,4'-Tetrachlorobiphenyl	32598-13-3	2001 NSSS
3,3',4,5,5'-Pentachlorobiphenyl	39635-33-1	2001 NSSS
3,3',4,5'-Tetrachlorobiphenyl	41464-48-6	2001 NSSS
3,3',4,5-Tetrachlorobiphenyl	70362-49-1	2001 NSSS
3,3',4-Trichlorobiphenyl	37680-69-6	2001 NSSS
3,3',5,5'-Tetrabromobisphenol A	79-94-7	BR No.1 (2004–2005)
3,3',5,5'-Tetrachlorobiphenyl	33284-52-5	2001 NSSS
3,3',5-Trichlorobiphenyl	38444-87-0	2001 NSSS
3,3'-Dichloro-1,1'-biphenyl	2050-67-1	2001 NSSS
3,4,4',5-Tetrachlorobiphenyl	70362-50-4	2001 NSSS
3,4,4'-Trichlorobiphenyl	38444-90-5	2001 NSSS
3,4,5-Trichlorobiphenyl	53555-66-1	2001 NSSS
3,4',5-Trichlorobiphenyl	38444-88-1	2001 NSSS
3,4'-Dichlorobiphenyl	2974-90-5	2001 NSSS
3,4-Dichlorobiphenyl	2974-92-7	2001 NSSS
3,4-Dihydroxybenzoic acid	99-50-3	BR No.7 (2016–2017)
3,5-Dichlorobiphenyl	34883-41-5	2001 NSSS
3,6-Dimethylphenanthrene	1576-67-6	1988 NSSS
3-Chlorobiphenyl	2051-61-8	2001 NSSS
3-Methylindole	83-34-1	BR No.2 (2006–2007)
4-(1,1,3,3-Tetramethylbutyl)phenol	140-66-9	BR No.2 (2006–2007)
4-(Butan-2-yl)-2,6-di-tert-butylphenol	17540-75-9	BR No.8 (2018–2019)
4,4'-Dichlorobiphenyl	2050-68-2	2001 NSSS
4,4'-Dichlorocarbanilide	1219-99-4	BR No.4 (2010–2011)
4,4'-Methylenebis(2,6-di-t-butylphenol)	118-82-1	BR No.8 (2018–2019)
4,4'-Thiobis(6-tert-butyl-m-cresol)	96-69-5	BR No.8 (2018–2019)
4-Androstene-3,17-dione	63-05-8	2006 TNSSS

Chemical	CAS number	When identified
4-Chloro-3-methylphenol	59-50-7	1988 NSSS
4-Chloroaniline	106-47-8	1988 NSSS
4-Chlorobiphenyl	2051-62-9	2001 NSSS
4-Dimethylaminoantipyrine	58-15-1	BR No.1 (2004–2005)
4-Epianhydrotetracycline	7518-17-4	2006 TNSSS
4-Epichlortetracycline	14297-93-9	2006 TNSSS
4-epi-Oxytetracycline	14206-58-7	2006 TNSSS
4-Hydroxybenzoic acid	99-96-7	BR No.7 (2016–2017)
4-Methyl-2-pentanone	108-10-1	1988 NSSS
4-Nitrophenol	100-02-7	BR No.1 (2004–2005)
4-Nonylphenol	104-40-5	BR No.1 (2004–2005)
4-Nonylphenol, branched	84852-15-3	BR No.1 (2004–2005)
5-Aminosalicylic acid	89-57-6	BR No.1 (2004–2005)
6:2 Fluorotelomer phosphate diester	57677-95-9	BR No.8 (2018–2019)
6:2 Fluorotelomer sulfonic acid	27619-97-2	BR No.8 (2018–2019)
6:2/8:2 Fluorotelomer phosphate diester	943913-15-3	BR No.8 (2018–2019)
7-Acetyl-1,1,3,4,4,6-hexamethyltetraline	21145-77-7	BR No.2 (2006–2007)
8:2 Fluorotelomer phosphate diester	678-41-1	BR No.8 (2018–2019)
8:2 Fluorotelomer sulfonic acid	39108-34-4	BR No.8 (2018–2019)
Acenaphthene	83-32-9	1988 NSSS
Acetaminophen	103-90-2	BR No.1 (2004–2005)
Acetone	67-64-1	1988 NSSS
Acetophenone	98-86-2	1988 NSSS
Albuterol	18559-94-9	BR No.1 (2004–2005)
Aldrin	309-00-2	1988 NSSS
Allyl alcohol	107-18-6	1988 NSSS
Allyl chloride	107-05-1	1988 NSSS
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	319-84-6	1988 NSSS
alpha-Solanine	20562-02-1	BR No.9 (2020–2021)
alpha-Terpineol	98-55-5	1988 NSSS
Alprazolam	28981-97-7	BR No.5 (2012–2013)
Aluminum	7429-90-5	1988 NSSS
Amitriptyline	50-48-6	BR No.5 (2012–2013)
Amlodipine	88150-42-9	BR No.5 (2012–2013)
Ammelide	645-93-2	BR No.8 (2018–2019)
Amoxicillin	26787-78-0	BR No.8 (2018–2019)
Amphetamine	300-62-9	BR No.2 (2006–2007)
Ampicillin	69-53-4	BR No.8 (2018–2019)
Androsterone	53-41-8	2006 TNSSS

Chemical	CAS number	When identified
Anhydrochlortetracycline	4497-08-9	2006 TNSSS
Anhydrotetracycline	1665-56-1	2006 TNSSS
Anthracene	120-12-7	1988 NSSS
Antimony	7440-36-0	1988 NSSS
Aroclor 1248	12672-29-6	1988 NSSS
Aroclor 1254	11097-69-1	1988 NSSS
Aroclor 1260	11096-82-5	1988 NSSS
Arsenic	7440-38-2	1988 NSSS
Aspirin	50-78-2	BR No.1 (2004–2005)
Atenolol	29122-68-7	BR No.5 (2012–2013)
Atorvastatin	134523-00-5	BR No.5 (2012–2013)
Azinphos-methyl	86-50-0	1988 NSSS
Azithromycin	83905-01-5	BR No.2 (2006–2007)
Barium	7440-39-3	1988 NSSS
BDE-196	446255-39-6	BR No.7 (2016–2017)
BDE-197	117964-21-3	BR No.7 (2016–2017)
BDE-207	437701-79-6	BR No.7 (2016–2017)
Bensulide	741-58-2	BR No.4 (2010–2011)
Benz(a)anthracene	56-55-3	1988 NSSS
Benzene	71-43-2	1988 NSSS
Benzene, 1,2,3,5-tetrabromo-4-(2,4,6-tribromophenoxy)-	117948-63-7	BR No.7 (2016–2017)
Benzenethiol	108-98-5	1988 NSSS
Benzo(a)pyrene	50-32-8	1988 NSSS
Benzo(b)fluoranthene	205-99-2	1988 NSSS
Benzo(g,h,i)perylene	191-24-2	1988 NSSS
Benzo(k)fluoranthene	207-08-9	1988 NSSS
Benzoic acid	65-85-0	1988 NSSS
Benzoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, 2,4-bis(1,1-dimethylethyl) phenyl ester	4221-80-1	BR No.8 (2018–2019)
Benzoylecgonine	519-09-5	BR No.5 (2012–2013)
Benztropine	86-13-5	BR No.5 (2012–2013)
Benzyl 4-hydroxybenzoate	94-18-8	BR No.7 (2016–2017)
Benzyl alcohol	100-51-6	1988 NSSS
Benzyl butyl phthalate	85-68-7	1988 NSSS
Berberine	2086-83-1	BR No.9 (2020–2021)
Beryllium	7440-41-7	1988 NSSS
beta-Hexachlorocyclohexane	319-85-7	1988 NSSS
beta-Sitosterol	83-46-5	BR No.2 (2006–2007)
Bezafibrate	41859-67-0	BR No.1 (2004–2005)

Chemical	CAS number	When identified
Biphenyl	92-52-4	1988 NSSS
Bis(1,3-dichloropropan-2-yl) hydrogen phosphate	72236-72-7	BR No.8 (2018–2019)
bis(1-Chloropropan-2-yl) hydrogen phosphate	789440-10-4	BR No.8 (2018–2019)
Bis(2-chloroethyl) phosphate	3040-56-0	BR No.8 (2018–2019)
Bis(2-ethylhexyl) phosphate	298-07-7	BR No.8 (2018–2019)
Bis(2-methylphenyl) hydrogen phosphate	35787-74-7	BR No.8 (2018–2019)
Bisphenol A	80-05-7	BR No.2 (2006–2007)
Boron	7440-42-8	1988 NSSS
Bromide	24959-67-9	BR No.9 (2020–2021)
Butylated hydroxyanisole	25013-16-5	BR No.1 (2004–2005)
Butylated hydroxytoluene	128-37-0	BR No.1 (2004–2005)
Butylparaben	94-26-8	BR No.7 (2016–2017)
Cadmium	7440-43-9	1988 NSSS
Caffeine	58-08-2	BR No.1 (2004–2005)
Calcium	7440-70-2	1988 NSSS
Campesterol	474-62-4	2006 TNSSS
Captan	133-06-2	1988 NSSS
Carbadox	6804-07-5	BR No.1 (2004–2005)
Carbamazepine	298-46-4	BR No.1 (2004–2005)
Carbon disulfide	75-15-0	1988 NSSS
Carbon tetrachloride	56-23-5	1988 NSSS
Carbophenothion	786-19-6	1988 NSSS
Cerium	7440-45-1	BR No.1 (2004–2005)
Cesium	7440-46-2	BR No.8 (2018–2019)
Chlorobenzene	108-90-7	1988 NSSS
Chlorobenzilate	510-15-6	1988 NSSS
Chloroethane	75-00-3	1988 NSSS
Chloroform	67-66-3	1988 NSSS
Chloromethane	74-87-3	1988 NSSS
Chlorpyrifos	2921-88-2	1988 NSSS
Chlortetracycline	57-62-5	2006 TNSSS
Cholestan-3-ol, (3.beta.,5.alpha.)-	80-97-7	2006 TNSSS
Cholesterol	57-88-5	BR No.1 (2004–2005)
Chromium	7440-47-3	1988 NSSS
Chrysene	218-01-9	1988 NSSS
Cimetidine	51481-61-9	BR No.1 (2004–2005)
Ciprofloxacin	85721-33-1	BR No.1 (2004–2005)
Clarithromycin	81103-11-9	BR No.2 (2006–2007)
Clindamycin	18323-44-9	BR No.4 (2010–2011)

Chemical	CAS number	When identified
Clofibric acid	882-09-7	BR No.1 (2004–2005)
Clomazone	81777-89-1	BR No.4 (2010–2011)
Clorophene	120-32-1	BR No.6 (2014–2015)
Clotrimazole	23593-75-1	BR No.4 (2010–2011)
Cobalt	7440-48-4	1988 NSSS
Cocaine	50-36-2	BR No.5 (2012–2013)
Codeine	76-57-3	BR No.1 (2004–2005)
Copper	7440-50-8	1988 NSSS
Coprosterol	360-68-9	BR No.2 (2006–2007)
Cotinine	486-56-6	BR No.1 (2004–2005)
Cresyl diphenyl phosphate	26444-49-5	BR No.8 (2018–2019)
Crotonaldehyde	4170-30-3	1988 NSSS
Crotoxyphos	7700-17-6	1988 NSSS
Cyanide	57-12-5	1988 NSSS
Cyanuric acid	108-80-5	BR No.8 (2018–2019)
Cyclopenta[g]-2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethyl-	1222-05-5	BR No.1 (2004–2005)
Cyclophosphamide	50-18-0	BR No.1 (2004–2005)
Decachlorobiphenyl	2051-24-3	2001 NSSS
Decamethylcyclopentasiloxane	541-02-6	BR No.6 (2014–2015)
Decane	124-18-5	1988 NSSS
Dechlorane Plus	13560-89-9	BR No.7 (2016–2017)
DEET	134-62-3	BR No.1 (2004–2005)
delta-Hexachlorocyclohexane	319-86-8	1988 NSSS
Demeclocycline	127-33-3	2006 TNSSS
Desmosterol	313-04-2	2006 TNSSS
Di(2-ethylhexyl) phthalate	117-81-7	1988 NSSS
Diallate	2303-16-4	1988 NSSS
Diazepam	439-14-5	BR No.1 (2004–2005)
Diazinon	333-41-5	1988 NSSS
Dibenzofuran	132-64-9	1988 NSSS
Dibenzofuran, 1,2,3,4,6,7,8,9-octabromo-	103582-29-2	BR No.6 (2014–2015)
Dibenzothiophene	132-65-0	1988 NSSS
Dibutyl phthalate	84-74-2	1988 NSSS
Dichlorobiphenyl	25512-42-9	BR No.8 (2018–2019)
Dichlorodiphenyltrichloroethane	50-29-3	1988 NSSS
Dichloromethane	75-09-2	1988 NSSS
Dichlorophen	97-23-4	BR No.6 (2014–2015)
Diclofenac	15307-86-5	BR No.1 (2004–2005)
Dicrotophos	141-66-2	1988 NSSS

Chemical	CAS number	When identified
Dieldrin	60-57-1	1988 NSSS
Diethyl hydrogen phosphate	598-02-7	BR No.8 (2018–2019)
Digoxin	20830-75-5	BR No.1 (2004–2005)
Diisobutyl hydrogen phosphate	6303-30-6	BR No.8 (2018–2019)
Dimethoate	60-51-5	1988 NSSS
Dimethyl 2,6-dimethyl-4-(2-nitrophenyl)-3,5-pyridinedicarboxylate	67035-22-7	2006 TNSSS
Dimethyl phthalate	131-11-3	1988 NSSS
Dimethyl sulfone	67-71-0	1988 NSSS
Di-n-octyl phthalate	117-84-0	1988 NSSS
Diphenhydramine	58-73-1	BR No.2 (2006–2007)
Diphenyl oxide	101-84-8	1988 NSSS
Diphenyl phosphate	838-85-7	BR No.8 (2018–2019)
Diphenylamine	122-39-4	1988 NSSS
D-Limonene	5989-27-5	BR No.2 (2006–2007)
dl-Norgestrel	6533-00-2	BR No.1 (2004–2005)
Docosane	629-97-0	1988 NSSS
Dodecane	112-40-3	1988 NSSS
Doxepin	1668-19-5	BR No.9 (2020–2021)
Doxycycline	564-25-0	BR No.1 (2004–2005)
Eicosane	112-95-8	1988 NSSS
Endosulfan I	959-98-8	1988 NSSS
Endosulfan II	33213-65-9	1988 NSSS
Endrin	72-20-8	1988 NSSS
Enrofloxacin	93106-60-6	2006 TNSSS
Epitetracycline	79-85-6	2006 TNSSS
EPN	2104-64-5	1988 NSSS
Equilenin	517-09-9	2006 TNSSS
Equilin	474-86-2	BR No.1 (2004–2005)
ERGOSTEROL	57-87-4	2006 TNSSS
Erythromycin	114-07-8	BR No.1 (2004–2005)
Estradiol benzoate	50-50-0	2006 TNSSS
Estriol	50-27-1	BR No.1 (2004–2005)
Estrone	53-16-7	BR No.1 (2004–2005)
Ethanaminium, 2-hydroxy-N-(2-hydroxyethyl)-N,N-dimethyl-, esters with C16-18 and C18-unsatd. fatty acids, chlorides	1079184-43-2	BR No.8 (2018–2019)
Ethanol, 2-butoxy-, hydrogen phosphate	14260-97-0	BR No.8 (2018–2019)
Ethylbenzene	100-41-4	1988 NSSS
Ethylene glycol nonylphenyl ether	27986-36-3	BR No.2 (2006–2007)
Ethylparaben	120-47-8	BR No.7 (2016–2017)

Chemical	CAS number	When identified
Fenofibric acid	42017-89-0	BR No.1 (2004–2005)
Fentanyl	437-38-7	BR No.9 (2020–2021)
Fenthion	55-38-9	BR No.1 (2004–2005)
Fipronil	120068-37-3	BR No.4 (2010–2011)
Fipronil amide	205650-69-7	BR No.8 (2018–2019)
Fipronil sulfide	120067-83-6	BR No.8 (2018–2019)
Fipronil sulfone	120068-36-2	BR No.8 (2018–2019)
Fipronil-desulfinyl	205650-65-3	BR No.8 (2018–2019)
Floxacillin	5250-39-5	BR No.1 (2004–2005)
Fluoranthene	206-44-0	1988 NSSS
Fluoride	16984-48-8	1988 NSSS
Fluoxetine	54910-89-3	BR No.1 (2004–2005)
Furosemide	54-31-9	BR No.5 (2012–2013)
Gemfibrozil	25812-30-0	BR No.1 (2004–2005)
Glybenclamide	10238-21-8	BR No.5 (2012–2013)
Heptachlor	76-44-8	1988 NSSS
Heptachlor epoxide B	1024-57-3	1988 NSSS
Heptachlorobiphenyl	28655-71-2	BR No.8 (2018–2019)
Hexabromobenzene	87-82-1	BR No.7 (2016–2017)
Hexabromocyclododecane	25637-99-4	BR No.7 (2016–2017)
Hexachlorobiphenyl	26601-64-9	BR No.8 (2018–2019)
Hexacosane	630-01-3	1988 NSSS
Hexadecane	544-76-3	1988 NSSS
Hexanoic acid	142-62-1	1988 NSSS
Hydrocodone	125-29-1	BR No.5 (2012–2013)
Hydromorphone	466-99-9	BR No.9 (2020–2021)
Hydroxychloroquine	118-42-3	BR No.9 (2020–2021)
Ibuprofen	15687-27-1	BR No.1 (2004–2005)
Indole	120-72-9	BR No.2 (2006–2007)
Iodine	7553-56-2	1988 NSSS
Iron	7439-89-6	1988 NSSS
Isochlortetracycline	514-53-4	2006 TNSSS
Isodecyl diphenyl phosphate	29761-21-5	BR No.8 (2018–2019)
Ketoprofen	22071-15-4	BR No.1 (2004–2005)
Lead	7439-92-1	1988 NSSS
Leptophos	21609-90-5	1988 NSSS
Levorphanol	77-07-6	BR No.9 (2020–2021)
Lincomycin	154-21-2	BR No.3 (2008–2009)
Lindane	58-89-9	1988 NSSS

Chemical	CAS number	When identified
Lomefloxacin	98079-51-7	2006 TNSSS
Losartan	114798-26-4	BR No.9 (2020–2021)
Magnesium	7439-95-4	1988 NSSS
Manganese	7439-96-5	1988 NSSS
MDMA	42542-10-9	BR No.3 (2008–2009)
Mefenamic acid	61-68-7	BR No.1 (2004–2005)
Melamine	108-78-1	BR No.8 (2018–2019)
Mercury	7439-97-6	1988 NSSS
Mestranol	72-33-3	BR No.1 (2004–2005)
Metformin	657-24-9	2006 TNSSS
Methacrylonitrile	126-98-7	1988 NSSS
Methadone	76-99-3	BR No.9 (2020–2021)
Methamphetamine	537-46-2	BR No.2 (2006–2007)
Methyl 3,4-dihydroxybenzoate	2150-43-8	BR No.7 (2016–2017)
Methyl ethyl ketone	78-93-3	1988 NSSS
Methyl triclosan	4640-01-1	BR No.7 (2016–2017)
Methylparaben	99-76-3	BR No.7 (2016–2017)
Metoprolol	51384-51-1	BR No.1 (2004–2005)
Mevinphos	7786-34-7	1988 NSSS
Miconazole	22916-47-8	2006 TNSSS
Minocycline	10118-90-8	2006 TNSSS
Molybdenum	7439-98-7	1988 NSSS
Monochlorobiphenyl	27323-18-8	BR No.8 (2018–2019)
Monuron	150-68-5	BR No.1 (2004–2005)
Musk ketone	81-14-1	BR No.1 (2004–2005)
m-Xylene	108-38-3	1988 NSSS
Nadolol	42200-33-9	BR No.1 (2004–2005)
Naled	300-76-5	1988 NSSS
Nalidixic acid	389-08-2	BR No.8 (2018–2019)
Naphthalene	91-20-3	1988 NSSS
Naproxen	22204-53-1	BR No.1 (2004–2005)
N-Desmethyldiltiazem	86408-45-9	BR No.5 (2012–2013)
Nickel	7440-02-0	1988 NSSS
Nitrobenzene	98-95-3	1988 NSSS
Nitrofen	1836-75-5	1988 NSSS
N-Nitrosodibutylamine	924-16-3	BR No.6 (2014–2015)
N-Nitrosodiethylamine	55-18-5	BR No.6 (2014–2015)
N-Nitrosodimethylamine	62-75-9	BR No.6 (2014–2015)
N-Nitrosodi-n-propylamine	621-64-7	BR No.6 (2014–2015)

Chemical	CAS number	When identified
N-Nitrosodiphenylamine	86-30-6	1988 NSSS
N-Nitrosopiperidine	100-75-4	BR No.6 (2014–2015)
N-Nitrosopyrrolidine	930-55-2	BR No.6 (2014–2015)
n-Nonylphenol	25154-52-3	BR No.1 (2004–2005)
n-Octylphenol	67554-50-1	BR No.1 (2004–2005)
Nonachlorobiphenyl	53742-07-7	BR No.8 (2018–2019)
Nonylphenol and Nonylphenol Ethoxylates (NP/NPEs)	NOCAS_872428	BR No.2 (2006–2007)
Norethindrone	68-22-4	BR No.1 (2004–2005)
Norfloxacin	70458-96-7	BR No.1 (2004–2005)
Norfluoxetine	83891-03-6	BR No.4 (2010–2011)
Norverapamil	67018-85-3	BR No.5 (2012–2013)
o-Cresol	95-48-7	1988 NSSS
Octabromodibenzo-p-dioxin	2170-45-8	BR No.6 (2014–2015)
Octachlorobiphenyl	55722-26-4	BR No.8 (2018–2019)
Octachlorodibenzofuran	39001-02-0	1988 NSSS
Octachlorodibenzo-p-dioxin	3268-87-9	1988 NSSS
Octacosane	630-02-4	1988 NSSS
Octadecane	593-45-3	1988 NSSS
Ofloxacin	82419-36-1	2006 TNSSS
Ormetoprim	6981-18-6	2006 TNSSS
Oxolinic acid	14698-29-4	2006 TNSSS
Oxycodone	76-42-6	BR No.5 (2012–2013)
o-Xylene	95-47-6	1988 NSSS
Oxytetracycline	79-57-2	BR No.1 (2004–2005)
p,p'-DDD	72-54-8	1988 NSSS
p,p'-DDE	72-55-9	1988 NSSS
Paroxetine	61869-08-7	BR No.5 (2012–2013)
PCB 026	38444-81-4	2001 NSSS
PCB 045	70362-45-7	2001 NSSS
PCB 131	61798-70-7	2001 NSSS
p-Cresol	106-44-5	1988 NSSS
p-Cymene	99-87-6	1988 NSSS
Penicillin V	87-08-1	BR No.1 (2004–2005)
Pentabromodiphenyl ether	32534-81-9	BR No.3 (2008–2009)
Pentachloro-1,1'-biphenyl	25429-29-2	BR No.8 (2018–2019)
Pentachloronitrobenzene	82-68-8	1988 NSSS
Pentachlorophenol	87-86-5	1988 NSSS
Perfluorobutanesulfonic acid	375-73-5	BR No.5 (2012–2013)
Perfluorobutanoic acid	375-22-4	BR No.5 (2012–2013)

Chemical	CAS number	When identified
Perfluorodecanesulfonic acid	335-77-3	BR No.8 (2018–2019)
Perfluorodecanoic acid	335-76-2	BR No.5 (2012–2013)
Perfluorododecanoic acid	307-55-1	BR No.5 (2012–2013)
Perfluoroheptanoic acid	375-85-9	BR No.5 (2012–2013)
Perfluorohexadecanoic acid	67905-19-5	BR No.9 (2020–2021)
Perfluorohexanesulfonic acid	355-46-4	BR No.5 (2012–2013)
Perfluorohexanoic acid	307-24-4	BR No.5 (2012–2013)
Perfluorononanoic acid	375-95-1	BR No.5 (2012–2013)
Perfluorooctanesulfonamide	754-91-6	BR No.5 (2012–2013)
Perfluorooctanesulfonic acid	1763-23-1	BR No.5 (2012–2013)
Perfluorooctanoic acid	335-67-1	BR No.5 (2012–2013)
Perfluoropentanoic acid	2706-90-3	BR No.5 (2012–2013)
Perfluorotetradecanoic acid	376-06-7	BR No.7 (2016–2017)
Perfluorotridecanoic acid	72629-94-8	BR No.7 (2016–2017)
Perfluoroundecanoic acid	2058-94-8	BR No.5 (2012–2013)
Perylene	198-55-0	1988 NSSS
Phenanthrene	85-01-8	1988 NSSS
Phenazone	60-80-0	BR No.1 (2004–2005)
Phenol	108-95-2	1988 NSSS
Phenol, 2,5-bis(1,1-dimethylethyl)-	5875-45-6	BR No.8 (2018–2019)
Phenol, 4,4',4''-(1-methyl-1-propanyl-3-ylidene)tris 2-(1,1-dimethylethyl)-5-methyl-	1843-03-4	BR No.8 (2018–2019)
Phosphamidon	13171-21-6	1988 NSSS
Phosphoric acid, 2,2-bis(chloromethyl)-1,3-propanediyl tetrakis (2-chloroethyl) ester	38051-10-4	BR No.8 (2018–2019)
Phosphoric acid, dibutyl ester	107-66-4	BR No.8 (2018–2019)
Phosphoric acid, dipropyl ester	1804-93-9	BR No.8 (2018–2019)
Phosphoric acid, P,P'-[(1-methylethylidene)di-4,1-phenylene] P,P,P',P'-tetraphenyl ester	5945-33-5	BR No.8 (2018–2019)
Polycarbonates	25766-59-0	BR No.8 (2018–2019)
Polychlorinated biphenyls	1336-36-3	BR No.8 (2018–2019)
Polyethylene glycol	25322-68-3	BR No.1 (2004–2005)
Polyethylene terephthalate	25038-59-9	BR No.8 (2018–2019)
Potassium	7440-09-7	1988 NSSS
Progesterone	57-83-0	BR No.1 (2004–2005)
Promethazine	60-87-7	BR No.5 (2012–2013)
Propionitrile	107-12-0	1988 NSSS
Propoxyphene	469-62-5	BR No.5 (2012–2013)
Propranolol	525-66-6	BR No.1 (2004–2005)
Propylparaben	94-13-3	BR No.7 (2016–2017)

Chemical	CAS number	When identified
p-Xylene	106-42-3	1988 NSSS
Pyrene	129-00-0	1988 NSSS
Quinine	130-95-0	BR No.1 (2004–2005)
Ranitidine	66357-35-5	BR No.1 (2004–2005)
Roxithromycin	80214-83-1	BR No.2 (2006–2007)
Rubidium	7440-17-7	BR No.1 (2004–2005)
Salicylic acid	69-72-7	BR No.1 (2004–2005)
Sarafloxacin	98105-99-8	2006 TNSSS
Selenium	7782-49-2	1988 NSSS
Sertraline	79617-96-2	BR No.5 (2012–2013)
Silicon	7440-21-3	1988 NSSS
Silver	7440-22-4	1988 NSSS
Sodium	7440-23-5	1988 NSSS
Squalene	7683-64-9	1988 NSSS
Stigmastan-3beta-ol	19466-47-8	2006 TNSSS
Stigmastanol	138126-65-5	BR No.2 (2006–2007)
Stigmasterol	83-48-7	2006 TNSSS
STK368415	5136-34-5	BR No.1 (2004–2005)
Strontium	7440-24-6	1988 NSSS
Styrene	100-42-5	1988 NSSS
Sulfachloropyridazine	80-32-0	2006 TNSSS
Sulfadiazine	68-35-9	2006 TNSSS
Sulfadimethoxine	122-11-2	2006 TNSSS
Sulfamerazine	127-79-7	BR No.1 (2004–2005)
Sulfamethazine	57-68-1	BR No.1 (2004–2005)
Sulfamethoxazole	723-46-6	2006 TNSSS
Sulfanilamide	63-74-1	2006 TNSSS
Sulfasalazine	599-79-1	BR No.1 (2004–2005)
Sulfate	14808-79-8	BR No.8 (2018–2019)
Sulfathiazole	72-14-0	2006 TNSSS
Sulfur	7704-34-9	1988 NSSS
Tenofovir	147127-20-6	BR No.4 (2010–2011)
Terephthalic acid	100-21-0	BR No.8 (2018–2019)
tert-Butylphenyl diphenyl phosphate	56803-37-3	BR No.8 (2018–2019)
Testosterone	58-22-0	2006 TNSSS
Tetrabutyl ethylidenebisphenol	35958-30-6	BR No.8 (2018–2019)
Tetrachlorobiphenyl	26914-33-0	BR No.8 (2018–2019)
Tetrachloroethylene	127-18-4	1988 NSSS
Tetracosane	646-31-1	1988 NSSS

Chemical	CAS number	When identified
Tetracycline	60-54-8	2006 TNSSS
Tetradecane	629-59-4	1988 NSSS
Tetraethyl pyrophosphate	107-49-3	1988 NSSS
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	BR No.8 (2018–2019)
Thallium	7440-28-0	1988 NSSS
Thiabendazole	148-79-8	2006 TNSSS
Thioxanthen-9-one	492-22-8	1988 NSSS
Tin	7440-31-5	1988 NSSS
Titanium	7440-32-6	1988 NSSS
Toluene	108-88-3	1988 NSSS
Triacontane	638-68-6	1988 NSSS
Triamterene	396-01-0	BR No.5 (2012–2013)
Tributyl phosphate	126-73-8	BR No.8 (2018–2019)
Trichlorfon	52-68-6	1988 NSSS
Trichlorobiphenyl	25323-68-6	BR No.8 (2018–2019)
Trichloroethylene	79-01-6	1988 NSSS
Trichlorofluoromethane	75-69-4	1988 NSSS
Triclocarban	101-20-2	BR No.2 (2006–2007)
Triclosan	3380-34-5	BR No.1 (2004–2005)
Triethyl phosphate	78-40-0	BR No.8 (2018–2019)
Triethylene glycol bis(3-tert-butyl-4-hydroxy-5-methylphenyl)propionate	36443-68-2	BR No.8 (2018–2019)
Trifluralin	1582-09-8	1988 NSSS
Triisobutyl phosphate	126-71-6	BR No.8 (2018–2019)
Trimethoprim	738-70-5	BR No.1 (2004–2005)
Trimethyl phosphate	512-56-1	BR No.8 (2018–2019)
Trimethylsilanol	1066-40-6	BR No.8 (2018–2019)
Tri-o-cresyl phosphate	78-30-8	1988 NSSS
Triphenyl phosphate	115-86-6	BR No.1 (2004–2005)
Triphenylene	217-59-4	1988 NSSS
Tripropyl phosphate	513-08-6	BR No.8 (2018–2019)
Tris(1,3-dichloro-2-propyl) phosphate	13674-87-8	BR No.8 (2018–2019)
Tris(2-butoxyethyl) phosphate	78-51-3	BR No.1 (2004–2005)
Tris(2-chloroethyl) phosphate	115-96-8	BR No.1 (2004–2005)
Tris(2-chloroisopropyl)phosphate	13674-84-5	BR No.8 (2018–2019)
Tris(2-ethylhexyl) phosphate	78-42-2	BR No.8 (2018–2019)
Tris(4-tert-butylphenyl) phosphate	78-33-1	BR No.8 (2018–2019)
Tris(methylphenyl) phosphate	1330-78-5	BR No.8 (2018–2019)
Tylosin	1401-69-0	BR No.1 (2004–2005)
Valproic acid	99-66-1	BR No.1 (2004–2005)

Chemical	CAS number	When identified
Valsartan	137862-53-4	BR No.5 (2012–2013)
Vanadium	7440-62-2	1988 NSSS
Virginiamycin	11006-76-1	BR No.1 (2004–2005)
Yttrium	7440-65-5	1988 NSSS
Zinc	7440-66-6	1988 NSSS
α-Dihydroequilin	651-55-8	2006 TNSSS

Notes:
BR = Biennial Report; CAS = Chemical Abstracts Service; NSSS = National Sewage Sludge Survey; TNSSS = Targeted National Sewage Sludge Survey
The list includes only chemicals identified through biennial reviews and sewage sludge surveys. This list does not include chemicals identified in the 2003 literature review conducted as part of the EPA response to the 2002 National Research Council (NRC) report reviewing the biosolids regulation (68 FR 75531).

