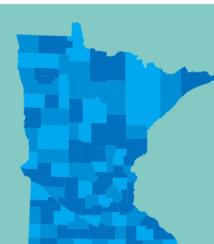
PFAS

August 2023

MPCA Remediation Division PFAS Guidance (*Draft)*

Life cycle-based guidance for PFAS at Superfund, Brownfield, and RCRA sites.

MINNESOTA POLLUTION CONTROL AGENCY



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Glossary of Terms, Acronyms and Abbreviations

Additive risk	combined risk from exposure to multiple chemicals by a single pathway and route of exposure
Aggregate risk	combined risk from exposure to a single chemical by multiple pathways and routes of exposure
AOC	Area of Concern
ASTM	American Society for Testing and Materials
Biota	The flora and fauna of a region
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
Contaminant	substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects
Cumulative risk	combined risk from exposure to multiple chemicals by multiple pathways and routes of exposure
CCA	Cross Cutting Area
CRP	Cooperative Responsible Party
EJ	Environmental Justice
EPA	Environmental Protection Agency
Excess lifetime cancer risk	an estimate of the probability that a person may develop cancer over their lifetime as the result of exposure to a carcinogen
Exposure area	geographically defined point or area where an exposure is expected
Exposure point concentration	representative contaminant concentration that is calculated for an exposure unit/area
Hazard index	the sum of noncancer hazard quotients used when evaluating multiple chemical exposures
Hazard quotient	ratio calculated to evaluate the potential for noncancer health hazards to occur from exposure to a contaminant with available noncancer toxicity values
Hazardous substance	any element, compound, mixture, or substance that causes harm to public health, welfare, or the environment. Hazardous substances include several categories which are defined in MERLA, CERCLA, and RCRA statutes.

Institutional Controls	land use restrictions, activity use limitations, and land use controls imposed on properties to protect cleanup work and avoid exposure to any remaining contamination
LCS	Life Cycle Stage
MDH	Minnesota Department of Health
MERLA	Minnesota Environmental Response and Liability Act
MPCA	Minnesota Pollution Control Agency
NPL	National Priorities List
PFAS	Per- and polyfluoroalkyl Substances
PLP	Permanent List of Priorities
Receptor	Any humans or biota which are, or may be expected to be, or have been, exposed to or affected by any hazardous substance, pollutant, or contaminant.
Release	spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing any hazardous substance or pollutant or contaminant) ...." per CERCLA section 101(22)
Remediation	(1) removal of pollution or contaminants from water and soil for the protection of human health and the environment (2) MPCA Program title
RCRA	Resource Conservation and Recovery Act
RBV	Risk-based values: an estimate of a contaminant concentration, taking into account default or site-specific exposure assumptions, that is unlikely to result in an appreciable risk of adverse health effects during a specific exposure duration, usually a lifetime.
RP	Responsible Party
Site	(1) Full geographic extent of contamination CERCLA/MERLA (Superfund) (2) Property boundary as identified by the legal description (BF)
Site Assessment	MPCA program that evaluates a site originating from a referral or notification of a release or potential release into the environment.
Superfund	Program that works with responsible parties under MERLA at the state-level and under CERCLA at national level
VP	Voluntary Party
VIC	Voluntary Investigation & Cleanup; MPCA program that works with non-responsible parties under MERLA

Introduction

What are PFAS?

Per- and polyfluoroalkyl substances (PFAS) are a large family of chemicals that are widely present in the environment. PFAS are manmade chemicals containing at least one fully fluorinated carbon in a chain with an attached "functional group" that has specific characteristics. Invented in the 1930s, PFAS have been used in applications across multiple industries for uses including repelling water and grease, reducing friction, reducing fire risk, and acting as an insulator, especially under conditions where non-reactive and heat-resistant materials are needed. PFAS are desirable in commercial and industrial applications because of their durability, but that durability also means that they do not readily break down over time in environmental conditions. PFAS are unlike other classes of environmental contaminants in terms of the number of unique structures in the group, their persistence in the environment, and their widespread use.