Table B-2. Categorization of Chemicals

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2-(N-Ethylperfluorooctanesulfonamido) acetic acid	2991-50-6	DTXSID5062760	N	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
2-(N-Methylperfluorooctanesulfonamido) acetic acid	2355-31-9	DTXSID10624392	N	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
alpha-Solanine	20562-02-1	DTXSID9030707	N	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
Berberine	2086-83-1	DTXSID9043857	N	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bromide	24959-67-9	DTXSID6043967	N	-	P	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	-	Y
Doxepin	1668-19-5	DTXSID7022966	N	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fentanyl	437-38-7	DTXSID9023049	N	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydromorphone	466-99-9	DTXSID8023133	N	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydroxychloroquine	118-42-3	DTXSID8023135	N	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Levorphanol	77-07-6	DTXSID3023213	N	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Losartan	114798-26-4	DTXSID7023227	N	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Methadone	76-99-3	DTXSID7023273	N	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Perfluorohexadecanoic acid	67905-19-5	DTXSID1070800	N	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
(E)-1,2-Dichloroethylene	156-60-5	DTXSID7024031	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
1,1,1-Trichloroethane	71-55-6	DTXSID0021381	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
1,2,3,4,6,7,8-Heptachlorodibenzo[b,d]furan	67562-39-4	DTXSID8052350	P*	-	E	-	-	-	-	-	-	-	-		-	-	-	-	-	Y	-	-	-	-
1,2,3,7,8,9-Hexachlorodibenzo[b,d]furan	72918-21-9	DTXSID9052470	P*	-	E	-	-	-	-	-	-	-	-		-	-	-	-	-	Y	-	-	-	-
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321-76-4	DTXSID7052078	P*	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-	-	-
1,2,3-Trichlorobenzene	87-61-6	DTXSID8026193	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
1,2,4-Trichlorobenzene	120-82-1	DTXSID0021965	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
1,2-Dichlorobenzene	95-50-1	DTXSID6020430	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
1,2-Dichloropropane	78-87-5	DTXSID0020448	P*	-	A.1	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
1,4-Dinitrobenzene	100-25-4	DTXSID0021836	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
1,4-Dioxane	123-91-1	DTXSID4020533	P*	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Methyl phenanthrene	832-69-9	DTXSID6025648	P*	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2-(2,4,5-Trichlorophenoxy)propionic acid	93-72-1	DTXSID0021387	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
2-(Methylthio)benzothiazole	615-22-5	DTXSID70274236	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	40186-72-9	DTXSID50865989	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	35694-08-7	DTXSID5074139	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl	52663-79-3	DTXSID6074172	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,4',5,6-Octachlorobiphenyl	52663-78-2	DTXSID1074171	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,4',6,6'-Octachlorobiphenyl	33091-17-7	DTXSID0074134	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,4',6-Heptachlorobiphenyl	52663-71-5	DTXSID4073540	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl	52663-77-1	DTXSID6074170	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	52663-75-9	DTXSID2074168	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5,5',6-Octachlorobiphenyl	68194-17-2	DTXSID1074204	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5,5'-Heptachlorobiphenyl	52663-74-8	DTXSID7074167	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5,6,6'-Octachlorobiphenyl	52663-73-7	DTXSID2074166	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5,6'-Heptachlorobiphenyl	38411-25-5	DTXSID4074142	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5,6-Heptachlorobiphenyl	68194-16-1	DTXSID6074203	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5',6'-Heptachlorobiphenyl	52663-70-4	DTXSID2074164	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5',6-Heptachlorobiphenyl	40186-70-7	DTXSID9074147	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5'-Hexachlorobiphenyl	52663-66-8	DTXSID5073539	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,6,6'-Heptachlorobiphenyl	52663-65-7	DTXSID7074161	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2,2',3,3',4,6'-Hexachlorobiphenyl	38380-05-1	DTXSID9074141	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4-Pentachlorobiphenyl	52663-62-4	DTXSID60274189	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',5,5',6,6'-Octachlorobiphenyl	2136-99-4	DTXSID0074132	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',5,5'-Hexachlorobiphenyl	35694-04-3	DTXSID4030045	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',5,6,6'-Heptachlorobiphenyl	52663-64-6	DTXSID0073538	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',5,6'-Hexachlorobiphenyl	52744-13-5	DTXSID9073541	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',5,6-Hexachlorobiphenyl	52704-70-8	DTXSID1074173	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',5-Pentachlorobiphenyl	60145-20-2	DTXSID0074188	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',6-Pentachlorobiphenyl	52663-60-2	DTXSID0073536	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3'-Tetrachlorobiphenyl	38444-93-8	DTXSID3073503	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',5,6,6'-Octachlorobiphenyl	74472-52-9	DTXSID7074240	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',5,6'-Heptachlorobiphenyl	60145-23-5	DTXSID9074191	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',5,6-Heptachlorobiphenyl	74472-47-2	DTXSID8074235	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',5',6-Heptachlorobiphenyl	52663-69-1	DTXSID7074163	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',5'-Hexabromodiphenyl Ether	182677-30-1	DTXSID60872265	P*	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	Y	-	-	-	-
2,2',3,4,4',5-Hexachlorobiphenyl	35694-06-5	DTXSID0074138	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',6,6'-Heptachlorobiphenyl	74472-48-3	DTXSID3074236	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',6'-Hexachlorobiphenyl	59291-64-4	DTXSID0074186	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',6-Hexachlorobiphenyl	56030-56-9	DTXSID5074183	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',5,5',6-Heptachloro-1,1'-biphenyl	52663-68-0	DTXSID5052832	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,5,5',6-Heptachlorobiphenyl	52712-05-7	DTXSID1074175	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,5,5'-Hexachlorobiphenyl	52712-04-6	DTXSID6074174	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',5,5'-Hexachlorobiphenyl	51908-16-8	DTXSID8074158	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2,2',3,4,5,6,6'-Heptachlorobiphenyl	74472-49-4	DTXSID8074237	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',5,6,6'-Heptachlorobiphenyl	74487-85-7	DTXSID7074242	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,5,6'-Hexachlorobiphenyl	68194-15-0	DTXSID1074202	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,5',6-Hexachlorobiphenyl	68194-14-9	DTXSID6074201	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',5,6'-Hexachlorobiphenyl	74472-41-6	DTXSID3074230	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',5,6-Hexachlorobiphenyl	68194-13-8	DTXSID1074200	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',5',6-Hexachlorobiphenyl	38380-04-0	DTXSID1073498	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,5-Pentachlorobiphenyl	55312-69-1	DTXSID1074179	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',5'-Pentachlorobiphenyl	41464-51-1	DTXSID2073510	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',5-Pentachlorobiphenyl	68194-07-0	DTXSID4074196	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,6,6'-Hexachlorobiphenyl	74472-40-5	DTXSID4074229	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',6,6'-Hexachlorobiphenyl	68194-08-1	DTXSID9074197	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,6'-Pentachlorobiphenyl	73575-57-2	DTXSID0074219	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,6-Pentachlorobiphenyl	55215-17-3	DTXSID6074178	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',6'-Pentachlorobiphenyl	60233-25-2	DTXSID9074193	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4',6-Pentachlorobiphenyl	68194-05-8	DTXSID1073608	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4'-Tetrachloro-1,1'-biphenyl	36559-22-5	DTXSID80873557	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4-Tetrachlorobiphenyl	52663-59-9	DTXSID5073535	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,5,5',6-Hexachlorobiphenyl	52663-63-5	DTXSID2074160	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,5,5'-Pentachlorobiphenyl	52663-61-3	DTXSID5073537	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,5,6,6'-Hexachlorobiphenyl	68194-09-2	DTXSID70867526	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,5,6'-Pentachlorobiphenyl	73575-55-0	DTXSID0074217	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,5,6-Pentachlorobiphenyl	73575-56-1	DTXSID5074218	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2,2',3,5'-tetrachlorobiphenyl	41464-39-5	DTXSID8038302	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,6,6'-Pentachlorobiphenyl	73575-54-9	DTXSID5074216	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,6'-Tetrachlorobiphenyl	41464-47-5	DTXSID40866046	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3-Trichlorobiphenyl	38444-78-9	DTXSID3073501	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,4',5,6'-Hexachlorobiphenyl	60145-22-4	DTXSID4074190	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,4',5-Pentachlorobiphenyl	38380-01-7	DTXSID1073496	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,4',6,6'-Hexachlorobiphenyl	33979-03-2	DTXSID3040302	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,4',6-Pentabromodiphenyl ether	189084-64-8	DTXSID4052689	P*	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	Y	-	-	-	-
2,2',4,4',6-Pentachlorobiphenyl	39485-83-1	DTXSID8073504	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,5,6'-Pentachlorobiphenyl	68194-06-9	DTXSID10867525	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,5',6-Pentachlorobiphenyl	60145-21-3	DTXSID5074189	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,6,6'-Pentachlorobiphenyl	56558-16-8	DTXSID0074184	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,6-Tetrachlorobiphenyl	62796-65-0	DTXSID4074194	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4-Trichlorobiphenyl	37680-66-3	DTXSID1073492	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',5,6'-Tetrachlorobiphenyl	41464-41-9	DTXSID3073509	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',5-Trichlorobiphenyl	37680-65-2	DTXSID6073491	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',6,6'-Tetrachlorobiphenyl	15968-05-5	DTXSID0065983	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2'-Bioxirane	1464-53-5	DTXSID0041307	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
2,3,3',4,4',5,5',6-Octachlorobiphenyl	74472-53-0	DTXSID2074241	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,4',5',6-Heptachlorobiphenyl	74472-50-7	DTXSID3074238	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,5,5',6-Heptachlorobiphenyl	74472-51-8	DTXSID8074239	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4',5,5',6-Heptachlorobiphenyl	69782-91-8	DTXSID30867845	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,5,5'-Hexachlorobiphenyl	39635-35-3	DTXSID4074146	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2,3,3',4',5,5'-Hexachlorobiphenyl	39635-34-2	DTXSID10865965	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,5,6-Hexachlorobiphenyl	41411-62-5	DTXSID20866044	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,5',6-Hexachlorobiphenyl	74472-43-8	DTXSID3074232	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4',5',6-Hexachlorobiphenyl	74472-45-0	DTXSID3074234	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,5'-Pentachlorobiphenyl	70362-41-3	DTXSID1074206	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4',5'-Pentachlorobiphenyl	76842-07-4	DTXSID2074243	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4',5-Pentachlorobiphenyl	70424-68-9	DTXSID0074211	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,6-Pentachlorobiphenyl	74472-35-8	DTXSID9074224	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4',6-Pentachlorobiphenyl	38380-03-9	DTXSID3038307	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4'-Tetrachlorobiphenyl	41464-43-1	DTXSID3074153	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4-Tetrachlorobiphenyl	74338-24-2	DTXSID4074221	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',5,5',6-Hexachlorobiphenyl	74472-46-1	DTXSID8073631	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',5,5'-Pentachlorobiphenyl	39635-32-0	DTXSID50865964	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',5',6-Pentachlorobiphenyl	68194-10-5	DTXSID4074198	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',5'-Tetrachlorobiphenyl	41464-49-7	DTXSID8074156	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',5-Tetrachlorobiphenyl	70424-67-8	DTXSID5074210	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',6-Tetrachlorobiphenyl	74472-33-6	DTXSID9074222	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3'-Trichlorobiphenyl	38444-84-7	DTXSID8073502	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4,4',5,6-Hexachlorobiphenyl	41411-63-6	DTXSID8074150	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,4',5',6-Hexachlorobiphenyl	59291-65-5	DTXSID5074187	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4,4',6-Pentachlorobiphenyl	74472-38-1	DTXSID4074227	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,4',6-Pentachlorobiphenyl	56558-17-9	DTXSID5074185	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,4'-Tetrabromodiphenyl ether	189084-61-5	DTXSID9052688	P*	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	Y	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2,3,4,4'-Tetrachlorobiphenyl	33025-41-1	DTXSID3073474	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,5,5'-Pentachlorobiphenyl	68194-12-7	DTXSID6073609	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4',5,5'-Pentachlorobiphenyl	70424-70-3	DTXSID0074213	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4,5,6-Pentachlorobiphenyl	18259-05-7	DTXSID40864820	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4',5,6-Pentachlorobiphenyl	68194-11-6	DTXSID9074199	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,5',6-Pentachlorobiphenyl	56558-18-0	DTXSID50866577	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4',5',6-Pentachlorobiphenyl	74472-39-2	DTXSID9074228	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4,5-Tetrachlorobiphenyl	33284-53-6	DTXSID5074135	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4',5-Tetrachlorobiphenyl	74472-34-7	DTXSID4074223	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,5'-Tetrachlorobiphenyl	73575-52-7	DTXSID5074214	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,5-Tetrachlorobiphenyl	73575-53-8	DTXSID0074215	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4',5'-Tetrachlorobiphenyl	70362-48-0	DTXSID60867919	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4',5-Tetrachlorobiphenyl	32598-11-1	DTXSID3038309	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4,6-Tetrachlorobiphenyl	54230-22-7	DTXSID1074177	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4',6-Tetrachlorobiphenyl	52663-58-8	DTXSID3074159	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,6-Tetrachlorobiphenyl	60233-24-1	DTXSID4074192	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4',6-Tetrachlorobiphenyl	41464-46-4	DTXSID8074154	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4-Trichlorobiphenyl	55702-46-0	DTXSID0074180	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4-Trichlorobiphenyl	55712-37-3	DTXSID5074181	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2',3,4-Trichlorobiphenyl	38444-86-9	DTXSID8040303	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',5,5'-Tetrachlorobiphenyl	41464-42-0	DTXSID8074152	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,5,6-Tetrachlorobiphenyl	33284-54-7	DTXSID0074136	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',5',6-Tetrachlorobiphenyl	74338-23-1	DTXSID9074220	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2,3,5-Trichlorobiphenyl	55720-44-0	DTXSID0074182	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',5'-Trichlorobiphenyl	37680-68-5	DTXSID4074140	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3'-Dichlorobiphenyl	25569-80-6	DTXSID3074024	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4,4',5-Tetrachlorobiphenyl	32690-93-0	DTXSID8073473	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4,4',6-Tetrachlorobiphenyl	32598-12-2	DTXSID5074133	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4,4'-Tribromodiphenyl ether	41318-75-6	DTXSID4052710	P*	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	Y	-	-	-	-
2,4,4'-Trichlorobiphenyl	7012-37-5	DTXSID2038310	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4,5-Trichlorobiphenyl	15862-07-4	DTXSID0073405	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4,5-Trichlorophenoxyacetic acid	93-76-5	DTXSID5021388	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4,5-Trimethylaniline	137-17-7	DTXSID9021398	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
2,4,6-Trichlorobiphenyl	35693-92-6	DTXSID7073482	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4',6-Trichlorobiphenyl	38444-77-8	DTXSID8073500	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4-Dichlorobiphenyl	33284-50-3	DTXSID8040301	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,5-Dichlorobiphenyl	34883-39-1	DTXSID7073480	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	606-20-2	DTXSID5020528	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
2-Chloro-4-phenylphenol	92-04-6	DTXSID0022353	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
2-Hexanone	591-78-6	DTXSID0022068	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
2-Methyl-1-propanol	78-83-1	DTXSID0021759	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
2-Methylpyridine	109-06-8	DTXSID9021899	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
3,3',4,5,5'-Pentachlorobiphenyl	39635-33-1	DTXSID9074145	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,3',4,5'-Tetrachlorobiphenyl	41464-48-6	DTXSID3074155	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,3',4,5-Tetrachlorobiphenyl	70362-49-1	DTXSID1074208	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,3',4-Trichlorobiphenyl	37680-69-6	DTXSID60865879	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
3,3',5,5'-Tetrachlorobiphenyl	33284-52-5	DTXSID4058657	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,3',5-Trichlorobiphenyl	38444-87-0	DTXSID50858937	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,3'-Dichloro-1,1'-biphenyl	2050-67-1	DTXSID70872817	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,4,5-Trichlorobiphenyl	53555-66-1	DTXSID6074176	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,4',5-Trichlorobiphenyl	38444-88-1	DTXSID40865913	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,4'-Dichlorobiphenyl	2974-90-5	DTXSID10863067	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,4-Dichlorobiphenyl	2974-92-7	DTXSID6073310	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,5-Dichlorobiphenyl	34883-41-5	DTXSID5074137	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,6-Dimethylphenanthrene	1576-67-6	DTXSID9052682	P*	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Chlorobiphenyl	2051-61-8	DTXSID1040299	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
4,4'-Dichlorobiphenyl	2050-68-2	DTXSID0022515	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
4-Androstene-3,17-dione	63-05-8	DTXSID8024523	P*	-	A.1.3	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Chloro-3-methylphenol	59-50-7	DTXSID4021717	P*	-	B	-	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Methyl-2-pentanone	108-10-1	DTXSID5021889	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Acenaphthene	83-32-9	DTXSID3021774	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Aldrin	309-00-2	DTXSID8020040	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Allyl alcohol	107-18-6	DTXSID8020044	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Allyl chloride	107-05-1	DTXSID4039231	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	319-84-6	DTXSID2020684	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
alpha-Terpineol	98-55-5	DTXSID5026625	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Anhydrochlortetracycline	4497-08-9	DTXSID50912301	P*	-	A.1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aroclor 1248	12672-29-6	DTXSID4023884	P*	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Aroclor 1254	11097-69-1	DTXSID5020100	P*	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	Y	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Aroclor 1260	11096-82-5	DTXSID0020101	P*	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Azinphos-methyl	86-50-0	DTXSID3020122	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Bensulide	741-58-2	DTXSID9032329	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Benzene	71-43-2	DTXSID3039242	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Benzenethiol	108-98-5	DTXSID7026811	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
Benzo(g,h,i)perylene	191-24-2	DTXSID5023908	P*	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Benzyl alcohol	100-51-6	DTXSID5020152	P*	-	B	Y	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Benzyl butyl phthalate	85-68-7	DTXSID3020205	P*	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	Y	-	-
beta-Hexachlorocyclohexane	319-85-7	DTXSID7020685	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Biphenyl	92-52-4	DTXSID4020161	P*	-	D	-	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Bisphenol A	80-05-7	DTXSID7020182	P*	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
Caffeine	58-08-2	DTXSID0020232	P*	-	A.1	Y	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Captan	133-06-2	DTXSID9020243	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbadox	6804-07-5	DTXSID6043913	P*	-	A.1.1	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon disulfide	75-15-0	DTXSID6023947	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbophenothion	786-19-6	DTXSID7022120	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorobenzene	108-90-7	DTXSID4020298	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Chlorobenzilate	510-15-6	DTXSID9020299	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Chloroethane	75-00-3	DTXSID1020302	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
Chloromethane	74-87-3	DTXSID0021541	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorpyrifos	2921-88-2	DTXSID4020458	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-
Clomazone	81777-89-1	DTXSID1032355	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Crotonaldehyde	4170-30-3	DTXSID8024864	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Crotoxyphos	7700-17-6	DTXSID6037514	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyanide	57-12-5	DTXSID6023991	P*	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y
Decane	124-18-5	DTXSID6024913	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
delta-Hexachlorocyclohexane	319-86-8	DTXSID5024134	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Diallate	2303-16-4	DTXSID2020391	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Diazinon	333-41-5	DTXSID9020407	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Dibenzofuran	132-64-9	DTXSID2021993	P*	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
Dibenzothiophene	132-65-0	DTXSID0047741	P*	-	K	-	-	-	-	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-	-
Dichlorodiphenyltrichloroethane	50-29-3	DTXSID4020375	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichloromethane	75-09-2	DTXSID0020868	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Dicrotophos	141-66-2	DTXSID9023914	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Dieldrin	60-57-1	DTXSID9020453	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-
Dimethyl sulfone	67-71-0	DTXSID4043937	P*	-	B	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diphenyl oxide	101-84-8	DTXSID9021847	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	Y	-	Y	-	-
Diphenylamine	122-39-4	DTXSID4021975	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
dl-Norgestrel	6533-00-2	DTXSID3047477	P*	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Docosane	629-97-0	DTXSID7047063	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Dodecane	112-40-3	DTXSID0026913	P*	-	B	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eicosane	112-95-8	DTXSID1025227	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Endrin	72-20-8	DTXSID6020561	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
EPN	2104-64-5	DTXSID7022174	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Heptachlor	76-44-8	DTXSID3020679	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-
Hexabromocyclododecane	25637-99-4	DTXSID8025383	P*	Y	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Hexacosane	630-01-3	DTXSID7060883	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Hexadecane	544-76-3	DTXSID0027195	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	Y	-	Y	-	-
Iodine	7553-56-2	DTXSID7034672	P*	-	G	Y	Y	-	-	-	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-
Leptophos	21609-90-5	DTXSID3040279	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-
Lindane	58-89-9	DTXSID2020686	P*	-	A.1	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-
Methacrylonitrile	126-98-7	DTXSID1024176	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
Methyl ethyl ketone	78-93-3	DTXSID3021516	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Methyl triclosan	4640-01-1	DTXSID0047874	P*	-	A.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mevinphos	7786-34-7	DTXSID2032683	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Naled	300-76-5	DTXSID1024209	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrobenzene	98-95-3	DTXSID3020964	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Nonylphenol and Nonylphenol Ethoxylates (NP/NPEs)	NOCAS_872428	DTXSID20872428	P*	Y	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-
o-Cresol	95-48-7	DTXSID8021808	P*	-	B	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
Octacosane	630-02-4	DTXSID6058639	P*	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Octadecane	593-45-3	DTXSID9047172	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
p,p'-DDD	72-54-8	DTXSID4020373	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
p,p'-DDE	72-55-9	DTXSID9020374	P*	-	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PCB 026	38444-81-4	DTXSID4074778	P*	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
p-Cymene	99-87-6	DTXSID3026645	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Penicillin V	87-08-1	DTXSID3023429	P*	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pentachlorophenol	87-86-5	DTXSID7021106	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Perfluorodecanesulfonic acid	335-77-3	DTXSID3040148	P*	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perylene	198-55-0	DTXSID4047753	P*	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Phenanthrene	85-01-8	DTXSID6024254	P*	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Phosphamidon	13171-21-6	DTXSID7021156	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Potassium	7440-09-7	DTXSID9049748	P*	-	G	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Propionitrile	107-12-0	DTXSID1021879	P*	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
Quinine	130-95-0	DTXSID0044280	P*	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silicon	7440-21-3	DTXSID0051441	P*	-	G	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Squalene	7683-64-9	DTXSID4064767	P*	-	B	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strontium	7440-24-6	DTXSID3024312	P*	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Tenofovir	147127-20-6	DTXSID9040132	P*	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetracosane	646-31-1	DTXSID8060955	P*	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetradecane	629-59-4	DTXSID1027267	P*	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetraethyl pyrophosphate	107-49-3	DTXSID3034957	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Thioxanthen-9-one	492-22-8	DTXSID8060082	P*	-	A.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triacontane	638-68-6	DTXSID0060935	P*	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichloroethylene	79-01-6	DTXSID0021383	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichlorofluoromethane	75-69-4	DTXSID5021384	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifluralin	1582-09-8	DTXSID4021395	P*	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Tri-o-cresyl phosphate	78-30-8	DTXSID6032192	P*	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
Triphenylene	217-59-4	DTXSID9059757	P*	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-
Valproic acid	99-66-1	DTXSID6023733	P*	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(+)-Diltiazem	42399-41-7	DTXSID9022940	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(+/-)-Verapamil	52-53-9	DTXSID9041152	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(3alpha,5beta)-Cholestan-3-ol	516-92-7	DTXSID7046700	P	-	A.1.3	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
1-(p-Chlorobenzoyl)-5-methoxy-2-methyl-Indole-3-acetic acid	53-86-1	DTXSID9020740	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1,1'-Ethane-1,2-diylbis(pentabromobenzene)	84852-53-9	DTXSID2052732	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
1,1'-Oxybis[2,3,4,5,6-pentabromobenzene]	1163-19-5	DTXSID9020376	P	-	J	-	-	-	-	-	Y	-	-	-	-	-	-	Y	-	-	-	-	-	-
1,2,3,4,5-Pentabromo-6-(2,3,4,5-tetrabromophenoxy)benzene	63387-28-0	DTXSID30881107	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
1,2,3,4,6,7,8,9,10,10,11,11-dodecachloro-1,4,4a,5a,6,9,9a,9b-octahydro-1,4:6,9-dimethanodibenzofuran	31107-44-5	DTXSID0052702	P	-	L	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2,3,4,6,7,8-Heptabromodibenzofuran	107555-95-3	DTXSID7073779	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2,3,4,6,7,8-Heptabromodibenzo-p-dioxin	110999-47-8	DTXSID2074245	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
1,2,3,4,6,7,8-Heptachlorodibenzodioxin	35822-46-9	DTXSID1052034	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
1,2,3,4,7,8,9-Heptabromodibenzo[b,d]furan	161880-51-9	DTXSID50936608	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673-89-7	DTXSID9052216	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2,3,4,7,8-Hexabromodibenzofuran	129880-08-6	DTXSID6073861	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2,3,4,7,8-Hexabromodibenzo-p-dioxin	110999-44-5	DTXSID5073793	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
1,2,3,4,7,8-Hexachlorodibenzodioxin	39227-28-6	DTXSID8052067	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
1,2,3,4,7,8-Hexachlorodibenzofuran	70648-26-9	DTXSID6029915	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2,3,5-Tetrabromo-4-(3,4,5-tribromophenoxy)benzene	446255-30-7	DTXSID10704805	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
1,2,3,6,7,8-Hexabromodibenzofuran	107555-94-2	DTXSID7074244	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2,3,6,7,8-Hexabromodibenzo-p-dioxin	110999-45-6	DTXSID0073794	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
1,2,3,6,7,8-Hexachlorodibenzofuran	57117-44-9	DTXSID2069155	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	57653-85-7	DTXSID0023824	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
1,2,3,7,8,9-Hexabromodibenzo[b,d]furan	161880-49-5	DTXSID30936606	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
1,2,3,7,8,9-Hexabromodibenzo-p-dioxin	110999-46-7	DTXSID5073795	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	19408-74-3	DTXSID6023781	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
1,2,3,7,8-Pentabromodibenzo[b,d]furan	107555-93-1	DTXSID60869478	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2,3,7,8-Pentabromodibenzo-p-dioxin	109333-34-8	DTXSID6073784	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
1,2,3,7,8-Pentachlorodibenzofuran	57117-41-6	DTXSID7052234	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
1,2-Bis(2,4,6-tribromophenoxy)ethane	37853-59-1	DTXSID1024627	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
1,3,5-Triazin-2(1H)-one, 4,6-diamino-	645-92-1	DTXSID3060950	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
1,3,5-Trichlorobenzene	108-70-3	DTXSID8026195	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1,3-Dichlorobenzene	541-73-1	DTXSID6022056	P	-	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1,4:5,8:9,10-Trimethanoanthracene, 1,2,3,4,5,6,7,8,12,12,13,13-dodecachloro-1,4,4a,5,8,8a,9,9a,10,10a-decahydro-	13560-92-4	DTXSID30108225	P	Y	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
1,4-Dichlorobenzene	106-46-7	DTXSID1020431	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
1,7-Dimethylxanthine	611-59-6	DTXSID2052281	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-Hydroxyamitriptyline	1159-82-6	DTXSID90873785	P	-	A.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17alpha-Estradiol	57-91-0	DTXSID8022377	P	-	A.1.3	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17alpha-Ethinylestradiol	57-63-6	DTXSID5020576	P	-	A.1.3	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17beta-Estradiol	50-28-2	DTXSID0020573	P	-	A.1.3	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,4',5,6'-Octachlorobiphenyl	42740-50-1	DTXSID3074157	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,4',5-Heptachlorobiphenyl	35065-30-6	DTXSID2073481	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,4'-Hexachlorobiphenyl	38380-07-3	DTXSID50858932	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5',6,6'-Octachlorobiphenyl	40186-71-8	DTXSID4074148	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',4,5-Hexachlorobiphenyl	55215-18-4	DTXSID8073554	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,3',5,5',6-Heptachlorobiphenyl	52663-67-9	DTXSID2074162	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2,2',3,3',6,6'-Hexachlorobiphenyl	38411-22-2	DTXSID6073499	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',5,5',6-Octachlorobiphenyl	52663-76-0	DTXSID7074169	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',5,5'-Heptachlorobiphenyl	35065-29-3	DTXSID6038299	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4',5',6-Heptabromodiphenyl ether	207122-16-5	DTXSID8052693	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
2,2',3,4,4',5'-Hexachlorobiphenyl	35065-28-2	DTXSID8038300	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,4'-Pentabromodiphenyl ether	182346-21-0	DTXSID4052685	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
2,2',3,4,4'-Pentachlorobiphenyl	65510-45-4	DTXSID9073599	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,4,5'-Pentachlorobiphenyl	38380-02-8	DTXSID6073497	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,5',6-Pentachlorobiphenyl	38379-99-6	DTXSID3038301	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',3,5-Tetrachlorobiphenyl	70362-46-8	DTXSID00867918	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,4',5,5'-Hexabromobiphenyl	59080-40-9	DTXSID70858838	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
2,2',4,4',5,5'-Hexabromodiphenyl ether	68631-49-2	DTXSID4030047	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
2,2',4,4',5,5'-Hexachlorobiphenyl	35065-27-1	DTXSID2032180	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,4',5,6'-Hexabromodiphenyl ether	207122-15-4	DTXSID3052692	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
2,2',4,4',5-Pentabromodiphenyl ether	60348-60-9	DTXSID9030048	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
2,2',4,4'-Tetrabromodiphenyl ether	5436-43-1	DTXSID3030056	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
2,2',4,4'-Tetrachlorobiphenyl	2437-79-8	DTXSID0022513	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,5,5'-Pentachlorobiphenyl	37680-73-2	DTXSID8038304	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,5'-Tetrachlorobiphenyl	41464-40-8	DTXSID8073508	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,5-Tetrachlorobiphenyl	70362-47-9	DTXSID6074207	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4,6'-Tetrachlorobiphenyl	68194-04-7	DTXSID9074195	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2',4-Tribromodiphenyl ether	147217-75-2	DTXSID40872703	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
2,2',5,5'-Tetrachlorobiphenyl	35693-99-3	DTXSID3038305	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2,2',6-Trichlorobiphenyl	38444-73-4	DTXSID9074777	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,2'-Dichlorobiphenyl	13029-08-8	DTXSID4044533	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,4',5,5'-Heptachlorobiphenyl	39635-31-9	DTXSID4074144	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,4',5,6-Heptachlorobiphenyl	41411-64-7	DTXSID3074151	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,4',5'-Hexachlorobiphenyl	69782-90-7	DTXSID6074205	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,4',5-Hexachlorobiphenyl	38380-08-4	DTXSID0052706	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,4',6-Hexachlorobiphenyl	74472-42-7	DTXSID8074231	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4,4'-Pentachlorobiphenyl	32598-14-4	DTXSID8038306	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,3',4',5,6-Hexachlorobiphenyl	74472-44-9	DTXSID8074233	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,4',5,5'-Hexachlorobiphenyl	52663-72-6	DTXSID7074165	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4,4',5-Pentachlorobiphenyl	74472-37-0	DTXSID9074226	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,4',5-Pentachlorobiphenyl	31508-00-6	DTXSID4032116	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2',3,4,4',5-Pentachlorobiphenyl	65510-44-3	DTXSID50867160	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',4,4'-Tetrachlorobiphenyl	32598-10-0	DTXSID3073472	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,4,5,6-Pentabromoethylbenzene	85-22-3	DTXSID7021782	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
2,3,4,6,7,8-Hexabromodibenzo[b,d]furan	161880-50-8	DTXSID90936607	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
2,3,4,6,7,8-Hexachlorodibenzo[b,d]furan	60851-34-5	DTXSID3052276	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
2,3,4,7,8-Pentabromodibenzofuran	131166-92-2	DTXSID5073870	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
2,3,4,7,8-Pentachlorodibenzofuran	57117-31-4	DTXSID7030066	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
2,3,4'-Trichlorobiphenyl	38444-85-8	DTXSID7091549	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,6-Trichlorobiphenyl	55702-45-9	DTXSID3073557	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3',6-Trichlorobiphenyl	38444-76-7	DTXSID9074143	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,3,7,8-Tetrabromodibenzofuran	67733-57-7	DTXSID6073605	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
2,3,7,8-Tetrabromodibenzo-p-dioxin	50585-41-6	DTXSID6073524	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9	DTXSID3052147	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	DTXSID2021315	P	-	F	-	-	-	-	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-
2,3-Dichlorobiphenyl	16605-91-7	DTXSID0073409	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4',5-Trichlorobiphenyl	16606-02-3	DTXSID9073410	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4,5-Trichlorophenol	95-95-4	DTXSID4024359	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4,6-Trinitro-1,3-dimethyl-5-tert-butylbenzene	81-15-2	DTXSID1021405	P	-	B	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4,6-Tris(tert-butyl)phenol	732-26-3	DTXSID2021311	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
2,4'-Dichlorobiphenyl	34883-43-7	DTXSID0022511	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,4-Dichlorophenol	120-83-2	DTXSID1020439	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
2,4-Dichlorophenoxyacetic acid	94-75-7	DTXSID0020442	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4-Di-tert-butylphenol	96-76-4	DTXSID2026602	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
2,4-Di-tert-pentylphenol	120-95-6	DTXSID9026974	P	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
2,6-Dichlorobiphenyl	33146-45-1	DTXSID7038313	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2,6-Di-tert-butylphenol	128-39-2	DTXSID6027052	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
2-Chlorobiphenyl	2051-60-7	DTXSID6040298	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
2-Chloronaphthalene	91-58-7	DTXSID8023971	P	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
2-Ethylhexyl diphenyl phosphate	1241-94-7	DTXSID1025300	P	-	I	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-	-	-	-	-	-
2H,2H,3H,3H-Perfluorooctanoic acid	914637-49-3	DTXSID20874028	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
2-Methylnaphthalene	91-57-6	DTXSID4020878	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-Henicosafluorododecyl 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl hydrogen phosphate	1158182-60-5	DTXSID60873414	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
3,3',4,4',5,5'-Hexachlorobiphenyl	32774-16-6	DTXSID2038314	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,3',4,4',5-Pentachlorobiphenyl	57465-28-8	DTXSID3032179	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,3',4,4'-Tetrachlorobiphenyl	32598-13-3	DTXSID5022514	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,3',5,5'-Tetrabromobisphenol A	79-94-7	DTXSID1026081	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
3,4,4',5-Tetrachlorobiphenyl	70362-50-4	DTXSID6074209	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,4,4'-Trichlorobiphenyl	38444-90-5	DTXSID00865914	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
3,4-Dihydroxybenzoic acid	99-50-3	DTXSID4021212	P	-	A.1	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Methylindole	83-34-1	DTXSID8021775	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
4-(1,1,3,3-Tetramethylbutyl)phenol	140-66-9	DTXSID9022360	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
4-(Butan-2-yl)-2,6-di-tert-butylphenol	17540-75-9	DTXSID8029315	P	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
4,4'-Dichlorocarbanilide	1219-99-4	DTXSID70153436	P	-	A.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4,4'-Methylenebis(2,6-di-t-butylphenol)	118-82-1	DTXSID7022411	P	-	B	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
4,4'-Thiobis(6-tert-butyl-m-cresol)	96-69-5	DTXSID4021341	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
4-Chloroaniline	106-47-8	DTXSID9020295	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Chlorobiphenyl	2051-62-9	DTXSID3040300	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
4-Dimethylaminoantipyrine	58-15-1	DTXSID7020504	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Epianhydrotetracycline	7518-17-4	DTXSID00873791	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Epichlortetracycline	14297-93-9	DTXSID60873792	P	-	A.1.1	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4-epi-Oxytetracycline	14206-58-7	DTXSID20873793	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Hydroxybenzoic acid	99-96-7	DTXSID3026647	P	-	A.1	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Nitrophenol	100-02-7	DTXSID0021834	P	-	A.1	Y	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Nonylphenol	104-40-5	DTXSID5033836	P	-	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	-	-
4-Nonylphenol, branched	84852-15-3	DTXSID5029055	P	Y	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
5-Aminosalicylic acid	89-57-6	DTXSID5024506	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6:2 Fluorotelomer phosphate diester	57677-95-9	DTXSID50561590	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-
6:2 Fluorotelomer sulfonic acid	27619-97-2	DTXSID6067331	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
6:2/8:2 Fluorotelomer phosphate diester	943913-15-3	DTXSID20873415	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-
7-Acetyl-1,1,3,4,4,6-hexamethyltetraline	21145-77-7	DTXSID7041544	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
8:2 Fluorotelomer phosphate diester	678-41-1	DTXSID90218051	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-
8:2 Fluorotelomer sulfonic acid	39108-34-4	DTXSID00192353	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Acetaminophen	103-90-2	DTXSID2020006	P	-	A.1	Y	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Acetone	67-64-1	DTXSID8021482	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Acetophenone	98-86-2	DTXSID6021828	P	-	A.1	Y	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Albuterol	18559-94-9	DTXSID5021255	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alprazolam	28981-97-7	DTXSID4022577	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aluminum	7429-90-5	DTXSID3040273	P	-	G	Y	-	-	-	Y	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-
Amitriptyline	50-48-6	DTXSID7022594	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amlodipine	88150-42-9	DTXSID7022596	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammelide	645-93-2	DTXSID10214757	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
Amoxicillin	26787-78-0	DTXSID3037044	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphetamine	300-62-9	DTXSID4022600	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ampicillin	69-53-4	DTXSID4022602	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Androsterone	53-41-8	DTXSID3036525	P	-	A.1	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Anhydrotetracycline	1665-56-1	DTXSID201016171	P	-	A.1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anthracene	120-12-7	DTXSID0023878	P	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Antimony	7440-36-0	DTXSID5023879	P	-	G	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Arsenic	7440-38-2	DTXSID4023886	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Aspirin	50-78-2	DTXSID5020108	P	-	A.1	Y	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Atenolol	29122-68-7	DTXSID2022628	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
Atorvastatin	134523-00-5	DTXSID8029868	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Azithromycin	83905-01-5	DTXSID8030760	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barium	7440-39-3	DTXSID8023894	P	-	G	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
BDE-196	446255-39-6	DTXSID3074789	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
BDE-197	117964-21-3	DTXSID9074775	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
BDE-207	437701-79-6	DTXSID30451985	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
Benz(a)anthracene	56-55-3	DTXSID5023902	P	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-
Benzene, 1,2,3,5-tetrabromo-4-(2,4,6-tribromophenoxy)-	117948-63-7	DTXSID50448655	P	-	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
Benzo(a)pyrene	50-32-8	DTXSID2020139	P	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Benzo(b)fluoranthene	205-99-2	DTXSID0023907	P	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Benzo(k)fluoranthene	207-08-9	DTXSID0023909	P	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Benzoic acid	65-85-0	DTXSID6020143	P	-	D	Y	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-		Y	-	-
Benzoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, 2,4-bis(1,1-dimethylethyl)phenyl ester	4221-80-1	DTXSID5063364	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
Benzoylecgonine	519-09-5	DTXSID7046758	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Benztropine	86-13-5	DTXSID9022659	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Benzyl 4-hydroxybenzoate	94-18-8	DTXSID9022526	P	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Beryllium	7440-41-7	DTXSID4023913	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
beta-Sitosterol	83-46-5	DTXSID5022481	P	-	A.1.3	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Bezafibrate	41859-67-0	DTXSID3029869	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bis(1,3-dichloropropan-2-yl) hydrogen phosphate	72236-72-7	DTXSID30992969	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
bis(1-Chloropropan-2-yl) hydrogen phosphate	789440-10-4	DTXSID90274172	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Bis(2-chloroethyl) phosphate	3040-56-0	DTXSID50184485	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Bis(2-ethylhexyl) phosphate	298-07-7	DTXSID1027134	P	-	I	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-	-	-	-	-	-
Bis(2-methylphenyl) hydrogen phosphate	35787-74-7	DTXSID70957173	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Boron	7440-42-8	DTXSID3023922	P	-	G	-	-	-	-	Y	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-
Butylated hydroxyanisole	25013-16-5	DTXSID7020215	P	Y	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Butylated hydroxytoluene	128-37-0	DTXSID2020216	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Butylparaben	94-26-8	DTXSID3020209	P	-	A.1	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Cadmium	7440-43-9	DTXSID1023940	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Calcium	7440-70-2	DTXSID9050484	P	-	G	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Campesterol	474-62-4	DTXSID801009891	P	-	A.1.3	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbamazepine	298-46-4	DTXSID4022731	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carbon tetrachloride	56-23-5	DTXSID8020250	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Cerium	7440-45-1	DTXSID0058641	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Cesium	7440-46-2	DTXSID5036767	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Chloroform	67-66-3	DTXSID1020306	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlortetracycline	57-62-5	DTXSID9022811	P	-	A.1.1	Y	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Cholestan-3-ol, (3.beta.,5.alpha.)-	80-97-7	DTXSID40883258	P	-	B	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cholesterol	57-88-5	DTXSID3022401	P	-	A.1.3	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromium	7440-47-3	DTXSID3031022	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Chrysene	218-01-9	DTXSID0022432	P	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Cimetidine	51481-61-9	DTXSID4020329	P	-	A.1	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ciprofloxacin	85721-33-1	DTXSID8022824	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clarithromycin	81103-11-9	DTXSID3022829	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clindamycin	18323-44-9	DTXSID2022836	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clofibric acid	882-09-7	DTXSID1040661	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clorophene	120-32-1	DTXSID5020154	P	-	D	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Clotrimazole	23593-75-1	DTXSID7029871	P	-	A.1.1	Y	-	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cobalt	7440-48-4	DTXSID1031040	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Cocaine	50-36-2	DTXSID2038443	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Codeine	76-57-3	DTXSID2020341	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copper	7440-50-8	DTXSID2023985	P	-	G	Y	-	-	-	Y	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-
Coprosterol	360-68-9	DTXSID1052036	P	-	A.1.3	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cotinine	486-56-6	DTXSID1047576	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cresyl diphenyl phosphate	26444-49-5	DTXSID3024861	P	Y	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Cyanuric acid	108-80-5	DTXSID7024873	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyclopenta[g]-2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethyl-	1222-05-5	DTXSID8027373	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyclophosphamide	50-18-0	DTXSID5020364	P	-	A.1	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Decachlorobiphenyl	2051-24-3	DTXSID4047541	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Decamethylcyclopentasiloxane	541-02-6	DTXSID1027184	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Dechlorane Plus	13560-89-9	DTXSID7027750	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
DEET	134-62-3	DTXSID2021995	P	-	D	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Demeclocycline	127-33-3	DTXSID1022893	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Desmosterol	313-04-2	DTXSID10878676	P	-	A.1.3	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Di(2-ethylhexyl) phthalate	117-81-7	DTXSID5020607	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Diazepam	439-14-5	DTXSID4020406	P	-	A.1	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Dibenzofuran, 1,2,3,4,6,7,8,9-octabromo-	103582-29-2	DTXSID90145919	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
Dibutyl phthalate	84-74-2	DTXSID2021781	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Dichlorobiphenyl	25512-42-9	DTXSID301026563	P	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Dichlorophen	97-23-4	DTXSID6021824	P	-	D	-	-	Y	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Diclofenac	15307-86-5	DTXSID6022923	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diethyl hydrogen phosphate	598-02-7	DTXSID1044699	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Digoxin	20830-75-5	DTXSID5022934	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diisobutyl hydrogen phosphate	6303-30-6	DTXSID30212316	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Dimethoate	60-51-5	DTXSID7020479	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Dimethyl 2,6-dimethyl-4-(2-nitrophenyl)-3,5-pyridinedicarboxylate	67035-22-7	DTXSID9052347	P	-	A.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dimethyl phthalate	131-11-3	DTXSID3022455	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Di-n-octyl phthalate	117-84-0	DTXSID1021956	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
Diphenhydramine	58-73-1	DTXSID4022949	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diphenyl phosphate	838-85-7	DTXSID1048207	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
D-Limonene	5989-27-5	DTXSID1020778	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Doxycycline	564-25-0	DTXSID0037653	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Endosulfan I	959-98-8	DTXSID9037539	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Endosulfan II	33213-65-9	DTXSID8037540	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Enrofloxacin	93106-60-6	DTXSID1045619	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Epitetracycline	79-85-6	DTXSID40873795	P	-	A.1.1	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Equilenin	517-09-9	DTXSID2052156	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Equilin	474-86-2	DTXSID7047433	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ERGOSTEROL	57-87-4	DTXSID90878679	P	-	A.1.3	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Erythromycin	114-07-8	DTXSID4022991	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Estradiol benzoate	50-50-0	DTXSID9022998	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Estriol	50-27-1	DTXSID9022366	P	-	A.1.3	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Estrone	53-16-7	DTXSID4022367	P	-	A.1.3	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ethanaminium, 2-hydroxy-N-(2-hydroxyethyl)-N,N-dimethyl-, esters with C16-18 and C18-unsatd. fatty acids, chlorides	1079184-43-2	DTXSID00108550	P	Y	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ethanol, 2-butoxy-, hydrogen phosphate	14260-97-0	DTXSID3065740	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Ethylbenzene	100-41-4	DTXSID3020596	P	-	B	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
Ethylene glycol nonylphenyl ether	27986-36-3	DTXSID9043809	P	Y	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ethylparaben	120-47-8	DTXSID9022528	P	-	A.1	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	Y	-	-	-
Fenofibric acid	42017-89-0	DTXSID8041030	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fenthion	55-38-9	DTXSID8020620	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Fipronil	120068-37-3	DTXSID4034609	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Fipronil amide	205650-69-7	DTXSID60873419	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Fipronil sulfide	120067-83-6	DTXSID50869644	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Fipronil sulfone	120068-36-2	DTXSID6074750	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Fipronil-desulfinyl	205650-65-3	DTXSID0043719	P	-	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Floxacillin	5250-39-5	DTXSID8023056	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoranthene	206-44-0	DTXSID3024104	P	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Fluoride	16984-48-8	DTXSID9049617	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	Y	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Fluoxetine	54910-89-3	DTXSID7023067	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Furosemide	54-31-9	DTXSID6020648	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gemfibrozil	25812-30-0	DTXSID0020652	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glybenclamide	10238-21-8	DTXSID0037237	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heptachlor epoxide B	1024-57-3	DTXSID1024126	P	-	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heptachlorobiphenyl	28655-71-2	DTXSID101026567	P	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Hexabromobenzene	87-82-1	DTXSID1024128	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
Hexachlorobiphenyl	26601-64-9	DTXSID001026564	P	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Hexanoic acid	142-62-1	DTXSID7021607	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Hydrocodone	125-29-1	DTXSID8023131	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ibuprofen	15687-27-1	DTXSID5020732	P	-	A.1	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Indole	120-72-9	DTXSID0020737	P	-	A.1	Y	-	-	-	Y	Y	-	-	-	-	-	-	-	Y	-	-	-	-	-
Iron	7439-89-6	DTXSID5043710	P	-	G	Y	-	-	-	Y	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-
Isochlortetracycline	514-53-4	DTXSID20873798	P	-	A.1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Isodecyl diphenyl phosphate	29761-21-5	DTXSID3025465	P	Y	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Ketoprofen	22071-15-4	DTXSID6020771	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lead	7439-92-1	DTXSID2024161	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Lincomycin	154-21-2	DTXSID3023215	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lomefloxacin	98079-51-7	DTXSID4040680	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Magnesium	7439-95-4	DTXSID0049658	P	-	G	Y	-	-	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Manganese	7439-96-5	DTXSID2024169	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
MDMA	42542-10-9	DTXSID90860791	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mefenamic acid	61-68-7	DTXSID5023243	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Melamine	108-78-1	DTXSID6020802	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-
Mercury	7439-97-6	DTXSID1024172	P	-	G	-	-	-	-	-	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-
Mestranol	72-33-3	DTXSID0020814	P	-	A.1.3	Y	-	-	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Metformin	657-24-9	DTXSID2023270	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
Methamphetamine	537-46-2	DTXSID8037128	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Methyl 3,4-dihydroxybenzoate	2150-43-8	DTXSID20301804	P	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
Methylparaben	99-76-3	DTXSID4022529	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	Y	-	-	-
Metoprolol	51384-51-1	DTXSID2023309	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Miconazole	22916-47-8	DTXSID6023319	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Minocycline	10118-90-8	DTXSID1045033	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Molybdenum	7439-98-7	DTXSID1024207	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Monochlorobiphenyl	27323-18-8	DTXSID401026566	P	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Monuron	150-68-5	DTXSID0020311	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Musk ketone	81-14-1	DTXSID6025690	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
m-Xylene	108-38-3	DTXSID6026298	P	-	B	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nadolol	42200-33-9	DTXSID3023342	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nalidixic acid	389-08-2	DTXSID3020912	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Naphthalene	91-20-3	DTXSID8020913	P	-	D	-	Y	-	-	-	Y	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Naproxen	22204-53-1	DTXSID4040686	P	-	A.1	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N-Desmethyldiltiazem	86408-45-9	DTXSID60873797	P	-	A.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel	7440-02-0	DTXSID2020925	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Nitrofen	1836-75-5	DTXSID7020970	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
N-Nitrosodibutylamine	924-16-3	DTXSID2021026	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
N-Nitrosodiethylamine	55-18-5	DTXSID2021028	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
N-Nitrosodimethylamine	62-75-9	DTXSID7021029	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
N-Nitrosodi-n-propylamine	621-64-7	DTXSID6021032	P	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
N-Nitrosodiphenylamine	86-30-6	DTXSID6021030	P	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
N-Nitrosopiperidine	100-75-4	DTXSID8021060	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
N-Nitrosopyrrolidine	930-55-2	DTXSID8021062	P	-	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
n-Nonylphenol	25154-52-3	DTXSID3021857	P	Y	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	-	-
n-Octylphenol	67554-50-1	DTXSID90897481	P	Y	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Nonachlorobiphenyl	53742-07-7	DTXSID001026176	P	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Norethindrone	68-22-4	DTXSID9023380	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Norfloxacin	70458-96-7	DTXSID7037680	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Norfluoxetine	83891-03-6	DTXSID80866540	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Norverapamil	67018-85-3	DTXSID80873799	P	-	A.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Octabromodibenzo-p-dioxin	2170-45-8	DTXSID70176089	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
Octachlorobiphenyl	55722-26-4	DTXSID801026568	P	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Octachlorodibenzofuran	39001-02-0	DTXSID3052062	P	-	E	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
Octachlorodibenzo-p-dioxin	3268-87-9	DTXSID4025799	P	-	F	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-
Ofloxacin	82419-36-1	DTXSID3041085	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ormetoprim	6981-18-6	DTXSID1046689	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxolinic acid	14698-29-4	DTXSID1021089	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxycodone	76-42-6	DTXSID5023407	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
o-Xylene	95-47-6	DTXSID3021807	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxytetracycline	79-57-2	DTXSID1034260	P	-	A.1.1	Y	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Paroxetine	61869-08-7	DTXSID3023425	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
PCB 045	70362-45-7	DTXSID9074779	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
PCB 131	61798-70-7	DTXSID8074780	P	-	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
p-Cresol	106-44-5	DTXSID7021869	P	-	A.1	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
Pentabromodiphenyl ether	32534-81-9	DTXSID2024246	P	Y	J	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-
Pentachloro-1,1'-biphenyl	25429-29-2	DTXSID10873621	P	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Pentachloronitrobenzene	82-68-8	DTXSID2021105	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Perfluorobutanesulfonic acid	375-73-5	DTXSID5030030	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorobutanoic acid	375-22-4	DTXSID4059916	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorodecanoic acid	335-76-2	DTXSID3031860	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorododecanoic acid	307-55-1	DTXSID8031861	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluoroheptanoic acid	375-85-9	DTXSID1037303	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorohexanesulfonic acid	355-46-4	DTXSID7040150	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorohexanoic acid	307-24-4	DTXSID3031862	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorononanoic acid	375-95-1	DTXSID8031863	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorooctanesulfonamide	754-91-6	DTXSID3038939	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorooctanesulfonic acid	1763-23-1	DTXSID3031864	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorooctanoic acid	335-67-1	DTXSID8031865	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluoropentanoic acid	2706-90-3	DTXSID6062599	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorotetradecanoic acid	376-06-7	DTXSID3059921	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluorotridecanoic acid	72629-94-8	DTXSID90868151	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Perfluoroundecanoic acid	2058-94-8	DTXSID8047553	P	-	H	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-
Phenazone	60-80-0	DTXSID6021117	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Phenol	108-95-2	DTXSID5021124	P	-	A.1.2	Y	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Phenol, 2,5-bis(1,1-dimethylethyl)-	5875-45-6	DTXSID0064046	P	-	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-
Phenol, 4,4',4"-(1-methyl-1-propanyl-3-ylidene)tris 2-(1,1-dimethylethyl)-5-methyl-	1843-03-4	DTXSID0038883	P	-	B	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
Phosphoric acid, 2,2-bis(chloromethyl)-1,3-propanediyl tetrakis(2-chloroethyl) ester	38051-10-4	DTXSID8028000	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
Phosphoric acid, dibutyl ester	107-66-4	DTXSID3040728	P	-	I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phosphoric acid, dipropyl ester	1804-93-9	DTXSID80883752	P	-	I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phosphoric acid, P,P'-[(1-methylethylidene) di-4,1-phenylene] P,P,P',P'-tetraphenyl ester	5945-33-5	DTXSID8052720	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-
Polycarbonates	25766-59-0	DTXSID201027532	P	Y	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polychlorinated biphenyls	1336-36-3	DTXSID5024267	P	Y	C	-	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-
Polyethylene glycol	25322-68-3	DTXSID4027862	P	Y	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	Y	Y	-	-
Polyethylene terephthalate	25038-59-9	DTXSID10872790	P	Y	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	Y	-	-	-	-
Progesterone	57-83-0	DTXSID3022370	P	-	A.1.3	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Promethazine	60-87-7	DTXSID7023518	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Propoxyphene	469-62-5	DTXSID1023524	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Propranolol	525-66-6	DTXSID6023525	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Propylparaben	94-13-3	DTXSID4022527	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	Y	-	-	-
p-Xylene	106-42-3	DTXSID2021868	P	-	B	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrene	129-00-0	DTXSID3024289	P	-	K	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-
Ranitidine	66357-35-5	DTXSID8045191	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
Roxithromycin	80214-83-1	DTXSID8041117	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rubidium	7440-17-7	DTXSID4064686	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Salicylic acid	69-72-7	DTXSID7026368	P	-	A.1.2	Y	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-		-	-	-
Sarafloxacin	98105-99-8	DTXSID8048494	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Selenium	7782-49-2	DTXSID9021261	P	-	G	-	-	-	-	-	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-
Sertraline	79617-96-2	DTXSID6023577	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silver	7440-22-4	DTXSID4024305	P	-	G	Y	Y	-	-	Y	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-
Sodium	7440-23-5	DTXSID1049774	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Stigmastan-3beta-ol	19466-47-8	DTXSID8051835	P	-	A.1.3	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stigmastanol	138126-65-5	DTXSID50860237	P	Y	A.1.3	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stigmasterol	83-48-7	DTXSID801015733	P	-	A.1.3	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
STK368415	5136-34-5	DTXSID30408651	P	-	A.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Styrene	100-42-5	DTXSID2021284	P	-	B	-	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Sulfachloropyridazine	80-32-0	DTXSID9045265	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfadiazine	68-35-9	DTXSID7044130	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfadimethoxine	122-11-2	DTXSID1023607	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfamerazine	127-79-7	DTXSID0023612	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfamethazine	57-68-1	DTXSID6021290	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfamethoxazole	723-46-6	DTXSID8026064	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfanilamide	63-74-1	DTXSID4023622	P	-	A.1.1	Y	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfasalazine	599-79-1	DTXSID0021256	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate	14808-79-8	DTXSID3042425	P	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y
Sulfathiazole	72-14-0	DTXSID8026068	P	-	A.1.1	Y	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfur	7704-34-9	DTXSID9034941	P	-	G	-	-	-	-	-	Y	-	-	-	Y	-	-	-	-	-	-	Y	-	-
Terephthalic acid	100-21-0	DTXSID6026080	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
tert-Butylphenyl diphenyl phosphate	56803-37-3	DTXSID6024701	P	Y	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Testosterone	58-22-0	DTXSID8022371	P	-	A.1.3	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetrabutyl ethylidenebisphenol	35958-30-6	DTXSID4038899	P	-	B	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetrachlorobiphenyl	26914-33-0	DTXSID701026565	P	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Tetrachloroethylene	127-18-4	DTXSID2021319	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetracycline	60-54-8	DTXSID7023645	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetraphenyl m-phenylene bis(phosphate)	57583-54-7	DTXSID8069197	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Thallium	7440-28-0	DTXSID2036035	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Thiabendazole	148-79-8	DTXSID0021337	P	-	D	Y	Y	Y	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Tin	7440-31-5	DTXSID1049801	P	-	G	-	-	-	-	Y	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Titanium	7440-32-6	DTXSID3047764	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Toluene	108-88-3	DTXSID7021360	P	-	A.1	Y	-	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Triamterene	396-01-0	DTXSID6021373	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tributyl phosphate	126-73-8	DTXSID3021986	P	-	I	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-	-	-	Y	-	-
Trichlorfon	52-68-6	DTXSID0021389	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichlorobiphenyl	25323-68-6	DTXSID601026562	P	Y	C	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-
Triclocarban	101-20-2	DTXSID4026214	P	-	A.1.2	-	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-
Triclosan	3380-34-5	DTXSID5032498	P	-	A.1.2	Y	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-		-	-	-
Triethyl phosphate	78-40-0	DTXSID8026228	P	-	D	Y	-	-	-	Y	Y	-	-	-	-	-	Y	-	-	-	-	-	-	-
Triethylene glycol bis(3-tert-butyl-4-hydroxy-5-methylphenyl)propionate	36443-68-2	DTXSID0044236	P	-	D	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	-	-
Triisobutyl phosphate	126-71-6	DTXSID8040698	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Trimethoprim	738-70-5	DTXSID3023712	P	-	A.1.1	Y	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trimethyl phosphate	512-56-1	DTXSID1021403	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-

Chemical	CAS number	DTXSID	New or previous	UVCB	CLASS[1]	A.1 Drugs/Metabolites	A.1.1 Antimicrobials	A.1.2 Antibiotics	A.1.3 Steroids/Sterols	B. Cosmetics (COSMOS)	C. Pesticides/Metabolites	D. PCBs	E. Dibenzofurans	F. Dioxins	G. Elements	H. PFAS	I. Phosphates	J. PBDEs	K. PAHs	L. Flame retardants	M. Surfactants	N. Extractables	O. Other Organics	P. Inorganic Anions
Trimethylsilanol	1066-40-6	DTXSID7061433	P	-	L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-
Triphenyl phosphate	115-86-6	DTXSID1021952	P	-	D	-	-	-	-	Y	Y	-	-	-	-	-	Y	-	-	-	-	Y	-	-
Tripropyl phosphate	513-08-6	DTXSID4052712	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Tris(1,3-dichloro-2-propyl) phosphate	13674-87-8	DTXSID9026261	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Tris(2-butoxyethyl) phosphate	78-51-3	DTXSID5021758	P	-	I	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-	-	-	-	-	-
Tris(2-chloroethyl) phosphate	115-96-8	DTXSID5021411	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Tris(2-chloroisopropyl)phosphate	13674-84-5	DTXSID5026259	P	-	I	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-	-	-	-	-	-
Tris(2-ethylhexyl) phosphate	78-42-2	DTXSID0021414	P	-	I	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-	-	-	-	-	-
Tris(4-tert-butylphenyl) phosphate	78-33-1	DTXSID3051466	P	-	I	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-
Tris(methylphenyl) phosphate	1330-78-5	DTXSID4021391	P	Y	I	-	-	-	-	-	Y	-	-	-	-	-	Y	-	-	-	-	-	-	-
Tylosin	1401-69-0	DTXSID3043996	P	-	A.1.1	Y	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Valsartan	137862-53-4	DTXSID6023735	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vanadium	7440-62-2	DTXSID2040282	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Virginiamycin	11006-76-1	DTXSID40880080	P	Y	A.1.1	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yttrium	7440-65-5	DTXSID0049816	P	-	G	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-
Zinc	7440-66-6	DTXSID7035012	P	-	G	Y	-	-	-	Y	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-
α-Dihydroequilin	651-55-8	DTXSID70873788	P	-	A.1	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Notes:
N = Newly identified chemical; P = Previously identified chemical; P* = Chemical identified during the curation process
[1]Classes:
A.1: DRUGS/METABOLITES (A.1.1: DRUGS/METABOLITES/ANTIBIOTICS; A.1.2: DRUGS/METABOLITES/ANTIMICROBIALS; A.1.3: DRUGS/METABOLITES/STEROLS); B: COSMETICS; C: PCBs; D: PESTICIDES/METABOLITES; E: DIBENZOFURANS; F: DIOXINS; G: ELEMENTS; H: PFAS; I: PHOSPHATE; J: PBDEs; K: PAHs; L: FLAME RETARDANTS; M: SURFACTANTS; N: EXTRACTABLES/ LEACHABLES; O: OTHER ORGANICS; P: INORGANIC ANIONS

Table B-3. Microbial Pollutants Identified in Biosolids

Microbial pollutant	When identified
Aerobic endospores	BR No.5 (2012–2013)
Aeromonas spp.	BR No.3 (2008–2009)
Antibiotic-resistant bacteria (ARB) or Antibiotic-resistant genes (ARG)	BR No.5 (2012–2013)
Clostridia spp.	BR No.2 (2006–2007)
Clostridium perfringens	BR No.8 (2018–2019)
Coronavirus HKU1	BR No.5 (2012–2013)
Cosavirus	BR No.5 (2012–2013)
Cryptosporidium parvum	BR No.2 (2006–2007)
Endotoxin	BR No.2 (2006–2007)
Enterovirus	BR No.3 (2008–2009)
Enterococcus spp.	BR No.8 (2018–2019)
Escherichia coli	BR No.3 (2008–2009)
Fecal coliforms	BR No.8 (2018–2019)
Giardia spp.	BR No.3 (2008–2009)
Human adenoviruses	BR No.3 (2008–2009)
Human norovirus	BR No.5 (2012–2013)
Human polyomaviruses	BR No.4 (2010–2011)
Klassevirus	BR No.5 (2012–2013)
Listeria spp.	BR No.3 (2008–2009)
Salmonella spp.	BR No.2 (2006–2007)
Total coliforms	BR No.8 (2018–2019)
Yersinia spp.	BR No.8 (2018–2019)
SARS COV2	BR No.9 (2020–2021)

Notes:
BR = Biennial Report

Appendix C: Concentrations of Chemicals Found in Biosolids

Table C-1. Concentrations of Newly and Previously Identified Chemicals in Biosolids for the 2020–2021 Biennial Review