How are they being addressed in the Remediation Program?

In 2021, the Minnesota Pollution Control Agency (MPCA) published the PFAS Blueprint, which identified current strategies for addressing PFAS. In 2022, the agency wide PFAS Monitoring Plan was launched. The Remediation section of the PFAS Monitoring Plan (Appendix E) identifies criteria for entering the program. The Remediation PFAS Guidance uses an adapted life cycle approach that is consistent with the Minnesota Environmental Response and Liability Act (MERLA) and the Resource Conservation and Recovery Act (RCRA) framework, to address the investigation and clean-up of PFAS in environmental media. Through the life cycle, a site is evaluated for a contaminant release to the environment, the extent and magnitude of contamination is assessed in all impacted media, risks to human health and the environment are assessed, remediation is completed as necessary, and institutional controls (ICs) are established, as appropriate to ensure continued protectiveness of the remedy prior to site closure. This guidance is based on currently available scientific data. It is recognized that knowledge regarding PFAS is evolving, and future versions of this guidance will incorporate emerging science and data.

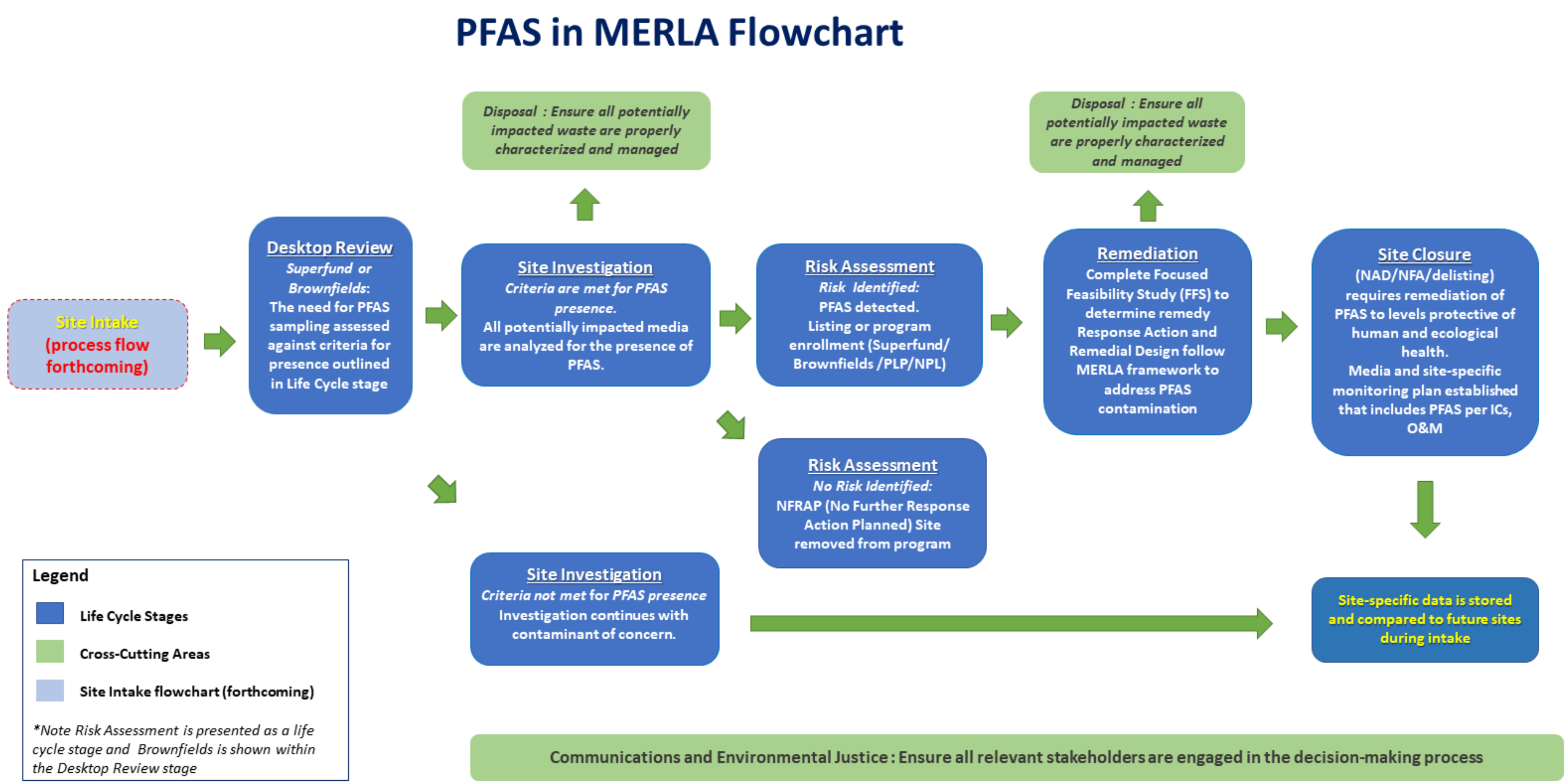
Guidance structure

The objective of this guidance is to provide instructions for entities addressing PFAS at sites enrolled in Remediation programs. The document is organized according to life cycle stages (LCS) and cross-cutting areas (CCA). Cross-cutting areas are present throughout the various stages of the life cycle. Links with other programs support source-reduction efforts and inform health-risk assessments. The environmental justice framework supports equitable decision-making and communications-related activities that ensure impacted stakeholders remain informed of outcomes during a site's duration in the program. Several LCS are divided into milestones which provide a feasible set of actions for reaching goals. A chart is shown below.

	Life Cycle Stages				
	Desktop Review	**Site Investigation**	**Risk Assessment**	**Remediation**	**Site Closure**
Cross Cutting Areas					
Risk Assessment	✓	✓		✓	✓
PFAS Disposal		✓	✓	✓	✓
Brownfield Assurances	✓	✓	✓	✓	✓
Communications	✓	✓	✓	✓	✓
Environmental Justice	✓	✓	✓	✓	✓

Contents

PFAS in MERLA flowchart



Life Cycle Stage 1: Desktop review

Desktop Review Goal: Determine whether a site will be evaluated for the presence of a PFAS release.

The actions identified in this section expand on those established by the Monitoring Plan and encourage the collection of information and data to adequately determine the presence of PFAS at a site.

During this life cycle stage, a site's current and historical use of PFAS and proximity to potential PFAS sources will be assessed to determine whether PFAS sampling ("site investigation") may be necessary. The desktop review process is the same for Superfund, Brownfields, and RCRA programs; however, follow up actions based on the gathered information may differ depending on whether an entity is a responsible party for the PFAS and whether a potential exposure pathway exists at the remediation site. If a site investigation is necessary, appropriate communication and outreach measures should be implemented to ensure that all stakeholders are informed and given the opportunity to participate, where applicable. See the *Communications* & *Environmental Justice* sections for additional information about these areas. The milestones and their corresponding actions described below present the areas to evaluate in determining the possible need for PFAS sampling:

Desktop Review Milestone 1: Assess criteria to determine potential need for PFAS sampling at sites in the Remediation Program

Desktop Review Milestone 1, Action 1: Identify historical and current site use(s)

During the initial desktop review, the site's current and historical commercial and industrial practices will be evaluated. This includes a review of business type(s), operations performed, chemicals handled, chemical disposal practices, hazardous waste records, regulatory history, and any other pertinent information in determining the potential for PFAS contamination at the site. A common format for the desktop review is a Phase I Environmental Site Assessment (ESA), which is described in the ASTM-E1527-21 Standard. Other desktop review reports include a Preliminary Assessment/Site Inspection (PA/SI) and a RCRA Facility Assessment (RFA).