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
2-(N-Ethylperfluorooctanesulfonamido) acetic acid	2991-50-6	New	Class B	7/16/2020	ND	µg/kg	Individual	Pepper et al. 2021
2-(N-Ethylperfluorooctanesulfonamido) acetic acid	2991-50-6	New	Class B	7/16/2020	ND	µg/kg	Individual	Pepper et al. 2021
2-(N-Ethylperfluorooctanesulfonamido) acetic acid	2991-50-6	New	Class B	7/27/2020	ND	µg/kg	Individual	Pepper et al. 2021
2-(N-Ethylperfluorooctanesulfonamido) acetic acid	2991-50-6	New	Class B	7/27/2020	11	µg/kg	Individual	Pepper et al. 2021
2-(N-Methylperfluorooctanesulfonamido) acetic acid	2355-31-9	New	Class B	7/16/2020	21	µg/kg	Individual	Pepper et al. 2021
2-(N-Methylperfluorooctanesulfonamido) acetic acid	2355-31-9	New	Class B	7/16/2020	22	µg/kg	Individual	Pepper et al. 2021
2-(N-Methylperfluorooctanesulfonamido) acetic acid	2355-31-9	New	Class B	7/27/2020	23	µg/kg	Individual	Pepper et al. 2021
2-(N-Methylperfluorooctanesulfonamido) acetic acid	2355-31-9	New	Class B	7/27/2020	18	µg/kg	Individual	Pepper et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/19/2020	37.388	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/20/2020	1.061	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/20/2020	2.876	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/21/2020	0.666	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/22/2020	2.419	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/23/2020	2.187	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/24/2020	1.713	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/25/2020	0	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/26/2020	2.099	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/28/2020	183.01	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/28/2020	9.323	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/29/2020	4.423	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
alpha-Solanine	20562-02-1	New	Primary sludge	3/30/2020	5.975	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	3/31/2020	0.688	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/1/2020	0.547	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/2/2020	4.163	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/3/2020	2.378	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/4/2020	1.931	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/4/2020	3.252	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/5/2020	0	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/6/2020	3.612	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/7/2020	1.284	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/9/2020	0.539	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/10/2020	8.771	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/11/2020	8.273	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/12/2020	1.962	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/13/2020	0.992	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/14/2020	2.593	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/15/2020	0	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	4/15/2020	0	ng/mL	Individual	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	March-April 2020	0.791	ng/mL	Composite	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	March-April 2020	1.498	ng/mL	Composite	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	March-April 2020	4.571	ng/mL	Composite	Nason et al. 2021
alpha-Solanine	20562-02-1	New	Primary sludge	March-April 2020	7.085	ng/mL	Composite	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/19/2020	22.711	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/20/2020	18.525	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/20/2020	17.656	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/21/2020	10.044	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/22/2020	20.608	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Berberine	2086-83-1	New	Primary sludge	3/23/2020	15.524	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/24/2020	23.986	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/25/2020	10.737	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/26/2020	14.89	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/28/2020	20.769	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/28/2020	21.017	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/29/2020	27.874	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/30/2020	16.859	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	3/31/2020	13.086	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/1/2020	18.197	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/2/2020	19.233	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/3/2020	20.209	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/4/2020	18.977	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/4/2020	25.221	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/5/2020	20.529	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/6/2020	21.784	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/7/2020	19.313	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/9/2020	17.22	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/10/2020	18.815	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/11/2020	16.572	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/12/2020	20.967	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/13/2020	23.526	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/14/2020	25.901	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/15/2020	16.514	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	4/15/2020	21.719	ng/mL	Individual	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	March-April 2020	12.57	ng/mL	Composite	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	March-April 2020	11.859	ng/mL	Composite	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Berberine	2086-83-1	New	Primary sludge	March-April 2020	14.817	ng/mL	Composite	Nason et al. 2021
Berberine	2086-83-1	New	Primary sludge	March-April 2020	16.751	ng/mL	Composite	Nason et al. 2021
Bromide	24959-67-9	New	Not specified	June 2016-Sep 2017	1.215	mg/L	Mean	Onchoke et al. 2018
Bromide	24959-67-9	New	Not specified	June 2016-Sep 2017	1.22	mg/L	Mean	Onchoke et al. 2018
Doxepin	1668-19-5	New	Primary sludge	3/19/2020	0.415	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/20/2020	0.325	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/20/2020	0.262	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/21/2020	0.099	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/22/2020	0.213	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/23/2020	0.177	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/24/2020	0.253	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/25/2020	0.114	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/26/2020	0.237	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/28/2020	0.54	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/28/2020	0.483	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/29/2020	0.234	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/30/2020	0.2	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	3/31/2020	0.082	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/1/2020	0.162	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/2/2020	0.189	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/3/2020	0.218	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/4/2020	0.258	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/4/2020	0.286	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/5/2020	0.249	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/6/2020	0.242	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Doxepin	1668-19-5	New	Primary sludge	4/7/2020	0.207	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/9/2020	0.223	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/10/2020	0.235	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/11/2020	0.21	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/12/2020	0.244	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/13/2020	0.273	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/14/2020	0.55	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/15/2020	0.211	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	4/15/2020	0.219	ng/mL	Individual	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	March-April 2020	0.194	ng/mL	Composite	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	March-April 2020	0.182	ng/mL	Composite	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	March-April 2020	0.217	ng/mL	Composite	Nason et al. 2021
Doxepin	1668-19-5	New	Primary sludge	March-April 2020	0.272	ng/mL	Composite	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/19/2020	0.257	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/20/2020	0.152	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/20/2020	0.136	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/21/2020	0.067	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/22/2020	0.16	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/23/2020	0.146	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/24/2020	0.231	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/25/2020	0.058	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/26/2020	0.095	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/28/2020	0.135	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/28/2020	0.138	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/29/2020	0.16	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/30/2020	0.113	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	3/31/2020	0.041	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Fentanyl	437-38-7	New	Primary sludge	4/1/2020	0.082	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/2/2020	0.105	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/3/2020	0.123	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/4/2020	0.139	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/4/2020	0.194	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/5/2020	0.168	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/6/2020	0.146	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/7/2020	0.182	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/9/2020	0.139	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/10/2020	0.192	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/11/2020	0.117	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/12/2020	0.163	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/13/2020	0.147	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/14/2020	0.33	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/15/2020	0.16	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	4/15/2020	0.188	ng/mL	Individual	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	March-April 2020	0.129	ng/mL	Composite	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	March-April 2020	0.122	ng/mL	Composite	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	March-April 2020	0.151	ng/mL	Composite	Nason et al. 2021
Fentanyl	437-38-7	New	Primary sludge	March-April 2020	0.188	ng/mL	Composite	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/19/2020	0.368	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/20/2020	0.287	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/20/2020	0.284	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/21/2020	0.306	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/22/2020	0.335	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/23/2020	0.328	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/24/2020	0.33	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Hydromorphone	466-99-9	New	Primary sludge	3/25/2020	0.305	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/26/2020	0.266	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/28/2020	0.267	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/28/2020	0.269	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/29/2020	0.309	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/30/2020	0.292	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	3/31/2020	0.286	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/1/2020	0.291	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/2/2020	0.295	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/3/2020	0.307	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/4/2020	0.299	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/4/2020	0.354	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/5/2020	0.316	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/6/2020	0.341	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/7/2020	0.305	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/9/2020	0.277	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/10/2020	0.302	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/11/2020	0.276	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/12/2020	0.307	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/13/2020	0.298	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/14/2020	0.3	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/15/2020	0.254	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	4/15/2020	0.249	ng/mL	Individual	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	March-April 2020	0.281	ng/mL	Composite	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	March-April 2020	0.263	ng/mL	Composite	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	March-April 2020	0.278	ng/mL	Composite	Nason et al. 2021
Hydromorphone	466-99-9	New	Primary sludge	March-April 2020	0.286	ng/mL	Composite	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Hydroxychloroquine	118-42-3	New	Primary sludge	3/19/2020	30.796	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/20/2020	37.407	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/20/2020	33.741	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/21/2020	10.273	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/22/2020	29.799	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/23/2020	27.863	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/24/2020	43.383	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/25/2020	8.403	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/26/2020	22.01	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/28/2020	25.729	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/28/2020	36.126	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/29/2020	39.686	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/30/2020	16.941	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	3/31/2020	6.858	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/1/2020	12.41	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/2/2020	30.491	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/3/2020	31.381	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/4/2020	34.172	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/4/2020	67.631	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/5/2020	51.209	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/6/2020	47.208	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/7/2020	46.945	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/9/2020	29.132	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/10/2020	35.313	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/11/2020	29.198	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/12/2020	42.572	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/13/2020	36.051	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Hydroxychloroquine	118-42-3	New	Primary sludge	4/14/2020	23.209	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/15/2020	19.582	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	4/15/2020	27.472	ng/mL	Individual	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	March-April 2020	13.415	ng/mL	Composite	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	March-April 2020	14.474	ng/mL	Composite	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	March-April 2020	25.18	ng/mL	Composite	Nason et al. 2021
Hydroxychloroquine	118-42-3	New	Primary sludge	March-April 2020	24.224	ng/mL	Composite	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/19/2020	2.268	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/20/2020	1.682	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/20/2020	1.934	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/21/2020	1.264	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/22/2020	2.111	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/23/2020	1.546	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/24/2020	1.47	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/25/2020	1.378	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/26/2020	1.52	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/28/2020	1.552	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/28/2020	1.425	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/29/2020	1.511	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/30/2020	1.412	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	3/31/2020	1.051	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/1/2020	1.367	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/2/2020	1.387	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/3/2020	1.326	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/4/2020	1.352	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/4/2020	2.01	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/5/2020	1.55	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Levorphanol	77-07-6	New	Primary sludge	4/6/2020	1.505	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/7/2020	1.206	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/9/2020	1.192	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/10/2020	1.308	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/11/2020	1.084	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/12/2020	1.153	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/13/2020	1.077	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/14/2020	1.585	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/15/2020	0.877	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	4/15/2020	1.02	ng/mL	Individual	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	March-April 2020	1.413	ng/mL	Composite	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	March-April 2020	1.1	ng/mL	Composite	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	March-April 2020	1.194	ng/mL	Composite	Nason et al. 2021
Levorphanol	77-07-6	New	Primary sludge	March-April 2020	1.149	ng/mL	Composite	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/19/2020	17.447	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/20/2020	2.844	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/20/2020	3.105	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/21/2020	1.655	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/22/2020	3.505	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/23/2020	2.448	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/24/2020	3.611	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/25/2020	1.923	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/26/2020	2.957	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/28/2020	4.257	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/28/2020	4.732	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/29/2020	3.056	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	3/30/2020	7.758	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Losartan	114798-26-4	New	Primary sludge	3/31/2020	1.914	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/1/2020	2.365	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/2/2020	3.109	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/3/2020	3.627	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/4/2020	3.135	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/4/2020	5.624	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/5/2020	4.674	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/6/2020	4.273	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/7/2020	5.174	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/9/2020	2.986	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/10/2020	3.759	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/11/2020	4.806	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/12/2020	4.412	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/13/2020	3.822	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/14/2020	3.136	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/15/2020	2.288	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	4/15/2020	3.238	ng/mL	Individual	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	March-April 2020	2.927	ng/mL	Composite	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	March-April 2020	1.959	ng/mL	Composite	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	March-April 2020	2.984	ng/mL	Composite	Nason et al. 2021
Losartan	114798-26-4	New	Primary sludge	March-April 2020	2.58	ng/mL	Composite	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/19/2020	0.852	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/20/2020	0.686	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/20/2020	0.726	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/21/2020	0.442	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/22/2020	0.745	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/23/2020	0.667	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Methadone	76-99-3	New	Primary sludge	3/24/2020	0.613	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/25/2020	0.497	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/26/2020	0.572	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/28/2020	0.654	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/28/2020	0.604	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/29/2020	0.561	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/30/2020	0.559	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	3/31/2020	0.504	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/1/2020	0.62	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/2/2020	0.685	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/3/2020	0.84	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/4/2020	0.584	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/4/2020	0.661	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/5/2020	0.754	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/6/2020	0.669	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/7/2020	0.722	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/9/2020	0.708	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/10/2020	0.569	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/11/2020	0.53	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/12/2020	0.706	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/13/2020	0.55	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/14/2020	0.88	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/15/2020	0.474	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	4/15/2020	0.532	ng/mL	Individual	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	March-April 2020	0.584	ng/mL	Composite	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	March-April 2020	0.544	ng/mL	Composite	Nason et al. 2021
Methadone	76-99-3	New	Primary sludge	March-April 2020	0.629	ng/mL	Composite	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Methadone	76-99-3	New	Primary sludge	March-April 2020	0.662	ng/mL	Composite	Nason et al. 2021
Perfluorohexadecanoic acid	67905-19-5	New	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Heat-treated granular biosolids	2014	1.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Heat-treated granular biosolids	2014	1.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Heat-treated granular biosolids	2016	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Heat-treated granular biosolids	2018	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Biosolids blended with sawdust, bark	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Composted biosolids with woodchips	2014	0.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Composted biosolids with woodchips	2014	0.8	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Composted biosolids with municipal solid waste	2014	0.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Composted biosolids with residential yard trimmings	2014	1.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexadecanoic acid	67905-19-5	New	Composted biosolids with plant materials	2014	0.5	µg/kg	Individual	Lazcano et al. 2020
Bisphenol A	80-05-7	Previous*	Biosolids	2009-2013	1300	ng/g dw	Median	Gewurtz et al. 2021
Bisphenol A	80-05-7	Previous*	Biosolids	2009-2013	520	ng/g dw	Median	Gewurtz et al. 2021
Bisphenol A	80-05-7	Previous*	Biosolids	2009-2013	100	ng/g dw	Median	Gewurtz et al. 2021
Perfluorodecanesulfonic acid	335-77-3	Previous*	Heat-treated granular biosolids	2014	3.2	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Heat-treated granular biosolids	2014	0.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Heat-treated granular biosolids	2014	1.8	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Heat-treated granular biosolids	2016	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Heat-treated granular biosolids	2018	<LOQ	µg/kg	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorodecanesulfonic acid	335-77-3	Previous*	Heat-treated granular biosolids	2014	2.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Biosolids blended with sawdust, bark	2014	0.67	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Composted biosolids with woodchips	2014	1.87	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Composted biosolids with woodchips	2014	2.8	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Composted biosolids with municipal solid waste	2014	0.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Composted biosolids with residential yard trimmings	2014	0.2	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanesulfonic acid	335-77-3	Previous*	Composted biosolids with plant materials	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Products that met Class A requirements for *E. coli* content mixed with sludge/biosolids from other facilities	2014-2016	3.1	kg/dry kg	Median	Archer et al. 2020
Potassium	7440-09-7	Previous*	Products that met Class A requirements for *E. coli* content mixed with sludge/biosolids from other facilities	2014-2016	0.9 - 6.0	kg/dry kg	Range	Archer et al. 2020
Potassium	7440-09-7	Previous*	Heat-treated granular biosolids	2014	339	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Heat-treated granular biosolids	2014	2819	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Heat-treated granular biosolids	2014	1495	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Heat-treated granular biosolids	2016	1062	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Heat-treated granular biosolids	2018	2154	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Heat-treated granular biosolids	2014	599	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Heat-treated granular biosolids	2014	9776	ppm	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Potassium	7440-09-7	Previous*	Biosolids blended with sawdust, bark	2014	486	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Composted biosolids with woodchips	2014	1469	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Composted biosolids with woodchips	2014	1271	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Composted biosolids with municipal solid waste	2014	1032	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Composted biosolids with residential yard trimmings	2014	1647	ppm	Individual	Lazcano et al. 2020
Potassium	7440-09-7	Previous*	Composted biosolids with plant materials	2014	1977	ppm	Individual	Lazcano et al. 2020
Azithromycin	83905-01-5	Previous	Class A	Not specified	0.06	mg/kg dw	Individual	Sidhu et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/19/2020	8.849	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/20/2020	6.561	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/20/2020	4.46	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/21/2020	3.056	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/22/2020	4.814	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/23/2020	7.176	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/24/2020	11.016	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/25/2020	1.353	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/26/2020	3.85	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/28/2020	7.426	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/28/2020	5.723	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/29/2020	5.364	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/30/2020	2.683	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	3/31/2020	2.394	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/1/2020	2.587	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Azithromycin	83905-01-5	Previous	Primary sludge	4/2/2020	3.473	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/3/2020	3.796	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/4/2020	4.449	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/4/2020	7.537	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/5/2020	6.806	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/6/2020	8.042	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/7/2020	7.905	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/9/2020	3.319	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/10/2020	21.276	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/11/2020	4.101	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/12/2020	5.899	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/13/2020	4.739	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/14/2020	9.677	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/15/2020	2.196	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	4/15/2020	4.042	ng/mL	Individual	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	March-April 2020	3.553	ng/mL	Composite	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	March-April 2020	2.86	ng/mL	Composite	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	March-April 2020	4.451	ng/mL	Composite	Nason et al. 2021
Azithromycin	83905-01-5	Previous	Primary sludge	March-April 2020	4.129	ng/mL	Composite	Nason et al. 2021
Carbamazepine	298-46-4	Previous	Class B	Not specified	100	µg/kg	Max[a]	Liu et al. 2021
Ciprofloxacin	85721-33-1	Previous	Primary sludge	Not specified	1835	ng/g dw	Mean	Li et al. 2021
Ciprofloxacin	85721-33-1	Previous	Class A	Not specified	1	mg/kg dw	Individual	Sidhu et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/19/2020	2.014	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/20/2020	0.882	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/20/2020	1.485	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/21/2020	0.833	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/22/2020	0.779	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Cocaine	50-36-2	Previous	Primary sludge	3/23/2020	0.62	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/24/2020	1.162	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/25/2020	0.565	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/26/2020	0.65	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/28/2020	0.735	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/28/2020	0.681	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/29/2020	0.857	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/30/2020	0.676	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	3/31/2020	0.546	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/1/2020	0.654	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/2/2020	0.8	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/3/2020	0.711	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/4/2020	0.681	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/4/2020	0.876	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/5/2020	0.946	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/6/2020	0.872	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/7/2020	0.583	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/9/2020	0.686	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/10/2020	1.156	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/11/2020	0.877	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/12/2020	0.727	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/13/2020	0.684	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/14/2020	1.423	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/15/2020	0.459	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	4/15/2020	0.524	ng/mL	Individual	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	March-April 2020	0.826	ng/mL	Composite	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	March-April 2020	0.53	ng/mL	Composite	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Cocaine	50-36-2	Previous	Primary sludge	March-April 2020	0.714	ng/mL	Composite	Nason et al. 2021
Cocaine	50-36-2	Previous	Primary sludge	March-April 2020	0.944	ng/mL	Composite	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/19/2020	0.167	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/20/2020	0.122	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/20/2020	0.074	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/21/2020	0.1	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/22/2020	0.097	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/23/2020	0.232	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/24/2020	0.118	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/25/2020	0.097	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/26/2020	0.088	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/28/2020	0.074	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/28/2020	0.094	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/29/2020	0.105	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/30/2020	0.069	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	3/31/2020	0.076	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/1/2020	0.097	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/2/2020	0.083	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/3/2020	0.08	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/4/2020	0.096	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/4/2020	0.138	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/5/2020	0.098	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/6/2020	0.109	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/7/2020	0.094	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/9/2020	0.078	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/10/2020	0.097	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/11/2020	0.098	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Codeine	76-57-3	Previous	Primary sludge	4/12/2020	0.116	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/13/2020	0.087	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/14/2020	0.093	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/15/2020	0.1	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	4/15/2020	0.143	ng/mL	Individual	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	March-April 2020	0.084	ng/mL	Composite	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	March-April 2020	0.086	ng/mL	Composite	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	March-April 2020	0.076	ng/mL	Composite	Nason et al. 2021
Codeine	76-57-3	Previous	Primary sludge	March-April 2020	0.099	ng/mL	Composite	Nason et al. 2021
Gemfibrozil	25812-30-0	Previous	Class B	Not specified	2	µg/kg	Max[a]	Liu et al. 2021
Ibuprofen	15687-27-1	Previous	Class B	Not specified	140	µg/kg	Max[a]	Liu et al. 2021
Iron	7439-89-6	Previous	Not specified	Not specified	22,000	mg/kg	Not specified	Adesanya et al. 2021
Magnesium	7439-95-4	Previous	Heat-treated granular biosolids	2014	550	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Heat-treated granular biosolids	2014	1260	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Heat-treated granular biosolids	2014	905	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Heat-treated granular biosolids	2016	780	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Heat-treated granular biosolids	2018	1210	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Heat-treated granular biosolids	2014	1175	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Heat-treated granular biosolids	2014	1055	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Biosolids blended with sawdust, bark	2014	430	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Composted biosolids with woodchips	2014	1145	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Composted biosolids with woodchips	2014	980	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Composted biosolids with municipal solid waste	2014	320	ppm	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Magnesium	7439-95-4	Previous	Composted biosolids with residential yard trimmings	2014	1235	ppm	Individual	Lazcano et al. 2020
Magnesium	7439-95-4	Previous	Composted biosolids with plant materials	2014	1020	ppm	Individual	Lazcano et al. 2020
Manganese	7439-96-5	Previous	Not specified	Not specified	500	mg/kg	Not specified	Adesanya et al. 2021
Miconazole	22916-47-8	Previous	Primary sludge	Not specified	10382	ng/g	Mean	Li et al. 2021
Naproxen	22204-53-1	Previous	Class B	Not specified	25	µg/kg	Max[a]	Liu et al. 2021
Ofloxacin	82419-36-1	Previous	Primary sludge	Not specified	148	ng/g	Mean	Li et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/19/2020	0.114	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/20/2020	0.108	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/20/2020	0.092	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/21/2020	0.092	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/22/2020	0.076	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/23/2020	0.097	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/24/2020	0.099	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/25/2020	0.079	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/26/2020	0.083	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/28/2020	0.067	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/28/2020	0.073	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/29/2020	0.091	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/30/2020	0.074	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	3/31/2020	0.074	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/1/2020	0.084	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/2/2020	0.078	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/3/2020	0.081	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/4/2020	0.088	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/4/2020	0.093	ng/mL	Individual	Nason et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Oxycodone	76-42-6	Previous	Primary sludge	4/5/2020	0.073	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/6/2020	0.102	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/7/2020	0.087	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/9/2020	0.071	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/10/2020	0.134	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/11/2020	0.078	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/12/2020	0.108	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/13/2020	0.098	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/14/2020	0.092	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/15/2020	0.083	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	4/15/2020	0.081	ng/mL	Individual	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	March-April 2020	0.071	ng/mL	Composite	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	March-April 2020	0.095	ng/mL	Composite	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	March-April 2020	0.093	ng/mL	Composite	Nason et al. 2021
Oxycodone	76-42-6	Previous	Primary sludge	March-April 2020	0.103	ng/mL	Composite	Nason et al. 2021
Perfluorobutanesulfonic acid	375-73-5	Previous	Class B	7/16/2020	1.9	µg/kg	Individual	Pepper et al. 2021
Perfluorobutanesulfonic acid	375-73-5	Previous	Class B	7/16/2020	1.4	µg/kg	Individual	Pepper et al. 2021
Perfluorobutanesulfonic acid	375-73-5	Previous	Class B	7/27/2020	6.5	µg/kg	Individual	Pepper et al. 2021
Perfluorobutanesulfonic acid	375-73-5	Previous	Class B	7/27/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorobutanesulfonic acid	375-73-5	Previous	Heat-treated granular biosolids	2014	1.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Heat-treated granular biosolids	2014	3	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Heat-treated granular biosolids	2014	0.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Heat-treated granular biosolids	2016	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Heat-treated granular biosolids	2018	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Heat-treated granular biosolids	2014	2.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Heat-treated granular biosolids	2014	0.5	µg/kg	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorobutanesulfonic acid	375-73-5	Previous	Biosolids blended with sawdust, bark	2014	4.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Composted biosolids with woodchips	2014	41.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Composted biosolids with woodchips	2014	19.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Composted biosolids with municipal solid waste	2014	3.8	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Composted biosolids with residential yard trimmings	2014	38.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanesulfonic acid	375-73-5	Previous	Composted biosolids with plant materials	2014	33.2	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Heat-treated granular biosolids	2014	0.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Heat-treated granular biosolids	2014	0.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Heat-treated granular biosolids	2014	3.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Heat-treated granular biosolids	2016	2.8	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Heat-treated granular biosolids	2018	2.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Heat-treated granular biosolids	2014	0.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Heat-treated granular biosolids	2014	0.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Biosolids blended with sawdust, bark	2014	1.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Composted biosolids with woodchips	2014	6.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Composted biosolids with woodchips	2014	3.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Composted biosolids with municipal solid waste	2014	3.2	µg/kg	Individual	Lazcano et al. 2020
Perfluorobutanoic acid	375-22-4	Previous	Composted biosolids with residential yard trimmings	2014	5.2	µg/kg	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorobutanoic acid	375-22-4	Previous	Composted biosolids with plant materials	2014	3.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Class B	7/16/2020	12	µg/kg	Individual	Pepper et al. 2021
Perfluorodecanoic acid	335-76-2	Previous	Class B	7/16/2020	13	µg/kg	Individual	Pepper et al. 2021
Perfluorodecanoic acid	335-76-2	Previous	Class B	7/27/2020	12	µg/kg	Individual	Pepper et al. 2021
Perfluorodecanoic acid	335-76-2	Previous	Class B	7/27/2020	12	µg/kg	Individual	Pepper et al. 2021
Perfluorodecanoic acid	335-76-2	Previous	Heat-treated granular biosolids	2014	1.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Heat-treated granular biosolids	2014	14.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Heat-treated granular biosolids	2014	5.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Heat-treated granular biosolids	2016	2.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Heat-treated granular biosolids	2018	2.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Heat-treated granular biosolids	2014	5.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Heat-treated granular biosolids	2014	1.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Biosolids blended with sawdust, bark	2014	4.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Composted biosolids with woodchips	2014	20.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Composted biosolids with woodchips	2014	11.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Composted biosolids with municipal solid waste	2014	2.2	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Composted biosolids with residential yard trimmings	2014	9.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorodecanoic acid	335-76-2	Previous	Composted biosolids with plant materials	2014	11.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Class B	7/16/2020	8	µg/kg	Individual	Pepper et al. 2021
Perfluorododecanoic acid	307-55-1	Previous	Class B	7/16/2020	7.3	µg/kg	Individual	Pepper et al. 2021
Perfluorododecanoic acid	307-55-1	Previous	Class B	7/27/2020	7.4	µg/kg	Individual	Pepper et al. 2021
Perfluorododecanoic acid	307-55-1	Previous	Class B	7/27/2020	6.5	µg/kg	Individual	Pepper et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorododecanoic acid	307-55-1	Previous	Heat-treated granular biosolids	2014	1.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Heat-treated granular biosolids	2014	7.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Heat-treated granular biosolids	2014	4.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Heat-treated granular biosolids	2016	1.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Heat-treated granular biosolids	2018	1.42	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Heat-treated granular biosolids	2014	3.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Heat-treated granular biosolids	2014	1.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Biosolids blended with sawdust, bark	2014	1.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Composted biosolids with woodchips	2014	7.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Composted biosolids with woodchips	2014	4.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Composted biosolids with municipal solid waste	2014	1	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Composted biosolids with residential yard trimmings	2014	6.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorododecanoic acid	307-55-1	Previous	Composted biosolids with plant materials	2014	4.8	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Class B	7/16/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluoroheptanoic acid	375-85-9	Previous	Class B	7/16/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluoroheptanoic acid	375-85-9	Previous	Class B	7/27/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluoroheptanoic acid	375-85-9	Previous	Class B	7/27/2020	0.15 J	µg/kg	Individual	Pepper et al. 2021
Perfluoroheptanoic acid	375-85-9	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Heat-treated granular biosolids	2016	3.75	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Heat-treated granular biosolids	2018	3.02	µg/kg	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluoroheptanoic acid	375-85-9	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Biosolids blended with sawdust, bark	2014	0.4	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Composted biosolids with woodchips	2014	6.5	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Composted biosolids with woodchips	2014	5.3	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Composted biosolids with municipal solid waste	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Composted biosolids with residential yard trimmings	2014	4.4	µg/kg	Individual	Lazcano et al. 2020
Perfluoroheptanoic acid	375-85-9	Previous	Composted biosolids with plant materials	2014	4.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Class B	7/16/2020	3.7	µg/kg	Individual	Pepper et al. 2021
Perfluorohexanesulfonic acid	355-46-4	Previous	Class B	7/16/2020	3.5	µg/kg	Individual	Pepper et al. 2021
Perfluorohexanesulfonic acid	355-46-4	Previous	Class B	7/27/2020	15	µg/kg	Individual	Pepper et al. 2021
Perfluorohexanesulfonic acid	355-46-4	Previous	Class B	7/27/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorohexanesulfonic acid	355-46-4	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Heat-treated granular biosolids	2014	0.42	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Heat-treated granular biosolids	2016	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Heat-treated granular biosolids	2018	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Biosolids blended with sawdust, bark	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Composted biosolids with woodchips	2014	1.9	µg/kg	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorohexanesulfonic acid	355-46-4	Previous	Composted biosolids with woodchips	2014	0.45	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Composted biosolids with municipal solid waste	2014	0.82	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Composted biosolids with residential yard trimmings	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanesulfonic acid	355-46-4	Previous	Composted biosolids with plant materials	2014	0.47	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Class B	7/16/2020	4.2	µg/kg	Individual	Pepper et al. 2021
Perfluorohexanoic acid	307-24-4	Previous	Class B	7/16/2020	4	µg/kg	Individual	Pepper et al. 2021
Perfluorohexanoic acid	307-24-4	Previous	Class B	7/27/2020	4.1	µg/kg	Individual	Pepper et al. 2021
Perfluorohexanoic acid	307-24-4	Previous	Class B	7/27/2020	2	µg/kg	Individual	Pepper et al. 2021
Perfluorohexanoic acid	307-24-4	Previous	Heat-treated granular biosolids	2014	2.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Heat-treated granular biosolids	2014	3.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Heat-treated granular biosolids	2014	61	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Heat-treated granular biosolids	2016	53.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Heat-treated granular biosolids	2018	41.63	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Heat-treated granular biosolids	2014	3.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Heat-treated granular biosolids	2014	0.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Biosolids blended with sawdust, bark	2014	8.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Composted biosolids with woodchips	2014	33	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Composted biosolids with woodchips	2014	17.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Composted biosolids with municipal solid waste	2014	6.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorohexanoic acid	307-24-4	Previous	Composted biosolids with residential yard trimmings	2014	21.5	µg/kg	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorohexanoic acid	307-24-4	Previous	Composted biosolids with plant materials	2014	11.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Class B	7/16/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorononanoic acid	375-95-1	Previous	Class B	7/16/2020	2	µg/kg	Individual	Pepper et al. 2021
Perfluorononanoic acid	375-95-1	Previous	Class B	7/27/2020	2	µg/kg	Individual	Pepper et al. 2021
Perfluorononanoic acid	375-95-1	Previous	Class B	7/27/2020	1.1	µg/kg	Individual	Pepper et al. 2021
Perfluorononanoic acid	375-95-1	Previous	Heat-treated granular biosolids	2014	3.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Heat-treated granular biosolids	2014	0.8	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Heat-treated granular biosolids	2014	2.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Heat-treated granular biosolids	2016	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Heat-treated granular biosolids	2018	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Heat-treated granular biosolids	2014	3.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Biosolids blended with sawdust, bark	2014	2.8	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Composted biosolids with woodchips	2014	6.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Composted biosolids with woodchips	2014	8.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Composted biosolids with municipal solid waste	2014	0.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Composted biosolids with residential yard trimmings	2014	3.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorononanoic acid	375-95-1	Previous	Composted biosolids with plant materials	2014	4.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Class B	7/16/2020	34	µg/kg	Individual	Pepper et al. 2021
Perfluorooctanesulfonic acid	1763-23-1	Previous	Class B	7/16/2020	36	µg/kg	Individual	Pepper et al. 2021
Perfluorooctanesulfonic acid	1763-23-1	Previous	Class B	7/27/2020	27	µg/kg	Individual	Pepper et al. 2021
Perfluorooctanesulfonic acid	1763-23-1	Previous	Class B	7/27/2020	14	µg/kg	Individual	Pepper et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorooctanesulfonic acid	1763-23-1	Previous	Heat-treated granular biosolids	2014	13.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Heat-treated granular biosolids	2014	15.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Heat-treated granular biosolids	2014	88.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Heat-treated granular biosolids	2016	29.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Heat-treated granular biosolids	2018	18.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Heat-treated granular biosolids	2014	10.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Heat-treated granular biosolids	2014	2.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Biosolids blended with sawdust, bark	2014	3	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Composted biosolids with woodchips	2014	37.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Composted biosolids with woodchips	2014	10.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Composted biosolids with municipal solid waste	2014	3.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Composted biosolids with residential yard trimmings	2014	5.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanesulfonic acid	1763-23-1	Previous	Composted biosolids with plant materials	2014	10.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Class B	7/16/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorooctanoic acid	335-67-1	Previous	Class B	7/16/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorooctanoic acid	335-67-1	Previous	Class B	7/27/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorooctanoic acid	335-67-1	Previous	Class B	7/27/2020	1.2	µg/kg	Individual	Pepper et al. 2021
Perfluorooctanoic acid	335-67-1	Previous	Heat-treated granular biosolids	2014	1.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Heat-treated granular biosolids	2014	6.9	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Heat-treated granular biosolids	2014	6.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Heat-treated granular biosolids	2016	2.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Heat-treated granular biosolids	2018	2.72	µg/kg	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorooctanoic acid	335-67-1	Previous	Heat-treated granular biosolids	2014	3.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Heat-treated granular biosolids	2014	1.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Biosolids blended with sawdust, bark	2014	11.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Composted biosolids with woodchips	2014	26	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Composted biosolids with woodchips	2014	19.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Composted biosolids with municipal solid waste	2014	8.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Composted biosolids with residential yard trimmings	2014	19	µg/kg	Individual	Lazcano et al. 2020
Perfluorooctanoic acid	335-67-1	Previous	Composted biosolids with plant materials	2014	21.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Class B	7/16/2020	3.2	µg/kg	Individual	Pepper et al. 2021
Perfluorotetradecanoic acid	376-06-7	Previous	Class B	7/16/2020	3.3	µg/kg	Individual	Pepper et al. 2021
Perfluorotetradecanoic acid	376-06-7	Previous	Class B	7/27/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorotetradecanoic acid	376-06-7	Previous	Class B	7/27/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorotetradecanoic acid	376-06-7	Previous	Heat-treated granular biosolids	2014	1.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Heat-treated granular biosolids	2014	2.4	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Heat-treated granular biosolids	2014	1.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Heat-treated granular biosolids	2016	0.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Heat-treated granular biosolids	2018	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Heat-treated granular biosolids	2014	1.5	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Biosolids blended with sawdust, bark	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Composted biosolids with woodchips	2014	1.6	µg/kg	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorotetradecanoic acid	376-06-7	Previous	Composted biosolids with woodchips	2014	1.2	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Composted biosolids with municipal solid waste	2014	0.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Composted biosolids with residential yard trimmings	2014	2.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorotetradecanoic acid	376-06-7	Previous	Composted biosolids with plant materials	2014	1.2	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Class B	7/16/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorotridecanoic acid	72629-94-8	Previous	Class B	7/16/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorotridecanoic acid	72629-94-8	Previous	Class B	7/27/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorotridecanoic acid	72629-94-8	Previous	Class B	7/27/2020	ND	µg/kg	Individual	Pepper et al. 2021
Perfluorotridecanoic acid	72629-94-8	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Heat-treated granular biosolids	2014	1	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Heat-treated granular biosolids	2014	1.2	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Heat-treated granular biosolids	2016	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Heat-treated granular biosolids	2018	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Heat-treated granular biosolids	2014	0.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Heat-treated granular biosolids	2014	<LOQ	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Biosolids blended with sawdust, bark	2014	0.1	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Composted biosolids with woodchips	2014	1.7	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Composted biosolids with woodchips	2014	2.3	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Composted biosolids with municipal solid waste	2014	0.6	µg/kg	Individual	Lazcano et al. 2020
Perfluorotridecanoic acid	72629-94-8	Previous	Composted biosolids with residential yard trimmings	2014	2.5	µg/kg	Individual	Lazcano et al. 2020

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Perfluorotridecanoic acid	72629-94-8	Previous	Composted biosolids with plant materials	2014	1.3	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Class B	7/16/2020	2.3	µg/kg	Individual	Pepper et al. 2021
Perfluoroundecanoic acid	2058-94-8	Previous	Class B	7/16/2020	2.1	µg/kg	Individual	Pepper et al. 2021
Perfluoroundecanoic acid	2058-94-8	Previous	Class B	7/27/2020	2.4	µg/kg	Individual	Pepper et al. 2021
Perfluoroundecanoic acid	2058-94-8	Previous	Class B	7/27/2020	1.8	µg/kg	Individual	Pepper et al. 2021
Perfluoroundecanoic acid	2058-94-8	Previous	Heat-treated granular biosolids	2014	2.1	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Heat-treated granular biosolids	2014	2.9	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Heat-treated granular biosolids	2014	3.5	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Heat-treated granular biosolids	2016	4.1	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Heat-treated granular biosolids	2018	2.4	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Heat-treated granular biosolids	2014	4.3	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Heat-treated granular biosolids	2014	0.6	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Biosolids blended with sawdust, bark	2014	1.3	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Composted biosolids with woodchips	2014	5.6	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Composted biosolids with woodchips	2014	8	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Composted biosolids with municipal solid waste	2014	1	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Composted biosolids with residential yard trimmings	2014	4.2	µg/kg	Individual	Lazcano et al. 2020
Perfluoroundecanoic acid	2058-94-8	Previous	Composted biosolids with plant materials	2014	4	µg/kg	Individual	Lazcano et al. 2020
Silver	7440-22-4	Previous	Mixed primary and secondary	1996	60	mg/kg	Mean[a,b]	Taylor et al. 2020
Silver	7440-22-4	Previous	Mixed primary and secondary	2017-2018	2.5	mg/kg	Mean[a,b]	Taylor et al. 2020
Triclocarban	101-20-2	Previous	Primary sludge	Not specified	86	ng/g	Mean	Li et al. 2021
Triclosan	3380-34-5	Previous	Primary sludge	Not specified	6165	ng/g	Mean	Li et al. 2021

Chemical	CAS number	New or previous	Biosolid type	Date(s) of sample collection	Biosolids concentr-ation	Biosolids units	Data type (individual, mean, median, min, max)	Source
Triclosan	3380-34-5	Previous	Mix of fermented primary sludge and thickened waste activated sludge	Not specified	4450	ng/g dry	Mean	Kor-Bicakci et al. 2020
Triclosan	3380-34-5	Previous	Mix of fermented primary sludge and thickened waste activated sludge	Not specified	6760-8240	ng/g dry	Range	Kor-Bicakci et al. 2020
Triclosan	3380-34-5	Previous	Mix of fermented primary sludge and thickened waste activated sludge	Not specified	1700-3530	ng/g dry	Range	Kor-Bicakci et al. 2020
Triclosan	3380-34-5	Previous	Un-pretreated raw mixed sludge	Not specified	4320	ng/g dry	Mean	Kor-Bicakci et al. 2020
Triclosan	3380-34-5	Previous	Mixed primary and secondary BNR sludge	Apr 2018-Apr 2019	111-214	ng/g	Range	Abbott and Eskicioglu 2020
Triclosan	3380-34-5	Previous	Undigested sludge	Apr 2018-Apr 2019	3963	ng/g	Mean	Abbott and Eskicioglu 2020
Triclosan	3380-34-5	Previous	Undigested sludge	Apr 2018-Apr 2019	2323-6127	ng/g	Range	Abbott and Eskicioglu 2020

Notes:
CAS = Chemical Abstracts Service; LOQ = Limit of quantitation; ND = Non-detect; New = Newly identified chemical; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process; J = Chemical was detected above the method detection limit but below the method reporting limit
[a] Approximate concentration
[b] Authors found that Ag in biosolids was in the form of Ag2S nanoparticles

Appendix D: Human Health Toxicity Values for Chemicals Found in Biosolids

Table D-1. Human Health Toxicity Values from EPA's Integrated Risk Information System (IRIS) for Chemicals Newly and Previously Identified in Biosolids

Chemical	CAS number	New or previous	RfD mg/kg/day	Date of last update	RfC mg/m^3	Date of last update	CSF mg/kg/day	Date of last update	IUR $\mu g/m^3$	Date of last update
(E)-1,2-Dichloroethylene	156-60-5	Previous*	0.02	9/30/2010	—	—	—	—	—	—
1,1,1-Trichloroethane	71-55-6	Previous*	2	9/28/2007	5	9/28/2007	—	—	—	—
1,1,1-Trichloroethane	71-55-6	Previous*	7	9/28/2007	5	9/28/2007	—	—	—	—
1,1,1-Trichloroethane	71-55-6	Previous*	—	—	5	9/28/2007	—	—	—	—
1,1,1-Trichloroethane	71-55-6	Previous*	—	—	6	9/28/2007	—	—	—	—
1,1,1-Trichloroethane	71-55-6	Previous*	—	—	7	9/28/2007	—	—	—	—
1,1,1-Trichloroethane	71-55-6	Previous*	—	—	7	9/28/2007	—	—	—	—
1,1,1-Trichloroethane	71-55-6	Previous*	—	—	9	9/28/2007		—	—	—
1,2,4-Trichlorobenzene	120-82-1	Previous*	0.01	5/1/1992	—	—	—	—	—	—
1,2-Dichlorobenzene	95-50-1	Previous*	0.09	8/1/1989	—	—	—	—	—	—
1,2-Dichloropropane	78-87-5	Previous*	—	—	0.004	12/1/1991	—	—	—	—
1,4-Dioxane	123-91-1	Previous*	0.03	8/11/2010	0.03	9/20/2013	0.1	—	0.000005	
2-(2,4,5-Trichlorophenoxy)propionic acid	93-72-1	Previous*	0.008	9/7/1988	—	—	—	—	—	—
2,4,5-Trichlorophenoxyacetic acid	93-76-5	Previous*	0.01	9/7/1988	—	—	—	—	—	—
2-Hexanone	591-78-6	Previous*	0.005	9/25/2009	0.03	9/25/2009	—	—	—	—
2-Methyl-1-propanol	78-83-1	Previous*	0.3	3/31/1987	—	—	—	—	—	—
4-Methyl-2-pentanone	108-10-1	Previous*	—	—	3	4/25/2003	—	—	—	—
Acenaphthene	83-32-9	Previous*	0.06	11/1/1990	—	—	—	—	—	—
Aldrin	309-00-2	Previous*	0.00003	3/31/1987	—	—	17	9/30/1987	0.0049	9/30/1987
Allyl alcohol	107-18-6	Previous*	0.005	1/31/1987	—	—	—	—	—	—
Allyl chloride	107-05-1	Previous*	—	—	0.001	12/1/1991	—	—	—	—
alpha-1,2,3,4,5,6-Hexachlorocyclo hexane	319-84-6	Previous*	—	—	—	—	6.3	3/31/1987	0.0018	3/31/1987
Aroclor 1254	11097-69-1	Previous*	0.00002	10/1/1994	—	—	—	—	—	—
Azinphos-methyl	86-50-0	Previous*	0.001	9/26/1988	—	—	—	—	—	—

Chemical	CAS number	New or previous	RfD mg/kg/day	Date of last update	RfC mg/m^3	Date of last update	CSF mg/kg/day	Date of last update	IUR **µg/m**^{3}	Date of last update
Benzene	71-43-2	Previous*	0.004	4/17/2003	0.03	4/17/2003	0.015 to 0.055	1/9/2000	0.0000022 to 0.0000078	1/9/2000
Benzyl butyl phthalate	85-68-7	Previous*	0.2	9/1/1989	—	—	—	—	—	—
beta-Hexachlorocyclohexane	319-85-7	Previous*	—	—	—	—	1.8	9/30/1987	0.00053	9/30/1987
Biphenyl	92-52-4	Previous*	0.5	8/27/2013	—	—	0.008	8/27/2013	—	—
Bisphenol A	80-05-7	Previous*	0.05	9/26/1988	—	—	—	—	—	—
Captan	133-06-2	Previous*	0.13	3/1/1989	—	—	—	—	—	—
Carbon disulfide	75-15-0	Previous*	0.1	9/30/1987	0.7	8/1/1995	—	—	—	—
Chlorobenzene	108-90-7	Previous*	0.02	8/1/1989	—	—	—	—	—	—
Chlorobenzilate	510-15-6	Previous*	0.02	12/1/1989	—	—	—	—	—	—
Chloroethane	75-00-3	Previous*	—	—	10	4/1/1991	—	—	—	—
Chloromethane	74-87-3	Previous*	—	—	0.09	7/17/2001	—	—	—	—
Cyanide	57-12-5	Previous*	0.00063	9/28/2010	—	—	—	—	—	—
Dichlorodiphenyltrichloroethane	50-29-3	Previous*	0.0005	3/31/1987	—	—	0.34	8/22/1988	0.000097	—
Dichloromethane	75-09-2	Previous*	0.006	11/18/2011	0.6	11/18/2011	0.002	11/18/2011	1 x 10^-8	11/18/2011
Dieldrin	60-57-1	Previous*	0.00005	9/7/1988	—	—	16	9/7/1988	0.0046	9/7/1988
Endrin	72-20-8	Previous*	0.0003	9/7/1988	—	—	—	—	—	—
EPN	2104-64-5	Previous*	0.00001	9/30/1987	—	—	—	—	—	—
Heptachlor	76-44-8	Previous*	0.0005	9/30/1987	—	—	4.5	9/30/1987	0.0013	9/30/1987
Lindane	58-89-9	Previous*	0.0003	1/31/1987	—	—	—	—	—	—
Methacrylonitrile	126-98-7	Previous*	0.0001	9/7/1988	—	—	—	—	—	—
Methyl ethyl ketone	78-93-3	Previous*	0.6	9/26/2003	5	9/26/2003	—	—	—	—
Naled	300-76-5	Previous*	0.002	3/31/1987	—	—	—	—	—	—
Nitrobenzene	98-95-3	Previous*	0.002	2/6/2009	0.009	2/6/2009	—	—	0.00004	2/6/2009
o-Cresol	95-48-7	Previous*	0.05	9/7/1988	—	—	—	—	—	—
p,p'-DDD	72-54-8	Previous*	—	—	—	—	0.24	8/22/1988	—	—
p,p'-DDE	72-55-9	Previous*	—	—	—	—	0.34	8/22/1988	—	—
Pentachlorophenol	87-86-5	Previous*	0.005	9/30/2010	—	—	0.4	9/30/2010	—	—

Chemical	CAS number	New or previous	RfD mg/kg/day	Date of last update	RfC mg/m^3	Date of last update	CSF mg/kg/day	Date of last update	IUR **µg/m**^{3}	Date of last update
Strontium	7440-24-6	Previous*	0.6	10/1/1992	—	—	—	—	—	—
Trichloroethylene	79-01-6	Previous*	0.0005	9/28/2011	0.002	9/28/2011	0.046	9/28/2011	0.0000041	9/28/2011
Trichlorofluoromethane	75-69-4	Previous*	0.3	1/31/1987	—	—	—	—	—	—
Trifluralin	1582-09-8	Previous*	0.0075	7/1/1989	—	—	0.0077	8/22/1988	—	—

Notes:
CAS = Chemical Abstracts Service; Previous* = Chemical was identified during the curation process; RfD = Reference dose; RfC = Reference concentration; CSF = Cancer slope factor; IUR = Inhalation unit risk

Table D-2. Human Health Toxicity Values from EPA's Human Health Benchmarks for Pesticides (HHBP) for Chemicals Newly and Previously Identified in Biosolids

Chemical	CAS number	New or previous	PAD or RfD	Units	Date	Notes
Azinphos-methyl	86-50-0	Previous*	0.0015	mg/kg/day	7/31/2006	Chronic or lifetime PAD
Azinphos-methyl	86-50-0	Previous*	0.003	mg/kg/day	7/31/2006	Acute or one day PAD
Bensulide	741-58-2	Previous*	0.005	mg/kg/day	6/16/1999	Chronic or lifetime PAD
Bensulide	741-58-2	Previous*	0.15	mg/kg/day	6/16/1999	Acute or one day PAD
Captan	133-06-2	Previous*	0.13	mg/kg/day	9/26/2018	Chronic or lifetime PAD
Captan	133-06-2	Previous*	0.1	mg/kg/day	9/26/2018	Acute or one day PAD
Clomazone	81777-89-1	Previous*	0.84	mg/kg/day	10/23/2018	Chronic or lifetime PAD
Clomazone	81777-89-1	Previous*	1	mg/kg/day	10/23/2018	Acute or one day PAD
Dicrotophos	141-66-2	Previous*	0.00003	mg/kg/day	9/15/2015	Chronic or lifetime PAD
Dicrotophos	141-66-2	Previous*	0.00007	mg/kg/day	9/15/2015	Acute or one day PAD
Diphenylamine	122-39-4	Previous*	0.1	mg/kg/day	8/30/2018	Chronic or lifetime PAD
Mevinphos	7786-34-7	Previous*	0.000025	mg/kg/day	5/17/2000	Chronic or lifetime PAD
Mevinphos	7786-34-7	Previous*	0.0003	mg/kg/day	5/17/2000	Acute or one day PAD
Naled	300-76-5	Previous*	0.0006	mg/kg/day	6/19/2020	Chronic or lifetime PAD
Naled	300-76-5	Previous*	0.0032	mg/kg/day	6/19/2020	Acute or one day PAD
Fipronil	120068-37-3	Previous	0.025	mg/kg/day	3/20/2020	Acute or one day PAD (RfD) for the general population
Fipronil	120068-37-3	Previous	0.0002	mg/kg/day	3/20/2020	Chronic or lifetime PAD (RfD) for children
Oxytetracycline	79-57-2	Previous	0.1	mg/kg/day	11/20/2018	Chronic dietary PAD, all populations
Oxytetracycline	79-57-2	Previous	0.1	mg/kg/day	11/20/2018	Incidental oral, short-term cPAD
Thiabendazole	148-79-8	Previous	0.5	mg/kg/day	3/28/2019	Acute dietary, all populations
Thiabendazole	148-79-8	Previous	0.1	mg/kg/day	3/28/2019	Chronic dietary
Trichlorfon	52-68-6	Previous	0.00007	mg/kg/day	6/19/2020	Acute or one day PAD (RfD) for the general population
Trichlorfon	52-68-6	Previous	0.00007	mg/kg/day	6/19/2020	Chronic or lifetime PAD (RfD) for children

Notes:
CAS = Chemical Abstracts Service; PAD = Population adjusted dose; RfD = Reference dose; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process

Table D-3. EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs) for Chemicals Newly and Previously Identified in Biosolids

Chemical	CAS number	New or previous	RfD mg/kg/day	RfC mg/m^3	CSF mg/kg/day	Date of last revision	Notes
(E)-1,2-Dichloroethylene	156-60-5	Previous*	—	0.04	—	10/15/2020	RfC is chronic
(E)-1,2-Dichloroethylene	156-60-5	Previous*	—	0.4*	—	10/15/2020	RfC is subchronic
1,2,3-Trichlorobenzene	87-61-6	Previous*	0.008	—	—	9/11/2009	Chronic RfD
1,2-Dichloropropane	78-87-5	Previous*	0.04	0.004	0.037	9/29/2016	OSF and URF
1,4-Dinitrobenzene	100-25-4	Previous*	0.0001	—	—	6/16/2006	Chronic RfD
1,4-Dinitrobenzene	100-25-4	Previous*	0.001*	—	—	6/16/2006	Subchronic RfD
2,6-Dinitrotoluene	606-20-2	Previous*	—	—	1.5	4/10/2013	Screening values available
Acenaphthene	83-32-9	Previous*	0.2*	—	—	4/6/2011	RfD is subchronic
Aldrin	309-00-2	Previous*	0.00004*	—	—	3/14/2005	RfD is subchronic
Allyl alcohol	107-18-6	Previous*	0.004*	0.001*	—	9/29/2009	RfD and RfC are subchronic values
Benzene	71-43-2	Previous*	0.01*	0.08*	—	9/29/2009	RfD and RfC are subchronic
Benzenethiol	108-98-5	Previous*	0.001	—	—	4/1/2011	
Benzenethiol	108-98-5	Previous*	0.01*	—	—	4/1/2011	RfD is subchronic
Benzyl alcohol	100-51-6	Previous*	0.1	—	—	9/30/2009	Chronic
Benzyl alcohol	100-51-6	Previous*	0.3*	—	—	9/30/2009	Subchronic
Benzyl butyl phthalate	85-68-7	Previous*	—	—	0.0019	10/1/2002	
Biphenyl	92-52-4	Previous*	0.1*	—	—	4/4/2011	RfD is subchronic
Chlorobenzene	108-90-7	Previous*	0.07*	0.05	—	10/12/2006	Chronic RfD and RfC
Chlorobenzene	108-90-7	Previous*	—	0.5*	—	10/12/2006	Subchronic RfC
Chloroethane	75-00-3	Previous*	0.1*	4*	—	7/24/2007	RfD and RfC are subchronic
Chloromethane	74-87-3	Previous*	—	3*	—	12/4/2012	RfC is subchronic
Dibenzofuran	132-64-9	Previous*	0.004*	—	—	6/11/2007	RfD is subchronic
Methacrylonitrile	126-98-7	Previous*	0.05*	0.03	—	11/20/2012	RfD is subchronic; RfC is chronic
Methacrylonitrile	126-98-7	Previous*	—	0.3*	—	11/20/2012	RfC is subchronic
o-Cresol	95-48-7	Previous*	0.2*	—	—	3/19/2014	RfD is subchronic

Chemical	CAS number	New or previous	RfD mg/kg/day	RfC mg/m^3	CSF mg/kg/day	Date of last revision	Notes
p,p'-DDE	72-55-9	Previous*	0.0003*	—	—	9/26/2017	RfD is subchronic
Trichlorofluoromethane	75-69-4	Previous*	—	1*	—	9/15/2009	RfC is subchronic

Notes:
CAS = Chemical Abstracts Service; Previous* = Chemical was identified during the curation process; RfD = Reference dose; RfC = Reference concentration; CSF = Cancer slope factor

Table D-4. Human Health Toxicity Values from EPA's Health Effects Support Documents (HESDs) for Chemicals Newly and Previously Identified in Biosolids

Chemical	CAS number	New or previous	Oral MRL (acute)	Units	Oral MRL (intermediate)	Units	Oral MRL (chronic)	Units	Inhalation MRL (acute)	Units	Inhalation MRL (intermediate)	Units	Inhalation MRL (chronic)	Units	Date of last revision
(E)-1,2-Dichloroethylene	156-60-5	Previous*	—	—	0.2	mg/kg/day	—	—	0.2	ppm	0.2	ppm	—	—	8/1/1996
1,1,1-Trichloroethane	71-55-6	Previous*	—	—	20	mg/kg/day	—	—	2	ppm	0.7	ppm	—	—	7/1/2006
1,2,4-Trichlorobenzene	120-82-1	Previous*	—	—	0.1	mg/kg/day	0.1	mg/kg/day	—	—	—	—	—	—	10/1/2014
1,2-Dichlorobenzene	95-50-1	Previous*	0.7	mg/kg/day	0.6	mg/kg/day	0.3	mg/kg/day	—	—	—	—	—	—	8/1/2006
1,2-Dichloropropane	78-87-5	Previous*	0.3	mg/kg/day	0.07	mg/kg/day	—	—	0.02	ppm	2	ppm	—	—	11/1/2021
1,4-Dioxane	123-91-1	Previous*	5	mg/kg/day	0.5	mg/kg/day	0.1	mg/kg/day	2	ppm	0.2	ppm	0.03	ppm	4/1/2012
2,6-Dinitrotoluene	606-20-2	Previous*	0.09	mg/kg/day	0.004	mg/kg/day	—	—	—	—	—	—	—	—	2/1/2016
2-Hexanone	591-78-6	Previous*	—	—	—	—	0.05	mg/kg/day	—	—	—	—	—	—	2/1/2020
Acenaphthene	83-32-9	Previous*	—	—	0.6	mg/kg/day	—	—	—	—	—	—	—	—	8/1/1995
Aldrin	309-00-2	Previous*	2	µg/kg/day	—	—	0.04	µg/kg/day	—	—	—	—	—	—	7/1/2021
alpha-1,2,3,4,5,6-Hexachloro cyclohexane	319-84-6	Previous*	—	—	—	—	0.008	mg/kg/day	—	—	—	—	—	—	8/1/2005
Aroclor 1248	12672-29-6	Previous*	—	—	0.03	µg/kg/day	0.02	µg/kg/day	—	—	—	—	—	—	11/1/2000
Aroclor 1254	11097-69-1	Previous*	—	—	0.03	µg/kg/day	0.02	µg/kg/day	—	—	—	—	—	—	11/1/2000
Azinphos-methyl	86-50-0	Previous*	0.01	mg/kg/day	0.003	mg/kg/day	0.003	mg/kg/day	0.02	mg/m^3	0.01	mg/m^3	0.01	mg/m^3	9/1/2008
Benzene	71-43-2	Previous*	—	—	—	—	0.0005	mg/kg/day	0.009	ppm	0.006	ppm	0.003	ppm	8/1/2007
beta-Hexachlorocyclo hexane	319-85-7	Previous*	0.05	mg/kg/day	0.0006	mg/kg/day	—	—	—	—	—	—	—	—	8/1/2005
Carbon disulfide	75-15-0	Previous*	0.01	mg/kg/day	—	—	—	—	—	—	—	—	0.3	ppm	8/1/1996
Chlorobenzene	108-90-7	Previous*	—	—	0.07	mg/kg/day	—	—	—	—	—	—	—	—	10/1/2020
Chloroethane	75-00-3	Previous*	—	—	—	—	—	—	15	ppm	—	—	—	—	12/1/1998
Chloromethane	74-87-3	Previous*	—	—	—	—	—	—	0.5	ppm	0.2	ppm	0.05	ppm	12/1/1998

Chemical	CAS number	New or previous	Oral MRL (acute)	Units	Oral MRL (intermediate)	Units	Oral MRL (chronic)	Units	Inhalation MRL (acute)	Units	Inhalation MRL (intermediate)	Units	Inhalation MRL (chronic)	Units	Date of last revision
Chlorpyrifos	2921-88-2	Previous*	0.003	mg/kg/day	0.003	mg/kg/day	0.001	mg/kg/day	—	—	—	—	—	—	9/1/1997
Diazinon	333-41-5	Previous*	0.006	mg/kg/day	0.002	mg/kg/day	0.0007	mg/kg/day	—	—	0.01	mg/m^3	—	—	9/1/2008
Dichlorodiphenyltrichloroethane	50-29-3	Previous*	0.5[a]	µg/kg/day	0.2[a]	µg/kg/day	0.1[a]	µg/kg/day	—	—	—	—	—	—	12/1/2019
Dichloromethane	75-09-2	Previous*	0.2	mg/kg/day	—	—	0.06	mg/kg/day	0.6	ppm	0.3	ppm	0.3	ppm	9/1/2000
Dieldrin	60-57-1	Previous*	—	—	0.1	µg/kg/day	0.05	µg/kg/day	—	—	—	—	—	—	7/1/2021
Endrin	72-20-8	Previous*	0.6	µg/kg/day	0.6	µg/kg/day	0.3	µg/kg/day	—	—	—	—	—	—	3/1/2021
Heptachlor	76-44-8	Previous*	0.0006	mg/kg/day	0.0001	mg/kg/day	—	—	—	—	—	—	—	—	8/1/2007
Iodine	7553-56-2	Previous*	0.01	mg/kg/day	0.01	mg/kg/day	—	—	—	—	—	—	—	—	4/1/2004
Methyl ethyl ketone	78-93-3	Previous*	—	—	—	—	—	—	1	ppm	—	—	—	—	10/1/2020
p,p'-DDD	72-54-8	Previous*	0.0005[a]	mg/kg/day	0.0002[a]	mg/kg/day	0.0001[a]	mg/kg/day	—	—	—	—	—	—	12/1/2019
p,p'-DDE	72-55-9	Previous*	0.0005[a]	mg/kg/day	0.0002[a]	mg/kg/day	0.0001[a]	mg/kg/day	—	—	—	—	—	—	12/1/2019
Pentachlorophenol	87-86-5	Previous*	5[b]	ug/kg/day	—	—	1[b]	ug/kg/day	—	—	—	—	—	—	7/1/2021
Strontium	7440-24-6	Previous*	—	—	2	mg/kg/day	—	—	—	—	—	—	—	—	4/1/2004
Trichloroethylene	79-01-6	Previous*	—	—	0.0005	mg/kg/day	0.0005	mg/kg/day	—	—	0.0004	ppm	0.0004	ppm	6/1/2019
Acetone	67-64-1	Previous			0.6[b]	mg/kg/day	—	—	8[b]	ppm					7/1/2021
Di(2-ethylhexyl) phthalate	117-81-7	Previous	3	µg/kg/day	0.1	µg/kg/day	—	—	—	—	0.2	ppb	—	—	1/1/2022
Molybdenum	7439-98-7	Previous	—	—	0.06	mg/kg/day	—	—	—	—	—	—	2	$\mu g/m^3$	5/1/2020
Perfluorononanoic acid	375-95-1	Previous	—	—	3	ng/kg/day	—	—	—	—	—	—	—	—	3/1/2020
Tetrachloroethylene	127-18-4	Previous	0.008	mg/kg/day	0.008	mg/kg/day	0.008	mg/kg/day	0.006	ppm	0.006	ppm	0.006	ppm	6/1/2019

Notes:
CAS = Chemical Abstracts Service; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process; MRL = Minimal risk level
[a] Provisional values
[b] Draft values

Table D-5. Human Health Toxicity Values from the California Environmental Protection Agency (CalEPA) for Chemicals Newly and Previously Identified in Biosolids

Chemical	CAS number	New or previous	Inhalation REL (acute) **µg/m**^{3}	Date reviewed	Inhalation REL (8-hour) **µg/m**^{3}	Inhalation REL (chronic) **µg/m**^{3}	Date reviewed	Unit risk **(µg/m**^{3}**)**$^{-1}$	Inhalation slope factor mg/kg/day	Date reviewed [added]	Oral slope factor mg/kg/day	Date reviewed [added]
1,1,1-Trichloroethane	71-55-6	Previous*	68000	1999	—	1000	Not reported	—	—	—	—	—
1,2,3,4,6,7,8-Heptachloro dibenzo[b,d]furan	67562-39-4	Previous*	—	—	—	—	—	0.38	1300	Not reported	1300	Not reported
1,2,3,7,8,9-Hexachloro dibenzo[b,d]furan	72918-21-9	Previous*	—	—	—	—	—	0.38	13000	Not reported	13000	Not reported
1,2,3,7,8-Pentachloro dibenzo-p-dioxin	40321-76-4	Previous*	—	—	—	—	—	0.38	130000	Not reported	130000	Not reported
1,2,4-Trichlorobenzene	120-82-1	Previous*	—	—	—	—	—	—	—	—	3.6 E-3	Not reported
1,2-Dichloropropane	78-87-5	Previous*	—	—	—	—	—	0.00001	3.6 E-2	Not reported	3.6 E-2	Not reported
1,4-Dioxane	123-91-1	Previous*	3000	1999	—	3000	Not reported	0.0000077	2.7 E-2	Not reported	2.7 E-2	Not reported
Aldrin	309-00-2	Previous*	—	—	—	—	—	0.0049	17	Not reported	17	Not reported
Allyl chloride	107-05-1	Previous*	—	—	—	—	—	0.000006	0.021	Not reported	0.021	Not reported
Benzene	71-43-2	Previous*	27	2014	3	3	2014	0.000029	1.0 E-1	Not reported	0.1	Not reported
Captan	133-06-2	Previous*	—	—	—	—	—	0.00000066	0.0023	Not reported	0.0023	Not reported
Carbon disulfide	75-15-0	Previous*	6200	1999	—	800	Not reported	—	—	—	—	—
Chlorobenzene	108-90-7	Previous*	—	—	—	1000	Not reported	—	—	—	—	—
Chlorobenzilate	510-15-6	Previous*	—	—	—	—	—	0.000031	0.11	Not reported	0.11	Not reported

Chemical	CAS number	New or previous	Inhalation REL (acute) **µg/m^3**	Date reviewed	Inhalation REL (8-hour) **µg/m^3**	Inhalation REL (chronic) **µg/m^3**	Date reviewed	Unit risk **(µg/m^3)$^{-1}$**	Inhalation slope factor mg/kg/day	Date reviewed [added]	Oral slope factor mg/kg/day	Date reviewed [added]
Chloroethane	75-00-3	Previous*	—	—	—	30000	Not reported	—	—	—	—	—
Dichlorodipheny ltrichloroethane	50-29-3	Previous*	—	—	—	—	—	0.000097	0.34	Not reported	0.34	Not reported
Dichloromethane	75-09-2	Previous*	14000	1999	—	400	Not reported	0.000001	0.0035	Not reported	0.014	Not reported
Dieldrin	60-57-1	Previous*	—	—	—	—	—	0.0046	16	Not reported	16	Not reported
Heptachlor	76-44-8	Previous*	—	—	—	—	—	—	4.1	Not reported	4.1	Not reported
Lindane	58-89-9	Previous*	—	—	—	—	—	0.00031	—	Not reported	1.1	Not reported
Methyl ethyl ketone	78-93-3	Previous*	13000	1999	—	—	—	—	—	—	—	—
p,p'-DDD	72-54-8	Previous*	—	—	—	—	—	0.000069	0.24	Not reported	0.24	Not reported
p,p'-DDE	72-55-9	Previous*	—	—	—	—	—	0.000097	0.34	Not reported	0.34	Not reported
Pentachlorophenol	87-86-5	Previous*	—	—	—	—	—	0.0000051	0.018	2011	0.081	2009
Trichloroethylene	79-01-6	Previous*	—	—	—	600	Not reported	0.000002	0.007	Not reported	0.0059	Not reported
Toluene	108-88-3	Previous	5000	2020	830	420	Not reported	—	—	—	—	—

Notes:
CAS = Chemical Abstracts Service; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process

Table D-6. Human Health Toxicity Values from Health Canada's List of Priority Substances for Chemicals Newly and Previously Identified in Biosolids

Chemical	CAS number	New or previous	Oral TDI (mg/kg/day)	Inhalation TDI (mg/m^3)	Oral CSF $(mg/kg/day)^{-1}$	Inhalation Unit Risk $(mg/m^3)^{-1}$	Units	Date
1,2,3-Trichlorobenzene	87-61-6	Previous*	0.0015	—	—	—	mg/kg/day	2007
1,2,4-Trichlorobenzene	120-82-1	Previous*	0.0016	—	—	—	mg/kg/day	2007
1,2-Dichlorobenzene	95-50-1	Previous*	0.43	—	—	—	mg/kg/day	2021
Aldrin	309-00-2	Previous*	0.0001	—	—	—	mg/kg/day	2007
Benzene	71-43-2	Previous*	—	—	0.083	0.015	mg/kg/day	3/1/2021
Chlorobenzene	108-90-7	Previous*	0.43	—	—	—	mg/kg/day	2007
Dichlorodiphenyltrichloroethane	50-29-3	Previous*	0.01	—	—	—	mg/kg/day	2007
Dichloromethane	75-09-2	Previous*	0.013	0.6	0.002	0.00001	mg/kg/day	3/1/2021
Dieldrin	60-57-1	Previous*	0.0001	—	—	—	mg/kg/day	2007
Trichloroethylene	79-01-6	Previous*	—	0.002	0.000811	0.0041	mg/kg/day	3/1/2021
1,4-Dichlorobenzene	106-46-7	Previous	0.11	0.06	—	—	mg/kg/day	3/1/2021
Benzo(a)pyrene	50-32-8	Previous	0.0000667	0.000002	1.289	0.6	mg/kg/day	3/1/2021
Beryllium	7440-41-7	Previous	0.002	0.00002	—	2.4	mg/kg/day	3/1/2021
Cadmium	7440-43-9	Previous	0.0008	—	—	4.2	mg/kg/day	3/1/2021
Carbon tetrachloride	56-23-5	Previous	0.00071	—	—	0.006	mg/kg/day	3/1/2021
Copper	7440-50-8	Previous	0.426	—	—	—	mg/kg/day	3/1/2021
Ethylbenzene	100-41-4	Previous	0.022	2	—	—	mg/kg/day	3/1/2021
Lead	7439-92-1	Previous	0.0005[c]	—	—	—	mg/kg/day	3/1/2021
Manganese	7439-96-5	Previous	0.025	—	—	—	mg/kg/day	3/1/2021
Naphthalene	91-20-3	Previous	0.02	0.01	—	—	mg/kg/day	3/1/2021
Perfluorooctanesulfonic acid	1763-23-1	Previous	0.00006	—	—	—	mg/kg/day	3/1/2021
Perfluorooctanoic acid	335-67-1	Previous	0.000021	—	—	—	mg/kg/day	3/1/2021
Selenium	7782-49-2	Previous	0.0055	—	—	—	mg/kg/day	3/1/2021
Selenium	7782-49-2	Previous	0.006	—	—	—	mg/kg/day	3/1/2021
Selenium	7782-49-2	Previous	0.0063	—	—	—	mg/kg/day	3/1/2021
Selenium	7782-49-2	Previous	0.0062	—	—	—	mg/kg/day	3/1/2021

Chemical	CAS number	New or previous	Oral TDI (mg/kg/day)	Inhalation TDI (mg/m^3)	Oral CSF $(mg/kg/day)^{-1}$	Inhalation Unit Risk $(mg/m^3)^{-1}$	Units	Date
Selenium	7782-49-2	Previous	0.0057	—	—	—	mg/kg/day	3/1/2021
Tetrachloroethylene	127-18-4	Previous	0.0047	0.04	—	—	mg/kg/day	3/1/2021
Zinc	7440-66-6	Previous	0.49	—	—	—	mg/kg/day	3/1/2021
Zinc	7440-66-6	Previous	0.48	—	—	—	mg/kg/day	3/1/2021
Zinc	7440-66-6	Previous	0.51	—	—	—	mg/kg/day	3/1/2021
Zinc	7440-66-6	Previous	0.54	—	—	—	mg/kg/day	3/1/2021
Zinc	7440-66-6	Previous	0.57	—	—	—	mg/kg/day	3/1/2021

Notes:
CAS = Chemical Abstracts Service; CSF = Cancer slope factor; TDI = Tolerable daily intake; REL = Reference exposure level; Previous = Previously identified chemical;
Previous* = Chemical was identified during the curation process

Table D-7. EPA's National Recommended Water Quality Criteria – Human Health Criteria for Chemicals Found in Biosolids

Chemical	CAS number	New or previous	Human health for the consumption of water + organism (µg/L)	Human health for the consumption of organism only (µg/L)	Publication year
(E)-1,2-Dichloroethylene	156-60-5	Previous*	100	4000	2015
1,1,1-Trichloroethane	71-55-6	Previous*	10000	200000	2015
1,2,4-Trichlorobenzene	120-82-1	Previous*	0.071	0.076	2015
1,2-Dichlorobenzene	95-50-1	Previous*	1000	3000	2015
1,2-Dichloropropane	78-87-5	Previous*	0.9	31	2015
2-(2,4,5-Trichlorophenoxy)propionic acid	93-72-1	Previous*	100	400	2015
4-Chloro-3-methylphenol	59-50-7	Previous*	500	2000	2015
Acenaphthene	83-32-9	Previous*	70	90	2015
Aldrin	309-00-2	Previous*	0.00000077	0.00000077	2015
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	319-84-6	Previous*	0.00036	0.00039	2015
Benzene	71-43-2	Previous*	0.58-2.1	16-58	2015
Benzyl butyl phthalate	85-68-7	Previous*	0.1	0.1	2015
beta-Hexachlorocyclohexane	319-85-7	Previous*	0.008	0.014	2015
Chlorobenzene	108-90-7	Previous*	100	800	2015
Cyanide	57-12-5	Previous*	4	400	2015
Dichlorodiphenyltrichloroethane	50-29-3	Previous*	0.00003	0.00003	2015
Dichloromethane	75-09-2	Previous*	20	1000	2015
Dieldrin	60-57-1	Previous*	0.0000012	0.0000012	2015
Endrin	72-20-8	Previous*	0.03	0.03	2015
Heptachlor	76-44-8	Previous*	0.0000059	0.0000059	2015
Lindane	58-89-9	Previous*	4.2	4.4	2015
Nitrobenzene	98-95-3	Previous*	10	600	2015
p,p'-DDD	72-54-8	Previous*	0.00012	0.00012	2015
p,p'-DDE	72-55-9	Previous*	0.000018	0.000018	2015
Pentachlorophenol	87-86-5	Previous*	0.03	0.04	2015
Trichloroethylene	79-01-6	Previous*	0.6	7	2015

Chemical	CAS number	New or previous	Human health for the consumption of water + organism (µg/L)	Human health for the consumption of organism only (µg/L)	Publication year
Zinc	7440-66-6	Previous*	7400	26000	2002
1,3-Dichlorobenzene	541-73-1	Previous	7	10	2015
1,4-Dichlorobenzene	106-46-7	Previous	300	900	2015
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	Previous	0.000000005	5.1E-09	2002
2,4,5-Trichlorophenol	95-95-4	Previous	300	600	2015
2,4-Dichlorophenol	120-83-2	Previous	10	60	2015
2,4-Dichlorophenoxyacetic acid	94-75-7	Previous	1300	12000	2015
2-Chloronaphthalene	91-58-7	Previous	800	1,000	2015
Anthracene	120-12-7	Previous	300	400	2015
Antimony	7440-36-0	Previous	5.6	640	1980
Arsenic	7440-38-2	Previous	0.018	0.14	1992
Barium	7440-39-3	Previous	1000	—	1986
Benz(a)anthracene	56-55-3	Previous	0.0012	0.0013	2015
Benzo(a)pyrene	50-32-8	Previous	0.00012	0.00013	2015
Benzo(b)fluoranthene	205-99-2	Previous	0.0012	0.0013	2015
Benzo(k)fluoranthene	207-08-9	Previous	0.012	0.013	2015
Cadmium	7440-43-9	Previous	—	—	—
Carbon tetrachloride	56-23-5	Previous	0.4	5	2015
Chloroform	67-66-3	Previous	60	2000	2015
Chromium	7440-47-3	Previous	VA	VA	VA
Chrysene	218-01-9	Previous	0.12	0.13	2015
Copper	7440-50-8	Previous	1300	—	1992
Di(2-ethylhexyl) phthalate	117-81-7	Previous	0.32	0.37	2015
Dibutyl phthalate	84-74-2	Previous	20	30	2015
Dimethyl phthalate	131-11-3	Previous	2000	2000	2015
Endosulfan I	959-98-8	Previous	20	30	2015
Endosulfan II	33213-65-9	Previous	20	40	2015

Chemical	CAS number	New or previous	Human health for the consumption of water + organism (µg/L)	Human health for the consumption of organism only (µg/L)	Publication year
Ethylbenzene	100-41-4	Previous	68	130	2015
Fluoranthene	206-44-0	Previous	20	20	2015
Heptachlor epoxide B	1024-57-3	Previous	0.000032	0.000032	2015
Manganese	7439-96-5	Previous	50	100	1993
Nickel	7440-02-0	Previous	610	4600	1998
N-Nitrosodibutylamine	924-16-3	Previous	0.0063	0.22	2002
N-Nitrosodiethylamine	55-18-5	Previous	0.0008	1.24	2002
N-Nitrosodimethylamine	62-75-9	Previous	0.00069	3	2002
N-Nitrosodi-n-propylamine	621-64-7	Previous	0.005	0.51	2002
N-Nitrosodiphenylamine	86-30-6	Previous	3.3	6	2002
N-Nitrosopyrrolidine	930-55-2	Previous	0.016	34	2002
Phenol	108-95-2	Previous	4000	300000	2015
Polychlorinated biphenyls	1336-36-3	Previous	0.000064	0.000064	2002
Pyrene	129-00-0	Previous	20	30	2015
Selenium	7782-49-2	Previous	170	4200	2002
Tetrachloroethylene	127-18-4	Previous	10	29	2015
Thallium	7440-28-0	Previous	0.24	0.47	2003
Toluene	108-88-3	Previous	57	520	2015

Notes:
CAS = Chemical Abstracts Service; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process; VA = Value Available (Toxicity data may be available for this chemical or a chemical in the same family. When comparing the National Recommended Water Quality Criteria – Human Health Criteria to the list of chemicals found in biosolids, some chemicals were reported using the same name but different CASRN. A chemical may be listed with multiple CASRN if (1) there are different forms of a chemical where each is considered unique for its particular properties of characteristics; or (2) when multiple CASRN have inadvertently been assigned to the same chemical. Further evaluation would be needed to determine whether the toxicity data is relevant.)

Table D-8. EPA's National Primary Drinking Water Regulations for Chemicals Found in Biosolids

Chemical	CAS number	New or previous	Standards			Status HA docu-ment	Health advisories						Cancer descrip-tor[1]
							10-kg Child						
			Status reg.	MCLG (mg/L)	MCL (mg/L)		1-day (mg/L)	10-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer risk	
(E)-1,2-Dichloroethylene	156-60-5	Previous*	F	0.1	0.1	F '87	20	2	0.02	0.7	0.1	—	I
1,1,1-Trichloroethane	71-55-6	Previous*	F	0.2	0.2	F '87	100	40	2	70	—	—	I
1,2,4-Trichlorobenzene	120-82-1	Previous*	F	0.07	0.07	F '89	0.1	0.1	0.01	0.35	0.07	—	D
1,2-Dichlorobenzene	95-50-1	Previous*	F	0.6	0.6	F '87	9	9	0.09	3	0.6	—	D
1,2-Dichloropropane	78-87-5	Previous*	F	zero	0.005	F '87	—	0.09	—	—	—	0.06	B2
1,4-Dioxane	123-91-1	Previous*	—	—	—	F '87	4	0.4	0.03	1	0.2	0.035	L
2-(2,4,5-Trichlorophenoxy)propionic acid	93-72-1	Previous*	F	0.05	0.05	F '88	0.2	0.2	0.008	0.3	0.05	—	D
2,4,5-Trichlorophenoxyacetic acid	93-76-5	Previous*	—	—	—	F '88	0.8	0.8	0.01	0.35	0.07	—	D
2,6-Dinitrotoluene	606-20-2	Previous*	—	—	—	F '08	0.4	0.04	0.001	0.04	—	0.005	L
Acenaphthene	83-32-9	Previous*	—	—	—	—	—	—	0.06	2	—	—	—
Aldrin	309-00-2	Previous*	—	—	—	F '92	0.0003	0.0003	0.00003	0.001	—	0.0002	B2
Benzene	71-43-2	Previous*	F	zero	0.005	F '87	0.2	0.2	0.004	0.1	0.003	1 to 10	H
Benzo(g,h,i)perylene	191-24-2	Previous*	—	—	—	—	—	—	—	—	—	—	D
Benzyl butyl phthalate	85-68-7	Previous*	—	—	—	—	—	—	0.2	7	—	—	C
Chlorobenzene	108-90-7	Previous*	F	0.1	0.1	F '87	4	4	0.02	0.7	0.1	—	D
Chloromethane	74-87-3	Previous*	—	—	—	F '89	9	0.4	—	—	—	—	I
Chlorpyrifos	2921-88-2	Previous*	—	—	—	F '92	0.03	0.03	0.0003	0.01	0.002	—	D
Cyanide	57-12-5	Previous*	VA	VA	VA	VA	VA	VA	VA				VA
Diazinon	333-41-5	Previous*	—	—	—	F '88	0.02	0.02	0.0002	0.007	0.001	—	E
Dichloromethane	75-09-2	Previous*	F	zero	0.005	D '93	10	2	0.06	2	0.2	0.5	L
Dieldrin	60-57-1	Previous*	—	—	—	F '88	0.0005	0.0005	0.00005	0.002	—	0.0002	B2
Endrin	72-20-8	Previous*	F	0.002	0.002	F '87	0.02	0.005	0.0003	0.01	0.002	—	I

Chemical	CAS number	New or previous	Standards			Status HA docu-ment	Health advisories						Cancer descrip-tor[1]
							10-kg Child						
			Status reg.	MCLG (mg/L)	MCL (mg/L)		1-day (mg/L)	10-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer risk	
Heptachlor	76-44-8	Previous*	F	zero	0.0004	F ‘87	0.01	0.01	0.0005	0.02	—	0.0008	B2
Lindane	58-89-9	Previous*	F	0.0002	0.0002	F ‘87	1	1	0.005	0.2	—	—	S
Methyl ethyl ketone	78-93-3	Previous*	—	—	—	F ‘87	75	7.5	0.6	20	4	—	D
Pentachlorophenol	87-86-5	Previous*	F	zero	0.001	F ‘87	1	0.3	0.005	0.2	0.04	0.009	L
Phenanthrene	85-01-8	Previous*	—	—	—	—	—	—	—	—	—	—	D
Strontium	7440-24-6	Previous*	—	—	—	D ‘93	25	25	0.6	20	4	—	D
Trichloroethylene[3]	79-01-6	Previous*	F	zero	0.005	F ‘87	—	—	0.007	0.2	—	0.3	B2
Trichlorofluoromethane	75-69-4	Previous*	—	—	—	F ‘89	7	7	0.3	10	2	—	D
Trifluralin	1582-09-8	Previous*	—	—	—	F ‘90	0.08	0.08	0.02	0.7	0.01	0.4	C
1,3,5-Trichlorobenzene	108-70-3	Previous	—	—	—	F ‘89	0.6	0.6	0.006	0.2	0.04	—	D
1,3-Dichlorobenzene[2]	541-73-1	Previous	—	—	—	F ‘87	9	9	0.09	3	0.6	—	D
1,4-Dichlorobenzene	106-46-7	Previous	F	0.075	0.075	F ‘87	11	11	0.1	4	0.075	—	C
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	Previous	F	zero	3E-08	F ’87	0.000001	0.0000001	1E-09	4E-08	—	2E-08	B2
2,4-Dichlorophenol	120-83-2	Previous	—	—	—	D ‘94	0.03	0.03	0.003	0.1	0.02	—	E
2,4-Dichlorophenoxyacetic acid	94-75-7	Previous	F	0.07	0.07	F ‘87	1	0.3	0.005	0.2	—	—	D
4-Nitrophenol	100-02-7	Previous	—	—	—	F ‘92	0.8	0.8	0.008	0.3	0.06	—	D
Anthracene	120-12-7	Previous	—	—	—	—	—	—	0.3	10	—	—	D
Antimony	7440-36-0	Previous	F	0.006	0.006	F ‘92	0.01	0.01	0.0004	0.01	0.006	—	D
Arsenic	7440-38-2	Previous	F	zero	0.01	—	—	—	0.0003	0.01	—	0.002	A
Barium	7440-39-3	Previous	F	2	2	D ‘93	0.7	0.7	0.2	7	—	—	N
Benz(a)anthracene	56-55-3	Previous	—	—	—	—	—	—	—	—	—	—	B2
Benzo(a)pyrene	50-32-8	Previous	F	zero	0.0002	—	—	—	—	—	—	0.0005	B2
Benzo(b)fluoranthene	205-99-2	Previous	—	—	—	—	—	—	—	—	—	—	B2
Benzo(k)fluoranthene	207-08-9	Previous	—	—	—	—	—	—	—	—	—	—	B2

Chemical	CAS number	New or previous	Standards			Status HA docu-ment	Health advisories						Cancer descrip-tor[1]
							10-kg Child						
			Status reg.	MCLG (mg/L)	MCL (mg/L)		1-day (mg/L)	10-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer risk	
Beryllium	7440-41-7	Previous	F	0.004	0.004	F ‘92	30	30	0.002	0.07	—	—	—
Boron	7440-42-8	Previous	—	—	—	F ‘08	3	3	0.2	7	6	—	I
Cadmium	7440-43-9	Previous	F	0.005	0.005	F ’87	0.04	0.04	0.0005	0.02	0.005	—	D
Carbon tetrachloride	56-23-5	Previous	F	zero	0.005	F ‘87	4	0.2	0.004	0.1	0.03	0.05	L
Chloroform	67-66-3	Previous	F	0.07	0.081	—	4	4	0.01	0.35	0.07	—	L/N
Chromium[4]	7440-47-3	Previous	F	0.1	0.1	F ‘87	1	1	0.003	0.1	—	—	D
Chrysene	218-01-9	Previous	—	—	—	—	—	—	—	—	—	—	B2
Copper[5]	7440-50-8	Previous	F	1.3	TT	D ‘98	—	—	—	—	—	—	D
Di(2-ethylhexyl) phthalate	117-81-7	Previous	F	zero	0.006	—	—	—	0.02	0.7	—	0.3	B2
Dibutyl phthalate	84-74-2	Previous	—	—	—	—	—	—	0.1	4	—	—	D
Dimethyl phthalate	131-11-3	Previous	—	—	—	—	—	—	—	—	—	—	D
Ethylbenzene	100-41-4	Previous	F	0.7	0.7	F ‘87	30	3	0.1	3	0.7	—	D
Fluoride	16984-48-8	Previous	VA	VA	VA	—	—	—	VA	—	—	—	—
Heptachlor epoxide B	1024-57-3	Previous	F	zero	0.0002	F ‘87	0.01	—	0.00001	0.0004	—	0.0004	B2
Lead[6]	7439-92-1	Previous	F	zero	TT	—	—	—	—	—	—	—	B2
Manganese[7]	7439-96-5	Previous	—	—	—	F”04	1	1	0.14	1.6	0.3	—	D
Mercury	7439-97-6	Previous	VA	VA	VA	VA	VA	VA	VA	VA	VA		VA
Molybdenum	7439-98-7	Previous	—	—	—	D ‘93	0.08	0.08	0.005	0.2	0.04	—	D
Naphthalene	91-20-3	Previous	—	—	—	F ‘90	0.5	0.5	0.02	0.7	0.1	—	I
Nickel	7440-02-0	Previous	F	—	—	F ‘95	1	1	0.02	0.7	0.1	—	—
Perfluorooctanesulfonic acid	1763-23-1	Previous	—	—	—	F ‘16	—	—	2 x 10-5	3.7 x 10-4	7 x 10-5	—	S
Perfluorooctanoic acid	335-67-1	Previous	—	—	—	F ‘16	—	—	2 x 10-5	3.7 x 10-4	7 x 10-5	5 x 10-2	S
Phenol	108-95-2	Previous	—	—	—	D ‘92	6	6	0.3	11	2	—	D
Polychlorinated biphenyls	1336-36-3	Previous	F	zero	0.0005	D ‘93	—	—	—	—	—	0.01	B2
Pyrene	129-00-0	Previous	—	—	—	—	—	—	0.03	—	—	—	D

Chemical	CAS number	New or previous	Standards			Status HA docu-ment	Health advisories						Cancer descrip-tor[1]
							10-kg Child						
			Status reg.	MCLG (mg/L)	MCL (mg/L)		1-day (mg/L)	10-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer risk	
Selenium	7782-49-2	Previous	F	0.05	0.05	—	—	—	0.005	0.2	0.05	—	D
Silver[8]	7440-22-4	Previous	—	—	—	F '92	0.2	0.2	0.005	0.2	0.13	—	D
Styrene	100-42-5	Previous	F	0.1	0.1	F '87	20	2	0.2	7	0.1	—	C
Tetrachloroethylene[3]	127-18-4	Previous	F	zero	0.005	F '87	2	2	0.01	0.5	0.01	—	—
Thallium	7440-28-0	Previous	F	0.0005	0.002	F '92	0.007	0.007	—	—	—	—	I
Toluene	108-88-3	Previous	F	1	1	D '93	20	2	0.08	3	—	—	I
Zinc	7440-66-6	Previous	—	—	—	D '93	6	6	0.3	10	2	—	I

Notes:

CAS = Chemical Abstracts Service; D = Draft; DWEL = Drinking Water Equivalent Level; F = Final; HA = Health Advisory; MCL = Maximum Contaminant Level; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process; RfD = Reference Dose; TT = Treatment Technique; VA = Value Available (Toxicity data may be available for this chemical or a chemical in the same family. When comparing available EPA's National Primary Drinking Water Regulations to the list of chemicals found in biosolids, some chemicals were reported using the same name but different CASRN. A chemical may be listed with multiple CASRN if: (1) there are different forms of a chemical where each is considered unique for its particular properties of characteristics; or (2) when multiple CASRN have inadvertently been assigned to the same chemical. Further evaluation would be needed to determine whether the toxicity data is relevant.)

Cancer Classification: A descriptive weight-of-evidence judgment as to the likelihood that an agent is a human carcinogen and the conditions under which the carcinogenic effects may be expressed. Under the 2005 EPA Guidelines for Carcinogen Risk Assessment, Cancer Descriptors replace the earlier alpha numeric Cancer Group designations (U.S. EPA 1986 guidelines). The Cancer Descriptors in the 2005 EPA Guidelines for Carcinogen Risk Assessment are as follows: "carcinogenic to humans" (H); "likely carcinogenic to humans" (L); "likely to be carcinogenic above a specified dose but not likely to be carcinogenic below that dose because a key event in tumor formation does not occur below that dose" (L/N); "suggestive evidence of carcinogenic potential" (S); "inadequate information to assess carcinogenic potential" (I); and "not likely to be carcinogenic to humans" (N). The letter abbreviations provided parenthetically above are now used in the DWSHA tables in place of the prior alpha numeric identifiers for chemicals that have been evaluated under the new guidelines (the 2005 guidelines or the 1996 and 1999 draft guidelines) or whose records in the DWSHA tables have been revised. Cancer Group: A qualitative weight-of-evidence judgment as to the likelihood that a chemical may be a carcinogen for humans. Each chemical was placed into one of the following five categories (U.S. EPA 1986 guidelines). The Cancer Group designations are given in the tables for chemicals that have not yet been evaluated under the new guidelines or whose records in the DWSHA tables have been revised. Group categories: (A) Human carcinogen; (B) Probable human carcinogen: (B1) Indicates limited human evidence, (B2) Indicates sufficient evidence in animals and inadequate or no evidence in humans; (C) Possible human carcinogen; (D) Not classifiable as to human carcinogenicity; (E) Evidence of noncarcinogenicity for humans.

[1] Chemicals evaluated under the 2005 Cancer Guidelines or the 1996 or 1999 drafts are demoted by an abbreviation for their weight-of-the-evidence descriptor (see page iii). If the agency has not completed a new assessment for the chemical, the 1986 Guidelines Group designation (see page iii) is given in the Cancer Descriptor column.

[2] The values for m-dichlorobenzene are based on data for o-dichlorobenzene.

[3] Under review at the time of publication 2018 document.

[4] RfD from IRIS value for chromium VI.

[5] MCL copper action level 1.3 mg/L.

[6] MCL lead action level 0.015 mg/L.

[7] RfD from Dietary manganese. The lifetime health advisory includes a 3-fold modifying factor to account for increased bioavailability from drinking water.

[8] RfD based on a cosmetic effect.

Appendix E: Ecological Toxicity Data

Table E-1. Summary of Papers Found in ECOTOX for Chemicals Newly Identified in Biosolids in the 2020–2021 Reporting Period

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
2-(N-Ethylperfluorooctanesulfonamido)acetic acid	2991-50-6	0	0	1	1
Fentanyl	437-38-7	1	1	0	0
Losartan	114798-26-4	0	0	1	1
Methadone	76-99-3	1	1	0	0
Perfluorohexadecanoic acid	67905-19-5	1	1	1	1

Notes:
CAS = Chemical Abstracts Service

Table E-2. Summary of Papers Found in ECOTOX for Chemicals Identified in Biosolids During the Curation Process

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
(E)-1,2-Dichloroethylene	156-60-5	4	3	3	6
1,1,1-Trichloroethane	71-55-6	16	18	20	35
1,2,3,4,6,7,8-Heptachlorodibenzo[b,d]furan	67562-39-4	0	0	1	1
1,2,3,7,8,9-Hexachlorodibenzo[b,d]furan	72918-21-9	0	0	1	1
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321-76-4	0	0	4	10
1,2,3-Trichlorobenzene	87-61-6	2	4	17	44
1,2,4-Trichlorobenzene	120-82-1	28	20	53	85
1,2-Dichlorobenzene	95-50-1	20	32	49	89
1,2-Dichloropropane	78-87-5	10	25	12	19
1,4-Dinitrobenzene	100-25-4	0	0	7	8
1,4-Dioxane	123-91-1	8	6	19	25
1-Methyl phenanthrene	832-69-9	1	1	2	2
2-(2,4,5-Trichlorophenoxy)propionic acid	93-72-1	70	39	22	17
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	40186-72-9	0	0	1	1
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	35694-08-7	0	0	5	6
2,2',3,3',4,4',5,6-Octachlorobiphenyl	52663-78-2	0	0	1	1
2,2',3,3',4,4',6-Heptachlorobiphenyl	52663-71-5	0	0	1	2
2,2',3,3',4,5,5',6-Octachlorobiphenyl	68194-17-2	0	0	1	1
2,2',3,3',4,5,6-Heptachlorobiphenyl	68194-16-1	0	0	1	1
2,2',3,3',4,5'-Hexachlorobiphenyl	52663-66-8	0	0	1	1
2,2',3,3',5,5',6,6'-Octachlorobiphenyl	2136-99-4	0	0	1	1
2,2',3,3',5,5'-Hexachlorobiphenyl	35694-04-3	0	0	1	2
2,2',3,3'-Tetrachlorobiphenyl	38444-93-8	0	0	2	2
2,2',3,4,4',5',6-Heptachlorobiphenyl	52663-69-1	0	0	1	1
2,2',3,4,4',6,6'-Heptachlorobiphenyl	74472-48-3	0	0	1	1
2,2',3,4,5,5',6-Heptachlorobiphenyl	52712-05-7	0	0	1	1
2,2',3,4,5,5'-Hexachlorobiphenyl	52712-04-6	0	0	2	2
2,2',3,4',5,6,6'-Heptachlorobiphenyl	74487-85-7	0	0	1	1
2,2',3,4,5,6'-Hexachlorobiphenyl	68194-15-0	0	0	1	1
2,2',3,4',5'-Pentachlorobiphenyl	41464-51-1	0	0	1	1
2,2',3,5,5',6-Hexachlorobiphenyl	52663-63-5	0	0	1	1
2,2',3,5'-tetrachlorobiphenyl	41464-39-5	0	0	1	1
2,2',4,4',6,6'-Hexachlorobiphenyl	33979-03-2	0	0	4	3
2,2',4,4',6-Pentabromodiphenyl ether	189084-64-8	0	0	3	3
2,2',4,4',6-Pentachlorobiphenyl	39485-83-1	2	1	6	6
2,2',4,6,6'-Pentachlorobiphenyl	56558-16-8	0	0	4	3
2,2',4,6-Tetrachlorobiphenyl	62796-65-0	1	1	3	4

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
2,2',5-Trichlorobiphenyl	37680-65-2	1	1	8	11
2,2',6,6'-Tetrachlorobiphenyl	15968-05-5	0	0	1	1
2,2'-Bioxirane	1464-53-5	2	3	2	2
2,3,3',4',6-Pentachlorobiphenyl	38380-03-9	0	0	2	2
2,3,3',5'-Tetrachlorobiphenyl	41464-49-7	0	0	1	1
2,3,3'-Trichlorobiphenyl	38444-84-7	0	0	2	1
2,3',4,4',6-Pentachlorobiphenyl	56558-17-9	0	0	1	1
2,3,4,4'-Tetrachlorobiphenyl	33025-41-1	0	0	2	1
2,3,4,5,6-Pentachlorobiphenyl	18259-05-7	0	0	2	2
2,3,4,5-Tetrachlorobiphenyl	33284-53-6	0	0	2	3
2,3',4',5-Tetrachlorobiphenyl	32598-11-1	0	0	2	2
2,3,5,6-Tetrachlorobiphenyl	33284-54-7	0	0	1	1
2,4,4',6-Tetrachlorobiphenyl	32598-12-2	0	0	1	1
2,4,4'-Tribromodiphenyl ether	41318-75-6	3	1	2	2
2,4,4'-Trichlorobiphenyl	7012-37-5	0	0	6	6
2,4,5-Trichlorobiphenyl	15862-07-4	1	1	4	3
2,4,5-Trichlorophenoxyacetic acid	93-76-5	67	77	46	48
2,4,5-Trimethylaniline	137-17-7	2	1	0	0
2,4,6-Trichlorobiphenyl	35693-92-6	0	0	1	1
2,4-Dichlorobiphenyl	33284-50-3	0	0	4	5
2,5-Dichlorobiphenyl	34883-39-1	0	0	5	4
2,6-Dinitrotoluene	606-20-2	10	6	15	24
2-Chloro-4-phenylphenol	92-04-6	0	0	2	1
2-Hexanone	591-78-6	2	3	3	3
2-Methylpyridine	109-06-8	0	0	2	2
2-Methyl-1-propanol	78-83-1	3	6	37	22
3,3',5,5'-Tetrachlorobiphenyl	33284-52-5	1	1	2	2
3,4-Dichlorobiphenyl	2974-92-7	0	0	1	2
3,5-Dichlorobiphenyl	34883-41-5	0	0	1	1
3,6-Dimethylphenanthrene	1576-67-6	0	0	1	2
3-Chlorobiphenyl	2051-61-8	0	0	5	6
4,4'-Dichlorobiphenyl	2050-68-2	1	1	11	11
4-Androstene-3,17-dione	63-05-8	0	0	3	4
4-Chloro-3-methylphenol	59-50-7	2	3	13	21
4-Methyl-2-pentanone	108-10-1	3	3	14	32
Acenaphthene	83-32-9	8	11	24	34
Aldrin	309-00-2	67	57	136	175
Allyl alcohol	107-18-6	3	5	16	11

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
Allyl chloride	107-05-1	3	3	13	17
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	319-84-6	4	4	34	33
alpha-Terpineol	98-55-5	11	9	4	5
Aroclor 1248	12672-29-6	6	6	27	31
Aroclor 1254	11097-69-1	35	74	135	235
Aroclor 1260	11096-82-5	9	13	30	32
Azinphos-methyl	86-50-0	138	172	136	154
Bensulide	741-58-2	137	144	14	17
Benzene	71-43-2	19	23	90	153
Benzenethiol	108-98-5	1	2	4	2
Benzo(g,h,i)perylene	191-24-2	1	1	4	6
Benzyl alcohol	100-51-6	7	10	13	15
Benzyl butyl phthalate	85-68-7	12	15	39	92
beta-Hexachlorocyclohexane	319-85-7	5	3	22	27
Biphenyl	92-52-4	6	19	20	36
Bisphenol A	80-05-7	36	39	96	279
Caffeine	58-08-2	12	21	32	49
Captan	133-06-2	160	294	51	49
Carbadox	6804-07-5	0	0	1	1
Carbon disulfide	75-15-0	28	50	11	11
Carbophenothion	786-19-6	26	18	38	27
Chlorobenzene	108-90-7	9	15	39	80
Chlorobenzilate	510-15-6	13	9	13	11
Chloroethane	75-00-3	1	1	2	1
Chloromethane	74-87-3	0	0	5	4
Chlorpyrifos	2921-88-2	1270	748	349	784
Clomazone	81777-89-1	16	44	17	32
Crotonaldehyde	4170-30-3	3	3	9	4
Crotoxyphos	7700-17-6	13	16	14	8
Cyanide	57-12-5	8	5	33	29
Decane	124-18-5	4	9	7	7
delta-Hexachlorocyclohexane	319-86-8	1	1	22	16
Diallate	2303-16-4	9	11	3	3
Diazinon	333-41-5	301	415	429	220
Dibenzofuran	132-64-9	0	0	11	12
Dibenzothiophene	132-65-0	1	1	10	8
Dichlorodiphenyltrichloroethane	50-29-3	219	283	325	610
Dichloromethane	75-09-2	14	18	40	55

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
Dicrotophos	141-66-2	69	84	20	25
Dieldrin	60-57-1	130	181	277	184
Diphenyl oxide	101-84-8	3	2	11	13
Diphenylamine	122-39-4	5	5	15	10
Docosane	629-97-0	1	1	4	7
Dodecane	112-40-3	5	5	3	3
Eicosane	112-95-8	1	1	0	0
Endrin	72-20-8	54	54	200	169
EPN	2104-64-5	20	26	56	44
Heptachlor	76-44-8	41	36	105	114
Hexabromocyclododecane	25637-99-4	7	11	28	24
Hexadecane	544-76-3	3	4	2	2
Iodine	7553-56-2	3	3	10	14
Leptophos	21609-90-5	39	16	20	36
Lindane	58-89-9	101	95	517	249
Methacrylonitrile	126-98-7	1	1	0	0
Methyl ethyl ketone	78-93-3	4	4	16	28
Methyl triclosan	4640-01-1	0	0	1	1
Mevinphos	7786-34-7	38	38	29	41
Naled	300-76-5	56	54	58	69
Nitrobenzene	98-95-3	6	5	58	25
o-Cresol	95-48-7	21	14	51	44
Octacosane	630-02-4	0	0	1	1
Octadecane	593-45-3	2	2	0	0
p,p'-DDD	72-54-8	9	12	54	52
p,p'-DDE	72-55-9	27	80	53	81
p-Cymene	99-87-6	10	15	9	8
Pentachlorophenol	87-86-5	97	77	470	235
Perylene	198-55-0	3	4	5	8
Phenanthrene	85-01-8	34	48	83	142
Phosphamidon	13171-21-6	58	60	136	80
Potassium	7440-09-7	3	4	2	2
Propionitrile	107-12-0	0	0	2	2
Quinine	130-95-0	2	2	2	2
Silicon	7440-21-3	1	1	0	0
Strontium	7440-24-6	0	0	10	8
Tetradecane	629-59-4	1	2	1	1
Tetraethyl pyrophosphate	107-49-3	16	18	17	19

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
Thioxanthen-9-one	492-22-8	0	0	1	3
Trichloroethylene	79-01-6	39	56	85	64
Trifluralin	1582-09-8	349	370	106	86
Tri-o-cresyl phosphate	78-30-8	11	6	6	6
Triphenylene	217-59-4	0	0	4	6
Valproic acid	99-66-1	2	3	2	7

Notes:
CAS = Chemical Abstracts Service

Table E-3. Summary of Papers Found in ECOTOX in the 2020–2021 Reporting Period for Chemicals Previously Identified in Biosolids

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
(+)-Diltiazem	42399-41-7	0	0	1	1
(+/-)-Verapamil	52-53-9	0	0	1	1
1-(p-Chlorobenzoyl)-5-methoxy-2-methyl-Indole-3-acetic acid	53-86-1	0	0	1	1
1,1'-Ethane-1,2-diylbis(pentabromobenzene)	84852-53-9	1	1	0	0
1,1'-Oxybis[2,3,4,5,6-pentabromobenzene]	1163-19-5	0	0	1	1
17alpha-Ethinylestradiol	57-63-6	2	2	14	4
17beta-Estradiol	50-28-2	2	1	3	7
2,2',4,4',5,5'-Hexachlorobiphenyl	35065-27-1	0	0	1	1
2,2',4,4'-Tetrabromodiphenyl ether	5436-43-1	0	0	2	2
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	0	0	1	1
2,4-Dichlorophenol	120-83-2	0	0	1	1
2,4-Dichlorophenoxyacetic acid	94-75-7	2	2	1	1
2H,2H,3H,3H-Perfluorooctanoic acid	914637-49-3	0	0	1	1
3,3',4,4',5-Pentachlorobiphenyl	57465-28-8	0	0	1	3
3,3',5,5'-Tetrabromobisphenol A	79-94-7	1	1	1	1
4-Nonylphenol, branched	84852-15-3	0	0	3	1
6:2 Fluorotelomer phosphate diester	57677-95-9	1	1	0	0
6:2 Fluorotelomer sulfonic acid	27619-97-2	0	0	1	2
7-Acetyl-1,1,3,4,4,6-hexamethyltetraline	21145-77-7	0	0	2	1
8:2 Fluorotelomer sulfonic acid	39108-34-4	0	0	1	1
Acetaminophen	103-90-2	0	0	1	1
Acetone	67-64-1	2	2	2	3
Amoxicillin	26787-78-0	0	0	2	1
Ampicillin	69-53-4	1	1	0	0
Arsenic	7440-38-2	1	1	2	2
Aspirin	50-78-2	0	0	1	1
Atenolol	29122-68-7	0	0	1	1
Atorvastatin	134523-00-5	0	0	1	1
Azithromycin	83905-01-5	0	0	2	1
Benzo(a)pyrene	50-32-8	3	3	3	5
Benzo(b)fluoranthene	205-99-2	0	0	1	1
Benzoic acid	65-85-0	1	1	0	0
Bezafibrate	41859-67-0	0	0	1	1
Bis(1,3-dichloropropan-2-yl) hydrogen phosphate	72236-72-7	0	0	1	1
Bis(2-chloroethyl) phosphate	3040-56-0	0	0	1	1
Butylparaben	94-26-8	1	1	0	0