PFAS have been widely used in industrial processes and in manufacturing consumer products for several decades. The PFAS Monitoring Plan identified a list of specific industry sector codes that may be associated with PFAS use and/or release. Broadly, these fall under the following primary industry categories, which are also included as Annex I.

- Airports
- Building and construction materials
- Chemicals and chemical products
- Cleaning products
- Cleaning and treatment services
- Commercial printing
- Defense sites
- Electronics and electrical components
- Industrial machinery

- Leather and textiles
- Medical products
- Metal plating and finishing
- Paints, coating, and varnishes
- Paper mills and paper products
- Petroleum refining and products
- Plastics, resin, and rubber
- Scrapyards
- Waste disposal and treatment

A site's current and historical practices should be compared to the above listed industry categories for indication of the potential for PFAS release. Numerical codes have often been assigned to businesses to aid in classification and data collection, namely the Standard Industrial Classification system (SIC codes, used from 1937-1997) and the North American Industry Classification System (NAICS codes, used from 1997-present). However, SIC and NAICS codes are self-reported by businesses, may not fully capture the range of operations of a business, and may change over time. Therefore, while these codes may represent useful pieces of data during the desktop review phase, they should not be the only information used to assess a site's potential for a PFAS release. Rather, the industrial practices performed at the site should be compared to the broad list of industry categories provided above to determine whether a site's use has presented the potential for PFAS release. If a site has a connection to one of these industry categories, a deeper look may be warranted to determine if the specific operations at the site may have used PFAS. For example, a paper mill that produced coated paper or food packaging may be viewed differently than a paper mill that solely produced paper towels or tissues.

The above listed industry categories include major manufacturing and industry sources as well as waste facilities. MPCA distinguishes between facilities that directly use or have used PFAS in commercial and industrial operations and facilities that are or have been receivers of PFAS waste, such as waste disposal, recycling, or treatment facilities. However, both types of facilities are included in this list as potentially associated with PFAS *release*.

PFAS release from industrial and manufacturing facilities is associated with either the production or use of PFAS in facility operations. PFAS were introduced in manufacturing and commercial production in the 1950s and are generally released via wastewater and stormwater discharges, solid waste disposal, accidental releases such as leaks and spills, and stack emissions.

PFAS release from solid waste facilities (including municipal solid waste landfills, legacy disposal sites, scrap yards, metal salvage facilities, and unpermitted dumps) is associated with the handling and disposal of PFAS-containing industrial waste or products. Solid waste facilities associated with PFAS-containing industrial waste, sludge, site mitigation waste, and consumer waste and septage are therefore of concern when identifying sources of PFAS. Unlined landfills and legacy disposal sites have a greater likelihood of releasing PFAS to the environment since waste is in direct contact with soil. Most landfills constructed prior to the 1990s were not required to be lined. In addition to industrial operations and waste disposal, PFAS can be released locally by use of aqueous film forming foams (AFFF) (Class B firefighting foams). These have been stored and used for fire suppression and training at defense sites, airports, and industrial facilities, as well as for training and emergency response by community fire departments.

There are unique situations where PFAS may be a concern despite no history of industrial activity at a site. Smaller releases of PFAS may be associated with various commercial and domestic activities involving PFAS-containing products, such as car washing, ski wax use, and apparel laundering. Other examples include using PFAS foam for killing livestock during infectious disease outbreaks and the application of PFAS-containing biosolids in farm fields.

More information about sources of PFAS to the environment can be found from ITRC and the resources provided at the end of this section.

Desktop Review Milestone 1, Action 2: Identify proximity to potential or known PFAS sources

It is important to identify the presence of potential or known off-site sources of PFAS because of the highly soluble and mobile nature of PFAS. A nearby source of PFAS contamination may pose a risk to receptors at a remediation site (ITRC, 2022). All risk exposure pathways should be considered, including but not limited to drinking water wells, commercial/industrial supply wells, surface water, foam, and sediment. If groundwater is not directly used as a drinking water source at a remediation site, it still may be considered a potential exposure pathway based on secondary uses, such as dewatering activities, sump discharges, and irrigation.