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
Carbamazepine	298-46-4	1	1	3	4
Chloroform	67-66-3	1	1	0	0
Cimetidine	51481-61-9	0	0	1	1
Ciprofloxacin	85721-33-1	6	1	2	2
Clofibric acid	882-09-7	0	0	1	1
Clorophene	120-32-1	0	0	1	1
Cocaine	50-36-2	0	0	1	1
Cyclopenta[g]-2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethyl-	1222-05-5	0	0	1	1
Di(2-ethylhexyl) phthalate	117-81-7	2	2	5	5
Diazepam	439-14-5	1	1	1	1
Dibutyl phthalate	84-74-2	1	1	3	6
Diclofenac	15307-86-5	6	1	12	4
Dimethoate	60-51-5	3	6	2	2
Dimethyl phthalate	131-11-3	1	1	1	1
Di-n-octyl phthalate	117-84-0	0	0	1	1
Diphenyl phosphate	838-85-7	0	0	1	1
Doxycycline	564-25-0	0	0	1	1
Endosulfan I	959-98-8	1	1	0	0
Endosulfan II	33213-65-9	1	1	0	0
Enrofloxacin	93106-60-6	0	0	3	3
Ethylparaben	120-47-8	1	1	0	0
Fenofibric acid	42017-89-0	0	0	1	1
Fenthion	55-38-9	1	1	0	0
Fipronil	120068-37-3	2	2	5	4
Fluoranthene	206-44-0	0	0	1	1
Fluoxetine	54910-89-3	0	0	1	1
Furosemide	54-31-9	0	0	1	1
Gemfibrozil	25812-30-0	0	0	1	1
Hexabromobenzene	87-82-1	0	0	1	1
Ibuprofen	15687-27-1	0	0	1	1
Ketoprofen	22071-15-4	1	1	2	2
Methamphetamine	537-46-2	0	0	1	1
Methylparaben	99-76-3	1	1	0	0
Metoprolol	51384-51-1	0	0	1	1
Monuron	150-68-5	1	1	0	0
Naphthalene	91-20-3	0	0	1	1
Naproxen	22204-53-1	0	0	1	1

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
Nitrofen	1836-75-5	1	1	0	0
Norethindrone	68-22-4	0	0	1	1
Norfloxacin	70458-96-7	0	0	6	4
Norfluoxetine	83891-03-6	0	0	1	1
Ofloxacin	82419-36-1	1	1	0	0
Oxytetracycline	79-57-2	1	1	0	0
Pentachloronitrobenzene	82-68-8	1	1	0	0
Perfluorobutanesulfonic acid	375-73-5	1	1	3	4
Perfluorobutanoic acid	375-22-4	2	1	1	2
Perfluorodecanoic acid	335-76-2	0	0	1	1
Perfluorododecanoic acid	307-55-1	0	0	1	1
Perfluoroheptanoic acid	375-85-9	0	0	2	3
Perfluorohexanesulfonic acid	355-46-4	1	1	3	4
Perfluorohexanoic acid	307-24-4	1	1	2	5
Perfluorononanoic acid	375-95-1	0	0	10	8
Perfluorooctanesulfonamide	754-91-6	1	1	3	4
Perfluorooctanesulfonic acid	1763-23-1	5	5	18	21
Perfluorooctanoic acid	335-67-1	20	18	31	30
Perfluoropentanoic acid	2706-90-3	0	0	1	2
Perfluorotridecanoic acid	72629-94-8	1	1	1	1
Perfluoroundecanoic acid	2058-94-8	1	1	2	2
Phenol	108-95-2	0	0	1	1
Polyethylene glycol	25322-68-3	1	1	0	0
Propranolol	525-66-6	0	0	1	1
Propylparaben	94-13-3	1	1	1	1
Roxithromycin	80214-83-1	0	0	2	2
Silver	7440-22-4	0	0	2	2
Sulfadiazine	68-35-9	2	1	2	2
Sulfamethazine	57-68-1	0	0	2	2
Sulfamethoxazole	678-41-1	0	0	1	1
Sulfamethoxazole	723-46-6	0	0	1	1
Sulfur	7704-34-9	1	1	0	0
Tetracycline	60-54-8	0	0	5	1
Thiabendazole	148-79-8	3	3	0	0
Trichlorfon	52-68-6	1	1	0	0
Triclocarban	101-20-2	0	0	2	2
Triclosan	3380-34-5	0	0	2	2
Triphenyl phosphate	115-86-6	1	2	1	2

Chemical	CAS number	# of terrestrial species	# of papers terrestrial	# of aquatic species	# of papers aquatic
Tris(1,3-dichloro-2-propyl) phosphate	13674-87-8	0	0	1	2
Tris(2-chloroethyl) phosphate	115-96-8	0	0	2	2
Tris(2-ethylhexyl) phosphate	78-42-2	0	0	1	1
Valsartan	137862-53-4	0	0	1	1
Yttrium	7440-65-5	1	1	0	0

Notes:
CAS = Chemical Abstracts Service

Table E-4. EPA's National Recommended Water Quality Criteria – Aquatic Life Criteria for Chemicals Found in Biosolids

Chemical	CAS number	New or Previous	Freshwater criteria maximum concentration (acute) (µg/L)	Freshwater criteria continuous concentration (chronic) (µg/L)	Saltwater criteria maximum concentration (acute) (µg/L)	Saltwater criteria continuous concentration (chronic) (µg/L)	Publication year
Aldrin	309-00-2	Previous*	3	—	1.3	—	1980
Azinphos-methyl	86-50-0	Previous*	—	0.01	—	0.01	1986
Chlorpyrifos	2921-88-2	Previous*	0.083	0.041	0.011	0.0056	1986
Cyanide	57-12-5	Previous*	22	5.2	1	1	1985
Diazinon	333-41-5	Previous*	0.17	0.17	0.82	0.82	2005
Dichlorodiphenyltrichloroethane	50-29-3	Previous*	1.1	0.001	0.13	0.001	1980
Dieldrin	60-57-1	Previous*	0.24	0.056	0.71	0.0019	1995
Endrin	72-20-8	Previous*	0.086	0.036	0.037	0.0023	1995
Heptachlor	76-44-8	Previous*	0.52	0.0038	0.053	0.0036	1980
Lindane	58-89-9	Previous*	0.95	—	0.16	—	1995
Pentachlorophenol	87-86-5	Previous*	19	15	13	7.9	1995
4-Nonylphenol, branched	84852-15-3	Previous	28	6.6	7	1.7	2005
Aluminum	7429-90-5	Previous	—	—	—	—	2018
Arsenic	7440-38-2	Previous	340	150	69	36	1995
Boron	7440-42-8	Previous	VA	VA	VA	VA	
Cadmium	7440-43-9	Previous	1.8	0.72	33	7.9	2016
Chromium	7440-47-3	Previous	VA	VA	VA	VA	
Copper	7440-50-8	Previous	—	—	4.8	3.1	2007
Endosulfan I	959-98-8	Previous	0.22	0.056	0.034	0.0087	1980
Endosulfan II	33213-65-9	Previous	0.22	0.056	0.034	0.0087	1980
Heptachlor epoxide B	1024-57-3	Previous	0.52	0.0038	0.053	0.0036	1981
Iron	7439-89-6	Previous	—	1000	—	—	1986
Lead	7439-92-1	Previous	65	2.5	210	8.1	1984
Mercury	7439-97-6	Previous	1.4	0.77	1.8	0.94	1995
Nickel	7440-02-0	Previous	470	52	74	8.2	1995

Chemical	CAS number	New or Previous	Freshwater criteria maximum concentration (acute) (µg/L)	Freshwater criteria continuous concentration (chronic) (µg/L)	Saltwater criteria maximum concentration (acute) (µg/L)	Saltwater criteria continuous concentration (chronic) (µg/L)	Publication year
Perfluorooctanesulfonic acid	1763-23-1	Previous	DA	DA	DA	DA	
Perfluorooctanoic acid	335-67-1	Previous	DA	DA	DA	DA	
Selenium	7782-49-2	Previous	—	—	290	71	2016 Freshwater, 1999 Saltwater
Silver	7440-22-4	Previous	3.2	—	1.9	—	1980
Zinc	7440-66-6	Previous	120	120	90	81	1995

Notes:
CAS = Chemical Abstracts Service; DA = Draft Available (At the time of publication, a draft value was available. This value is subject to change.); Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process; VA = Value Available (Toxicity data may be available for this chemical or a chemical in the same family. When comparing available Aquatic Life Criteria to the list of chemicals found in biosolids, some chemicals were reported using the same name but different CASRN. A chemical may be listed with multiple CASRN if (1) there are different forms of a chemical where each is considered unique for its particular properties of characteristics; or (2) when multiple CASRN have inadvertently been assigned to the same chemical. Further evaluation would be needed to determine whether the toxicity data is relevant).

Table E-5. EPA's Aquatic Life Benchmarks for Registered Pesticides for Chemicals Found in Biosolids

Chemical	CAS number	New or previous	Year up-dated	Fish		Invertebrates		Non-vascular plants[5] (µg/L)	Vascular plants[6] (µg/L)
				Acute[1] (µg/L)	Chronic[2] (µg/L)	Acute[3] (µg/L)	Chronic[4] (µg/L)		
Azinphos-methyl	86-50-0	Previous*	2016	0.18	0.44	0.08	0.25		
Bensulide	741-58-2	Previous*	2016	550	169	290	11	780	140
Captan	133-06-2	Previous*	2014	13.1	16.5	4200	560	320	> 12700
Carbon disulfide	75-15-0	Previous*		435		430		520	
Chlorpyrifos	2921-88-2	Previous*	2022	0.85	< 0.251	0.0069	< 0.005	140	
Clomazone	81777-89-1	Previous*		1450	350	2700	2200	167	30200
Diazinon	333-41-5	Previous*	2016	45	< 0.55	0.105	0.17	3700	
Dicrotophos	141-66-2	Previous*	2015	2850	9880	6.3	1.7	> 118000	> 117000
EPN	2104-64-5	Previous*	2016						
Lindane	58-89-9	Previous*	2016	0.85	2.9	0.5	54		
Mevinphos	7786-34-7	Previous*	2016						
Naled	300-76-5	Previous*	2021	46	3.4	0.0575	0.01	24	> 1800
Pentachlorophenol	87-86-5	Previous*		47.5		25			
Trifluralin	1582-09-8	Previous*	2016	9.25	1.9	125.5	2.4	21.9	49.7
2,4-Dichlorophenoxyacetic acid	94-75-7	Previous	2016			12500			299.2
Acetaminophen	103-90-2	Previous	2015			14750			
Benzoic acid	65-85-0	Previous	2022			> 50000			
Copper	7440-50-8	Previous		15.7	9.01	2.05	1.11	3.1	2300
DEET	134-62-3	Previous	2015	37500		37500			
Dimethoate	60-51-5	Previous	2016	3100	430	21.5	0.5	20000	> 92600
D-Limonene	5989-27-5	Previous	2017	40000		19500		9353	29650
Fenthion	55-38-9	Previous	2016	415	7.5	2.6	0.013	400	> 2800
Fipronil	120068-37-3	Previous	2021	41.5	6.6	0.11	0.011	76	> 100
Melamine	108-78-1	Previous	2015	> 60000	500000	30000	18000	940000	
Oxytetracycline	79-57-2	Previous	2020	> 28200	8850	> 29700	13500	125	3044
Pentachloronitrobenzene	82-68-8	Previous		50	13	385	18		

Chemical	CAS number	New or previous	Year up-dated	Fish		Invertebrates		Non-vascular plants[5] (µg/L)	Vascular plants[6] (µg/L)
				Acute[1] (µg/L)	Chronic[2] (µg/L)	Acute[3] (µg/L)	Chronic[4] (µg/L)		
Thiabendazole	148-79-8	Previous	2020	280	110	155	42	1420	2320
Trichlorfon	52-68-6	Previous	2021	58.5	6.1	0.0389	0.0057	16300	70600

Notes:

CAS = Chemical Abstracts Service; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process

Empty cells indicate that acceptable aquatic toxicity values are not available.

Benchmarks preceded by a "greater-than" symbol (for example, >265,000) were derived from a "greater-than" value and may overestimate toxicity. Conversely, benchmarks preceded by a "less-than" symbol (for example, <1,500) were derived from a "less-than" value and may underestimate toxicity.

Values in bold are those that changed in the September 2022 update.

[1] Benchmark = Toxicity value x LOC. For acute fish, toxicity value is generally the lowest 96-hour LC50 in a standardized test (usually with rainbow trout (*Oncorhynchus mykiss*); fathead minnow (*Pimephales promelas*); bluegill sunfish (*Lepomis macrochirus*)), and the LOC is 0.5.

[2] Benchmark = Toxicity value x LOC. For chronic fish, toxicity value is usually the lowest NOEAC from a life-cycle or early life stage test (usually with rainbow trout (*Oncorhynchus mykiss*) or fathead minnow (*Pimephales promelas*)), and the LOC is 1.

[3] Benchmark = Toxicity value x LOC. For acute invertebrate, toxicity value is usually the lowest 48- or 96-hour EC50 or LC50 in a standardized test, and the LOC is 0.5.

[4] Benchmark = Toxicity value x LOC. For chronic invertebrates, toxicity value is usually the lowest NOAEC from a life-cycle test with invertebrates, and the LOC is 1.

[5] Benchmark = Toxicity value x LOC. For nonvascular plants, toxicity value is usually a short-term (less than 10 days) EC50 (usually with green algae or diatoms), and the LOC is 1.

[6] Benchmark = Toxicity value x LOC. For vascular plants, toxicity value is usually a short-term (less than 10 days) EC50 (usually with duckweed), and the LOC is 1.

Appendix F: Environmental Fate and Transport Data: Bioaccumulation and Bioconcentration Data

Table F-1. Bioaccumulation and Bioconcentration Factors as Reported in the Literature, Arnot & Gobas 2006, and Environment and Climate Change Canada for Newly and Previously Identified Chemicals in Biosolids

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,1,1-Trichloroethane	Previous*	NA	71-55-6	0.40	BCF	*Cyprinodontidae*	Killifish	ECCC 2020
1,1,1-Trichloroethane	Previous*	NA	71-55-6	0.27	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,1,1-Trichloroethane	Previous*	NA	71-55-6	0.46	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,1,1-Trichloroethane	Previous*	NA	71-55-6	0.46	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
1,1,1-Trichloroethane	Previous*	NA	71-55-6	0.27	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
1,1,1-Trichloroethane	Previous*	NA	71-55-6	0.40	BCF	*Cyprinodontidae*	Killifish	Arnot & Gobas 2006
1,1,1-Trichloroethane	Previous*	NA	71-55-6	0.95	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.34	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.63	BCF	*Gambusia affinis*	Western mosquitofish	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.82	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.82	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.90	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	1.72	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.03	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.85	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.85	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.00	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.04	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.11	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.20	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.36	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.46	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.52	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.15	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.28	BCF	*Poecilia reticulata*	Guppy	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.25	BCF	Various	Phytoplankton	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.95	BAF	*Pontoporeia hoyi*	Amphipod	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.77	BAF	*Mysis relicta*	Shrimp	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.28	BAF	*Callinectes sapidus*	Blue crab	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.47	BAF	*Callinectes sapidus*	Blue crab	ECCC 2020
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.28	BAF	*Callinectes sapidus*	Blue crab	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.95	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.77	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.47	BAF	*Callinectes sapidus*	Blue crab	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.25	BCF	Various	Phytoplankton	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.34	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.63	BCF	*Gambusia affinis*	Western mosquitofish	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.82	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.82	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.90	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.85	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.03	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	1.72	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.85	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.52	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.36	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.46	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.20	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.11	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.04	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.00	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.28	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.15	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.04	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	3.40	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.52	BAF	*Brevoortia patronus*	Gulf menhaden	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.43	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.53	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.60	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.11	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.04	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.08	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.28	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.48	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.38	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.64	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.26	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.15	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.75	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.72	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.36	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.34	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.60	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.18	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.28	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.30	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.31	BCF	*Jordanella floridae*	Flagfish	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.86	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.89	BCF	*Cyprinus carpio*	Common carp	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.93	BCF	*Leiostomus xanthurus*	Spot	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.16	BCF	*Leiostomus xanthurus*	Spot	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.84	BCF	*Leiostomus xanthurus*	Spot	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.13	BCF	*Leiostomus xanthurus*	Spot	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.54	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.61	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.21	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.19	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.25	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.12	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.26	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.11	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.15	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.07	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.04	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.20	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.03	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.18	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.24	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.13	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.08	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.13	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.06	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.03	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.03	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.09	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.59	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.66	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.62	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.68	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.65	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.51	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.60	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.48	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.63	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.71	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.43	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.51	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.58	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.72	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.46	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.00	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.84	BCF	*Penaeus duorarum*	Northern pink shrimp	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.40	BCF	*Chlorella fusca*	Green algae	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.99	BCF	Various	Phytoplankton	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.47	BAF	*Cottus cognatus*	Sculpin	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.00	BAF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.34	BAF	*Fundulus heteroclitus*	Mummichog	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.41	BAF	*Micropogonias undulatus*	Atlantic croaker	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.10	BAF	*Micropogonias undulatus*	Atlantic croaker	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.90	BAF	*Cynoscion nebulosis*	Spotted sea trout	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.20	BAF	*Ichtalurus furcatus*	Blue catfish	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.91	BAF	*Tubifex tubifex*	Oligocheate	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	4.10	BAF	*Pontoporeia hoyi*	Amphipod	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.60	BAF	*Mysis relicta*	Shrimp	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.60	BAF	*Callinectes sapidus*	Blue crab	ECCC 2020
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.91	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	4.10	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.60	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.60	BAF	*Callinectes sapidus*	Blue crab	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.52	BAF	*Brevoortia patronus*	Gulf menhaden	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.34	BAF	*Fundulus heteroclitus*	Mummichog	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.41	BAF	*Micropogonias undulatus*	Atlantic croaker	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.47	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.00	BAF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.10	BAF	*Micropogonias undulatus*	Atlantic croaker	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.90	BAF	*Cynoscion nebulosis*	Spotted sea trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.20	BAF	*Ichtalurus furcatus*	Blue catfish	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.99	BCF	Various	Phytoplankton	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.40	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.84	BCF	*Penaeus duorarum*	Northern pink shrimp	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.15	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.22	BCF	*Chironomus decorus*	Midge	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.43	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.72	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.71	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.68	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.66	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.65	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.63	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.61	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.62	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.60	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.58	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.51	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.51	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.48	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.43	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.46	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.89	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.86	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.54	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.59	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.26	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.25	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.24	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.21	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.20	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.19	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.18	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.15	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.13	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.13	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.12	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.11	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.09	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.08	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.07	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.06	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.04	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.03	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.03	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.03	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.48	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.60	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.53	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.28	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.11	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.08	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.04	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.30	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.28	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.60	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.75	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.72	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.64	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.34	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.36	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.18	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.38	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.26	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.15	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.31	BCF	*Jordanella floridae*	Flagfish	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.16	BCF	*Leiostomus xanthurus*	Spot	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.13	BCF	*Leiostomus xanthurus*	Spot	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.93	BCF	*Leiostomus xanthurus*	Spot	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	1.84	BCF	*Leiostomus xanthurus*	Spot	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.00	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.04	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.46	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.69	BCF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.26	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.32	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.32	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.95	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	3.37	BCF	*Lepomis cyanellus*	Green sunfish	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.60	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.60	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.00	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.00	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.41	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.51	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.34	BAF	*Ichtalurus furcatus*	Blue catfish	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.70	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.85	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.83	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.48	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.43	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.40	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.40	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.60	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.41	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.70	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.24	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.28	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.28	BAF	*Micropogonias undulatus*	Atlantic croaker	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.15	BAF	*Cynoscion nebulosis*	Spotted sea trout	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.16	BAF	*Callinectes sapidus*	Blue crab	ECCC 2020
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.16	BAF	*Callinectes sapidus*	Blue crab	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.34	BAF	*Ichtalurus furcatus*	Blue catfish	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.28	BAF	*Micropogonias undulatus*	Atlantic croaker	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.15	BAF	*Cynoscion nebulosis*	Spotted sea trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	4.29	BCF	*Selenastrum capricornutum*	Green algae	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	1.49	BCF	*Chironomus decorus*	Midge	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.70	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.28	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.24	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.70	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.85	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.83	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.60	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.48	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.43	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.41	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.40	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.40	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.70	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.40	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
1,2-Dichlorobenzene	Previous*	NA	95-50-1	2.35	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
1,2-Dichlorobenzene	Previous*	NA	95-50-1	1.95	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
1,2-Dichloropropane	Previous*	NA	78-87-5	0.35	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,2-Dichloropropane	Previous*	NA	78-87-5	0.57	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,4-Dinitrobenzene	Previous*	NA	100-25-4	-0.40	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
1,4-Dioxane	Previous*	NA	123-91-1	-0.40	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
1,4-Dioxane	Previous*	NA	123-91-1	-0.30	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	Previous*	206	40186-72-9	5.38	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.66	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.25	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.06	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.20	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.27	BAF	*Salvelinus namaycush*	Lake trout	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.92	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.21	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.16	BAF	*Osmerus mordax*	Rainbow smelt	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.97	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.97	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.93	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.28	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.47	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.89	BAF	*Ambloplites rupestris*	Rock bass	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.82	BAF	*Noturus flavus*	Stonecat	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.18	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.12	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.52	BAF	*Moxostoma macrolepidotum*	Shorthead redhorse	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.30	BAF	*Cottus bairdi*	Mottled sculpin	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.82	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.00	BAF	*Ambloplites rupestris*	Rock bass	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.20	BAF	*Notropis hudsonius*	Spottail shiner	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	5.74	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.04	BAF	*Ambloplites rupestris*	Rock bass	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.88	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	6.45	BAF	*Labidesthes sicculus*	Brook silversides	Arnot & Gobas 2006
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	4.41	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,3',4,4',5,6-Octachlorobiphenyl	Previous*	195	52663-78-2	5.51	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,3',4,4',5,6-Octachlorobiphenyl	Previous*	195	52663-78-2	6.61	BAF	*Salvelinus namaycush*	Lake trout	Arnot & Gobas 2006
2,2',3,3',4,4',5,6-Octachlorobiphenyl	Previous*	195	52663-78-2	6.38	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4,4',5,6-Octachlorobiphenyl	Previous*	195	52663-78-2	6.58	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,3',4,4',5,6-Octachlorobiphenyl	Previous*	195	52663-78-2	6.36	BAF	*Osmerus mordax*	Rainbow smelt	Arnot & Gobas 2006
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	Previous*	199	52663-75-9	5.39	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	Previous*	199	52663-75-9	6.39	BAF	*Salvelinus namaycush*	Lake trout	Arnot & Gobas 2006
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	Previous*	199	52663-75-9	6.14	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	Previous*	199	52663-75-9	6.16	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	Previous*	199	52663-75-9	6.37	BAF	*Osmerus mordax*	Rainbow smelt	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.27	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.30	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.27	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.30	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.39	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.69	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.02	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	5.42	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	5.72	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.10	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.70	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.38	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	5.97	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.96	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.43	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.76	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	7.37	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.90	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.95	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.50	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.90	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.94	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.35	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.76	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.80	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	6.59	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	7.23	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	5.93	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	5.02	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	6.73	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	6.24	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	5.66	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	6.61	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	6.85	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	6.85	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	7.00	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	7.51	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	5.26	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	5.70	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	5.53	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	5.02	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	5.41	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	6.02	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	6.05	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	6.07	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	6.36	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	4.88	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	6.02	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	6.08	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	5.28	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	6.25	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	6.63	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	6.59	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	6.38	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	7.05	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	5.19	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	6.20	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	6.15	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	5.51	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	6.41	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	6.80	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	6.66	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	6.87	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	7.24	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	5.15	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	5.95	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	5.49	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	5.56	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	4.74	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	4.23	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	4.23	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	4.11	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	4.00	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	3.36	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	3.75	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.20	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.25	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.45	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.47	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.48	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.72	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.24	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	5.75	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	5.61	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	5.98	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.63	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.43	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.26	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.88	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.37	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.69	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	7.30	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.80	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.82	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.43	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.80	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.84	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.58	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.83	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	6.68	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	7.09	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	7.45	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	5.55	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	5.08	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4',5,5',6-Heptachloro-1,1'-biphenyl	Previous*	187	52663-68-0	6.00	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,4',5,5',6-Heptachloro-1,1'-biphenyl	Previous*	187	52663-68-0	6.34	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,4',5,5',6-Heptachloro-1,1'-biphenyl	Previous*	187	52663-68-0	6.22	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4',5,5',6-Heptachloro-1,1'-biphenyl	Previous*	187	52663-68-0	6.37	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,4',5,5',6-Heptachloro-1,1'-biphenyl	Previous*	187	52663-68-0	6.86	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.03	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.02	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.50	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.15	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.34	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.16	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	5.79	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	5.16	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	5.91	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.55	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.09	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.05	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.78	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.30	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.53	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	7.22	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.81	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.69	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.44	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.81	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.75	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.08	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.40	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.44	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	6.65	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	7.00	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	5.64	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	4.86	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.07	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.18	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.30	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.49	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.54	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.21	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.22	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	5.50	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	5.58	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	5.89	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.53	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.34	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.08	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.73	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.31	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.51	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	7.15	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.74	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.68	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.42	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.74	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.56	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.50	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.85	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.74	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	6.99	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	7.36	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	5.49	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	5.12	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.76	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.79	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.04	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.78	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.75	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.90	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.72	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.20	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.29	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.76	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.23	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.13	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.65	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.52	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.08	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.16	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.96	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.47	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.40	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.13	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.47	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.66	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.95	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.31	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.31	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.90	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	6.75	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	5.40	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	4.75	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.17	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.20	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.82	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.24	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.19	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	4.90	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.03	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.81	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.44	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.12	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.89	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.48	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.67	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	6.41	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.71	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.96	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	5.67	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	6.11	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	6.06	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	4.93	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	5.16	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	4.93	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	4.48	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	4.90	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	5.40	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	5.48	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	5.24	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	5.86	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	4.18	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	4.95	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	4.85	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.60	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	6.14	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.66	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.56	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	4.91	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.42	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	4.92	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.03	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.33	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.20	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.43	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.97	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.29	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.79	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.31	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.97	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.80	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.74	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	6.19	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	6.18	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	5.93	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	6.48	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	4.30	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	4.78	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.71	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.82	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.05	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.81	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.67	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.32	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.05	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.52	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	4.85	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.95	BAF	*Salvelinus namaycush*	Lake trout	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.68	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.83	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.92	BAF	*Osmerus mordax*	Rainbow smelt	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.28	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.58	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.25	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.89	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.47	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.21	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.27	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.19	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.89	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.44	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.42	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.12	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.44	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.61	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.07	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.61	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.74	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	6.97	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	7.28	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	5.37	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	4.87	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,5,5'-Pentachlorobiphenyl	Previous*	92	52663-61-3	6.35	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,5,5'-Pentachlorobiphenyl	Previous*	92	52663-61-3	5.88	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,5,5'-Pentachlorobiphenyl	Previous*	92	52663-61-3	5.61	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,5,5'-Pentachlorobiphenyl	Previous*	92	52663-61-3	6.24	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,5,5'-Pentachlorobiphenyl	Previous*	92	52663-61-3	6.61	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,5,5'-Pentachlorobiphenyl	Previous*	92	52663-61-3	6.44	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,5,5'-Pentachlorobiphenyl	Previous*	92	52663-61-3	6.99	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,5,5'-Pentachlorobiphenyl	Previous*	92	52663-61-3	5.27	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.77	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.92	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.51	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.99	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.28	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.72	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.92	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.14	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.23	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	6.09	BAF	*Salvelinus namaycush*	Lake trout	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.56	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	6.07	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.96	BAF	*Osmerus mordax*	Rainbow smelt	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.44	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.69	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.32	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.92	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.75	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.28	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.04	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.15	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.80	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.07	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.49	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.15	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.71	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.41	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.95	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.48	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.66	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.51	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	5.95	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.69	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.53	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',3-Trichlorobiphenyl	Previous*	16	38444-78-9	4.95	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.27	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.41	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.80	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.51	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.76	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.89	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.04	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.37	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.31	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	6.48	BAF	*Salvelinus namaycush*	Lake trout	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.91	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	6.29	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	6.13	BAF	*Osmerus mordax*	Rainbow smelt	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	4.91	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.23	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.71	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.52	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.20	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.84	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.53	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.69	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	6.39	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.83	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	6.08	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.64	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	6.14	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.99	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	4.86	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	5.83	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	6.04	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	6.26	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	4.81	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	4.91	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',4,4',6-Pentachlorobiphenyl	Previous*	100	39485-83-1	4.06	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,2',4,4',6-Pentachlorobiphenyl	Previous*	100	39485-83-1	3.37	BCF	*Leuciscus idus*	Ide, silver or golden orfe	Arnot & Gobas 2006
2,2',4,6-Tetrachlorobiphenyl	Previous*	50	62796-65-0	4.26	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
2,2',4,6-Tetrachlorobiphenyl	Previous*	50	62796-65-0	3.50	BCF	*Leuciscus idus*	Ide, silver or golden orfe	Arnot & Gobas 2006
2,2',4-Trichlorobiphenyl	Previous*	17	37680-66-3	5.12	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',5,6'-Tetrachlorobiphenyl	Previous*	53	41464-41-9	5.72	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',5,6'-Tetrachlorobiphenyl	Previous*	53	41464-41-9	5.18	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',5,6'-Tetrachlorobiphenyl	Previous*	53	41464-41-9	5.51	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',5,6'-Tetrachlorobiphenyl	Previous*	53	41464-41-9	4.64	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	5.12	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	4.37	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	4.89	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	5.31	BAF	*Salvelinus namaycush*	Lake trout	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	4.86	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	4.47	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	5.22	BAF	*Osmerus mordax*	Rainbow smelt	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	5.22	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	4.86	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	4.78	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	3.84	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	4.23	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	4.23	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	4.08	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	3.97	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	3.43	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	3.81	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
2,3,3',4,4',5,5',6-Octachlorobiphenyl	Previous*	205	74472-53-0	6.14	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.29	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.41	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.88	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.21	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	4.95	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.71	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.60	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.13	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	4.96	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.05	BAF	*Salvelinus namaycush*	Lake trout	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.74	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.78	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.11	BAF	*Osmerus mordax*	Rainbow smelt	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.00	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.16	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.87	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.55	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.16	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.95	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.54	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.75	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.47	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.18	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.07	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.78	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.18	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.33	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.80	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.20	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.15	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.14	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	6.62	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	5.10	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	4.67	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,3,3',4'-Tetrachlorobiphenyl	Previous*	56	41464-43-1	6.22	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,3,3',4'-Tetrachlorobiphenyl	Previous*	56	41464-43-1	6.60	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,3,3',4'-Tetrachlorobiphenyl	Previous*	56	41464-43-1	6.52	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,3,3',4'-Tetrachlorobiphenyl	Previous*	56	41464-43-1	6.27	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,3,3',4'-Tetrachlorobiphenyl	Previous*	56	41464-43-1	6.88	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.11	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.13	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.94	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.31	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	4.86	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.55	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.22	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.20	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.50	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.60	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.80	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.34	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	6.11	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	5.66	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	4.58	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.66	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.71	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	5.25	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.68	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.18	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.39	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.15	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	5.10	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.69	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.42	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.93	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.73	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.99	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	5.66	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	5.05	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	5.46	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.95	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	5.67	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	5.55	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	5.81	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	6.20	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	6.05	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	5.85	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	6.49	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.09	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.23	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.68	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	4.81	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.96	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.59	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.41	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	4.71	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	4.96	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.62	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.16	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	4.95	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.49	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.23	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.54	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	6.14	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.47	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.97	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.47	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	6.11	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	6.50	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.67	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	6.07	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	6.07	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	6.00	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	6.48	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	5.65	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	4.73	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2',3,4-Trichlorobiphenyl	Previous*	33	38444-86-9	5.35	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2',3,4-Trichlorobiphenyl	Previous*	33	38444-86-9	4.46	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2',3,4-Trichlorobiphenyl	Previous*	33	38444-86-9	5.11	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2',3,4-Trichlorobiphenyl	Previous*	33	38444-86-9	4.33	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2',3,4-Trichlorobiphenyl	Previous*	33	38444-86-9	4.15	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.01	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.18	BAF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.54	BAF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.30	BAF	*Hydropychidae alterans*	Caddisfly larvae	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	6.02	BAF	*Orconectes propinquus*	Crayfish	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.91	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.60	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.34	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	4.63	BAF	*Stizostedion vitreum*	Walleye	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	4.72	BAF	*Pomoxis nigromaculatus*	Black crappie	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.46	BAF	*Micropterus dolomieu*	Smallmouth bass	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.13	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	4.81	BAF	*Aplodinotus grunniens*	Freshwater drum	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.47	BAF	*Catostomus commersonii*	White sucker	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.01	BAF	*Perca flavescens*	Yellow perch	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.23	BAF	*Percopsis omiscomaycus*	Troutperch	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	6.09	BAF	*Micropterus salmoides*	Largemouth bass	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.38	BAF	*Morone americana*	White perch	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.86	BAF	*Dorosoma cepedianum*	Gizzard shad	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.32	BAF	Mixed (mostly yellow perch and smelt)	Young of the year	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	6.08	BAF	*Notropis atherinoides*	Emerald shiner	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.72	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	5.79	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	6.15	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	6.08	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	6.08	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	6.58	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	4.59	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	4.60	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,4,4'-Trichlorobiphenyl	Previous*	28	7012-37-5	5.14	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
2,4,4'-Trichlorobiphenyl	Previous*	28	7012-37-5	5.48	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
2,4,4'-Trichlorobiphenyl	Previous*	28	7012-37-5	5.48	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
2,4,4'-Trichlorobiphenyl	Previous*	28	7012-37-5	5.23	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
2,4,4'-Trichlorobiphenyl	Previous*	28	7012-37-5	5.89	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,4',6-Trichlorobiphenyl	Previous*	32	38444-77-8	6.53	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
2,4',6-Trichlorobiphenyl	Previous*	32	38444-77-8	6.15	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
2,4',6-Trichlorobiphenyl	Previous*	32	38444-77-8	5.78	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
2,4',6-Trichlorobiphenyl	Previous*	32	38444-77-8	5.08	BCF	Various	Phytoplankton	Arnot & Gobas 2006
2,6-Dinitrotoluene	Previous*	NA	606-20-2	1.34	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
4-Chloro-3-methylphenol	Previous*	NA	59-50-7	0.92	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
4-Chloro-3-methylphenol	Previous*	NA	59-50-7	0.99	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
4-Chloro-3-methylphenol	Previous*	NA	59-50-7	0.92	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
4-Chloro-3-methylphenol	Previous*	NA	59-50-7	0.99	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Acenaphthene	Previous*	NA	83-32-9	2.59	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Acenaphthene	Previous*	NA	83-32-9	2.87	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Acenaphthene	Previous*	NA	83-32-9	2.88	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Acenaphthene	Previous*	NA	83-32-9	2.87	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Acenaphthene	Previous*	NA	83-32-9	2.88	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Acenaphthene	Previous*	NA	83-32-9	2.59	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Aldrin	Previous*	NA	309-00-2	4.09	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Aldrin	Previous*	NA	309-00-2	4.07	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Aldrin	Previous*	NA	309-00-2	3.74	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Aldrin	Previous*	NA	309-00-2	3.57	BCF	*Leuciscus idus*	Ide, silver or golden orfe	Arnot & Gobas 2006
Aldrin	Previous*	NA	309-00-2	3.11	BCF	*Leuciscus idus*	Ide, silver or golden orfe	Arnot & Gobas 2006
Allyl chloride	Previous*	NA	107-05-1	-0.30	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Allyl chloride	Previous*	NA	107-05-1	0.54	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.88	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.59	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	2.59	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.17	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.32	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.67	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.59	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.73	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	2.40	BCF	Various	Phytoplankton	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	2.40	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	2.15	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	2.15	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.11	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.45	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	2.97	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.26	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.30	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.38	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.36	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.43	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.32	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.20	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	2.97	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	3.04	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	2.33	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.51	BCF	*Morone saxatilis*	Striped bass	ECCC 2020
Benzene	Previous*	NA	71-43-2	0.63	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Benzene	Previous*	NA	71-43-2	1.05	BCF	*Morone saxatilis*	Striped bass	ECCC 2020
Benzene	Previous*	NA	71-43-2	1.48	BCF	*Chlorella fusca*	Green algae	ECCC 2020
Benzene	Previous*	NA	71-43-2	1.48	BAF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	3.35	BAF	*Selenustrum capricornutum*	Green algae	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	2.00	BAF	*Brachionus plicatilis*	Rotifer	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	4.00	BAF	*Brachionus plicatilis*	Rotifer	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	3.00	BAF	*Brachionus plicatilis*	Rotifer	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.63	BAF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.51	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.05	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.00	BAF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.05	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.06	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.43	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.47	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.74	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.75	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.85	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.85	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.88	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.90	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.96	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	0.99	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Benzene	Previous*	NA	71-43-2	1.00	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.17	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.36	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.48	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.48	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.50	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.54	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.54	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.62	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.65	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.73	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.74	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	1.78	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	2.05	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	2.32	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	2.36	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	2.49	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	2.70	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	3.64	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	3.93	BAF	*Engraulis mordax*	Northern anchovy	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	2.67	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzene	Previous*	NA	71-43-2	3.15	BAF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Benzyl butyl phthalate	Previous*	NA	85-68-7	4.01	BAF	*Leptocottus armatus*	Pacific Staghorn Sculpin	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	1.09	BCF	*Lepomis macrochirus*	Bluegill sunfish	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	0.04	BCF	*Lepomis macrochirus*	Bluegill sunfish	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	1.28	BCF	*Lepomis macrochirus*	Bluegill sunfish	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	3.25	BAF	*Squalus acanthias*	Spiny Dogfish	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Benzyl butyl phthalate	Previous*	NA	85-68-7	2.77	BAF	*Squalus acanthias*	Spiny Dogfish	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	3.31	BAF	*Hexogrammos stelleri*	Whitespotted Greenling	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	3.67	BAF	*Pleuronectes ventulus*	English Sole	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	3.98	BAF	*Rhacochilus vaccu*	Pile Perch	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	4.01	BAF	*Leptocottus armatus*	Pacific Staghorn Sculpin	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	4.06	BAF	*Embiotoea lateralis*	Striped Seaperch	ECCC 2020
Benzyl butyl phthalate	Previous*	NA	85-68-7	4.01	BAF	*Leptocottus armatus*	Pacific Staghorn Sculpin	Arnot & Gobas 2006
Benzyl butyl phthalate	Previous*	NA	85-68-7	3.25	BAF	*Squalus acanthias*	Spiny Dogfish	Arnot & Gobas 2006
Benzyl butyl phthalate	Previous*	NA	85-68-7	1.09	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Benzyl butyl phthalate	Previous*	NA	85-68-7	1.28	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Benzyl butyl phthalate	Previous*	NA	85-68-7	0.04	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Benzyl butyl phthalate	Previous*	NA	85-68-7	2.82	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.73	BCF	*Chlorella fusca*	Green algae	ECCC 2020
Biphenyl	Previous*	NA	92-52-4	2.73	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.53	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.59	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.62	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.68	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.66	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.67	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.64	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.45	BCF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006
Biphenyl	Previous*	NA	92-52-4	2.45	BCF	*Leuciscus idus*	Ide, silver or golden orfe	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	0.96	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Bisphenol A	Previous*	NA	80-05-7	1.64	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Bisphenol A	Previous*	NA	80-05-7	0.96	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	1.64	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Bisphenol A	Previous*	NA	80-05-7	0.23	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	0.34	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	0.56	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	0.94	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	1.03	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	1.34	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	1.40	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	1.58	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Bisphenol A	Previous*	NA	80-05-7	2.00	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Captan	Previous*	NA	133-06-2	2.30	BCF	*Gnathopogon coerulescens*	Willow shiner	ECCC 2020
Captan	Previous*	NA	133-06-2	1.87	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Captan	Previous*	NA	133-06-2	1.90	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Captan	Previous*	NA	133-06-2	1.96	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Captan	Previous*	NA	133-06-2	1.98	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Captan	Previous*	NA	133-06-2	2.20	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Captan	Previous*	NA	133-06-2	2.40	BCF	*Gnathopogon coerulescens*	Willow shiner	ECCC 2020
Captan	Previous*	NA	133-06-2	2.43	BCF	*Gnathopogon coerulescens*	Willow shiner	ECCC 2020
Captan	Previous*	NA	133-06-2	2.70	BCF	*Gnathopogon coerulescens*	Willow shiner	ECCC 2020
Captan	Previous*	NA	133-06-2	2.71	BCF	*Gnathopogon coerulescens*	Willow shiner	ECCC 2020
Carbon disulfide	Previous*	NA	75-15-0	1.78	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Carbon disulfide	Previous*	NA	75-15-0	0.79	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	2.88	BAF	*Ichtalurus furcatus*	Blue catfish	ECCC 2020
Chlorobenzene	Previous*	NA	108-90-7	1.13	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Chlorobenzene	Previous*	NA	108-90-7	1.34	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Chlorobenzene	Previous*	NA	108-90-7	1.70	BCF	*Chlorella fusca*	Green algae	ECCC 2020
Chlorobenzene	Previous*	NA	108-90-7	2.09	BAF	*Micropogonias undulatus*	Atlantic croaker	ECCC 2020
Chlorobenzene	Previous*	NA	108-90-7	1.81	BAF	*Cynoscion nebulosis*	Spotted sea trout	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Chlorobenzene	Previous*	NA	108-90-7	1.70	BAF	*Callinectes sapidus*	Blue crab	ECCC 2020
Chlorobenzene	Previous*	NA	108-90-7	1.70	BAF	*Callinectes sapidus*	Blue crab	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	2.88	BAF	*Ichtalurus furcatus*	Blue catfish	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	2.09	BAF	*Micropogonias undulatus*	Atlantic croaker	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	1.81	BAF	*Cynoscion nebulosis*	Spotted sea trout	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	1.70	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	3.34	BCF	*Selenustrum capricornutum*	Green algae	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	1.04	BCF	*Chironomus decorus*	Midge	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	1.13	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	1.34	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	2.65	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Chlorobenzene	Previous*	NA	108-90-7	1.50	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.53	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	1.76	BCF	*Leuresthes tenuis*	California grunion	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	1.82	BCF	*Leuresthes tenuis*	California grunion	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.65	BCF	*Leuresthes tenuis*	California grunion	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.79	BCF	*Leuresthes tenuis*	California grunion	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.85	BCF	*Leuresthes tenuis*	California grunion	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.00	BCF	*Leuresthes tenuis*	California grunion	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.49	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.53	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.61	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.73	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.74	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.27	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.93	BCF	*Gasterosteus aculeatus*	Threespine stickleback	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.98	BCF	*Gasterosteus aculeatus*	Threespine stickleback	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Chlorpyrifos	Previous*	NA	2921-88-2	3.01	BCF	*Gasterosteus aculeatus*	Threespine stickleback	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.04	BCF	*Gasterosteus aculeatus*	Threespine stickleback	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.04	BCF	*Gasterosteus aculeatus*	Threespine stickleback	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.06	BCF	*Gasterosteus aculeatus*	Threespine stickleback	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.12	BCF	*Gasterosteus aculeatus*	Threespine stickleback	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.13	BCF	*Gasterosteus aculeatus*	Threespine stickleback	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.18	BCF	*Gasterosteus aculeatus*	Threespine stickleback	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.43	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.27	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.00	BCF	*Lepomis macrochirus*	Bluegill sunfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.65	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.22	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.00	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.41	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.43	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.67	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.68	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.79	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.81	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.83	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.95	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.28	BCF	*Opsanus beta*	Gulf toadfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	1.62	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	1.84	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	1.85	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.08	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.11	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Chlorpyrifos	Previous*	NA	2921-88-2	2.18	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.30	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.40	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.41	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.41	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.48	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.60	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.60	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.63	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.79	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.82	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.82	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.85	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.85	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.87	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.93	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.99	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.00	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.00	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.03	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.16	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.26	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.02	BCF	*Menidia beryllina*	Inland silverside	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.11	BCF	*Menidia beryllina*	Inland silverside	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.30	BCF	*Menidia beryllina*	Inland silverside	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.64	BCF	*Menidia beryllina*	Inland silverside	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.60	BCF	*Menidia peninsulae*	Tidewater silverside	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Chlorpyrifos	Previous*	NA	2921-88-2	2.61	BCF	*Menidia peninsulae*	Tidewater silverside	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.76	BCF	*Menidia peninsulae*	Tidewater silverside	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.76	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.86	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.90	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.18	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.20	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.15	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.18	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.36	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.40	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.78	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	2.94	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.18	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.19	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	3.50	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	0.73	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	0.63	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	0.83	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	0.59	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	1.07	BAF	*Asellus aquaticus*	Aquatic sowbug	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	1.12	BAF	*Asellus aquaticus*	Aquatic sowbug	ECCC 2020
Chlorpyrifos	Previous*	NA	2921-88-2	1.07	BAF	*Asellus aquaticus*	Aquatic sowbug	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.12	BAF	*Asellus aquaticus*	Aquatic sowbug	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	0.73	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	0.63	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	0.83	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Chlorpyrifos	Previous*	NA	2921-88-2	0.59	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.10	BCF	*Hydrophilus sp*	Black beetle	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.83	BCF	*Simulium vittatum*	Blackfly	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	0.73	BCF	*Stenacron*	Mayfly	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.60	BCF	*Trichoptera*	Caddisfly order	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.10	BCF	*Zygoptera*	Damselfly order	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.53	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.26	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.16	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.03	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.00	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.00	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.99	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.93	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.87	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.85	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.85	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.82	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.82	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.79	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.63	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.60	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.60	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.48	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.41	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.41	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.40	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Chlorpyrifos	Previous*	NA	2921-88-2	2.30	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.18	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.11	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.08	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.85	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.84	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.62	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.50	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.18	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.13	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.12	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.06	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.04	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.04	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.01	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.19	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.18	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.98	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.93	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.94	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.78	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.76	BCF	*Menidia peninsulae*	Tidewater silverside	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.64	BCF	*Menidia beryllina*	Inland silverside	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.61	BCF	*Menidia peninsulae*	Tidewater silverside	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.60	BCF	*Menidia peninsulae*	Tidewater silverside	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.30	BCF	*Menidia beryllina*	Inland silverside	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.11	BCF	*Menidia beryllina*	Inland silverside	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Chlorpyrifos	Previous*	NA	2921-88-2	2.02	BCF	*Menidia beryllina*	Inland silverside	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.00	BCF	*Leuresthes tenuis*	California grunion	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.85	BCF	*Leuresthes tenuis*	California grunion	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.79	BCF	*Leuresthes tenuis*	California grunion	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.65	BCF	*Leuresthes tenuis*	California grunion	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.82	BCF	*Leuresthes tenuis*	California grunion	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.76	BCF	*Leuresthes tenuis*	California grunion	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.28	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.95	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.83	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.81	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.79	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.68	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.67	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.41	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.43	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.00	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.22	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.27	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.43	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.40	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.36	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.18	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.15	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.20	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.18	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.90	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Chlorpyrifos	Previous*	NA	2921-88-2	2.86	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.76	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.74	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.73	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.61	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.53	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.49	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.65	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.00	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.27	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.96	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.97	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.05	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.07	BCF	*Gasterosteus aculeatus*	Threespine stickleback	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.71	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.71	BCF	*Opsanus beta*	Gulf toadfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	1.93	BCF	*Tilapia aurea*	Tilapia	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.70	BCF	*Tilapia aurea*	Tilapia	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.71	BCF	*Tilapia aurea*	Tilapia	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.92	BCF	*Tilapia aurea*	Tilapia	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.29	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.30	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.33	BCF	*Tanichthys albonubes*	White cloud mountain minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.36	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.43	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.46	BCF	*Tanichthys albonubes*	White cloud mountain minnow	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Chlorpyrifos	Previous*	NA	2921-88-2	2.46	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.51	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.54	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.55	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.55	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.65	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.66	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.70	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.85	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.86	BCF	*Tanichthys albonubes*	White cloud mountain minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	2.88	BCF	*Tanichthys albonubes*	White cloud mountain minnow	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.01	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Chlorpyrifos	Previous*	NA	2921-88-2	3.02	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.28	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.15	BCF	*Salvelinus fontinalis*	Brook trout	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.54	BCF	*Salvelinus fontinalis*	Brook trout	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.71	BCF	*Salvelinus fontinalis*	Brook trout	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.37	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.43	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.17	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.33	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.99	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.03	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.07	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.16	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Diazinon	Previous*	NA	333-41-5	2.18	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.18	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.23	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.31	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.32	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.93	BCF	*Brachydanio rerio*	Zebrafish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.23	BCF	*Brachydanio rerio*	Zebrafish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.59	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.77	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.77	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.27	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.08	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.08	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.11	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.38	BCF	*Misgurnus anguillicaudatus*	Oriental weatherfish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.38	BCF	*Misgurnus anguillicaudatus*	Oriental weatherfish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.45	BCF	*Misgurnus anguillicaudatus*	Oriental weatherfish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.79	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.81	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.96	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.38	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.41	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.56	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.62	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.69	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.41	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.48	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Diazinon	Previous*	NA	333-41-5	1.57	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.60	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.61	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.68	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.72	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.75	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.80	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.91	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.97	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.54	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.60	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.62	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.69	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.85	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.88	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.92	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.99	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.09	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.15	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.21	BCF	*Tanichthys albonubes*	White cloud mountain minnow	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.31	BCF	*Tanichthys albonubes*	White cloud mountain minnow	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.55	BCF	*Tanichthys albonubes*	White cloud mountain minnow	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.34	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	ECCC 2020
Diazinon	Previous*	NA	333-41-5	2.39	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Diazinon	Previous*	NA	333-41-5	2.44	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	ECCC 2020
Diazinon	Previous*	NA	333-41-5	1.45	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Diazinon	Previous*	NA	333-41-5	0.48	BCF	*Paratya compressa compressa*	Shrimp	ECCC 2020
Diazinon	Previous*	NA	333-41-5	0.48	BCF	*Paratya compressa compressa*	Shrimp	ECCC 2020
Diazinon	Previous*	NA	333-41-5	0.60	BCF	*Paratya compressa compressa*	Shrimp	ECCC 2020
Diazinon	Previous*	NA	333-41-5	0.30	BCF	*Paratya compressa compressa*	Shrimp	ECCC 2020
Diazinon	Previous*	NA	333-41-5	0.48	BCF	*Paratya compressa compressa*	Shrimp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	0.48	BCF	*Paratya compressa compressa*	Shrimp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	0.60	BCF	*Paratya compressa compressa*	Shrimp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	0.30	BCF	*Paratya compressa compressa*	Shrimp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	0.49	BCF	*Cipangopaludina malleata*	Mud snail	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	0.79	BCF	*Cipangopaludina malleata*	Mud snail	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	0.93	BCF	*Cipangopaludina malleata*	Mud snail	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.21	BCF	*Indoplanorbis exustus*	Snail	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.23	BCF	*Indoplanorbis exustus*	Snail	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.25	BCF	*Indoplanorbis exustus*	Snail	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	0.65	BCF	*Procambarus clarkii*	Red swamp crayfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	0.72	BCF	*Procambarus clarkii*	Red swamp crayfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.75	BCF	*Crassostrea virginica*	American or Virginia oyster	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.28	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Diazinon	Previous*	NA	333-41-5	1.43	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.37	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.33	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.17	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.32	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.31	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.18	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.23	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.18	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.16	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.07	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.03	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.99	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.23	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.93	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.77	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.59	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.27	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.77	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.11	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.08	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.08	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.96	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.81	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.79	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.45	BCF	*Misgurnus anguillicaudatus*	Oriental weatherfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.38	BCF	*Misgurnus anguillicaudatus*	Oriental weatherfish	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Diazinon	Previous*	NA	333-41-5	1.38	BCF	*Misgurnus anguillicaudatus*	Oriental weatherfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.15	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.09	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.99	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.92	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.97	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.88	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.91	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.85	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.69	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.80	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.62	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.69	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.75	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.56	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.72	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.62	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.68	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.60	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.61	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.54	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.60	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.41	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.57	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.38	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.48	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.55	BCF	*Tanichthys albonubes*	White cloud mountain minnow	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Diazinon	Previous*	NA	333-41-5	1.41	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.31	BCF	*Tanichthys albonubes*	White cloud mountain minnow	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.21	BCF	*Tanichthys albonubes*	White cloud mountain minnow	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.44	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.39	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.34	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.45	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.71	BCF	*Salvelinus fontinalis*	Brook trout	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.54	BCF	*Salvelinus fontinalis*	Brook trout	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.15	BCF	*Salvelinus fontinalis*	Brook trout	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.73	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.78	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.83	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.89	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	3.27	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.90	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	3.20	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.90	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	3.20	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	3.36	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.04	BCF	*Misgurnus anguillicaudatus*	Oriental weatherfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.76	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.76	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Diazinon	Previous*	NA	333-41-5	1.20	BCF	*Tanichthys albonubes*	White cloud mountain minnow	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.28	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.38	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.45	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.55	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.63	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	0.46	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.06	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.07	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.08	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.15	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.15	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.40	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.40	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.52	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.56	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.56	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.58	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.64	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.70	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.71	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.76	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.85	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.95	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.12	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Diazinon	Previous*	NA	333-41-5	2.17	BCF	*Gnathopogon coerulescens*	Biwi lake gudgeon, goby or willow shiner	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.17	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.19	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.24	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.56	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.80	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.18	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.18	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.89	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.94	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	3.27	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	1.00	BCF	*Fundulus heteroclitus*	Mummichog	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.89	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.90	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	2.94	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	3.20	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	3.27	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	3.36	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Diazinon	Previous*	NA	333-41-5	3.44	BCF	*Anguilla anguilla*	Common eel	Arnot & Gobas 2006
Dibenzofuran	Previous*	NA	132-64-9	3.22	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Dibenzofuran	Previous*	NA	132-64-9	3.16	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Dibenzofuran	Previous*	NA	132-64-9	3.18	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Dibenzothiophene	Previous*	NA	132-65-0	3.17	BCF	*Scophthalmus maximus*	Turbot	ECCC 2020
Dibenzothiophene	Previous*	NA	132-65-0	3.05	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Dibenzothiophene	Previous*	NA	132-65-0	3.26	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Dibenzothiophene	Previous*	NA	132-65-0	2.78	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Dibenzothiophene	Previous*	NA	132-65-0	3.17	BCF	*Scophthalmus maximus*	Turbot	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Dibenzothiophene	Previous*	NA	132-65-0	3.26	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dibenzothiophene	Previous*	NA	132-65-0	3.05	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dibenzothiophene	Previous*	NA	132-65-0	3.82	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.80	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	5.66	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	5.45	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.40	BAF	*Chironomus sp*	Midge	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.67	BAF	*Erpobdella punctata*	Red leech	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.00	BAF	*Notonectidae*	Backswimmer family	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.34	BAF	*Orconectes immunis*	Crayfish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.67	BAF	*Planorbidae*	Orb snail family	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.45	BAF	*Invertebrates*	Invertebrates	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.46	BAF	*Invertebrates*	Invertebrates	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	6.33	BAF	*Osmerus mordax*	Smelt	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	6.27	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	6.18	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	6.62	BAF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	5.84	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	6.33	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	6.62	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.42	BCF	Various	Phytoplankton	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.97	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.92	BCF	*Ephemera danica*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.46	BCF	*Ephemera danica*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.64	BCF	*Ephemera danica*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.79	BCF	*Ephemera danica*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.35	BCF	*Ephemera danica*	Mayfly	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.30	BCF	*Ephemera danica*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.49	BCF	*Ephemera danica*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.46	BCF	*Ephemera danica*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.94	BCF	*Orconectes nais*	Crayfish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.32	BCF	*Orconectes nais*	Crayfish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.46	BCF	*Orconectes nais*	Crayfish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.96	BCF	*Libellula*	Dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.66	BCF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.08	BCF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.31	BCF	*Gammarus fasciatus*	Amphipod	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.18	BCF	*Palaemonetes kadiakensis*	Grass shrimp, freshwater prawn	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.57	BCF	*Palaemonetes kadiakensis*	Grass shrimp, freshwater prawn	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.70	BCF	*Palaemonetes kadiakensis*	Grass shrimp, freshwater prawn	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.89	BCF	*Chironomus sp*	Midge	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.39	BCF	*Chironomus sp*	Midge	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.68	BCF	*Chironomus sp*	Midge	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.36	BCF	*Siphlonurus*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.51	BCF	*Hexagenia bilineata*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.54	BCF	*Ischnura verticalis*	Damselfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	5.13	BCF	*Culex pipiens*	Northern house mosquito	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.01	BCF	*Siphlonurus*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.30	BCF	*Siphlonurus*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.97	BCF	*Hexagenia bilineata*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.22	BCF	*Hexagenia bilineata*	Mayfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.40	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.84	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	5.06	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.30	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.32	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.35	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.43	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.30	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.48	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.48	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.51	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.54	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.61	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.65	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.65	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.74	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.76	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.78	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.80	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.81	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.95	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.70	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.81	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.85	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.95	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.98	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.89	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.90	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.95	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.98	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.02	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.04	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.08	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.12	BCF	*Epitheca sp.*	Baskettail dragonfly	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.56	BCF	*Cipangopaludina japonica*	Mud snail	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.41	BCF	*Daphnia pulex*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.38	BCF	*Pyganodon grandis*	Mussel	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.36	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.20	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	1.60	BCF	*Indonaia caerulea*	Unionid clam	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.29	BCF	*Indonaia caerulea*	Unionid clam	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.44	BCF	*Indonaia caerulea*	Unionid clam	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.69	BCF	*Indonaia caerulea*	Unionid clam	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.84	BCF	*Indonaia caerulea*	Unionid clam	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.37	BCF	*Indonaia caerulea*	Unionid clam	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.52	BCF	*Indonaia caerulea*	Unionid clam	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.52	BCF	*Indonaia caerulea*	Unionid clam	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.79	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.80	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	5.17	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	5.14	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.30	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.40	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.20	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.95	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.00	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.13	BCF	*Simocephalus*	Water flea	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	0.95	BCF	*Neanthes grubei*	Polychaete	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	0.18	BCF	*Nereis arenaceodentata*	Polychaete worm	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	2.94	BCF	*Blepharisma intermedium*	Ciliate	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.18	BCF	*Blepharisma intermedium*	Ciliate	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.48	BCF	*Blepharisma intermedium*	Ciliate	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.45	BCF	*Blepharisma intermedium*	Ciliate	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.46	BCF	*Blepharisma intermedium*	Ciliate	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.56	BCF	*Blepharisma intermedium*	Ciliate	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.53	BCF	*Blepharisma intermedium*	Ciliate	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.78	BCF	*Blepharisma intermedium*	Ciliate	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.20	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.17	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.72	BCF	*Salvelinus namaycush*	Lake trout, siscowet	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.66	BCF	*Salvelinus namaycush*	Lake trout, siscowet	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.65	BCF	*Salvelinus namaycush*	Lake trout, siscowet	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.40	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.40	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.36	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	5.00	BCF	*Notemigonus crysoleucas*	Golden shiner	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.38	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.97	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.47	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.24	BCF	*Lepomis cyanellus*	Green sunfish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	1.04	BCF	*Gambusia affinis*	Western mosquitofish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.58	BCF	*Lagodon rhomboides*	Pinfish	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.58	BCF	*Micropogonias undulatus*	Atlantic croaker	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.58	BCF	*Lagodon rhomboides*	Pinfish	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.58	BCF	*Micropogonias undulatus*	Atlantic croaker	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.67	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.43	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	3.70	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.36	BCF	*Tilapia nilotica*	Nile tilapia	Arnot & Gobas 2006
Dichloromethane	Previous*	NA	75-09-2	0.57	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Dichloromethane	Previous*	NA	75-09-2	1.36	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Dichloromethane	Previous*	NA	75-09-2	0.57	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dichloromethane	Previous*	NA	75-09-2	1.36	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dieldrin	Previous*	NA	60-57-1	3.99	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dieldrin	Previous*	NA	60-57-1	3.95	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Dieldrin	Previous*	NA	60-57-1	3.65	BCF	*Pseudorasbora parva*	Motsuga, stone moroko	Arnot & Gobas 2006
Diphenyl oxide	Previous*	NA	101-84-8	2.67	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Diphenyl oxide	Previous*	NA	101-84-8	2.50	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Diphenyl oxide	Previous*	NA	101-84-8	2.54	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Diphenyl oxide	Previous*	NA	101-84-8	2.69	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Diphenylamine	Previous*	NA	122-39-4	2.18	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Diphenylamine	Previous*	NA	122-39-4	2.23	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Dodecane	Previous*	NA	112-40-3	1.72	BCF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006
Dodecane	Previous*	NA	112-40-3	2.38	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Endrin	Previous*	NA	72-20-8	3.87	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Endrin	Previous*	NA	72-20-8	3.77	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Heptachlor	Previous*	NA	76-44-8	4.00	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Heptachlor	Previous*	NA	76-44-8	3.94	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Heptachlor	Previous*	NA	76-44-8	3.98	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Hexadecane	Previous*	NA	544-76-3	1.38	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Hexadecane	Previous*	NA	544-76-3	1.45	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Hexadecane	Previous*	NA	544-76-3	-0.34	BCF	*Salmo salar*	Atlantic salmon	Arnot & Gobas 2006
Hexadecane	Previous*	NA	544-76-3	0.70	BCF	*Salmo salar*	Atlantic salmon	Arnot & Gobas 2006
Hexadecane	Previous*	NA	544-76-3	0.75	BCF	*Salmo salar*	Atlantic salmon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.97	BAF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.32	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.28	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.08	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.32	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.32	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.89	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.23	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.32	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.15	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.89	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.04	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.94	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.38	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.57	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.10	BCF	*Pseudorasbora parva*	Topmouth gudgeon	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.56	BCF	*Lepomis macrochirus*	Bluegill sunfish	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.47	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.86	BCF	*Poecilia reticulata*	Guppy	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.75	BCF	*Brachydanio rerio*	Zebrafish	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.30	BCF	*Lagodon rhomboides*	Pinfish	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.46	BCF	*Lagodon rhomboides*	Pinfish	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Lindane	Previous*	NA	58-89-9	2.22	BCF	*Lagodon rhomboides*	Pinfish	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.68	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.62	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.53	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.86	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.76	BCF	*Salmo salar*	Atlantic salmon	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.84	BCF	*Salmo salar*	Atlantic salmon	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.41	BCF	*Salmo salar*	Atlantic salmon	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.43	BCF	*Salmo salar*	Atlantic salmon	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.95	BCF	*Brachydanio rerio*	Zebrafish	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.16	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.67	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.00	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.98	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.04	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.95	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.87	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.96	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.95	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.38	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.61	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.08	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.54	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.70	BCF	*Asellus aquaticus*	Aquatic sowbug	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.89	BCF	*Penaeus duorarum*	Northern pink shrimp	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.16	BCF	*Penaeus duorarum*	Northern pink shrimp	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.51	BCF	*Penaeus duorarum*	Northern pink shrimp	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Lindane	Previous*	NA	58-89-9	1.90	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.83	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.89	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	ECCC 2020
Lindane	Previous*	NA	58-89-9	1.40	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.08	BCF	*Tetrahymena pyriformis*	Ciliate	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.59	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.38	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.15	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.55	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.36	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.18	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.62	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.26	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.04	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.04	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.38	BCF	*Chlorella fusca*	Green algae	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.82	BCF	Various	Phytoplankton	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.18	BCF	*Selenastrum capricornutum*	Green algae	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.43	BAF	*Osmerus mordax*	Smelt	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.85	BAF	*Alosa pseudoharengus*	Alewife	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.95	BAF	*Cottus cognatus*	Sculpin	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.12	BAF	*Corbicula manilensis*	Asiatic clam	ECCC 2020
Lindane	Previous*	NA	58-89-9	4.01	BAF	*Dreissena polymorpha*	Zebra mussel	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.52	BAF	*Tubifex tubifex*	Oligocheate	ECCC 2020
Lindane	Previous*	NA	58-89-9	4.04	BAF	*Pontoporeia hoyi*	Amphipod	ECCC 2020
Lindane	Previous*	NA	58-89-9	3.78	BAF	*Mysis relicta*	Shrimp	ECCC 2020
Lindane	Previous*	NA	58-89-9	2.52	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Lindane	Previous*	NA	58-89-9	4.04	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.78	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	4.01	BAF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.12	BAF	*Corbicula manilensis*	Asiatic clam	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.75	BAF	*Ceratophyllum submersum*	Coon-tail	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.37	BAF	*Lymnaea palustris*	Marsh snail	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.97	BAF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.43	BAF	*Osmerus mordax*	Smelt	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.85	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.95	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.82	BCF	Various	Phytoplankton	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.38	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.18	BCF	*Selenastrum capricornutum*	Green algae	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.38	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.61	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.08	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.59	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.38	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.15	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.55	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.36	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.18	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.62	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.26	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.04	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.04	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.89	BCF	*Penaeus duorarum*	Northern pink shrimp	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Lindane	Previous*	NA	58-89-9	2.16	BCF	*Penaeus duorarum*	Northern pink shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.51	BCF	*Penaeus duorarum*	Northern pink shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.90	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.83	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.89	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.40	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.00	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.98	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.04	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.95	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.87	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.96	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.95	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.54	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.70	BCF	*Asellus aquaticus*	Aquatic sowbug	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.08	BCF	*Tetrahymena pyriformis*	Ciliate	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.58	BCF	*Aedes aegypti*	Yellow fever mosquito	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.85	BCF	*Heterocypris incongruens*	Ostracod	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.98	BCF	*Artemia salina*	Brine shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.34	BCF	*Aedes aegypti*	Yellow fever mosquito	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.35	BCF	*Heterocypris incongruens*	Ostracod	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.34	BCF	*Aedes aegypti*	Yellow fever mosquito	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.75	BCF	*Lymnaea palustris*	Marsh snail	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.65	BCF	*Lymnaea palustris*	Marsh snail	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.60	BCF	*Lymnaea palustris*	Marsh snail	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.19	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.23	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Lindane	Previous*	NA	58-89-9	2.13	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.18	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.11	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.13	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.04	BCF	*Chironomus tentans*	Midge	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.98	BCF	*Chironomus tentans*	Midge	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.97	BCF	*Chironomus tentans*	Midge	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.97	BCF	*Chironomus tentans*	Midge	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.88	BCF	*Chironomus tentans*	Midge	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.38	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.30	BCF	*Aplysia punctata*	Gastropod	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.45	BCF	*Aplysia punctata*	Gastropod	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.30	BCF	*Aplysia punctata*	Gastropod	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.64	BCF	*Aplysia punctata*	Gastropod	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.14	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.09	BCF	*Lanice conchilega*	Polychaete	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	0.68	BCF	*Metapenaeus macleayi*	Eastern school shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	0.82	BCF	*Metapenaeus macleayi*	Eastern school shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	0.59	BCF	*Metapenaeus macleayi*	Eastern school shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	0.74	BCF	*Metapenaeus macleayi*	Eastern school shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	0.64	BCF	*Metapenaeus macleayi*	Eastern school shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	0.89	BCF	*Metapenaeus macleayi*	Eastern school shrimp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.08	BCF	*Venerupis japonica*	Short-necked clam	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.32	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.95	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.84	BCF	*Salmo salar*	Atlantic salmon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.76	BCF	*Salmo salar*	Atlantic salmon	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Lindane	Previous*	NA	58-89-9	2.43	BCF	*Salmo salar*	Atlantic salmon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.41	BCF	*Salmo salar*	Atlantic salmon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.10	BCF	*Pseudorasbora parva*	Topmouth gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.86	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.75	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.56	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.47	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.04	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.94	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.32	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.23	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.32	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.32	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.15	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.28	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.08	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.89	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.89	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.86	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.68	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.62	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.53	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.46	BCF	*Lagodon rhomboides*	Pinfish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.30	BCF	*Lagodon rhomboides*	Pinfish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.22	BCF	*Lagodon rhomboides*	Pinfish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.57	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.16	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Lindane	Previous*	NA	58-89-9	2.38	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.67	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.55	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.03	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.15	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	0.55	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.25	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.55	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.73	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.22	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.12	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.43	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	0.52	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.70	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.70	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.70	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.27	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.88	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.70	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.10	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.10	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.70	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.10	BCF	*Gobio gobio*	Gudgeon	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.57	BCF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.26	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.92	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.34	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Lindane	Previous*	NA	58-89-9	2.70	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.09	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.29	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.03	BCF	*Salvelinus fontinalis*	Brook trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.71	BCF	*Salvelinus fontinalis*	Brook trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.79	BCF	*Salvelinus fontinalis*	Brook trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.94	BCF	*Salvelinus fontinalis*	Brook trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.86	BCF	*Salvelinus fontinalis*	Brook trout	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.65	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.43	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.36	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.52	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	1.43	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.45	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.65	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.71	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.83	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.61	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.00	BCF	*Sillago japonica*	Japanese whiting	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.08	BCF	*Sillago japonica*	Japanese whiting	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.78	BCF	*Sillago japonica*	Japanese whiting	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.79	BCF	*Sillago japonica*	Japanese whiting	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.40	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	3.21	BCF	*Labidesthes sicculus*	Brook silverside	Arnot & Gobas 2006
Lindane	Previous*	NA	58-89-9	2.84	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Nitrobenzene	Previous*	NA	98-95-3	0.60	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Nitrobenzene	Previous*	NA	98-95-3	0.37	BCF	*Poecilia reticulata*	Guppy	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Nitrobenzene	Previous*	NA	98-95-3	0.67	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Nitrobenzene	Previous*	NA	98-95-3	1.38	BCF	*Chlorella fusca*	Green algae	ECCC 2020
Nitrobenzene	Previous*	NA	98-95-3	1.38	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Nitrobenzene	Previous*	NA	98-95-3	0.60	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Nitrobenzene	Previous*	NA	98-95-3	0.67	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Nitrobenzene	Previous*	NA	98-95-3	0.37	BCF	*Poecilia reticulata*	Guppy	Arnot & Gobas 2006
Nitrobenzene	Previous*	NA	98-95-3	1.00	BCF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006
Nitrobenzene	Previous*	NA	98-95-3	1.18	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Nitrobenzene	Previous*	NA	98-95-3	0.78	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
o-Cresol	Previous*	NA	95-48-7	1.03	BCF	*Brachydanio rerio*	Zebrafish	ECCC 2020
p,p'-DDD	Previous*	NA	72-54-8	4.76	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
p,p'-DDD	Previous*	NA	72-54-8	4.95	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
p,p'-DDD	Previous*	NA	72-54-8	4.21	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
p,p'-DDD	Previous*	NA	72-54-8	5.31	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
p,p'-DDD	Previous*	NA	72-54-8	5.35	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
p,p'-DDD	Previous*	NA	72-54-8	5.54	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
p,p'-DDD	Previous*	NA	72-54-8	5.70	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
p,p'-DDD	Previous*	NA	72-54-8	5.95	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006
p,p'-DDD	Previous*	NA	72-54-8	4.48	BCF	Various	Phytoplankton	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	5.68	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	6.03	BAF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.95	BAF	*Tubifex tubifex*	Oligocheate	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	6.37	BAF	*Osmerus mordax*	Smelt (small)	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	6.53	BAF	*Osmerus mordax*	Smelt (large)	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	6.37	BAF	*Alosa pseudoharengus*	Alewife	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	6.40	BAF	*Cottus cognatus*	Sculpin	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	7.05	BAF	Mixed – see reference	Salmonid	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
p,p'-DDE	Previous*	NA	72-55-9	4.75	BCF	Various	Phytoplankton	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.66	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.54	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.70	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.68	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.43	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.62	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.08	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.41	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.41	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.83	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.76	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.90	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.74	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.18	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.79	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.18	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.89	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.93	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.82	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.26	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.15	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.70	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.00	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.92	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.94	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.91	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
p,p'-DDE	Previous*	NA	72-55-9	3.91	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.86	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.57	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.34	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.59	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	3.26	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
p,p'-DDE	Previous*	NA	72-55-9	4.71	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.69	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.67	BCF	*Fundulus similis*	Longnose killifish	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.70	BCF	*Fundulus similis*	Longnose killifish	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.81	BCF	*Fundulus similis*	Longnose killifish	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.99	BCF	*Brachydanio rerio*	Zebrafish	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.32	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.32	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.48	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.59	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.33	BCF	*Jordanella floridae*	Flagfish	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.07	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.13	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	0.70	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	0.95	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.11	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.20	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.28	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.34	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.41	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.43	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Pentachlorophenol	Previous*	NA	87-86-5	1.43	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.53	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.58	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.68	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.75	BCF	*Mugil cephalus*	Striped mullet	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.90	BCF	*Mugil cephalus*	Striped mullet	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.57	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.23	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.72	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.11	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.78	BCF	*Carassius auratus*	Goldfish	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.61	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.68	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.58	BCF	*Oryzias latipes*	Medaka, high-eyes	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.43	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.45	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.45	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.45	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.46	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.47	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.60	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.61	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.63	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.65	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.65	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.66	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.96	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Pentachlorophenol	Previous*	NA	87-86-5	2.99	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.03	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.11	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.12	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	2.66	BCF	*Oncorhynchus mykiss*	Rainbow trout	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.91	BCF	*Anodonta anatina*	Fresh-water mussel	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.79	BCF	*Pseudanodonta complanata*	Depressed river mussel	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	4.00	BCF	*Dreissena polymorpha*	Zebra mussel	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	4.65	BCF	*Dreissena polymorpha*	Zebra mussel	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	4.45	BCF	*Dreissena polymorpha*	Zebra mussel	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	4.15	BCF	*Dreissena polymorpha*	Zebra mussel	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	4.36	BCF	*Dreissena polymorpha*	Zebra mussel	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	4.08	BCF	*Dreissena polymorpha*	Zebra mussel	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.52	BCF	*Crassostrea virginica*	American or Virginia oyster	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	1.82	BCF	*Crassostrea virginica*	American or Virginia oyster	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	0.19	BCF	*Palaemonetes pugio*	Shrimp	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	0.48	BCF	*Palaemonetes pugio*	Shrimp	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.10	BCF	*Chlorella fusca*	Green algae	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.79	BCF	*Chlorella fusca*	Green algae	ECCC 2020
Pentachlorophenol	Previous*	NA	87-86-5	3.10	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.79	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	4.00	BCF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	4.65	BCF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	4.45	BCF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	4.15	BCF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	4.36	BCF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	4.08	BCF	*Dreissena polymorpha*	Zebra mussel	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Pentachlorophenol	Previous*	NA	87-86-5	1.91	BCF	*Anodonta anatina*	Fresh-water mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.79	BCF	*Pseudanodonta complanata*	Depressed river mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.52	BCF	*Crassostrea virginica*	American or Virginia oyster	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.82	BCF	*Crassostrea virginica*	American or Virginia oyster	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	0.19	BCF	*Palaemonetes pugio*	Shrimp	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	0.48	BCF	*Palaemonetes pugio*	Shrimp	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.85	BCF	*Haemopis marmorata*	Leech	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.72	BCF	*Nephelopsis obscura*	Leech	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.40	BCF	*Nephelopsis obscura*	Leech	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.97	BCF	*Nephelopsis obscura*	Leech	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.24	BCF	*Anodonta anatina*	Fresh-water mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.34	BCF	*Anodonta anatina*	Fresh-water mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.07	BCF	*Anodonta anatina*	Fresh-water mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.73	BCF	*Anodonta anatina*	Fresh-water mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.50	BCF	*Anodonta anatina*	Fresh-water mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.81	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.57	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.16	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.28	BCF	*Haliotis cracherodii*	Black abalone	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.79	BCF	*Haliotis cracherodii*	Black abalone	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.83	BCF	*Haliotis cracherodii*	Black abalone	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.58	BCF	*Haliotis cracherodii*	Black abalone	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.06	BCF	*Haliotis cracherodii*	Black abalone	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.08	BCF	*Haliotis cracherodii*	Black abalone	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.04	BCF	*Haliotis rufescens*	Red abalone	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.08	BCF	*Haliotis rufescens*	Red abalone	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.11	BCF	*Haliotis rufescens*	Red abalone	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Pentachlorophenol	Previous*	NA	87-86-5	0.88	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.18	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.36	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.27	BCF	*Palaemonetes pugio*	Daggerblade grass shrimp	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.45	BCF	*Montipora verrucosa*	Coral	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.98	BCF	*Anodonta anatina*	Fresh-water mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.08	BCF	*Anodonta anatina*	Fresh-water mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.81	BCF	*Pseudanodonta complanata*	Depressed river mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.93	BCF	*Pseudanodonta complanata*	Depressed river mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.59	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.58	BCF	*Lanice conchilega*	Polychaete	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.66	BCF	*Chironomus riparius*	Midge	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.11	BCF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.97	BCF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.69	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.99	BCF	*Brachydanio rerio*	Zebrafish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.59	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.48	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.32	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.32	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.13	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.07	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.68	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.58	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.53	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.43	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.43	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Pentachlorophenol	Previous*	NA	87-86-5	1.41	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.34	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.28	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.20	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.11	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	0.95	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	0.70	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.33	BCF	*Jordanella floridae*	Flagfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.12	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.11	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.03	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.99	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.96	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.66	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.65	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.65	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.63	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.61	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.60	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.47	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.46	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.45	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.45	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.45	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.43	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.23	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.57	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Pentachlorophenol	Previous*	NA	87-86-5	1.81	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.70	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.67	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.61	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.68	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.58	BCF	*Oryzias latipes*	Medaka, high-eyes	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.66	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.78	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.11	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.72	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.90	BCF	*Mugil cephalus*	Striped mullet	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.75	BCF	*Mugil cephalus*	Striped mullet	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.54	BCF	*Oncorhyncus gorbuscha*	Pink salmon	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.88	BCF	*Oncorhyncus gorbuscha*	Pink salmon	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	0.90	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.00	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.20	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.28	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.48	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.56	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.58	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.69	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	1.69	BCF	*Fundulus similis*	Longnose killifish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.00	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.01	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.07	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.07	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Pentachlorophenol	Previous*	NA	87-86-5	2.10	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.24	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.26	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.22	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.68	BCF	*Carassius auratus*	Goldfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.00	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.41	BCF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.02	BCF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.04	BCF	*Leuciscus idus*	Ide, silver or golden orfe	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.89	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.21	BCF	*Morone saxatilis*	Striped bass	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.26	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	2.29	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Pentachlorophenol	Previous*	NA	87-86-5	3.73	BCF	*Oncorhynchus mykiss*	Rainbow trout	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.30	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	2.85	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.21	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.11	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.15	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.18	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.30	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.49	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.36	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.52	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.57	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.62	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.71	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Phenanthrene	Previous*	NA	85-01-8	2.91	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.35	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	2.97	BCF	*Scophthalmus maximus*	Turbot	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	2.46	BCF	*Crangon septemspinosa*	Bay shrimp, sand shrimp	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.11	BCF	*Mya arenaria*	Sand gaper, soft shell clam	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.09	BCF	*Mytilus edulis*	Common bay mussel	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	2.70	BCF	*Nereis virens*	Polychaete worm	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	2.80	BCF	*Asellus aquaticus*	Isopod	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	2.51	BCF	*Daphnia magna*	Water flea	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	2.51	BCF	*Daphnia pulex*	Water flea	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.43	BCF	*Mysis relicta*	Shrimp	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	4.45	BCF	*Pontoporeia hoyi*	Amphipod	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.77	BCF	*Stylodrilus heringianus*	Worm	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.21	BCF	*Hexagenia limbata*	Mayfly	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	3.25	BCF	*Chlorella fusca*	Green algae	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	4.28	BAF	*Pontoporeia hoyi*	Amphipod	ECCC 2020
Phenanthrene	Previous*	NA	85-01-8	4.28	BAF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.15	BAF	*Daphnia pulex*	Water flea	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.25	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	4.03	BCF	*Selenastrum capricornutum*	Green algae	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	2.46	BCF	*Crangon septemspinosa*	Bay shrimp, sand shrimp	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.11	BCF	*Mya arenaria*	Sand gaper, soft shell clam	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.09	BCF	*Mytilus edulis*	Common bay mussel	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	2.70	BCF	*Nereis virens*	Polychaete worm	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	2.80	BCF	*Asellus aquaticus*	Isopod	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.43	BCF	*Mysis relicta*	Shrimp	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Phenanthrene	Previous*	NA	85-01-8	4.45	BCF	*Pontoporeia hoyi*	Amphipod	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.77	BCF	*Stylodrilus heringianus*	Worm	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.21	BCF	*Hexagenia limbata*	Mayfly	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	2.51	BCF	*Daphnia pulex*	Water flea	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	2.51	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	2.78	BCF	*Daphnia magna*	Water flea	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.07	BCF	*Daphnia pulex*	Water flea	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	1.06	BCF	*Polychaete sp*	Worm	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.30	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	2.97	BCF	*Scophthalmus maximus*	Turbot	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.71	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.62	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.57	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.52	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.49	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.36	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.30	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.18	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.15	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.11	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.35	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.21	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	2.91	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	2.85	BCF	*Cyprinodon variegatus*	Sheepshead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.23	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.30	BCF	*Pimephales promelas*	Fathead minnow	Arnot & Gobas 2006
Phenanthrene	Previous*	NA	85-01-8	3.25	BCF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006

Chemical	New or Previous*	PCB #	CAS number	Log BAF or Log BCF (L/kg, ww)	BAF or BCF	Organism scientific name	Organism common name	Source
Trichloroethylene	Previous*	NA	79-01-6	1.00	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Trichloroethylene	Previous*	NA	79-01-6	0.43	BCF	*Cyprinodontidae*	Killifish	ECCC 2020
Trichloroethylene	Previous*	NA	79-01-6	1.03	BCF	*Cyprinus carpio*	Common carp	ECCC 2020
Trichloroethylene	Previous*	NA	79-01-6	1.95	BCF	*1. Chlorella fusca*	Green algae	ECCC 2020
Trichloroethylene	Previous*	NA	79-01-6	1.95	BCF	*Chlorella fusca*	Green algae	Arnot & Gobas 2006
Trichloroethylene	Previous*	NA	79-01-6	1.00	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Trichloroethylene	Previous*	NA	79-01-6	1.03	BCF	*Cyprinus carpio*	Common carp	Arnot & Gobas 2006
Trichloroethylene	Previous*	NA	79-01-6	0.43	BCF	*Cyprinodontidae*	Killifish	Arnot & Gobas 2006
Trichloroethylene	Previous*	NA	79-01-6	1.23	BCF	*Lepomis macrochirus*	Bluegill sunfish	Arnot & Gobas 2006
Trichloroethylene	Previous*	NA	79-01-6	1.95	BCF	*Leuciscus idus melanotus*	Golden ide	Arnot & Gobas 2006
Trifluralin	Previous*	NA	1582-09-8	4.06	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.16	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.46	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.63	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.65	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.68	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.85	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	4.06	BCF	*Cyprinodon variegatus*	Sheepshead minnow	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.51	BCF	*Pimephales promelas*	Fathead minnow	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.50	BCF	*Pseudorasbora parva*	Topmouth gudgeon	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.45	BCF	*Moxostoma macrolepidotum*	Shorthead redhorse	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.23	BCF	N/R	Golden redhorse	ECCC 2020
Trifluralin	Previous*	NA	1582-09-8	3.73	BCF	N/R	Sauger	ECCC 2020
Tri-o-cresyl phosphate	Previous*	NA	78-30-8	2.90	BCF	*Alburnus alburnus*	Bleak	ECCC 2020
Tri-o-cresyl phosphate	Previous*	NA	78-30-8	2.90	BCF	*Alburnus alburnus*	Bleak	Arnot & Gobas 2006

Notes:
BAF = Bioaccumulation factor; BCF = Bioconcentration factor; CAS = Chemical Abstracts Service; ECCC = Environment and Climate Change Canada; N/R = Not reported; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process

Table F-2. Bioaccumulation and Bioconcentration Factors from EPISuite for Newly and Previously Identified Chemicals in Biosolids

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
2-(N-Ethylperfluorooctanesulfonamido) acetic acid	New	NA	2991-50-6	1.75	4.082	4.211	4.242	6.033	5.787	5.617
alpha-Solanine	New	NA	20562-02-1	0.99	1.026	0.875	0.828	1.026	0.875	0.828
Berberine	New	NA	2086-83-1	0.5	0.737	0.731	0.719	0.737	0.731	0.719
Bromide	New	NA	24959-67-9	0.5	0.053	0.055	0.053	0.053	0.055	0.055
Doxepin	New	NA	1668-19-5	2.5	2.091	2.201	2.23	2.091	2.202	2.243
Fentanyl	New	NA	437-38-7	2.34	1.244	1.37	1.408	1.244	1.37	1.411
Hydromorphone	New	NA	466-99-9	0.72	0.205	0.243	0.25	0.205	0.243	0.25
Hydroxychloroquine	New	NA	118-42-3	1.41	0.996	1.09	1.114	0.996	1.09	1.114
Levorphanol	New	NA	77-07-6	1.72	0.949	1.051	1.078	0.949	1.051	1.078
Losartan	New	NA	114798-26-4	2.06	2.499	2.515	2.508	2.5	2.518	2.521
Methadone	New	NA	76-99-3	2.26	1.666	1.779	1.809	1.666	1.779	1.813
Perfluorohexadecanoic acid	New	NA	67905-19-5	0.5	1.749	1.929	1.985	5.443	5.079	4.795
(E)-1,2-Dichloroethylene	Previous*	NA	156-60-5	0.99	1.3	0.875	0.828	1.03	0.875	0.828
1,1,1-Trichloroethane	Previous*	NA	71-55-6	1.31	1.014	1.029	1.023	1.014	1.029	1.023
1,2,3,4,6,7,8-Heptachlorodibenzo[b,d]furan	Previous*	NA	67562-39-4	3.673	2.239	2.379	2.422	4.089	4.486	4.723
1,2,3,7,8,9-Hexachlorodibenzo[b,d]furan	Previous*	NA	72918-21-9	3.839	2.744	2.887	2.931	4.811	5.037	5.175
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	Previous*	NA	40321-76-4	4.048	3.736	3.886	3.929	5.713	5.655	5.613
1,2,3-Trichlorobenzene	Previous*	NA	87-61-6	2.339	2.94	2.816	2.771	2.954	2.84	2.806
1,2,4-Trichlorobenzene	Previous*	NA	120-82-1	2.319	2.969	2.818	2.766	3.004	2.854	2.808
1,2-Dichlorobenzene	Previous*	NA	95-50-1	1.93	2.372	2.224	2.174	2.372	2.227	2.18
1,2-Dichloropropane	Previous*	NA	78-87-5	0.973	0.87	0.786	0.753	0.87	0.786	0.753

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
1,4-Dinitrobenzene	Previous*	NA	100-25-4	0.63	0.521	0.429	0.399	0.521	0.429	0.399
1,4-Dioxane	Previous*	NA	123-91-1	0.5	-0.034	-0.019	-0.016	-0.034	-0.019	-0.016
1-Methyl phenanthrene	Previous*	NA	832-69-9	3.68	3.173	3.258	3.277	3.215	3.38	3.503
2-(2,4,5-Trichlorophenoxy)propionic acid	Previous*	NA	93-72-1	0.5	2.789	2.618	2.563	2.821	2.645	2.591
2-(Methylthio)benzothiazole	Previous*	NA	615-22-5	1.745	1.697	1.698	1.687	1.697	1.698	1.688
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	Previous*	206	40186-72-9	3.66	2.482	2.647	2.697	6.091	5.745	5.486
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Previous*	194	35694-08-7	3.89	2.994	3.173	3.228	6.624	6.274	6.002
2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl	Previous*	207	52663-79-3	3.46	2.076	2.237	2.287	5.687	5.34	5.081
2,2',3,3',4,4',5,6-Octachlorobiphenyl	Previous*	195	52663-78-2	3.77	2.625	2.788	2.837	6.196	5.862	5.613
2,2',3,3',4,4',6,6'-Octachlorobiphenyl	Previous*	197	33091-17-7	3.77	2.828	3.007	3.061	6.482	6.126	5.851
2,2',3,3',4,4',6-Heptachlorobiphenyl	Previous*	171	52663-71-5	4.09	3.155	3.329	3.381	6.659	6.337	6.093
2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl	Previous*	208	52663-77-1	4.14	3.277	3.457	3.511	6.785	6.458	6.206
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	Previous*	199	52663-75-9	3.77	2.592	2.753	2.802	6.147	5.818	5.575
2,2',3,3',4,5,5',6-Octachlorobiphenyl	Previous*	198	68194-17-2	3.77	2.828	3.007	3.061	6.482	6.126	5.851
2,2',3,3',4,5,5'-Heptachlorobiphenyl	Previous*	172	52663-74-8	4.09	3.153	3.326	3.378	6.655	6.334	6.09
2,2',3,3',4,5,6,6'-Octachlorobiphenyl	Previous*	200	52663-73-7	3.77	2.828	3.007	3.061	6.482	6.126	5.851
2,2',3,3',4,5,6'-Heptachlorobiphenyl	Previous*	174	38411-25-5	4.09	3.133	3.305	3.356	6.623	6.305	6.066
2,2',3,3',4,5,6-Heptachlorobiphenyl	Previous*	173	68194-16-1	4.09	3.277	3.463	3.519	6.848	6.508	6.241
2,2',3,3',4,5',6'-Heptachlorobiphenyl	Previous*	177	52663-70-4	4.09	3.149	3.322	3.374	6.648	6.328	6.084
2,2',3,3',4,5',6-Heptachlorobiphenyl	Previous*	175	40186-70-7	4.09	3.277	3.463	3.519	6.848	6.508	6.241
2,2',3,3',4,5'-Hexachlorobiphenyl	Previous*	130	52663-66-8	4.52	3.766	3.957	4.013	6.956	6.642	6.394
2,2',3,3',4,6,6'-Heptachlorobiphenyl	Previous*	176	52663-65-7	4.09	3.277	3.463	3.519	6.848	6.508	6.241
2,2',3,3',4,6'-Hexachlorobiphenyl	Previous*	132	38380-05-1	4.69	3.876	4.052	4.103	6.705	6.429	6.219

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
2,2',3,3',4-Pentachlorobiphenyl	Previous*	82	52663-62-4	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',3,3',5,5',6,6'-Octachlorobiphenyl	Previous*	202	2136-99-4	4.35	3.59	3.782	3.839	6.985	6.66	6.402
2,2',3,3',5,5'-Hexachlorobiphenyl	Previous*	133	35694-04-3	4.68	3.934	4.118	4.171	6.877	6.568	6.326
2,2',3,3',5,6,6'-Heptachlorobiphenyl	Previous*	179	52663-64-6	4.09	3.277	3.463	3.519	6.848	6.508	6.241
2,2',3,3',5,6'-Hexachlorobiphenyl	Previous*	135	52744-13-5	4.64	3.839	4.019	4.072	6.785	6.498	6.276
2,2',3,3',5,6-Hexachlorobiphenyl	Previous*	134	52704-70-8	4.59	3.842	4.03	4.085	6.93	6.619	6.373
2,2',3,3',5-Pentachlorobiphenyl	Previous*	83	60145-20-2	4.86	3.968	4.149	4.2	6.821	6.517	6.28
2,2',3,3',6-Pentachlorobiphenyl	Previous*	84	52663-60-2	4.24	4.173	4.276	4.294	6.068	5.743	5.521
2,2',3,3'-Tetrachlorobiphenyl	Previous*	40	38444-93-8	4.33	4.103	4.228	4.256	6.037	5.776	5.595
2,2',3,4,4',5,6,6'-Octachlorobiphenyl	Previous*	204	74472-52-9	3.77	2.828	3.007	3.061	6.482	6.126	5.851
2,2',3,4,4',5,6'-Heptachlorobiphenyl	Previous*	182	60145-23-5	4.09	3.151	3.324	3.377	6.652	6.331	6.088
2,2',3,4,4',5,6-Heptachlorobiphenyl	Previous*	181	74472-47-2	4.09	3.277	3.463	3.519	6.848	6.508	6.241
2,2',3,4,4',5',6-Heptachlorobiphenyl	Previous*	183	52663-69-1	4.09	3.184	3.361	3.414	6.705	6.378	6.128
2,2',3,4,4',5'-Hexabromodiphenyl Ether	Previous*	NA	182677-30-1	3.36	2.585	2.736	2.782	5.878	5.648	5.487
2,2',3,4,4',5-Hexachlorobiphenyl	Previous*	137	35694-06-5	4.49	3.663	3.845	3.899	6.81	6.521	6.298
2,2',3,4,4',6,6'-Heptachlorobiphenyl	Previous*	184	74472-48-3	4.44	3.684	3.876	3.932	6.98	6.661	6.408
2,2',3,4,4',6'-Hexachlorobiphenyl	Previous*	140	59291-64-4	4.59	3.842	4.03	4.085	6.93	6.619	6.373
2,2',3,4,4',6-Hexachlorobiphenyl	Previous*	139	56030-56-9	4.4	3.638	3.83	3.886	6.972	6.652	6.399
2,2',3,4',5,5',6-Heptachloro-1,1'-biphenyl	Previous*	187	52663-68-0	4.09	3.127	3.298	3.349	6.612	6.296	6.058
2,2',3,4,5,5',6-Heptachlorobiphenyl	Previous*	185	52712-05-7	4.25	3.383	3.563	3.616	6.794	6.483	6.244
2,2',3,4,5,5'-Hexachlorobiphenyl	Previous*	141	52712-04-6	4.62	3.873	4.061	4.115	6.915	6.605	6.36
2,2',3,4',5,5'-Hexachlorobiphenyl	Previous*	146	51908-16-8	4.65	3.877	4.06	4.133	6.826	6.53	6.299
2,2',3,4,5,6,6'-Heptachlorobiphenyl	Previous*	186	74472-49-4	4.09	3.277	3.463	3.519	6.848	6.508	6.241

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
2,2',3,4',5,6,6'-Heptachlorobiphenyl	Previous*	188	74487-85-7	4.09	3.277	3.463	3.519	6.848	6.508	6.241
2,2',3,4,5,6'-Hexachlorobiphenyl	Previous*	143	68194-15-0	4.4	3.638	3.83	3.886	6.972	6.652	6.399
2,2',3,4,5',6-Hexachlorobiphenyl	Previous*	144	68194-14-9	4.4	3.498	3.673	3.726	6.7	6.425	6.216
2,2',3,4',5,6'-Hexachlorobiphenyl	Previous*	148	74472-41-6	4.79	4.025	4.203	4.252	6.79	6.482	6.243
2,2',3,4',5,6-Hexachlorobiphenyl	Previous*	147	68194-13-8	4.4	3.638	3.83	3.886	6.972	6.652	6.399
2,2',3,4',5',6-Hexachlorobiphenyl	Previous*	149	38380-04-0	4.57	3.826	4.015	4.07	6.937	6.625	6.379
2,2',3,4,5-Pentachlorobiphenyl	Previous*	86	55312-69-1	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',3,4',5'-Pentachlorobiphenyl	Previous*	97	41464-51-1	4.65	4.132	4.302	4.347	6.749	6.422	6.17
2,2',3,4',5-Pentachlorobiphenyl	Previous*	90	68194-07-0	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',3,4,6,6'-Hexachlorobiphenyl	Previous*	145	74472-40-5	4.4	3.638	3.83	3.886	6.972	6.652	6.399
2,2',3,4',6,6'-Hexachlorobiphenyl	Previous*	150	68194-08-1	4.71	4.072	4.244	4.29	6.723	6.414	6.178
2,2',3,4,6'-Pentachlorobiphenyl	Previous*	89	73575-57-2	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',3,4,6-Pentachlorobiphenyl	Previous*	88	55215-17-3	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',3,4',6'-Pentachlorobiphenyl	Previous*	91	60233-25-2	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',3,4',6-Pentachlorobiphenyl	Previous*	98	68194-05-8	4.86	4.002	4.187	4.239	6.898	6.578	6.327
2,2',3,4'-Tetrachloro-1,1'-biphenyl	Previous*	42	36559-22-5	4.43	4.239	4.379	4.409	6.563	6.201	5.932
2,2',3,4-Tetrachlorobiphenyl	Previous*	41	52663-59-9	4.28	4.169	4.282	4.305	6.131	5.815	5.595
2,2',3,5,5',6-Hexachlorobiphenyl	Previous*	151	52663-63-5	4.4	3.638	3.83	3.886	6.972	6.652	6.399
2,2',3,5,5'-Pentachlorobiphenyl	Previous*	92	52663-61-3	4.73	4.052	4.225	4.273	6.734	6.428	6.194
2,2',3,5,6,6'-Hexachlorobiphenyl	Previous*	152	68194-09-2	4.4	3.638	3.83	3.886	6.972	6.652	6.399
2,2',3,5,6'-Pentachlorobiphenyl	Previous*	94	73575-55-0	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',3,5,6-Pentachlorobiphenyl	Previous*	93	73575-56-1	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',3,5'-tetrachlorobiphenyl	Previous*	44	41464-39-5	4.09	4.197	4.255	4.256	5.937	5.54	5.285
2,2',3,6,6'-Pentachlorobiphenyl	Previous*	96	73575-54-9	4.86	3.972	4.153	4.204	6.83	6.524	6.285