The MPCA recommends starting with a baseline radius of 1,000 feet from the edge of all receptors identified at a Site. Further expansion of the radius may be needed based on factors such as site geology, groundwater flow direction, aquifer sensitivity, receptor characteristics, and types and duration of sources. The ASTM standard suggests using Approximate Minimum Search Distances of 0.5 to 1 mile for reviewing several types of records such as NPL sites and RCRA TSD facilities. The purpose of these search distances for records review is to assess the likelihood of an impact to the subject property from PFAS migrating to the site from areas outside the subject property. Off-site sources that may be of particular concern that may require expansion of the 1,000-foot site radius could include fire training facilities or other AFFF releases, land disposal facilities, and wastewater treatment plants.

Another important consideration in the desktop review is traditional ecological knowledge (TEK) pertaining to the site. TEK is a collection of knowledge held by people in communities with a long history of direct dependence on local resources. Not only does the information provide valuable context, but local/indigenous names can provide context for where or what to sample. For example, a local place name associated with a remediation site that translates to “to drink” might indicate a potential exposure pathway related to an off-site source and may warrant sampling for PFAS during the investigation stage.

Communication with MPCA program staff is necessary to determine if the off-site source is being evaluated under other programs and what data already exists. If at any point in the desktop review it is suspected that a drinking water receptor is at risk for PFAS exposure from on or off-site sources, a receptor evaluation and sampling effort should be conducted expeditiously prior to initial investigations at the site. See the Investigation life cycle stage for information on the receptor evaluation.

In summary, the below criteria are important in determining when PFAS sampling may be necessary at a site. This is not an exhaustive list:

- Current or historical use of the remediation site indicates potential or known use of PFAS. This observation may stem from a combined evaluation of NAICS codes, industry categories, specific operational practices and site activities, a review of hazardous waste records, such as Safety Data Sheets (SDSs), etc. This information may or may not be identified as Recognized Environmental Conditions (RECs) in a Phase I report.
- Site or nearby sampling results have identified PFAS-impacted media.
- There is a potential risk to site receptors from a known or potential PFAS release from an on-site or off-site source.

- Whether the entity is a responsible party for the PFAS contamination. For nuances related to non-responsible parties, refer to the Brownfield section of this document.

Incoming or new remediation sites may include PFAS sampling in the Phase I or II Environmental Site Assessment (ESA), the Preliminary Assessment (PA)/Site Investigation (SI), or the RCRA RFA/RFI. Existing sites will be required to conduct a full evaluation of the potential for PFAS releases.

Life Cycle Stage 2: Site investigation

Site investigation goal 1

Determine if there is an identified release of PFAS by collecting and analyzing samples of all potentially impacted environmental media for the presence of PFAS. The Minnesota Environmental Response and Liability Act (MERLA) Section 115B.02, subd.15 defines a release as any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment which occurred at a point in time, or which continues to occur. The MPCA responds whenever a hazardous substance, pollutant, or contaminant is released or there is a threatened release which presents an imminent and substantial danger to the public health or welfare or environment.

The initial decision to sample for PFAS is made during the desktop review life cycle stage, where a site's current and historical industrial practices, nearby off-site sources, and potential risk exposure pathways are evaluated to assess the need for a site investigation. The decision matrix for determining if PFAS sampling is necessary is summarized in life cycle Stage 1 (desktop review). For nuances related to non-responsible parties, refer to the Brownfield section of this document.

The actions outlined in this section are applicable during all life cycle stages during which an investigation is required.

Site Investigation Goal 1, Milestone 1: Initial Investigations

Initial Investigations Action 1: Receptor Evaluation and Sampling

A responsible party for a PFAS release, or a state-led investigation of a PFAS release, must complete a full receptor survey to identify all on-site and off-site potential exposure pathways related to the PFAS release. A non-responsible party must complete a receptor survey within the boundary of the Brownfield site, taking into account the current and proposed use of the property.