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
2,2',3,6'-Tetrachlorobiphenyl	Previous*	46	41464-47-5	4.43	4.142	4.282	4.315	6.324	6.028	5.814
2,2',3-Trichlorobiphenyl	Previous*	16	38444-78-9	3.76	3.957	3.935	3.913	5.002	4.667	4.495
2,2',4,4',5,6'-Hexachlorobiphenyl	Previous*	154	60145-22-4	4.4	3.638	3.83	3.886	6.972	6.652	6.399
2,2',4,4',5-Pentachlorobiphenyl	Previous*	99	38380-01-7	4.61	3.895	4.087	4.143	6.988	6.666	6.408
2,2',4,4',6,6'-Hexachlorobiphenyl	Previous*	155	33979-03-2	4.44	3.679	3.87	3.927	6.971	6.653	6.401
2,2',4,4',6-Pentachlorobiphenyl	Previous*	100	39485-83-1	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',4,5,6'-Pentachlorobiphenyl	Previous*	102	68194-06-9	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',4,5',6-Pentachlorobiphenyl	Previous*	103	60145-21-3	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',4,6,6'-Pentachlorobiphenyl	Previous*	104	56558-16-8	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,2',4,6-Tetrachlorobiphenyl	Previous*	50	62796-65-0	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,2',4-Trichlorobiphenyl	Previous*	17	37680-66-3	4.05	4.117	4.117	4.18	5.672	5.346	5.143
2,2',5,6'-Tetrachlorobiphenyl	Previous*	53	41464-41-9	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,2',5-Trichlorobiphenyl	Previous*	18	37680-65-2	3.91	4.02	4.051	4.045	5.261	4.973	4.81
2,2',6,6'-Tetrachlorobiphenyl	Previous*	54	15968-05-5	4.17	4.156	4.245	4.258	5.929	5.604	5.389
2,2'-Bioxirane	Previous*	NA	1464-53-5	0.5	-0.037	-0.02	-0.017	-0.037	-0.02	-0.017
2,3,3',4,4',5,5',6-Octachlorobiphenyl	Previous*	205	74472-53-0	3.77	2.678	2.845	2.895	6.275	5.933	5.675
2,3,3',4,4',5',6-Heptachlorobiphenyl	Previous*	191	74472-50-7	4.09	3.277	3.463	3.519	6.848	6.508	6.241
2,3,3',4,5,5',6-Heptachlorobiphenyl	Previous*	192	74472-51-8	4.09	3.277	3.463	3.519	6.848	6.508	6.241
2,3,3',4',5,5',6-Heptachlorobiphenyl	Previous*	193	69782-91-8	4.09	3.277	3.463	3.519	6.848	6.508	6.241
2,3,3',4,5,5'-Hexachlorobiphenyl	Previous*	159	39635-35-3	4.5	3.745	3.935	3.992	6.962	6.647	6.397
2,3,3',4',5,5'-Hexachlorobiphenyl	Previous*	162	39635-34-2	4.48	3.723	3.914	3.97	6.966	6.65	6.4
2,3,3',4,5,6-Hexachlorobiphenyl	Previous*	160	41411-62-5	4.56	3.815	4.004	4.06	6.941	6.629	6.382
2,3,3',4,5',6-Hexachlorobiphenyl	Previous*	161	74472-43-8	4.66	3.919	4.104	4.158	6.888	6.578	6.335
2,3,3',4',5',6-Hexachlorobiphenyl	Previous*	164	74472-45-0	4.4	3.638	3.83	3.886	6.972	6.652	6.399

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
2,3,3',4,5'-Pentachlorobiphenyl	Previous*	108	70362-41-3	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3,3',4',5'-Pentachlorobiphenyl	Previous*	122	76842-07-4	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3,3',4',5-Pentachlorobiphenyl	Previous*	107	70424-68-9	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3,3',4,6-Pentachlorobiphenyl	Previous*	109	74472-35-8	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3,3',4',6-Pentachlorobiphenyl	Previous*	110	38380-03-9	4.36	4.256	4.381	4.405	6.474	6.097	5.823
2,3,3',4'-Tetrachlorobiphenyl	Previous*	56	41464-43-1	4.43	4.213	4.353	4.384	6.5	6.155	5.901
2,3,3',4-Tetrachlorobiphenyl	Previous*	55	74338-24-2	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,3,3',5,5',6-Hexachlorobiphenyl	Previous*	165	74472-46-1	4.53	3.777	3.967	4.023	6.954	6.64	6.392
2,3,3',5,5'-Pentachlorobiphenyl	Previous*	111	39635-32-0	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3,3',5',6-Pentachlorobiphenyl	Previous*	113	68194-10-5	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3,3',5'-Tetrachlorobiphenyl	Previous*	58	41464-49-7	4.32	4.169	4.291	4.316	6.198	5.884	5.663
2,3,3',5-Tetrachlorobiphenyl	Previous*	57	70424-67-8	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,3,3',6-Tetrachlorobiphenyl	Previous*	59	74472-33-6	4.43	4.214	4.354	4.385	6.502	6.157	5.902
2,3,3'-Trichlorobiphenyl	Previous*	20	38444-84-7	3.93	4.063	4.089	4.081	5.402	5.068	4.875
2,3,4,4',5,6-Hexachlorobiphenyl	Previous*	166	41411-63-6	4.56	3.81	3.999	4.055	6.943	6.631	6.384
2,3',4,4',5',6-Hexachlorobiphenyl	Previous*	168	59291-65-5	4.59	3.842	4.03	4.085	6.93	6.619	6.373
2,3,4,4',6-Pentachlorobiphenyl	Previous*	115	74472-38-1	4.86	3.733	3.895	3.942	6.269	6.094	5.966
2,3',4,4',6-Pentachlorobiphenyl	Previous*	119	56558-17-9	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3',4,4'-Tetrabromodiphenyl ether	Previous*	NA	189084-61-5	4.13	3.58	3.729	3.773	5.512	5.53	5.538
2,3,4,4'-Tetrachlorobiphenyl	Previous*	60	33025-41-1	4.11	4.14	4.213	4.22	5.8	5.47	5.259
2,3',4,5,5'-Pentachlorobiphenyl	Previous*	120	68194-12-7	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3',4',5,5'-Pentachlorobiphenyl	Previous*	124	70424-70-3	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3,4,5,6-Pentachlorobiphenyl	Previous*	116	18259-05-7	4.71	3.826	3.983	4.028	6.124	5.966	5.852
2,3,4',5,6-Pentachlorobiphenyl	Previous*	117	68194-11-6	4.86	3.972	4.153	4.204	6.83	6.524	6.285

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
2,3',4,5',6-Pentachlorobiphenyl	Previous*	121	56558-18-0	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3',4',5',6-Pentachlorobiphenyl	Previous*	125	74472-39-2	4.86	3.972	4.153	4.204	6.83	6.524	6.285
2,3,4,5-Tetrachlorobiphenyl	Previous*	61	33284-53-6	4.48	3.884	4.027	4.065	5.755	5.642	5.563
2,3,4',5-Tetrachlorobiphenyl	Previous*	63	74472-34-7	4.43	4.205	4.345	4.377	6.481	6.141	5.892
2,3',4,5'-Tetrachlorobiphenyl	Previous*	68	73575-52-7	4.34	4.169	4.294	4.32	6.23	5.917	5.696
2,3',4,5-Tetrachlorobiphenyl	Previous*	67	73575-53-8	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,3',4',5'-Tetrachlorobiphenyl	Previous*	70	70362-48-0	4.36	4.258	4.384	4.409	6.488	6.111	5.836
2,3',4',5-Tetrachlorobiphenyl	Previous*	76	32598-11-1	4.36	4.258	4.384	4.409	6.488	6.111	5.836
2,3,4,6-Tetrachlorobiphenyl	Previous*	62	54230-22-7	4.43	3.89	4.029	4.066	5.668	5.563	5.491
2,3,4',6-Tetrachlorobiphenyl	Previous*	64	52663-58-8	4.43	4.188	4.328	4.36	6.44	6.111	5.871
2,3',4,6-Tetrachlorobiphenyl	Previous*	69	60233-24-1	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,3',4',6-Tetrachlorobiphenyl	Previous*	71	41464-46-4	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,3,4-Trichlorobiphenyl	Previous*	21	55702-46-0	4.12	3.847	3.953	3.976	4.996	4.959	4.936
2,3',4-Trichlorobiphenyl	Previous*	25	55712-37-3	4.01	4.099	4.147	4.146	5.576	5.246	5.047
2',3,4-Trichlorobiphenyl	Previous*	33	38444-86-9	4.13	4.138	4.217	4.227	5.819	5.498	5.291
2,3',5,5'-Tetrachlorobiphenyl	Previous*	72	41464-42-0	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,3,5,6-Tetrachlorobiphenyl	Previous*	65	33284-54-7	4.43	3.89	4.029	4.066	5.668	5.563	5.491
2,3',5',6-Tetrachlorobiphenyl	Previous*	73	74338-23-1	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,3,5-Trichlorobiphenyl	Previous*	23	55720-44-0	4.01	3.812	3.901	3.918	4.749	4.73	4.721
2,3',5'-Trichlorobiphenyl	Previous*	34	37680-68-5	4.01	4.099	4.147	4.146	5.576	5.246	5.047
2,3'-Dichlorobiphenyl	Previous*	6	25569-80-6	3.57	3.792	3.722	3.688	4.508	4.202	4.067
2,4,4',5-Tetrachlorobiphenyl	Previous*	74	32690-93-0	4.65	4.133	4.303	4.348	6.752	6.424	6.172
2,4,4',6-Tetrachlorobiphenyl	Previous*	75	32598-12-2	4.43	4.159	4.299	4.332	6.367	6.059	5.835
2,4,4'-Tribromodiphenyl ether	Previous*	NA	41318-75-6	3.55	3.696	3.812	3.842	4.602	4.703	4.764

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
2,4,4'-Trichlorobiphenyl	Previous*	28	7012-37-5	3.96	4.04	4.083	4.081	5.358	5.073	4.906
2,4,5-Trichlorobiphenyl	Previous*	29	15862-07-4	4.09	4.048	4.128	4.139	5.516	5.273	5.123
2,4,5-Trichlorophenoxyacetic acid	Previous*	NA	93-76-5	0.5	2.323	2.14	2.083	2.33	2.148	2.092
2,4,5-Trimethylaniline	Previous*	NA	137-17-7	1.165	1.057	0.997	0.969	1.057	0.997	0.969
2,4,6-Trichlorobiphenyl	Previous*	30	35693-92-6	3.86	3.749	3.814	3.822	4.427	4.429	4.434
2,4',6-Trichlorobiphenyl	Previous*	32	38444-77-8	4.05	4.205	4.247	4.243	5.922	5.496	5.244
2,4-Dichlorobiphenyl	Previous*	7	33284-50-3	3.66	3.618	3.644	3.639	3.972	3.998	4.019
2,5-Dichlorobiphenyl	Previous*	9	34883-39-1	3.62	3.928	3.837	3.798	5.01	4.509	4.265
2,6-Dinitrotoluene	Previous*	NA	606-20-2	1.053	0.996	0.9	0.864	0.996	0.9	0.864
2-Chloro-4-phenylphenol	Previous*	NA	92-04-6	2.25	2.484	2.479	2.465	2.484	2.482	2.476
2-Hexanone	Previous*	NA	591-78-6	0.578	0.462	0.378	0.35	0.462	0.378	0.35
2-Methyl-1-propanol	Previous*	NA	78-83-1	0.5	0.12	0.099	0.092	0.12	0.099	0.092
2-Methylpyridine	Previous*	NA	109-06-8	0.399	0.269	0.222	0.206	0.269	0.222	0.206
3,3',4,5,5'-Pentachlorobiphenyl	Previous*	127	39635-33-1	4.86	3.972	4.153	4.204	6.83	6.524	6.285
3,3',4,5'-Tetrachlorobiphenyl	Previous*	79	41464-48-6	4.43	4.159	4.299	4.332	6.367	6.059	5.835
3,3',4,5-Tetrachlorobiphenyl	Previous*	78	70362-49-1	4.43	4.159	4.299	4.332	6.367	6.059	5.835
3,3',4-Trichlorobiphenyl	Previous*	35	37680-69-6	4.01	4.099	4.147	4.146	5.576	5.246	5.047
3,3',5,5'-Tetrachlorobiphenyl	Previous*	80	33284-52-5	4.61	4.108	4.27	4.312	6.594	6.291	6.062
3,3',5-Trichlorobiphenyl	Previous*	36	38444-87-0	4.09	4.127	1.296	4.202	5.74	5.416	5.211
3,3'-Dichloro-1,1'-biphenyl	Previous*	11	2050-67-1	3.73	3.931	3.904	3.881	4.915	4.592	4.43
3,4,5-Trichlorobiphenyl	Previous*	38	53555-66-1	4.01	3.812	3.901	3.918	4.749	4.73	4.721
3,4',5-Trichlorobiphenyl	Previous*	39	38444-88-1	4.01	4.099	4.147	4.146	5.576	5.246	5.047
3,4'-Dichlorobiphenyl	Previous*	13	2974-90-5	3.65	3.868	3.82	3.791	4.721	4.404	4.254
3,4-Dichlorobiphenyl	Previous*	12	2974-92-7	3.74	3.671	3.715	3.716	4.139	4.165	4.184

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
3,5-Dichlorobiphenyl	Previous*	14	34883-41-5	3.82	3.579	3.658	3.672	3.967	4.103	4.185
3,6-Dimethylphenanthrene	Previous*	NA	1576-67-6	3.917	2.774	2.903	2.94	2.788	3.009	3.235
3-Chlorobiphenyl	Previous*	2	2051-61-8	2.69	3.3	3.246	3.218	3.365	3.336	3.337
4,4'-Dichlorobiphenyl	Previous*	15	2050-68-2	3.7	3.911	3.876	3.851	4.851	4.529	4.371
4-Androstene-3,17-dione	Previous*	NA	63-05-8	1.48	1.7	1.554	1.505	1.7	1.554	1.506
4-Chloro-3-methylphenol	Previous*	NA	59-50-7	1.712	1.273	1.347	1.362	1.273	1.347	1.362
4-Methyl-2-pentanone	Previous*	NA	108-10-1	0.53	0.41	0.334	0.309	0.41	0.334	0.309
Acenaphthene	Previous*	NA	83-32-9	2.253	1.978	2.065	2.085	1.978	2.066	2.09
Aldrin	Previous*	NA	309-00-2	3.956	3.653	3.796	3.837	5.265	5.317	5.347
Allyl alcohol	Previous*	NA	107-18-6	0.5	-0.004	0.005	0.005	-0.004	0.005	0.005
Allyl chloride	Previous*	NA	107-05-1	0.94	0.873	0.77	0.733	0.873	0.77	0.733
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	NA	319-84-6	2.399	3.121	2.954	2.899	3.287	3.048	2.971
alpha-Terpineol	Previous*	NA	98-55-5	1.831	2.103	2.009	1.972	2.103	2.01	1.974
Aroclor 1248	Previous*	NA	12672-29-6	4.344	4.169	4.294	4.32	6.23	5.917	5.696
Aroclor 1254	Previous*	NA	11097-69-1	4.733	3.94	4.106	4.152	6.471	6.228	6.047
Aroclor 1260	Previous*	NA	11096-82-5	4.44	3.684	3.876	3.932	6.98	6.661	6.408
Azinphos-methyl	Previous*	NA	86-50-0	1.481	1.754	1.581	1.527	1.754	1.581	1.528
Bensulide	Previous*	NA	741-58-2	2.44	2.429	2.495	2.506	2.429	2.498	2.523
Benzene	Previous*	NA	71-43-2	1.072	1.17	1	0.949	1.17	1	0.949
Benzo(g,h,i)perylene	Previous*	NA	191-24-2	4.041	1.823	1.96	2.002	1.831	2.06	2.852
Benzyl alcohol	Previous*	NA	100-51-6	0.137	0.19	0.179	0.171	0.19	0.179	0.171
Benzyl butyl phthalate	Previous*	NA	85-68-7	2.788	1.603	1.735	1.775	1.603	1.737	1.796
beta-Hexachlorocyclohexane	Previous*	NA	319-85-7	2.399	3.121	2.954	2.899	3.287	3.048	2.971

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
Biphenyl	Previous*	NA	92-52-4	2.313	2.629	2.608	2.589	2.63	2.613	2.605
Bisphenol A	Previous*	NA	80-05-7	1.86	2.237	2.102	2.055	2.238	2.103	2.058
Caffeine	Previous*	NA	58-08-2	0.5	-0.029	-0.014	-0.011	-0.029	-0.014	-0.011
Captan	Previous*	NA	133-06-2	1.51	1.804	1.63	1.576	1.804	1.631	1.577
Carbadox	Previous*	NA	6804-07-5	0.5	-0.049	-0.03	-0.026	-0.049	-0.03	-0.026
Carbon disulfide	Previous*	NA	75-15-0	0.95	0.818	0.742	0.712	0.818	0.742	0.712
Carbophenothion	Previous*	NA	786-19-6	3.18	3.49	3.57	3.584	3.747	3.915	4.018
Chlorobenzene	Previous*	NA	108-90-7	1.54	1.398	1.399	1.387	1.4	1.399	1.388
Chlorobenzilate	Previous*	NA	510-15-6	2.79	2.513	2.625	2.654	2.514	2.638	2.713
Chloroethane	Previous*	NA	75-00-3	0.61	0.535	0.426	0.393	0.535	0.426	0.393
Chloromethane	Previous*	NA	74-87-3	0.5	0.215	0.161	0.146	0.215	0.161	0.146
Chlorpyrifos	Previous*	NA	2921-88-2	2.94	3.269	3.324	3.329	3.33	3.448	3.533
Clomazone	Previous*	NA	81777-89-1	1.32	1.439	1.304	1.258	1.439	1.304	1.259
Crotonaldehyde	Previous*	NA	4170-30-3	0.5	0.099	0.073	0.066	0.099	0.073	0.066
Crotoxyphos	Previous*	NA	7700-17-6	1.02	0.876	0.988	1.02	0.876	0.988	1.02
Cyanide	Previous*	NA	57-12-5	0.5	-0.036	-0.019	-0.016	-0.036	-0.019	-0.016
Decane	Previous*	NA	124-18-5	1.6	2.959	3.059	3.083	2.973	3.125	3.245
delta-Hexachlorocyclohexane	Previous*	NA	319-86-8	2.399	3.121	2.954	2.899	3.287	3.048	2.971
Diallate	Previous*	NA	2303-16-4	2.63	2.406	2.507	2.533	2.406	2.513	2.563
Diazinon	Previous*	NA	333-41-5	2.18	2.455	2.425	2.404	2.455	2.428	2.413
Dibenzofuran	Previous*	NA	132-64-9	2.39	3.072	2.919	2.868	3.14	2.976	2.924
Dibenzothiophene	Previous*	NA	132-65-0	2.56	3.113	3.054	3.024	3.134	3.095	3.091
Dichlorodiphenyltrichloroethane	Previous*	NA	50-29-3	4.23	3.818	3.983	4.03	6.365	6.16	6.01
Dichloromethane	Previous*	NA	75-09-2	0.49	0.42	0.322	0.294	0.42	0.322	0.294

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
Dicrotophos	Previous*	NA	141-66-2	0.5	-0.035	-0.017	-0.013	-0.035	-0.017	-0.013
Dieldrin	Previous*	NA	60-57-1	3.1	3.802	3.792	—	4.489	4.317	—
Dimethyl sulfone	Previous*	NA	67-71-0	0.5	-0.048	-0.03	-0.026	-0.048	-0.03	-0.026
Diphenyl oxide	Previous*	NA	101-84-8	2.44	2.457	2.52	2.53	2.457	2.524	2.548
Diphenylamine	Previous*	NA	122-39-4	1.98	2.393	2.268	2.223	2.393	2.27	2.229
dl-Norgestrel	Previous*	NA	6533-00-2	1.96	2.261	2.184	2.15	2.261	2.184	2.153
Docosane	Previous*	NA	629-97-0	1.5	0.373	0.477	0.51	3.613	3.332	3.133
Dodecane	Previous*	NA	112-40-3	2.32	2.777	2.913	2.955	2.859	3.305	3.711
Eicosane	Previous*	NA	112-95-8	1.98	0.967	1.101	1.142	4.186	3.985	3.849
Endrin	Previous*	NA	72-20-8	3.098	3.802	3.792	—	4.489	4.317	—
EPN	Previous*	NA	2104-64-5	2.82	2.608	2.716	2.744	2.609	2.734	2.815
Heptachlor	Previous*	NA	76-44-8	3.28	3.809	3.864	3.867	4.593	4.531	4.501
Hexabromocyclododecane	Previous*	NA	25637-99-4	3.76	3.354	3.523	3.574	6.551	6.296	6.107
Hexacosane	Previous*	NA	630-01-3	1.13	-0.032	-0.008	-0.001	2.176	1.829	1.573
Hexadecane	Previous*	NA	544-76-3	2.94	2.505	2.65	2.694	5.278	5.265	5.256
Iodine	Previous*	NA	7553-56-2	1.31	0.992	1.013	1.008	0.992	1.013	1.008
Leptophos	Previous*	NA	21609-90-5	3.83	3.632	3.77	3.809	4.3	5.047	5.117
Lindane	Previous*	NA	58-89-9	2.4	3.802	3.792	3.774	4.489	4.317	4.238
Methacrylonitrile	Previous*	NA	126-98-7	0.5	0.119	0.09	0.081	0.119	0.09	0.081
Methyl ethyl ketone	Previous*	NA	78-93-3	0.5	0.013	0.017	0.016	0.013	0.017	0.016
Mevinphos	Previous*	NA	7786-34-7	0.5	-0.037	-0.017	-0.013	-0.037	-0.017	-0.013
Naled	Previous*	NA	300-76-5	-0.25	0.362	0.326	0.31	0.362	0.326	0.31
Nitrobenzene	Previous*	NA	98-95-3	0.89	0.808	0.705	0.669	0.808	0.705	0.669
o-Cresol	Previous*	NA	95-48-7	0.95	0.961	0.821	0.777	0.961	0.821	0.777

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
Octacosane	Previous*	NA	630-02-4	0.65	0.047	0.028	0.023	1.354	1.017	0.777
Octadecane	Previous*	NA	593-45-3	2.46	1.662	1.802	1.845	4.639	4.563	4.514
p,p'-DDD	Previous*	NA	72-54-8	3.639	4.235	4.33	4.343	6.214	5.832	5.568
p,p'-DDE	Previous*	NA	72-55-9	3.96	3.88	4.028	4.068	5.889	5.758	5.666
PCB 026	Previous*	26	38444-81-4	4.05	4.117	4.117	4.18	5.672	5.346	5.143
p-Cymene	Previous*	NA	99-87-6	2.37	2.716	2.696	2.677	2.718	2.703	2.699
Penicillin V	Previous*	NA	87-08-1	0.5	0.768	0.756	0.742	0.768	0.756	0.742
Pentachlorophenol	Previous*	NA	87-86-5	3.05	2.405	2.534	2.572	2.406	2.557	2.687
Perfluorodecanesulfonic acid	Previous*	NA	335-77-3	1	3.949	4.043	4.06	5.253	5.115	5.03
Perylene	Previous*	NA	198-55-0	3.79	2.428	2.565	2.607	2.457	2.865	3.356
Phenanthrene	Previous*	NA	85-01-8	3.27	3.08	3.059	3.04	3.094	3.096	3.11
Phosphamidon	Previous*	NA	13171-21-6	0.5	0.081	0.082	0.08	0.081	0.082	0.08
Potassium	Previous*	NA	7440-09-7	0.5	-0.006	0.005	0.007	-0.006	0.005	0.007
Propionitrile	Previous*	NA	107-12-0	0.5	0.001	0.006	0.007	0.001	0.006	0.007
Quinine	Previous*	NA	130-95-0	1.68	1.653	1.721	1.733	1.653	1.721	1.735
Silicon	Previous*	NA	7440-21-3	0.5	0.042	0.043	0.041	0.042	0.043	0.041
Squalene	Previous*	NA	7683-64-9	0.63	-0.046	-0.026	-0.022	1.52	1.172	0.911
Strontium	Previous*	NA	7440-24-6	0.5	-0.012	0.002	0.004	-0.012	0.002	0.004
Tetracosane	Previous*	NA	646-31-1	1.61	0.054	0.105	0.121	2.938	2.611	2.373
Tetradecane	Previous*	NA	629-59-4	3.43	3.358	3.51	3.556	5.709	5.692	5.677
Tetraethyl pyrophosphate	Previous*	NA	107-49-3	0.5	-0.024	-0.003	0.001	-0.024	-0.003	0.001
Thioxanthen-9-one	Previous*	NA	492-22-8	1.71	2.433	2.458	2.455	2.433	2.461	2.466
Triacontane	Previous*	NA	638-68-6	0.5	-0.049	-0.03	-0.026	0.565	0.33	0.197
Trichloroethylene	Previous*	NA	79-01-6	1.26	1.375	1.235	1.188	1.375	1.235	1.188

Chemical	New or Previous	PCB #	CAS number	EPISuite Log BCF (regression based estimate) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BCF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas upper trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas mid trophic incl biotrans) (L/kg, ww)	EPISuite Log BAF (Arnot-Gobas lower trophic incl biotrans) (L/kg, ww)
Trichlorofluoromethane	Previous*	NA	75-69-4	1.34	1.52	1.359	1.308	1.52	1.359	1.308
Trifluralin	Previous*	NA	1582-09-8	3.19	3.176	3.286	3.14	3.247	3.482	3.661
Tri-o-cresyl phosphate	Previous*	NA	78-30-8	2.21	3.107	3.203	3.225	3.14	3.314	3.449
Triphenylene	Previous*	NA	217-59-4	3.29	2.516	2.65	2.69	2.521	2.718	2.948
Valproic acid	Previous*	NA	99-66-1	0.5	1.667	1.537	1.491	1.667	1.537	1.492

Notes:
BAF = Bioaccumulation factor; BCF = Bioconcentration factor; CAS = Chemical Abstracts Service; NEW = Newly identified chemical; Previous = Previously identified chemical; Prevoius* = Chemical was identified during the curation process

Table F-3. Bioconcentration Factors (BCF) as Reported by ORNL for Newly and Previously Identified Chemicals in Biosolids

Chemical	New or Previous	CAS number	BCF (L/g)	Source
Perfluorohexadecanoic acid	New	67905-19-5	4800	ORNL 2022
(E)-1,2-Dichloroethylene	Previous*	156-60-5	11.12	ORNL 2022
1,1,1-Trichloroethane	Previous*	71-55-6	5.00034535	ORNL 2022
1,2,3-Trichlorobenzene	Previous*	87-61-6	664.9668571	ORNL 2022
1,2,4-Trichlorobenzene	Previous*	120-82-1	2084.97091	ORNL 2022
1,2-Dichlorobenzene	Previous*	95-50-1	270.0225287	ORNL 2022
1,2-Dichloropropane	Previous*	78-87-5	7.000031591	ORNL 2022
1,4-Dinitrobenzene	Previous*	100-25-4	4.269	ORNL 2022
1,4-Dioxane	Previous*	123-91-1	0.500034535	ORNL 2022
1-Methyl phenanthrene	Previous*	832-69-9	4780	ORNL 2022
2,2'-Bioxirane	Previous*	1464-53-5	3.162	ORNL 2022
2-(2,4,5-Trichlorophenoxy)propionic acid	Previous*	93-72-1	3.162	ORNL 2022
2,4,5-Trichlorophenoxyacetic acid	Previous*	93-76-5	3.162	ORNL 2022
2,6-Dinitrotoluene	Previous*	606-20-2	22.03433764	ORNL 2022
2-Hexanone	Previous*	591-78-6	3.78	ORNL 2022
2-Methyl-1-propanol	Previous*	78-83-1	3.162	ORNL 2022
2-Methylpyridine	Previous*	109-06-8	2.508	ORNL 2022
4-Chloro-3-methylphenol	Previous*	59-50-7	8.499629594	ORNL 2022
4-Methyl-2-pentanone	Previous*	108-10-1	3.399	ORNL 2022
Acenaphthene	Previous*	83-32-9	755.0922277	ORNL 2022
Aldrin	Previous*	309-00-2	5500.472529	ORNL 2022
Allyl Alcohol	Previous*	107-18-6	3.162	ORNL 2022
Allyl Chloride	Previous*	107-05-1	5.00034535	ORNL 2022
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	319-84-6	371.5352291	ORNL 2022
Azinphos-methyl	Previous*	86-50-0	30.3	ORNL 2022
Benzene	Previous*	71-43-2	4.265795188	ORNL 2022
Benzenethiol	Previous*	108-98-5	21.36	ORNL 2022
Benzo(g,h,i)perylene	Previous*	191-24-2	11000	ORNL 2022
Benzyl Alcohol	Previous*	100-51-6	1.371	ORNL 2022
Benzyl butyl phthalate	Previous*	85-68-7	16.32675967	ORNL 2022
beta-Hexachlorocyclohexane	Previous*	319-85-7	371.5352291	ORNL 2022
Biphenyl	Previous*	92-52-4	436.5158322	ORNL 2022
Bisphenol A	Previous*	80-05-7	43.80261112	ORNL 2022
Captan	Previous*	133-06-2	96.2941713	ORNL 2022
Carbon Disulfide	Previous*	75-15-0	19.498446	ORNL 2022
Carbophenothion	Previous*	786-19-6	1527	ORNL 2022
Chlorobenzene	Previous*	108-90-7	17.7827941	ORNL 2022
Chlorobenzilate	Previous*	510-15-6	482.5029801	ORNL 2022

Chemical	New or Previous	CAS number	BCF (L/g)	Source
Chloroethane	Previous*	75-00-3	4.079	ORNL 2022
Chloromethane	Previous*	74-87-3	3.162	ORNL 2022
Chlorpyrifos	Previous*	2921-88-2	1523.000339	ORNL 2022
Crotonaldehyde	Previous*	4170-30-3	3.162	ORNL 2022
Decane	Previous*	124-18-5	39.66	ORNL 2022
delta-Hexachlorocyclohexane	Previous*	319-86-8	371.5352291	ORNL 2022
Diallate	Previous*	2303-16-4	426.1	ORNL 2022
Diazinon	Previous*	333-41-5	71.46608639	ORNL 2022
Dibenzofuran	Previous*	132-64-9	1519.497535	ORNL 2022
Dibenzothiophene	Previous*	132-65-0	1129.015749	ORNL 2022
Dichlorodiphenyltrichloroethane	Previous*	50-29-3	19601.98263	ORNL 2022
Dichloromethane	Previous*	75-09-2	23.0993628	ORNL 2022
Dicrotophos	Previous*	141-66-2	3.162	ORNL 2022
Dieldrin	Previous*	60-57-1	7479.972479	ORNL 2022
Diphenyl oxide	Previous*	101-84-8	319	ORNL 2022
Endrin	Previous*	72-20-8	7479.972479	ORNL 2022
EPN	Previous*	2104-64-5	939.0743969	ORNL 2022
Heptachlor	Previous*	76-44-8	8765.970403	ORNL 2022
Lindane	Previous*	58-89-9	1150	ORNL 2022
Methacrylonitrile	Previous*	126-98-7	3.162	ORNL 2022
Methyl ethyl ketone	Previous*	78-93-3	3.162	ORNL 2022
Naled	Previous*	300-76-5	0.5657	ORNL 2022
Nitrobenzene	Previous*	98-95-3	4.700023182	ORNL 2022
o-Cresol	Previous*	95-48-7	10.71519305	ORNL 2022
p,p'-DDD	Previous*	72-54-8	4355	ORNL 2022
p,p'-DDE	Previous*	72-55-9	12022.64435	ORNL 2022
p-Cymene	Previous*	99-87-6	235.6	ORNL 2022
Pentachlorophenol	Previous*	87-86-5	595.9365193	ORNL 2022
Perylene	Previous*	198-55-0	6177	ORNL 2022
Phenanthrene	Previous*	85-01-8	2511.886432	ORNL 2022
Propionitrile	Previous*	107-12-0	3.162	ORNL 2022
Strontium	Previous*	7440-24-6	60	ORNL 2022
Trichloroethylene	Previous*	79-01-6	15.99926383	ORNL 2022
Trichlorofluoromethane	Previous*	75-69-4	21.69	ORNL 2022
Trifluralin	Previous*	1582-09-8	2279.817064	ORNL 2022
Cadmium	Previous	7440-43-9	200	ORNL 2022
Manganese	Previous	7439-96-5	400	ORNL 2022
Polychlorinated biphenyls	Previous	1336-36-3	25300	ORNL 2022

Notes:
CAS = Chemical Abstracts Service; BCF = Bioconcentration factor; New = Newly identified chemical; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process

Table F-4. Additional Uptake and Transfer Data as Reported by ORNL for Newly and Previously Identified Chemicals in Biosolids

Chemical	New or previous	CAS number	Diffusivity in air (cm^2/s) - ORNL	Diffusivity in water (cm^2/s) - ORNL	Beef transfer coefficient (day/kg) - ORNL	Milk transfer coefficient (day/kg) - ORNL	Soil-to-dry plant uptake - ORNL	Soil-to-wet plant uptake - ORNL	Kd – soil-water partition coefficient (cm^3/g) - ORNL	Foc - organic carbon partition coefficient (L/kg) - ORNL
2-(N-Methylperfluorooctanesulfonamido) acetic acid	New	2355-31-9	0.0275991	3.225E-06	—	—	—	—	—	—
Perfluorohexadecanoic acid	New	67905-19-5	0.0217922	2.546E-06	—	—	—	—	—	—
(E)-1,2-Dichloroethylene	Previous*	156-60-5	0.0876094	1.119E-05	3.08E-06	9.72E-07	2.3619	0.47238	—	39.6
1,1,1-Trichloroethane	Previous*	71-55-6	0.0648174	9.599E-06	7.73E-06	2.44E-06	1.3844	0.27688	—	43.89
1,2,3,4,6,7,8-Heptachlorodibenzo [b,d]furan	Previous*	67562-39-4	0.0417103	5.901E-06	2.079409	0.657093	0.00098	0.0002	—	650300
1,2,3,7,8,9-Hexachlorodibenzo[b,d]furan	Previous*	72918-21-9	0.0435842	6.097E-06	0.950473	0.30035	0.00155	0.00031	—	389300
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	Previous*	40321-76-4	0.044698	6.164E-06	0.109129	0.034485	0.00542	0.00108	—	416100
1,2,3-Trichlorobenzene	Previous*	87-61-6	0.03953	8.384E-06	0.000281	8.86E-05	0.17237	0.03447	—	1383
1,2,4-Trichlorobenzene	Previous*	120-82-1	0.0395992	8.403E-06	0.000262	8.27E-05	0.17942	0.03588	—	1356
1,2-Dichlorobenzene	Previous*	95-50-1	0.0561703	8.921E-06	6.73E-05	2.13E-05	0.39451	0.0789	—	382.9
1,2-Dichloropropane	Previous*	78-87-5	0.0733402	9.725E-06	2.39E-06	7.54E-07	2.73565	0.54713	—	60.7
1,4-Dinitrobenzene	Previous*	100-25-4	0.0491668	9.385E-06	7.21E-07	2.28E-07	5.47849	1.0957	—	351.6
1,4-Dioxane	Previous*	123-91-1	0.0873739	1.054E-05	1.34E-08	4.24E-09	55.2155	11.0431	—	2.633
1-Methyl phenanthrene	Previous*	832-69-9	0.0570376	6.664E-06	0.003006	0.00095	0.04356	0.00871	—	27330
2,2'-Bioxirane	Previous*	1464-53-5	0.0863267	1.024E-05	1.31E-08	4.15E-09	55.9578	11.1916	—	2.529
2-(2,4,5-Trichlorophenoxy)propionic acid	Previous*	93-72-1	0.0233585	5.919E-06	0.000158	4.98E-05	0.24069	0.04814	—	175.3
2,4,5-Trichlorophenoxyacetic acid	Previous*	93-76-5	0.0288853	7.763E-06	5.1E-05	1.61E-05	0.46309	0.09262	—	107
2,6-Dinitrotoluene	Previous*	606-20-2	0.0370256	7.763E-06	3.15E-06	9.95E-07	2.33056	0.46611	—	587.4
2-Hexanone	Previous*	591-78-6	0.0703564	8.44E-06	6E-07	1.9E-07	6.09622	1.21924	—	14.98
2-Methyl-1-propanol	Previous*	78-83-1	0.0896677	1.004E-05	1.44E-07	4.55E-08	13.9528	2.79056	—	2.919
2-Methylpyridine	Previous*	109-06-8	0.0802252	9.658E-06	3.22E-07	1.02E-07	8.74301	1.7486	—	115.1
4-Chloro-3-methylphenol	Previous*	59-50-7	0.0696136	8.134E-06	3.15E-05	9.95E-06	0.613	0.1226	—	491.8

Chemical	New or previous	CAS number	Diffusivity in air (cm^2/s) - ORNL	Diffusivity in water (cm^2/s) - ORNL	Beef transfer coefficient (day/kg) - ORNL	Milk transfer coefficient (day/kg) - ORNL	Soil-to-dry plant uptake - ORNL	Soil-to-wet plant uptake - ORNL	Kd – soil-water partition coefficient (cm^3/g) - ORNL	Foc - organic carbon partition coefficient (L/kg) - ORNL
4-Methyl-2-pentanone	Previous*	108-10-1	0.0697797	8.348E-06	5.1E-07	1.61E-07	6.69362	1.33872	—	12.6
Acenaphthene	Previous*	83-32-9	0.0506143	8.33E-06	0.000208	6.57E-05	0.20505	0.04101	—	5027
Aldrin	Previous*	309-00-2	0.0228116	5.84E-06	0.079057	0.024982	0.00654	0.00131	—	82020
Allyl Alcohol	Previous*	107-18-6	0.1097535	1.207E-05	3.7E-08	1.17E-08	30.6804	6.13608	—	1.904
Allyl Chloride	Previous*	107-05-1	0.093611	1.082E-05	2.13E-06	6.72E-07	2.92456	0.58491	—	39.6
alpha-1,2,3,4,5,6-Hexachlorocyclohexane	Previous*	319-84-6	0.043284	5.057E-06	0.000158	4.98E-05	0.24069	0.04814	—	2807
Aroclor 1248	Previous*	12672-29-6	0.0240593	6.175E-06	0.039622	0.012521	0.00976	0.00195	—	76530
Aroclor 1254	Previous*	11097-69-1	0.0237205	6.102E-06	0.079057	0.024982	0.00654	0.00131	—	130500
Aroclor 1260	Previous*	11096-82-5	0.0220239	5.608E-06	0.887033	0.280303	0.00161	0.00032	—	349700
Azinphos-methyl	Previous*	86-50-0	0.0233162	5.962E-06	1.41E-05	4.44E-06	0.97827	0.19565	—	51.93
Bensulide	Previous*	741-58-2	0.0351437	4.106E-06	0.000396	0.000125	0.14108	0.02822	—	—
Benzene	Previous*	71-43-2	0.089534	1.026E-05	3.37E-06	1.07E-06	2.23903	0.44781	—	145.8
Benzenethiol	Previous*	108-98-5	0.0728564	9.451E-06	8.28E-06	2.62E-06	1.33003	0.26601	—	233.9
Benzo(g,h,i)perylene	Previous*	191-24-2	0.0238659	6.092E-06	0.106645	0.0337	0.0055	0.0011	—	1951000
Benzyl Alcohol	Previous*	100-51-6	0.0731186	9.366E-06	3.15E-07	9.95E-08	8.86055	1.77211	—	21.46
Benzyl butyl phthalate	Previous*	85-68-7	0.0208319	5.173E-06	0.001343	0.000424	0.06951	0.0139	—	7155
beta-Hexachlorocyclohexane	Previous*	319-85-7	0.0276672	7.395E-06	0.000151	4.76E-05	0.24721	0.04944	—	2807
Biphenyl	Previous*	92-52-4	0.0470592	7.562E-06	0.000256	8.08E-05	0.18183	0.03637	—	5129
Bisphenol A	Previous*	80-05-7	0.0253469	6.495E-06	5.22E-05	1.65E-05	0.45694	0.09139	—	37670
Captan	Previous*	133-06-2	0.0261941	6.899E-06	1.58E-05	4.98E-06	0.91508	0.18302	—	252.2
Carbon Disulfide	Previous*	75-15-0	0.1064373	1.298E-05	2.18E-06	6.88E-07	2.88576	0.57715	—	21.73
Carbophenothion	Previous*	786-19-6	0.0210983	5.281E-06	0.005345	0.001689	0.03119	0.00624	—	8311
Chlorobenzene	Previous*	108-90-7	0.0721306	9.476E-06	1.73E-05	5.47E-06	0.86748	0.1735	—	233.9
Chlorobenzilate	Previous*	510-15-6	0.0217767	5.478E-06	0.001374	0.000434	0.06859	0.01372	—	1539
Chloroethane	Previous*	75-00-3	0.1037597	1.162E-05	6.73E-07	2.13E-07	5.70244	1.14049	—	21.73

Chemical	New or previous	CAS number	Diffusivity in air (cm^2/s) - ORNL	Diffusivity in water (cm^2/s) - ORNL	Beef transfer coefficient (day/kg) - ORNL	Milk transfer coefficient (day/kg) - ORNL	Soil-to-dry plant uptake - ORNL	Soil-to-wet plant uptake - ORNL	Kd – soil-water partition coefficient (cm^3/g) - ORNL	Foc - organic carbon partition coefficient (L/kg) - ORNL
Chloromethane	Previous*	74-87-3	0.1239651	1.365E-05	2.03E-07	6.42E-08	11.4199	2.28397	—	13.22
Chlorpyrifos	Previous*	2921-88-2	0.0382138	4.465E-06	0.00228	0.00072	0.05113	0.01023	—	7283
Clomazone	Previous*	81777-89-1	0.0492389	5.753E-06	7.91E-06	2.5E-06	1.36603	0.27321	—	—
Crotonaldehyde	Previous*	4170-30-3	0.0959907	1.078E-05	9.95E-08	3.15E-08	17.2767	3.45534	—	1.793
Cyanide	Previous*	57-12-5	0.2109549	2.465E-05	5.1E-09	1.61E-09	96.7522	19.3504	9.9	—
Decane	Previous*	124-18-5	0.0450934	6.399E-06	0.002558	0.000808	0.04783	0.00957	—	1451
delta-Hexachlorocyclohexane	Previous*	319-86-8	0.043284	5.057E-06	0.000345	0.000109	0.15285	0.03057	—	2807
Diallate	Previous*	2303-16-4	0.0454578	5.311E-06	0.000773	0.000244	0.09578	0.01916	—	644.3
Diazinon	Previous*	333-41-5	0.0210264	5.226E-06	0.000161	5.1E-05	0.2375	0.0475	—	3034
Dibenzofuran	Previous*	132-64-9	0.0650663	7.377E-06	0.00033	0.000104	0.15699	0.0314	—	9161
Dibenzothiophene	Previous*	132-65-0	0.0355475	7.596E-06	0.0006	0.00019	0.11093	0.02219	—	9161
Dichlorodiphenyltrichloroethane	Previous*	50-29-3	0.037933	4.432E-06	0.203208	0.064214	0.00378	0.00076	—	168600
Dichloromethane	Previous*	75-09-2	0.0999362	1.252E-05	4.45E-07	1.4E-07	7.25205	1.45041	—	21.73
Dicrotophos	Previous*	141-66-2	0.0250474	6.415E-06	2.5E-08	7.9E-09	38.5	7.7	—	16.58
Dieldrin	Previous*	60-57-1	0.0232865	6.006E-06	0.00628	0.001984	0.02841	0.00568	—	20090
Diphenyl oxide	Previous*	101-84-8	0.0396863	7.234E-06	0.000405	0.000128	0.13921	0.02784	—	1950
Endrin	Previous*	72-20-8	0.0361581	4.225E-06	0.003962	0.001252	0.03711	0.00742	—	20090
EPN	Previous*	2104-64-5	0.0217475	5.467E-06	0.001506	0.000476	0.06502	0.013	—	15470
Heptachlor	Previous*	76-44-8	0.0223441	5.696E-06	0.031473	0.009946	0.01115	0.00223	—	41260
Iodine	Previous*	7553-56-2	—	—	0.007	0.01	0.15	0.0375	60	—
Lindane	Previous*	58-89-9	0.043284	5.057E-06	0.000131	4.15E-05	0.26783	0.05357	—	2807
Methacrylonitrile	Previous*	126-98-7	0.0964299	1.065E-05	1.2E-07	3.78E-08	15.526	3.10521	—	13.05
Methyl ethyl ketone	Previous*	78-93-3	0.0914462	1.019E-05	4.87E-08	1.54E-08	26.1373	5.22746	—	4.51
Mevinphos	Previous*	7786-34-7	0.0514906	6.016E-06	3.37E-08	1.07E-08	32.3639	6.47278	—	—
Naled	Previous*	300-76-5	0.0245667	6.43E-06	6E-07	1.9E-07	6.09622	1.21924	—	126.7

Chemical	New or previous	CAS number	Diffusivity in air (cm^2/s) - ORNL	Diffusivity in water (cm^2/s) - ORNL	Beef transfer coefficient (day/kg) - ORNL	Milk transfer coefficient (day/kg) - ORNL	Soil-to-dry plant uptake - ORNL	Soil-to-wet plant uptake - ORNL	Kd – soil-water partition coefficient (cm^3/g) - ORNL	Foc - organic carbon partition coefficient (L/kg) - ORNL
Nitrobenzene	Previous*	98-95-3	0.068054	9.449E-06	1.77E-06	5.59E-07	3.25432	0.65086	—	226.4
o-Cresol	Previous*	95-48-7	0.072835	9.317E-06	2.23E-06	7.04E-07	2.84748	0.5695	—	306.5
p,p'-DDD	Previous*	72-54-8	0.0406077	4.745E-06	0.026178	0.008272	0.01241	0.00248	—	117500
p,p'-DDE	Previous*	72-55-9	0.0229959	5.859E-06	0.080898	0.025564	0.00645	0.00129	—	117500
p-Cymene	Previous*	99-87-6	0.0526944	7.319E-06	0.000315	9.95E-05	0.16124	0.03225	—	1120
Pentachlorophenol	Previous*	87-86-5	0.0295197	8.012E-06	0.003296	0.001041	0.04129	0.00826	—	592
Perfluorodecanesulfonic acid	Previous*	335-77-3	0.0267057	3.12E-06	—	—	—	—	—	—
Perylene	Previous*	198-55-0	0.0254676	6.581E-06	0.044457	0.014048	0.00913	0.00183	—	599400
Phenanthrene	Previous*	85-01-8	0.0344784	6.69E-06	0.000721	0.000228	0.09969	0.01994	—	16690
Phosphamidon	Previous*	13171-21-6	0.0424267	4.957E-06	1.54E-07	4.87E-08	13.4048	2.68096	—	—
Potassium	Previous*	7440-09-7	—	—	0.02	0.007	1	0.25	5.5	—
Propionitrile	Previous*	107-12-0	0.1097206	1.182E-05	3.61E-08	1.14E-08	31.0929	6.21857	—	8.511
Strontium	Previous*	7440-24-6	—	—	0.0003	0.0015	2.5	0.625	35	—
Trichloroethylene	Previous*	79-01-6	0.0686618	1.022E-05	6.58E-06	2.08E-06	1.52006	0.30401	—	60.7
Trichlorofluoromethane	Previous*	75-69-4	0.065356	1.005E-05	8.47E-06	2.68E-06	1.31238	0.26248	—	43.89
Trifluralin	Previous*	1582-09-8	0.0220519	5.574E-06	0.005469	0.001728	0.03078	0.00616	—	16390
Cadmium[a]	Previous	7440-43-9	—	—	0.00055	0.001	0.5	0.125	75	—
Cadmium[b]	Previous	7440-43-9	—	—	0.00055	0.001	0.55	0.1375	75	—
Manganese	Previous	7439-96-5	—	—	0.0004	0.00035	0.25	0.0625	65	—
Polychlorinated biphenyls	Previous	1336-36-3	0.0243397	6.267E-06	0.314731	0.099455	0.00293	0.00059	—	78100
Polychlorinated biphenyls	Previous	1336-36-3	0.0243397	6.267E-06	0.314731	0.099455	0.00293	0.00059	—	78100
Polychlorinated biphenyls	Previous	1336-36-3	0.0243397	6.267E-06	0.314731	0.099455	0.00293	0.00059	—	78100

Notes:
CAS = Chemical Abstracts Service; New = Newly identified chemical; Previous = Previously identified chemical; Previous* = Chemical was identified during the curation process
[a] Diet
[b] Water

EXHIBIT L

DEPARTMENT OF
ECOLOGY
State of Washington

PFAS Concentrations in Effluent, Influent, Solids, and Biosolids of Three Wastewater Treatment Plants

November 2022

Publication 22-03-028

Publication Information

This report is available on the Department of Ecology's website at:
https://apps.ecology.wa.gov/publications/SummaryPages/2203028.html.

Data for this project are available in Appendix B of this report.

The Activity Tracker Code for this study is 21-023.

Suggested Citation
Bothfeld, F. and C. Mathieu. 2022. PFAS Concentrations in Influent, Effluent, Solids, and Biosolids of Three Wastewater Treatment Plants. Publication 22-03-028. Washington State Department of Ecology, Olympia.
https://apps.ecology.wa.gov/publications/SummaryPages/2203028.html.

Contact Information

Publications Team
Environmental Assessment Program
Washington State Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600
Phone: 360-407-6764

Washington State Department of Ecology – https://ecology.wa.gov

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Shoreline 206-594-0000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Union Gap 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

PFAS Concentrations in Influent, Effluent, Solids, and Biosolids of Three Wastewater Treatment Plants

by

Frances Bothfeld

Water Quality Program
Washington State Department of Ecology
Olympia, Washington

Callie Mathieu

Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington

Table of Contents

List of Tables

Acknowledgments

The authors of this report thank the following people for their contributions to this study:

- Washington State Legislature
- Staff of the three wastewater treatment plants sampled
- Washington State Department of Ecology staff:
  - Jakub Bednarek
  - Lisa Euster
  - Charles Hoffman
  - Emily Kijowski
  - Karen Dinicola
  - Christina Frans
  - Nancy Rosenbower

Abstract

Per- and polyfluoroalkyl substances (PFAS) are a class of chemicals that have a wide range of commercial and industrial uses. However, they are also known as “forever chemicals” due to widespread ubiquity and persistence in the environment. While not considered a source themselves, wastewater treatment plants (WWTPs) are a known pathway for PFAS to enter surface water and groundwater.

In 2021, the Washington State Department of Ecology (Ecology) carried out a study to evaluate concentrations of PFAS from three municipal WWTPs that receive influent likely to contain PFAS. In February 2021, Ecology collected samples of influent, effluent, sludge, and biosolids for analysis of PFAS. The goals of this study were to (1) have an initial reconnaissance of PFAS concentrations along several points in a wastewater system in Washington state, (2) better understand how PFAS moves through WWTPs with varying treatment types, and (3) evaluate PFAS speciation in a WWTP.

The study found that the three WWTPs sampled generally contained PFAS concentrations consistent with levels typically found in non-industrial effluents in the United States. PFAS concentrations in the WWTP effluent were below the five state action levels (SALs) for drinking water, with the exception of perfluorooctanoate (PFOA) concentrations in the effluent of one WWTP that were above the SAL of 10 ng/L. PFAS concentrations in the solids were a magnitude higher than concentrations found in the influents and effluents (parts per billion vs parts per trillion) with longer chained PFAS often partitioning out into the solids.

A larger scale study with more data, both in frequency and location, is recommended before determining the need for WWTPs to monitor for PFAS. Also, more information is needed before determining if regular monitoring of PFAS in biosolids is necessary.

Introduction

Introduction to Per- and Polyfluoroalkyl Substances

Per- and polyfluoroalkyl substances (PFAS) are a class of synthetic chemicals that contain carbon-fluorine bonds. PFAS usually have a hydrophilic head, followed by a chain of carbon and fluorine bonds. Perfluoroalkyl carboxylic acids (PFCAs) with less than seven carbons, and perfluoroalkyl sulfonic acids (PFSAs) with less than six carbon chain lengths, are considered "short chain." Whereas PFCAs and PFSAs with carbon chain lengths greater than seven and six, respectively, are considered "long chain." Perfluoroalkyl substances are fully fluorinated and every hydrogen in the carbon chain has been replaced with a fluorine. Polyfluoroalkyl substances are not fully fluorinated and at least one hydrogen bond remains.

PFAS chemicals have been produced since the 1940s and over 6,000 substances have entered commerce since (US EPA, 2021). However, there are more PFAS than the known, commercially derived PFAS because they can degrade into breakdown products (Washington et al., 2015). Moreover, there is a class of PFAS chemicals known as precursors that are chemicals, both known and unknown, which break down to form perfluoroalkyl acids in the environment (Washington et al., 2015).

PFAS are useful chemicals because they repel oil, water, and grease. They are used in many applications, such as household products, clothing, food packaging, manufacturing processes, and firefighting foam. However, research now shows that PFAS can be bioaccumulative and toxic to human and aquatic life. Furthermore, PFAS received the moniker "forever chemicals" because they are persistent in the environment and not easily removed.

While there is a lot of research on common PFAS, the full extent of PFAS toxicity is not fully known (ITRC, 2020). A lot of information and data goes into developing a toxicity profile, which is hard to gather due to the sheer amount of PFAS in commerce. There are many PFAS chemicals, like precursors and terminal breakdown products, which are unknown and, therefore, have unknown toxicological effects. Furthermore, there is little information gathered about synergistic toxicological effects (Aherns & Bundschuh, 2014).

PFAS and Wastewater Treatment Plants

PFAS is widespread in surface water, but information on the sources, extent, and toxicological impacts is lacking. One potential environmental pathway that needs to be further explored is PFAS discharged from wastewater treatment plants (WWTPs) via effluent. WWTP effluent can contain PFAS contamination from industrial sources; personal care products, laundry and other household sources; and landfill leachate. It is anticipated that in comparison to household/domestic sources and landfill leachate, industrial sources can contribute much larger loads of PFAS by volume to WWTPs.

Once PFAS enter a WWTP, little is known about how PFAS transforms within the treatment plant (Liu & Mejia Avendaño, 2013). PFAS can either settle out into solids (sludge or biosolids) or end up in the effluent in its original form or as a breakdown or transformed chemical (Ebrahimi et al., 2021). Most WWTPs currently do not use treatment technologies that are able to remove PFAS from effluent. Removal requires advanced treatment technologies (e.g., reverse osmosis, ozonation plus granular activated carbon, ion resin exchange) that are not used at most WWTPs (Kucharzyk et al., 2017).

WWTPs are a central collection point for multiple wastewater/sanitary sewer streams that contain PFAS. Due to the lack of advanced treatment methods, PFAS can be found in the WWTPs' effluent and downstream receiving waters. A 2016 study of PFAS in Washington state surface waters found that PFAS were elevated in waterbodies receiving a large proportion of WWTP effluent and that WWTP effluent appears to be a significant pathway for short-chain PFAAs and PFOA into surface water under hydrological conditions of limited dilution (Mathieu & McCall, 2017).

Goals of This Study

The Washington State Department of Ecology (Ecology) developed a Chemical Action Plan (CAP) to address PFAS contamination in Washington's waters (Ecology, 2021). One of the recommendations of the CAP was to evaluate PFAS in wastewater. Ecology received funding to start this evaluation. Ecology sampled three WWTPs with differing treatment trains at the influent, effluent, sludge, and biosolids (when applicable).

The goals of this study were to:

- Characterize PFAS concentrations along several points of a wastewater treatment process.
- Better understand how PFAS moves through a WWTP in different wastewater treatment trains.
- Evaluate PFAS speciation in a WWTP.

This study will add to Ecology's growing list of PFAS studies supporting a broader perspective on PFAS in Washington state.

Methods

Sample Collection

In 2021, Ecology field staff collected samples of influent, effluent, waste activated sludge (WAS), and biosolids (when applicable) from three selected WWTPs. Sampling occurred on February 9 and February 11. Table 1 describes the sampling locations for each plant. Sampling occurred during a period of dry weather. Plant operators confirmed that no infiltration and inflow was occurring at the time of collection. Light snow was observed on the February 11 sampling date, but no accumulation occurred prior to or during sampling.

All aspects of sampling followed the Quality Assurance Project Plan (QAPP; Hoffman, 2021), including protocols to avoid PFAS cross contamination. Field equipment was decontaminated prior to and between sampling with the following protocol:

1. Rinse with tap water.
2. Hand wash/scrub with Liquinox soap.
3. Rinse with tap water.
4. Rinse with 100% methanol.

Field staff used new, clean nitrile gloves for each sampling point within a facility and followed practices for low-level contaminant sampling.

All samples were stored on ice until the end of the sample collection day, at which point they were placed inside Ecology Headquarters chain of custody room freezers. Samples were held frozen at -20 °C and shipped to AXYS SGS Analytical Services Ltd. laboratory for analysis. Chain of custody was maintained and recorded throughout the study.

Table 1. Collection dates and sampling point location descriptions

WWTP	Date of Sample Collection	Plant Type	Influent Sampling Point	Effluent Sampling Point	Sludge Sampling Point	Biosolids Sampling Point
Plant A	2/11/2021	Activated sludge, biological nitrogen removal	After headworks screens and grit tanks	Effluent channel before discharge/ outfall	WAS daylighted tank, post-secondary clarifier	Dewatered cake solids at conveyor belt
Plant B	2/11/2021	Activated sludge, pure oxygen	After headworks screen, post-sand/grit removal	Final effluent port before discharge/ outfall	WAS pump line before DAF thickeners, after secondary clarifier and return solids well	Dewatered cake solids at screw press
Plant C	2/9/2021	Reclaimed water facility, biological treatment and microfiltration	After headworks screen, before any treatment (no grit removal at this plant)	At final effluent sampler point, distribution pump/ clear well	WAS pump line	n/a

WAS = waste activated sludge; DAF = dissolved air flotation; n/a = not applicable

Influent and Effluent

Field staff collected individual grab samples in the morning, mid-day, and afternoon from each influent and effluent sampling point. Grab samples were then hand composited by equal volumes (about 166 mL) from each grab into laboratory-provided 500 mL HDPE containers. Grab samples and finished composite samples were kept in laboratory-provided enclosure bags and stored in coolers with bagged wet ice.

Influent and effluent samples were collected at, or as near as possible to, the plants' compositor sampling points. The plant composite samplers were not used for sample collection to avoid potential PFAS contamination from tubing or other parts inside the equipment. Field staff removed grates nearest to the plant sampling locations and lowered a clean, laboratory-provided transfer bottle attached to a sampling pole into the influent or effluent channel. Samples were collected from a representative, well-mixed location in the channel accessible from the grate at about 10-20 cm below the surface.

All influent and effluent samples were collected by sampling pole from the channel with the exception of effluent from Plant B. The Plant B effluent sample was collected from the final effluent port prior to discharge/outfall for accessibility reasons. The final effluent port was purged for about two minutes prior to sample collection.

Waste Activated Sludge

WAS samples were collected from each of the WWTPs as individual grab samples. WAS from Plants A and B was collected mid-day, and WAS from Plant C was collected mid-morning. Ecology field staff collected WAS from Plant A by lowering a decontaminated stainless steel dip sampler into a daylight WAS tank about 10-20 cm below the surface and filling all three sample jars from the first dip sample. At Plants B and C, WAS samples were collected via ports. For these samples, the plant operator purged the WAS sample port for two minutes, then Ecology field staff filled sampling jars directly from the port. WAS samples were placed into laboratory-provided 250 mL HDPE jars and enclosure bags and placed in coolers with bagged wet ice.

Biosolids

Biosolids samples were collected mid-day as individual grabs from only Plants A and B. No biosolids were sampled from Plant C because a representative sample was not possible at this plant. Biosolid samples consisted of dewatered cake solids at the final accessible sampling point prior to leaving the facility. For Plant A, biosolids were collected directly from the conveyor belt by hand. At Plant B, biosolids were collected from a screw press auger removed by the WWTP operator. Ecology field staff filled laboratory-provided 250 mL HDPE jars about 80% full of the solids, then placed the jars into enclosure bags and stored them in coolers with bagged wet ice.

Laboratory Analysis

AXYS SGS Analytical Services Ltd. analyzed all samples for 40 PFAS following their in-house method, MLA-110 Rev. 02 Ver. 11., *Analytical Procedure for the Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous Samples, Solids, Tissues, AFF Products, Blood/Serums and Solvent Extracts by LC-MS/MS.* Appendix A lists the PFAS analyzed for, along with their CAS numbers, median reporting limits, and median detection limits.

Influent and effluent samples were extracted and cleaned up using solid phase extraction as required by the Department of Defense Quality Systems Manual (DOD QSM) Table B-15 criteria (DOD/DOE, 2019) with weak anion exchange cartridges. Extracts were then treated with carbon powder and spiked with recovery standards. Isotopically labeled surrogate standards (extracted internal standards) were added to all field and quality control (QC) samples prior to extraction.

WAS and biosolids samples were spiked with isotopically labeled surrogate standards then extracted by shaking with a methanolic ammonium hydroxide solution. The supernatants were then combined, treated with ultra-pure carbon powder and evaporated to remove methanol. The solutions were cleaned up by solid phase extraction using weak anion exchange cartridges and spiked with recovery standards.

All sample extracts were analyzed on an ultrahigh performance liquid chromatograph with a reversed phase C18 column coupled to a triple quadrupole mass spectrometer (LC-MS/MS). Final sample concentrations were determined by isotopic dilution/internal standard quantification. Samples were analyzed in three batches: (1) influent samples, (2) effluent samples, and (3) WAS and biosolid samples.

Limits of quantitation (LOQs) were based on the lowest calibration standard analyzed during calibration with adjustments for sample amount extracted and considerations to baseline noise levels. The sample-specific detection limit (SDL) was based on the signal to noise ratio (S/N > 3.0) of the instrument per target analyte. PFAS concentrations reported include the total of linear and branched isomers. An accreditation waiver was obtained from Ecology's Quality Assurance Officer for seven analytes, as these compounds are newly developed, and no laboratory currently holds accreditation with Washington state for them. These compounds are denoted in Appendix A by asterisk.

Data Quality

Manchester Environmental Laboratory's (MEL's) Quality Assurance Coordinator completed an independent party Stage 4 data validation on all lab results for this project. The data validation was conducted using manual review and verification per the technical specifications of the method, the QAPP (Hoffman, 2021), and validation guidance documents (DOD/DOE, 2019; DOD, 2020; EPA, 2016). MEL provided a written data validation report describing the analytical method used, holding times, initial and ongoing calibrations, and results of QC tests analyzed with each batch. All QC tests outlined in the QAPP were analyzed with each batch, including method blanks, laboratory control samples (LCS), matrix spikes, matrix spike duplicates, field replicates, and field/equipment blanks.

The data validation confirmed that the lab followed the analytical method for all samples, with no errors or omissions. All results were deemed usable as qualified for this study, with the following exception. The data validator recommended rejection of several samples based on corrective actions outlined in DOD (2020) for detected and non-detected analytes quantitated with surrogates having percent recoveries of less than 20%. The QC tests associated with the rejected results all had acceptable surrogate recoveries, suggesting that matrix effects in the samples were responsible for poor surrogate performance. The samples rejected include PFBA in all influent and effluent samples collected from Plant C, as well as several samples for N-EtFOSA, N-MeFOSA, and N-EtFOSE, N-MeFOSE, and one sample for PFTeDA.

Qualifiers were added to final results based on QC tests that fell outside of acceptance limits. All detected concentrations below the LOQ, but above the SDL were qualified "J" as estimated values. No results were reported below the SDL. Results that met all qualitative criteria for compound detection except for mass-ion ratios were qualified as "NJ" or tentatively identified and estimated.

Method Blanks

No target analytes were detected in any of the method blanks at or above the method detection limit. No results were qualified based on method blanks.

Laboratory Control Samples

All LCS percent recoveries were within MQOs outlined in the QAPP and requirements of the DOD QSM Table B-15.

Matrix Spikes/Matrix Spike Duplicates

Six results were qualified "J" as estimates based on a potential high bias indicated by matrix spike recoveries. The affected results included PFBS (A-EFF-3), PFDA (A-INF-3), PFOS (A-INF-3), PFTrDA (A-BIO-3), PFBS (A-BIO-3), and N-EtFOSAA (A-BIO-3). The relative

percent difference between matrix spikes and matrix spike duplicates were within MQOs and resulted in no qualifications to the data.

Field Blanks

At each influent and effluent sampling point, a field blank was collected prior to the morning grab sample. Field blanks consisted of laboratory-provided blank water poured into new laboratory-provided sampling bottles at the sampling site with the same sampling pole used for field sample collection. PFDA was detected at a concentration of 0.576 ng/L in one field blank collected alongside the Plant A effluent samples. PFDA results in the associated effluent samples were less than five times the field blank result, and thus qualified as not detected ("U"). No other analytes were detected in the field blanks.

An equipment rinseate blank was collected from the stainless-steel dip sampler used to sample WAS from Plant A. No PFAS analytes were detected in the equipment rinseate blank.

Field Replicates

Triplicate samples were collected at every sampling point for this study. Results of triplicate analysis were assessed by calculating relative standard deviation (RSD) of each analyte. For influent and effluent samples, the RSD control limit was 30% for results greater than 5 times the LOQ. For results less than five times the LOQ, the absolute difference between the sample and replicate had to be less than the LOQ for aqueous matrices and less than two times the LOQ for solid matrices. Six out of 440 replicate RSDs exceeded the control limit. Affected results were qualified "J" or "UJ" (if undetected), to indicate the value is an estimate.

Results

PFAS concentrations measured in influent, effluent, sludge, and biosolids from the three WWTPs are presented in Tables 2 through 7. Values given in the tables represent the average of triplicate results for each sample. Appendix B provides individual sample results of the full dataset. Aqueous samples are reported as ng/L (parts per trillion; ppt), and solids samples are reported on a ng/g dry weight (dw) basis (parts per billion; ppb).

Perfluoroalkyl Carboxylates

Table 2 presents average PFCA concentrations in influent and effluent and Table 3 presents PFCA concentrations measured in the sludge and biosolids sampled. Short chain PFCAs were generally detected more frequently in the influent and effluent and long chain PFCAs were mostly present in the sludge and biosolids samples. PFHxA and PFOA were detected in all samples and matrices.

The influent and effluent samples contained short chain PFCAs and PFOA in the range of 1.0 – 13 ng/L, with the exception of higher concentrations of PFPeA and PFHxA measured in the effluent of Plant C (231 and 133 ng/L, respectively). Concentrations of PFPeA and PFHxA in the influent of this plant were much lower (10.5 and 8.6 ng/L, respectively).

PFPeA, PFHxA, and PFDA were present in the sludge of Plant C at relatively higher concentrations (18.4 – 21.8 ng/g). PFHxA and long chain PFCAs were present in all biosolids samples, at relatively low concentrations (0.3 – 3.1 ng/g).

Table 2. Perfluoroalkyl carboxylate results in aqueous samples (ng/L, ppt).

Plant	Sample Type	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA
Plant A	Influent	**7.02 J**	**5.09**	**7.31**	**1.77**	**3.85**	**0.88 NJ**	**0.55 J**	ND	ND	ND	ND
Plant A	Effluent	**12.6**	**6.03**	**13.5**	**2.22**	**5.00**	**0.64 J**	ND	ND	ND	ND	ND
Plant B	Influent	**6.89 J**	**5.70**	**11.81**	**3.34**	**6.33**	**1.42 J**	**0.55 J**	ND	ND	ND	ND
Plant B	Effluent	**7.95**	**6.53**	**18**	**3.38**	**7.13**	**1.09 J**	**0.58 J**	ND	ND	ND	ND
Plant C	Influent	REJ	**10.5**	**8.60**	**0.86 J**	**2.57**	ND	ND	ND	ND	ND	ND
Plant C	Effluent	REJ	**231**	**133**	**2.76**	**12.3**	**0.57 J**	**0.76 J**	ND	ND	ND	ND

J = Analyte was positively identified, and the associated numerical result is an estimate.
ND = Analyte was not detected in any of the samples at or above the detection limit.
REJ = Result was rejected.

Table 3. Perfluoroalkyl carboxylate results in solids samples (ng/g dw, ppb).

Plant	Sample Type	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA
Plant A	Sludge	ND	ND	**2.50 J**	ND	**1.53 J**	ND	**2.28 J**	**1.23 NJ**	**1.66 J**	ND	ND
Plant A	Biosolids	ND	ND	**1.14 J**	ND	**0.99 J**	**1.87**	**3.13 J**	**1.32 J**	**1.91 J**	**1.12 J**	**0.84 J**
Plant B	Sludge	ND	ND	**8.19 J**	ND	**2.43 J**	ND	**2.03 NJ**	ND	ND	ND	ND
Plant B	Biosolids	ND	ND	**1.49 J**	ND	**0.34 J**	**0.91 J**	**1.84**	**0.82 J**	**1.32 NJ**	**0.579 J**	**0.73 J**
Plant C	Sludge	ND	**18.4**	**21.8**	ND	**6.96**	**1.80 J**	**18.6**	**1.43 NJ**	**4.21 J**	ND	ND

J = Analyte was positively identified, and the associated numerical result is an estimate.
ND = Analyte was not detected in any of the samples at or above the detection limit.
NJ = There is evidence the analyte is present and the associated numerical result is an estimate.

Perfluoroalkyl Sulfonates

Average PFSA concentrations in influent and effluent samples are provided in Table 4 and concentrations in sludge and biosolids are presented in Table 5. PFBS and PFOS were consistently detected in all samples and matrices. PFHxS was detected in all influent, effluent, and biosolids, but in only one sludge sample. Other PFSAs were infrequently detected, and at low concentrations.

In influent and effluent samples, PFBS was found at the highest concentrations (2.3 – 26.7 ng/L), followed by PFOS (2.0 – 11.9 ng/L), and PFHxS (0.99 – 6.9 ng/L). PFBS concentrations were higher in effluent than influent at all plants, and PFOS concentrations in the effluent were lower than in the influent at all plants.

PFOS was the dominant PFSA in the sludge and biosolids, with concentrations in the range of 22 – 37 ng/g in the sludge and 26 – 29 ng/g in the biosolids. PFDS and PFDoS were present at 5.0 and 8.8 ng/g in the sludge of Plant B, and all other detected PFSAs were present at less than 5 ng/g.

Table 4. Perfluoroalkyl sulfonate results in aqueous samples (ng/L, ppt).

Plant	Sample Type	PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFDoS
Plant A	Influent	**15.1**	**1.18 J**	**6.94**	ND	**11.9**	ND	**0.51**	ND
Plant A	Effluent	**26.7**	**1.15 J**	**5.98**	ND	**5.92**	ND	ND	ND
Plant B	Influent	**15.2**	**ND**	**4.43**	ND	**11.5 NJ**	ND	ND	ND
Plant B	Effluent	**22.7**	**0.54 NJ**	**3.92**	ND	**7.04**	ND	ND	ND
Plant C	Influent	**2.33**	**ND**	**2.37 NJ**	ND	**5.36 NJ**	ND	**0.51 NJ**	ND
Plant C	Effluent	**7.93**	**ND**	**0.99 J**	ND	**2.03**	ND	ND	ND

J = Analyte was positively identified, and the associated numerical result is an estimate.
ND = Analyte was not detected in any of the samples at or above the detection limit.
NJ = There is evidence the analyte is present and the associated numerical result is an estimate.

Table 5. Perfluoroalkyl sulfonate results in solids samples (ng/g dw).

Plant	Sample Type	PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFDoS
Plant A	Sludge	**1.69 J**	ND	ND	ND	**21.6**	ND	**1.15 NJ**	ND
Plant A	Biosolids	**4.49 NJ**	ND	**0.44 NJ**	ND	**28.5**	ND	**1.52 NJ**	ND
Plant B	Sludge	**2.34 J**	ND	**ND**	ND	**36.6**	ND	**5.01 J**	**8.83 NJ**
Plant B	Biosolids	**1.79 NJ**	ND	**1.51 NJ**	ND	**29.1**	**0.42 NJ**	**2.04 NJ**	**1.33 NJ**
Plant C	Sludge	**1.45 NJ**	ND	**3.94 NJ**	ND	**22.2**	ND	**ND**	ND

J = Analyte was positively identified, and the associated numerical result is an estimate.
ND = Analyte was not detected in any of the samples at or above the detection limit.
NJ = There is evidence the analyte is present and the associated numerical result is an estimate.

Perfluoroalkyl Acid Precursors

Tables 6 and 7 present the results of perfluoroalkyl acid precursors in aqueous and solids samples. Of the precursor analyte suite, 5:3 FTCA was the most frequently detected, and at the highest concentrations. Concentrations of 5:3 were highly variable, ranging from non-detect – 199 ng/L in the influent and effluent, and 151 – 329 ng/g in the sludge and biosolids. 7:3 FTCA was also detected in the solids of two of the plants, at concentrations of 23 – 46 ng/g.

6:2 FTS was detected in several aqueous samples (2.6 – 6.0 ng/L), but not in the sludge or biosolids. Several perfluoroalkane sulfonamido substances were detected, primarily in the sludge and biosolids samples: MeFOSAA, EtFOSAA, N-MeFOSE, and N-EtFOSE. Concentrations of the perfluoroalkane sulfonamidos ranged from non-detect – 29 ng/g in the solids samples.

Table 6. Perfluoroalkyl acid precursor results in aqueous samples (ng/L).

Plant	Sample Type	6:2 FTS	PFOSA	MeFOSAA	EtFOSAA	N-MeFOSE	N-EtFOSE	5:3 FTCA	7:3 FTCA
Plant A	Influent	**2.68 J**	ND	**0.66 J**	ND	ND	REJ	**199 J**	ND
Plant A	Effluent	ND	ND	**0.68 J**	ND	ND	ND	ND	ND
Plant B	Influent	**4.52 J**	ND	ND	ND	ND	REJ	**113**	ND
Plant B	Effluent	**6.01 J**	ND	ND	**0.78 J**	ND	ND	**27.4 J**	ND
Plant C	Influent	ND	ND	ND	ND	ND	ND	ND	ND
Plant C	Effluent	ND	ND	ND	ND	ND	ND	ND	ND

J = Analyte was positively identified, and the associated numerical result is an estimate.
ND = Analyte was not detected in any of the samples at or above the detection limit. REJ = Result was rejected.
Analytes in this group not shown because they were not detected in any samples: 4:2 FTS, 8:2 FTS, N-MeFOSA, N-EtFOSA, HFPO-DA, ADONA, 9Cl-PF3ONS, 11Cl-PF3OUdS, 3:3 FTCA, PFEESA, PFMPA, PFMBA, NFDHA.

Table 7. Perfluoroalkyl acid precursor results in solids samples (ng/g dw).

Plant	Sample Type	6:2 FTS	PFOSA	MeFOSAA	EtFOSAA	N-MeFOSE	N-EtFOSE	5:3 FTCA	7:3 FTCA
Plant A	Sludge	ND	ND	**9.77 J**	**3.29 J**	ND	**4.71 J**	**329**	**46.2 J**
Plant A	Biosolids	ND	**0.53 J**	**21.0**	**3.91**	ND	**4.90 J**	**267**	**23.3 J**
Plant B	Sludge	ND	**ND**	**3.51 J**	**11.6 J**	**29.3 J**	**10.6 J**	**307**	**ND**
Plant B	Biosolids	ND	**0.81 J**	**4.76**	**6.53**	**REJ**	**REJ**	**151**	**25.1 J**
Plant C	Sludge	ND	**2.89 J**	**7.33 J**	**4.10 J**	ND	ND	ND	**167**

J = Analyte was positively identified, and the associated numerical result is an estimate.
ND = Analyte was not detected in any of the samples at or above the detection limit. REJ = Result was rejected.

Analytes in this group not shown because they were not detected in any samples: 4:2 FTS, 8:2 FTS, N-MeFOSA, N-EtFOSA, HFPO-DA, ADONA, 9Cl-PF3ONS, 11Cl-PF3OUdS, 3:3 FTCA, PFEESA, PFMPA, PFMBA, NFDHA.

Discussion

Comparison to Other U.S. WWTPs

Table 8 presents a comparison of this study's PFAS concentrations in effluent with a nationwide, non-industrial average calculated by Thompson et al. (2022), as well as previous effluent sampling in Washington state.

PFAS concentrations in the effluents tested for this study were within the range of non-industrial WWTP effluent throughout the United States. Thompson et al. (2022) calculated nationwide mean PFOA and PFOS concentrations in effluents with no industrial source and outliers omitted as 8.4 ng/L and 10 ng/L, respectively. PFOA and PFOS concentrations measured for this study ranged from 5.0 – 12 ng/L (PFOA) and 2.0 – 7.0 ng/L (PFOS), which agree well with the nationwide non-industrial effluent averages. Other PFAS measured by this study had concentrations very close to national averages calculated by Thompson et al. (2022), including PFBA, PFHpA, PFNA, PFDA, and PFHxS. Concentrations of these PFAS were also quite similar to other WWTP effluent sampling conducted in previous Washington state studies (Furl and Meredith, 2010; Ecology and Herrera, 2010; Mathieu and McCall, 2017).

Concentrations of PFPeA and PFHxA in Plant C effluents were an order of magnitude higher than the non-industrial national average. PFBS concentrations were also slightly above the national average in the effluent of Plant A and B. It is unclear what the source of these analytes might be. These samples were also higher than previous Washington effluent sampling, with the exception of a similarly elevated PFHxA concentration from one of the WWTPs sampled in 2008.

Table 8. PFAS concentrations in WWTP effluents from the U.S. and previous Washington studies.

Analyte	U.S. WWTPs (mean*, ng/L)	WA WWTPs, 2008 (range, ng/L)	WA WWTPs, 2010 (range, ng/L)	WA WWTPs, 2016 (range, ng/L)	This study (range, ng/L)
PFBA	8.2	0.7 - 5.4	ND - 6.0	1.6 - 7.1	7.9 - 13
PFPeA	19	3.8 - 47	ND - 18	5.5 - 57	6.0 - 231
PFHxA	23	11 - 141	9.6 - 52	11 - 49	14 - 133
PFHpA	5.6	ND - 35	2.1 - 10	2.2 - 5.5	2.2 - 3.4
PFOA	8.4	17 - 128	11 - 70	6.6 - 20	5.0 - 12.3
PFNA	3.9	3.6 - 18	1.4 - 134	ND - 4.0	0.6 - 1.1
PFDA	1.9	3.6 - 13	1.4 - 10	ND - 5.0	ND - 0.8
PFBS	4.5	ND - 6.6	ND - 18	ND - 14	7.9 - 27
PFHxS	4.8	1.3 - 16	ND - 8.3	ND - 7.1	1.0 - 6.0
PFOS	10	3.9 - 31	ND - 55	ND - 6.5	2.0 - 7.0
reference:	Thompson et al., 2022	Furl and Meredith, 2010	Ecology and Herrera, 2010	Mathieu and McCall, 2017	

*See Thompson et al. (2022) for calculation of mean, simple random sample, no outliers.
ND = not detected

Fewer data were available to compare this study's PFAS concentrations in solids. Thompson et al. (2022) calculated a national biosolids and sludge mean for PFOA and PFOS with 0.1% industrial sources as 15.3 and 167 ng/g, respectively. The biosolids and sludges tested for this study were an order of magnitude lower, at 0.3 – 7.0 ng/g (PFOA) and 22 – 37 ng/g (PFOS). In addition, Michigan has adopted a biosolids PFOS concentration of 125 ng/g as a threshold to indicate that the solids are industrially impacted (EGLE, 2022). Michigan calculated an average PFOS concentration in their biosolids with industrially impacted samples removed as 18 ng/g (AECOM and EGLE, 2021). Biosolids collected for this study were very similar to the Michigan non-industrial mean and well below the 125 ng/g industrial threshold. However, Michigan does encourage investigation into sources of PFAS when biosolids contain over 20 ng/g of PFOS, a level that all of the Washington biosolids samples exceeded. None of these thresholds are risk-based; Michigan is waiting on EPA to establish risk-based thresholds for biosolids.

Comparison to Action Thresholds

Washington state currently has state action levels (SALs) for PFAS in drinking water. SALs are levels set by Washington State Department of Health for long-term daily drinking water to protect people's health. These SALs only cover five PFAS: PFOA, PFOS, PFNA, PFHxS, and PFBS (Table 9). All PFAS concentrations in aqueous samples analyzed for this study were below the SALs, with the exception of PFOA in the effluent of Plant C. The effluent samples from Plant C contained PFOA concentrations of 11.7 – 13.5 ng/L (mean = 12.3 ng/L), slightly above the SAL of 10 ng/L for PFOA. The influent samples from this WWTP were below the SAL, at concentrations ranging 2.5 – 2.64 ng/L (mean = 2.57 ng/L). Effluent from Plant C is considered reclaimed water and is the only plant in this study that had microfiltration as a tertiary treatment.

Table 9. PFAS state action levels for Washington

Type of PFAS	SAL (ng/L)
PFOA	10
PFOS	15
PFNA	9
PFHxS	65
PFBS	345

While Washington's SALs are not directly applicable to WWTP effluent, they provide an indication that the majority of effluent samples collected for this study do not contain the five PFAS in Table 9 at levels of concern for human health via drinking water. These thresholds are not protective of human health from exposure to PFAS in surface water via consumption of fish and other aquatic species. This consideration is particularly important for PFAS that are highly bioaccumulative, like PFOS. The EPA expects to draft recommended surface water quality criteria for human health that would be protective of both drinking water and fish consumption for PFOA and PFOS by Fall 2024 (EPA, 2021). That type of threshold would be helpful to determine the relevance of the concentrations observed in the WWTP effluents sampled for this study.

The EPA has proposed draft aquatic life criteria for PFOA and PFOS to provide surface water and biota-based levels protective of aquatic life against adverse effects (EPA, 2022a; EPA, 2022b). All effluents tested in this study contained PFOA and PFOS concentrations that were orders of magnitude below the draft aquatic life criteria. The draft aquatic life criteria for PFOA are 49 mg/L for acute effects and 0.094 mg/L for chronic effects. Draft PFOS aquatic life criteria are 3.0 mg/L (acute) and 0.0084 mg/L (chronic). Though surface water quality criteria are not applied to effluent concentrations, these thresholds indicate that the effluents would not cause direct adverse effects to aquatic biota themselves in receiving waters. This doesn't take into account wildlife that are consuming the aquatic biota, which is again a concern for the bioaccumulative PFAS.

PFAS Partitioning within WWTPs

Long chain PFAS concentrations were less frequently detected in the aqueous samples than in the sludge and biosolids samples of this study. This was expected because PFAS tends to partition to solids in a WWTP. Long chain PFAS partition into the solids as they are more hydrophobic compared to their shorter chain counter parts (Ebrahimi et al., 2021). The data in this study do not have the granularity to determine the effect of treatment type on PFAS partitioning. Other, more in-depth, studies have shown that there are many conditions that affect PFAS partitioning into solids, including: temperature, pH, chain length, solid and hydraulic retention time, sludge composition, sludge stabilization additive, ions present, and presence of oxygen (Ebrahimi et al., 2021).

With the data collected in this study, it is not possible to determine whether there is more total PFAS in the effluent than in the solids. There was an order of magnitude more of each type of PFAS sampled in the solids phase than the liquid for some compounds (ppb vs ppt). However, the solids are amassed over time, which allows for a higher concentration of PFAS to accumulate in the solid phases sampled. For example, a study from Australia estimated that effluent contained more PFOA and PFOS (65kg and 26kg per year) than biosolids (2kg and 8kg per year) on an annual volume basis (Gallen et al., 2018). Regardless, the presence of PFAS at concentrations in the ppb range indicate further research is needed to understand the relevance and impact of these levels.

The samples show concentration differences between influent concentrations and effluent for multiple PFAS compounds. This is especially true for 5:3 FTCA in Plant A and B and for PFPEA and PFHxA in Plant C. Fluorotelomers such as 5:3 FTCA are known to readily degrade and/or transform in a treatment plant and PFPEA and PFHxA are known degradation products of multiple other PFAS substances (Van Hees, 2013). These transformation products are also likely responsible for all three plants having species of PFAS in the solids that are not found in the influent or effluent.

Transformation of PFAS within a treatment plant is a well-known occurrence, though not well understood. There are multiple biotransformation pathways for PFAS in WWTPs. Abiotic transformation pathways include hydrolysis, photolysis, and oxidation. All of these processes create new PFAS rather than removing them (Houtz et al., 2016). Total organic fluorine (TOF) and total oxidizable precursor (TOP) assays would help to determine how much PFAS, if any at all, is removed. EPA approved methods for TOP and TOF are in development at the time of this report.

The data indicate that PFAS concentrations in influent, effluent, solids, and biosolids are unique to each treatment plant. Influent concentrations can vary due to industrial sources and other differences in the service area of each WWTP. While not investigated in this study, PFAS concentrations and speciation can also vary with time (Thompson et al., 2022).

Future Research Needs

PFAS is now considered a ubiquitous type of chemical because it is found wherever surface water and groundwater samples are analyzed for PFAS (CDC & NCEH, 2016). This study's preliminary reconnaissance shows that most of the WWTP effluents contain PFAS concentrations below the five existing SALs. However, little is known about the other PFAS species detected for which no SAL has been established. More toxicological information is needed about the other PFAS detected.

Concentrations of PFAS in biosolids also need more research. This study shows PFAS concentrations in biosolids that are an order of magnitude higher than in aqueous substances and contain types of PFAS that are not found in influent and effluent. This is in line with other literature values (Gallen et al., 2018). Little is known about transport of PFAS after biosolids are

land applied. One study in Arizona found that PFAS remained highly absorbed to solids with limited migration into the soil depths. The study concluded that PFAS in biosolids was not a large threat to groundwater contamination due to the low concentrations of PFAS in biosolids, low rainfall and the depth to groundwater (Pima County Wastewater Reclamation, 2020). However, conditions in Washington state are different and there are currently no thresholds for biosolids in soil. Therefore, it is not possible to assess localized effects of PFAS at biosolids land application sites.

Conclusions

In February 2021, Ecology conducted a reconnaissance survey of PFAS concentrations in influent, effluent, sludge, and biosolids from three WWTPs. This study evaluated PFAS concentrations at several points along a wastewater treatment process, as recommended in the state's PFAS Chemical Action Plan. Conclusions of this study include the following:

- Short chain PFCAs were generally detected more frequently in the influent and effluent and long chain PFCAs were mostly present in the sludge and biosolids samples. PFHxA, PFOA, PFBS, and PFOS were detected in all samples and matrices. PFAS precursors were also present, with 5:3 FTCA at the highest concentrations of all analytes measured. 6:2 FTS was detected in several influent and effluent samples, and perfluoroalkane sulfonamido substances were detected mostly in the sludge and biosolids.
- PFAA concentrations in the effluents tested for this study were within the range of non-industrial WWTP effluent found throughout the United States. Slightly elevated concentrations of PFPeA and PFHxA were found in the effluent of Plant C, and the source of those analytes are unknown. All PFAS concentrations in effluent samples analyzed for this study were below the drinking water state action levels (SALs) for five PFAS, except for PFOA in the effluent of Plant C which was slightly above.
- PFOS concentrations in the biosolids and sludges were (1) lower than what other states consider industrially impacted, and (2) similar to or lower than national and state averages of PFOS in biosolids lacking industrial PFAS sources.
- Information from this study does not, on its own, justify a need for widespread PFAS monitoring at WWTPs. Additional monitoring on a larger scale would be needed before making that determination.
- This study was not able to draw conclusions about treatment technologies and PFAS removal efficiency or partitioning within WWTPs.

Recommendations

Results of this 2021 study support the following recommendations:

- The limited sample size of this study precludes the ability to make recommendations on a WWTP PFAS monitoring program. A larger scale study with more data, both in frequency and location, is recommended before requiring WWTPs to regularly monitor influent, effluent, and/or biosolids for PFAS. It would be helpful to have (1) more data on PFAS concentrations found at WWTPs across Washington state, (2) samples taken across a larger time scale, and (3) sampling coordinated when there are known industrial releases.
- More research is needed to determine if PFAS from biosolids causes localized PFAS contamination.

References

AECOM and EGLE [Michigan Department of Environment, Great Lakes, and Energy]. 2021. Evaluation of PFAS in Influent, Effluent, and Residuals of Wastewater Treatment Plants (WWTPs) in Michigan. Project Number: 60588767.

Aherns, L., & Bundschuh, M. 2014. Fate and effects of poly- and perfluoroalkyl substances in the aquatic.pdf. 33(9), 1921–1929.

CDC, & NCEH. 2016. Fourth National Report on Human Exposure to Environmental Chemicals Update. March. https://www.cdc.gov/exposurereport/pdf/FourthReport_UpdatedTables_Volume1_Mar2018.pdf

DoD [Department of Defense]. 2020. Data Validation Guidelines Module 3: Data Validation Procedure for Per- and Polyfluoroalkyl Substances Analysis by QSM Table B-15. Environmental Data Quality Workgroup 05/01/2020. https://denix.osd.mil/edqw/documents/documents/module-3-data-validation/

DoD [Department of Defense] / DOE [Department of Energy]. 2019. Department of Defense (DoD) Department of Energy (DOE) Consolidated Quality Systems Manual (QSM) for Environmental Laboratories. DoD Quality Systems Manual Version 5.3. https://denix.osd.mil/edqw/documents/manuals/qsm-version-5-3-final/

Ebrahimi, F., Lewis, A. J., Sales, C. M., Suri, R., & McKenzie, E. R. 2021. Linking PFAS partitioning behavior in sewage solids to the solid characteristics, solution chemistry, and treatment processes. Chemosphere, 271. https://doi.org/10.1016/j.chemosphere.2020.129530

Ecology. 2021. Per- and Polyfluoroalkyl Substances Chemical Action Plan. Washington State Department of Ecology, Olympia, WA. Publication 21-04-048. https://apps.ecology.wa.gov/publications/summarypages/2104048.html

Ecology and Herrera. 2010. Control of Toxic Chemicals in Puget Sound - Summary Technical Report for Phase 3: Loadings from POTW Discharge of Treated Wastewater. Washington State Department of Ecology, Olympia, WA. Publication 10-10-057. https://apps.ecology.wa.gov. /publications/SummaryPages/1010057.html

EGLE [Michigan Department of Environment, Great Lakes, and Energy]. 2022. Land Application of Biosolids Containing PFAS, Interim Strategy Updated 2022. EGLE, Water Resources Division.

EPA [Environmental Protection Agency]. 2016. National Functional Guidelines for High Resolution Superfund Methods Data Review. Office of Superfund Remediation and Technology Innovation (OSRTI), Washington, DC. Publication OLEM 9200.3-115, EPA 542-B-16-001. https://www.epa.gov/sites/production/files/2016-05/documents/hrsm_nfg.pdf

EPA [Environmental Protection Agency]. 2021. PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024. https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf

EPA [Environmental Protection Agency]. 2022a. Draft Aquatic Life Ambient Water Quality Criteria for Perfluorooctanoic Acid (PFOA). U.S. Environmental Protection Agency Office of Water, Washington D.C. Publication Number EPA-842-D-22-001.

EPA [Environmental Protection Agency]. 2022b. Draft Aquatic Life Ambient Water Quality Criteria for Perfluorooctane Sulfonate (PFOS). U.S. Environmental Protection Agency Office of Water, Washington D.C. Publication Number EPA-842-D-22-002.

Furl, C. and C. Meredith. 2010. Perfluorinated Compounds in Washington Rivers and Lakes. Washington State Department of Ecology, Olympia, WA. Publication 10-03-034. https://apps.ecology.wa.gov. /publications/summarypages/1003034.html

Gallen, C., Eaglesham, G., Drage, D., Nguyen, T. H., & Mueller, J. F. 2018. A mass estimate of perfluoroalkyl substance (PFAS) release from Australian wastewater treatment plants. Chemosphere, 208, 975–983. https://doi.org/10.1016/j.chemosphere.2018.06.024

Hoffman, C. 2021. Quality Assurance Project Plan: PFAS Concentrations in Influent, Effluent, and Solids in Three Municipal Wastewater Treatment Plants in Washington State. Washington State Department of Ecology, Olympia. Publication 21-10-006. https://apps.ecology.wa.gov/publications/SummaryPages/2110048.html

Houtz, E. F., Sutton, R., Park, J. S., & Sedlak, M. 2016. Poly- and perfluoroalkyl substances in wastewater: Significance of unknown precursors, manufacturing shifts, and likely AFFF impacts. Water Research, 95, 142–149. https://doi.org/10.1016/j.watres.2016.02.055

ITRC. 2020. Human and Ecological Health Effects and Risk Assessment of Per- and Polyfluoroalkyl Substances (PFAS). 1–4. https://pfas-1.itrcweb.org/

Kucharzyk, K. H., Darlington, R., Benotti, M., Deeb, R., & Hawley, E. 2017. Novel treatment technologies for PFAS compounds: A critical review. Journal of Environmental Management, 204(August), 757–764. https://doi.org/10.1016/j.jenvman.2017.08.016

Liu, J., & Mejia Avendaño, S. 2013. Microbial degradation of polyfluoroalkyl chemicals in the environment: A review. Environment International, 61, 98–114. https://doi.org/10.1016/j.envint.2013.08.022

Mathieu, C., & McCall, M. 2017. Survey of Per- and Poly-fluoroalkyl Substances (PFASs) in Rivers and Lakes, 2016. https://apps.ecology.wa.gov. /publications/SummaryPages/1703021.html

Pima County Wastewater Reclamation. 2020. PFAS in Biosolids: A Southern Arizona Case Study.

Thompson, K. A., Mortazavian, S., Gonzalez, D. J., Bott, C., Hooper, J., Schaefer, C. E., & Dickenson, E. R. V. 2022. Poly- and Perfluoroalkyl Substances in Municipal Wastewater Treatment Plants in the United States: Seasonal Patterns and Meta-Analysis of Long-Term Trends and Average Concentrations. ACS ES&T Water. https://doi.org/10.1021/acsestwater.1c00377

US EPA. 2021. Multi-Industry Per- and Polyfluoroalkyl Substances (PFAS) Study – 2021 Preliminary Report. September.

Van Hees, P. 2013. Analysis of the unknown pool of PFAS: Total Oxidizable Precursors (TOP), PFOS Precursor (PreFOS) and Telomer Degradation. https://cdnmedia.eurofins.com/european-east/media/1568225/top_precursor_short_facts_170613.pdf

Washington, J. W., Jenkins, T. M., Rankin, K., & Naile, J. E. 2015. Decades-scale degradation of commercial, side-chain, fluorotelomer-based polymers in soils and water. Environmental Science and Technology, 49(2), 915–923. https://doi.org/10.1021/es504347u

Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

Synergistic toxicological effect: Adverse effects caused by exposures to two or more toxic substances at a time, which is greater than would be caused by one substance alone.

Acronyms and Abbreviations

DOD	U.S. Department of Defense
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
MEL	Manchester Environmental Laboratory
NPDES	National Pollutant Discharge Elimination System (see glossary)
PFAS	Per- and polyfluoroalkyl substances
PFCA	Perfluoroalkyl carboxylates
PFSA	Perfluoroalkyl sulfonates
PFOA	Perfluorooctanoate

PFOS	Perfluorooctane sulfonate
QAPP	Quality Assurance Project Plan
QC	Quality control
QSM	Quality Systems Manual
RSD	Relative standard deviation
SAL	State action level
TOF	Total organic fluorine
TOP	Total oxidizable precursors
WAS	Waste activated sludge
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
dw	dry weight
ng/g	nanograms per gram (parts per billion)
ng/L	nanograms per liter (parts per trillion)
ppb	parts per billion
ppt	parts per trillion

Appendices

Appendix A. Analytes and Reporting Limits

Table A-1. Analytes measured and median reporting limits for this study.

Analyte	CAS number	Abbreviation	QSM Analyte	Influent median LOQ (ng/L)	Influent median SDL (ng/L)	Effluent median LOQ (ng/L)	Effluent median SDL (ng/L)	Solids median LOQ (ng/g)	Solids median SDL (ng/g)
Perfluorobutanoate	45048-62-2	PFBA	•	6.5	1.6	6.5	1.6	16.1	4.0
Perfluoropentanoate	45167-47-3	PFPeA	•	3.3	0.8	3.2	0.8	8.1	2.0
Perfluorohexanoate	92612-52-7	PFHxA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluoroheptanoate	120885-29-2	PFHpA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorooctanoate	45285-51-6	PFOA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorononanoate	72007-68-2	PFNA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorodecanoate	73829-36-4	PFDA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluoroundecanoate	196859-54-8	PFUnA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorododecanoate	171978-95-3	PFDoA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorotridecanoate	862374-87-6	PFTrDA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorotetradecanoate	365971-87-5	PFTeDA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorobutane sulfonate	45187-15-3	PFBS	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluoropentane sulfonate	175905-36-9	PFPeS	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorohexane sulfonate	108427-53-8	PFHxS	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluoroheptane sulfonate	146689-46-5	PFHpS	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorooctane sulfonate	45298-90-6	PFOS	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorononane sulfonate	474511-07-4	PFNS	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorodecane sulfonate	126105-34-8	PFDS	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorododecane sulfonate	343629-43-6	PFDoS		1.6	0.4	1.6	0.4	4.0	1.0
4:2 fluorotelomer sulfonate	414911-30-1	4:2 FTS	•	6.5	1.6	6.5	1.6	16.1	4.0
6:2 fluorotelomer sulfonate	425670-75-3	6:2 FTS	•	5.9	2.5	5.8	2.5	14.5	3.6
8:2 fluorotelomer sulfonate	481071-78-7	8:2 FTS	•	6.5	1.6	6.5	1.6	16.1	4.0
N-Methylperfluorooctane sulfonamidoacetic acid	2355-31-9	N-MeFOSAA	•	1.6	0.4	1.6	0.4	4.0	1.0
N-Ethylperfluorooctane sulfonamidoacetic acid	2991-50-6	N-EtFOSAA	•	1.6	0.4	1.6	0.4	4.0	1.0
Perfluorooctane sulfonamide	754-91-6	PFOSA	•	1.6	0.4	1.6	0.4	4.0	1.0
N-Methylperfluorooctane sulfonamide	31506-32-8	N-MeFOSA	•	1.9	0.5	1.9	0.5	4.6	1.2
N-Ethylperfluorooctane sulfonamide	4151-50-2	N-EtFOSA	•	4.1	1.0	4.0	1.0	10.1	2.5
N-Methylperfluorooctane sulfonamidoethanol	24448-09-7	N-MeFOSE	•	16.3	4.1	16.2	4.0	40.3	10.1
N-Ethylperfluorooctane sulfonamidoethanol	1691-99-2	N-EtFOSE	•	12.2	3.1	12.1	3.0	30.3	2.5
Perfluoro-2-propoxypropanoate	122499-17-6	HFPO-DA	•	6.2	1.6	6.1	1.5	15.3	3.8
4-dioxa-3H-perfluorononanoate	2127366-90-7	ADONA	•	6.5	1.6	6.5	1.6	16.1	4.0
9-chlorohexadecafluoro-3-oxanonane-1-sulfonate	1621485-21-9	9Cl-PF3ONS	•	6.5	1.6	6.5	1.6	16.1	4.0
11-chloroeicosafluoro-3-oxaundecane-1-sulfonate	2196242-82-5	11Cl-PF3OUdS	•	6.5	1.6	6.5	1.6	16.1	4.0
3:3 perfluorohexanoic acid*	1169706-83-5	3:3 FTCA		6.5	1.6	6.5	1.6	16.1	4.0
5:3 perfluorooctanoic acid*	1799325-94-2	5:3 FTCA		40.8	10.2	40.4	10.1	101	25.2
7:3 perfluorodecanoic acid*	1799325-95-3	7:3 FTCA		40.8	10.2	40.4	10.1	101	25.2

Analyte	CAS number	Abbreviation	QSM Analyte	Influent median LOQ (ng/L)	Influent median SDL (ng/L)	Effluent median LOQ (ng/L)	Effluent median SDL (ng/L)	Solids median LOQ (ng/g)	Solids median SDL (ng/g)
Perfluoro (2-ethoxyethane)sulfonic acid*	220689-13-4	PFEESA		1.6	0.4	1.6	0.4	4.0	1.0
Perfluoro-4-methoxybutanoate*	1432017-36-1	PFMBA		1.6	0.4	1.6	0.4	4.0	1.0
Perfluoro-3-methoxypropanoate*	n/a	PFMPA		3.3	0.8	3.2	0.8	8.1	2.0
Perfluoro-3,6-dioxaheptanoate*	39187-41-2	NFDHA		3.3	0.8	3.2	0.8	8.1	2.0

LOQ = limit of quantitation
SDL = sample specific detection limit

Appendix B. PFAS Results Table

Table B-1. Individual PFAS results of all samples analyzed for this study.

This table is available only online, linked to this report at https://apps.ecology.wa.gov/publications/SummaryPages/2203028.html.