Receptor Survey (provide the necessary elements of a receptor survey, how to complete the survey and how to interpret the results to determine next steps for mitigation, remediation and/or additional investigation work)

- A receptor survey should be completed to identify all human and ecological receptors within a specific radius of the release area. This release area is dependent on the impacted media and the area hydrogeology. The receptor survey will identify all potential contaminant migration pathways including, but not limited to:
  - Utility corridors
  - Surface water bodies
  - Drinking water supply management areas
  - Wells
  - Bedrock/fractured bedrock/springs/seeps/sinkholes
- Sample all potentially impacted drinking water wells and municipal water supply wells first.
- When necessary, off-site sampling will be conducted to adequately delineate contamination. See the communications section for additional details about property access for off-site sampling

Water supply well receptor survey

The water supply well receptor survey identifies water wells that may be at risk and provides information regarding the geology and groundwater use near the release site.

Sample all potentially impacted drinking water wells and municipal water supply wells first. For the water supply well receptor survey, complete the following:

I. Generate a map of all well locations including
   a. all wells within the search radius of groundwater contamination
   b. all irrigation, industrial wells and wells with a water appropriation permit within the search radius of ground water contamination.
   c. Monitoring well information from adjacent contaminated sites is not required to be mapped or submitted for the receptor evaluation
II. Prepare a base map showing property boundaries and relevant features, such as buildings, roads, and surface water within the search radius of the source.
III. Identify property ownership.
IV. Contact residents, property owners, and business owners within the search radius of the source and obtain the following information for each property:
   a. Presence of a water supply well(s) or connection to a public water supply. Include a description of how this information was obtained, such as visual observation, personal contact, telephone conversation, returned postcard, or assumed.
   b. Type of well usage, such as private, domestic, or irrigation
   c. Possible PFAS sources
V. Document sources used to conduct well search
VI. Determine if groundwater contamination is in a well head protection area
   a. If contamination is within a designated area, the next step is to determine the aquifer's susceptibility to contamination.

Land use survey

I. Identify all current land use at the site and within the search radius of site boundary
   a. Provide a map and a table with the address of each of the following located within the search radius of site boundary:
      i. Residence
      ii. School
      iii. Childcare center
      iv. Other sensitive population
II. Identify and describe all proposed/planned changes to land use at the site or within the search radius of site boundary

The decision to limit the evaluation of land use must be based on existing site data and conditions and on your professional judgment.

Utility survey

Migration Pathway Identification: Identify and indicate the depth of all subsurface utilities and structures that may serve as preferential migration pathways.

I. Locate all underground utility lines and conduits within the area of known or likely soil and groundwater impacts, for both on-site and any off-site properties, to which a release may have migrated or to which a release may migrate in the future (includes communications lines, water lines, sanitary sewers, storm sewers, and natural gas lines).

Ecological receptor survey

I. Determine if any environmentally sensitive natural resources are present on or adjacent to the site or AOC that may be, have been, or are impacted by contamination from the site

II. Determine if contamination is present at the site or AOC in excess of any ecological screening criterion or aquatic surface water quality standard

III. Prepare a map showing the locations of all surface water features within the search radius of the site.

   a. Obtain surface water information from a variety of sources, including United States Geological Survey (USGS) topographical maps and in-field surveys.

   b. Identify any potential pathways such as ditches, drain tiles, and storm sewers that may lead to an identified surface water feature.

Initial Investigations Action 2: Identify media and locations to sample

In general, the following approach should be taken to determine baseline sampling requirements at a Site. For nuances related to non-responsible parties, refer to the Brownfield section of this document:

- Use the information from the Desktop review to develop a conceptual site model (CSM) for the Site. The CSM should incorporate historical PFAS usage, pathways, and receptors throughout the site. Use the CSM to assist in selecting the appropriate number and location of potentially impacted media to sample.
- Baseline sampling requirements will be determined by potential impacted environmental media (soil, groundwater, sediment, or surface water) that have likely been impacted as a result of current or historical use of the site and/or from off-site sources (i.e., groundwater flow, surface drainage runoff, etc.), as identified during the Desktop review stage. At this time, sampling for air deposition of PFAS from off-site sources is not included in baseline sampling.
- If the Site has previously been investigated for PFAS, existing data should be evaluated further to inform the baseline sampling requirements and determine if previous data were sufficient to meet current guidance or regulatory criteria. Examples: evaluate boring logs for soil types, evaluate any potential subsurface conduits for PFAS migration, identify data gaps such as areas of the Site where potential pathways/receptors have not been investigated.
- If the site has not previously been investigated, more comprehensive data collection (e.g., identify soil types, site-specific depth to groundwater, etc.) will be required.
- Impacts to aqueous media will require sampling in affected groundwater units and drinking water wells (see the receptor evaluation milestone). If the extent of impacts is unclear, further consideration of potential or likely hydrogeological pathways, including but not limited to site-specific groundwater flow direction, and the physical characteristics of known water-bearing units should be evaluated.
- If permanent monitoring wells are not present or available, initial groundwater samples can be collected from temporary wells. In a preliminary groundwater investigation, potable use of all groundwater is assumed, so the quantity and locations of samples is not solely receptor dependent.
- Surface water sampling is necessary if there was a known direct release of PFAS to the surface water body or if there is a confirmed or likely PFAS contaminant migration pathway to the surface water via surface runoff, impacted groundwater discharge to surface water, aerial deposition from an on-site source, or effluent discharge.
- Impacts to solid matrices are assessed through the collection and laboratory analysis of soil and sediment samples.
- Within unconsolidated units, soil intervals will require careful logging to determine where PFAS is likely to be present based on its known characteristics, such as preferential soil adsorption. Soil types identified during the investigation will help determine which interval(s) to sample.

- Assessment of potential impacts from facility operations may include sampling sumps, wastewater, and stormwater discharge.

Initial Investigations Action 3: Prepare SAP/QAPP/Work Plan

- Prepare a site-specific Sampling and Analysis Plan (SAP) to define the goal of investigative activities (e.g., current site usage is residential/industrial/commercial and future site usage will be residential/industrial/commercial).
- If required by the MPCA or regulated party, a site-specific Quality Assurance Project Plan (QAPP) will be prepared.
- PFAS sampling when other contaminants of concern (CoC) are present may require alternative sampling collection and analysis methods. In cases where PFAS and another CoC are present, separate sampling procedures as outlined in the MPCA Guidance for PFAS field sampling should be observed.
- An important functional aspect of project planning is the data quality objective (DQO) process. It is necessary to formalize these planning steps to inform the type, quantity, and quality of PFAS data used in decision-making. Thoughtfully derived DQOs provide the qualitative and quantitative framework by which data collection activities are successful in terms of achieving project objectives. The qualitative aspect of DQOs seeks to encourage good planning for field investigations. The quantitative aspect of DQOs involves designing an efficient field investigation that reduces the possibility of incorrect decision-making.
- The DQO process is defined in MPCA guidance document p-eao2-14: Data Quality Objectives (state.mn.us). The DQO process consists of seven steps. Note that every project is different, and the DQO process should yield project-specific objectives.
- Refer to MPCA's PFAS analytical guidance and sampling guidance for information on selecting appropriate DQO's: Guidance for Per- and Polyfluoroalkyl substances (PFAS): Sampling (state.mn.us), Guidance for Per- and Polyfluoroalkyl Substance: Analytical (state.mn.us). Data quality objectives should be established prior to data collection and sampling and the prescribed quality assurance/quality control (QA/QC) procedures followed throughout sampling, laboratory analysis, and data analysis.
- The ongoing, expanding nature of PFAS environmental awareness and the need for more comprehensive investigations have caused increased demand for PFAS environmental sampling and analysis. There are limited analytical method options available, particularly across the full spectrum of environmental media for a range of PFAS compounds. In many cases, the primary source in the search for available analytical methods for any environmental application is the U.S. Environmental Protection Agency (EPA) . The USEPA has published analytical methods for the analysis of select PFAS analytes in drinking water and non-potable water, and USEPA released a draft method for the analysis of select PFAS analytes in non-potable water, soil, sediment, biosolids, and tissue.
- There are several accepted analytical methods that may be utilized for various media; the most appropriate analytical method selection depends on the following key inputs:
    - Is a **specific** method required or cited for use, e.g., drinking water compliance, NPDES permit, MPCA regulation?
    - What are the project DQOs?
    - Is the laboratory certified by MDH for a specific method (where certification is required)?

The SAP/Work Plan must include analytical sampling of all investigation derived waste to determine the presence and concentration of PFAS for appropriate disposal. See the Disposal section for details regarding appropriate management of investigation derived waste (IDW).

Method	537.1	533	8327	1633	537.1 Modified	TOP Assay	Draft Method 1621 (AOF)	Non-Targeted Analysis
Author	USEPA ORD	USEPA Office of Water	USEPA Office of Solid Waste	USEPA Office of Water	Lab SOP	Lab SOP	USEPA Office of Water	Lab SOP
Version (Latest)	2	0	0 (2021)	3 (Draft)	NA	NA	0 (Draft)	NA
MPCA/MDOH Offer Certification?	Yes	Yes	Yes	Yes	Yes	No	No	No
Applicable Sample Media	DW	DW	Non-DW: GW, SW, WW	Non-DW: GW, SW, WW; Solid: Soil, Sediment, Biosolids, Tissue	Non-DW: GW, SW, WW; Solid: Soil, Sediment, Biosolids, Tissue	Non-DW: GW, SW, WW; Solid: Soil, Sediment, Biosolids, Tissue	Non-DW: GW, SW, WW	Non-DW: GW, SW, WW; Solid: Soil, Sediment, Biosolids, Tissue
Compounds Determined	18	25	24	40	Lab-specific	Lab-specific	1	Lab-specific
Preservative	Tris buffer	Ammonium acetate	none	none	none	none	none	none
Hold Time (Extract / Analyze)	14 / 28 days	28 / 28 days	28 / 30 days	28 / 28 days 90/ 28 days (frozen)	28 / 28 days	28/ 28 days	90 days	28/ 28 days
Instrument	LC/MS/MS	LC/MS/MS	LC/MS/MS	LC/MS/MS	LC/MS/MS	LC/MS/MS	Combustion-IC	qTOF/ HRMS
Calibration/ Quantification	Internal standard (non-isotope dilution)	Internal standard (isotope dilution)	External standard (non-isotope dilution)	Internal standard (isotope dilution)	Internal standard (isotope dilution)	Internal standard (isotope dilution)	External standard	Exact mass determination via library search
Primary Use/Application	Drinking water compliance		Testing for all matrices except drinking water			Forensic tools (where needed)		

The summary table above provides the current primary methods available for PFAS testing.

DW= Drinking Water, GW = Groundwater, SW = Surface Water, WW = Wastewater

Site Investigation Goal 2

Site Investigation Goal 2, Milestone 1: Delineate extent and magnitude of site contamination

Delineate extent and magnitude of site contamination in all impacted environmental media. If PFAS are present above risk-based values (RBVs) at the site, investigation is necessary to define the full extent and magnitude of contamination. See the Risk Assessment section of this guidance for information on RBVs. For nuances related to non-responsible parties, refer to the Brownfield section of this document.

If a release is identified at a site, it must be reported to the Minnesota Duty Officer. Minnesota statute § 115.061 requires that a person notify the Duty Officer immediately when any amount of any substance is released into the environment that may cause pollution of waters of the state. Note that independent, additional reporting requirements may exist under Federal Law. When in doubt, **report.** If there is an immediate threat to life or property, call 911 first!

- MPCA Incident Response: https://www.pca.state.mn.us/about-mpca/incident-response
- MN Duty Officer: https://dps.mn.gov/divisions/bca/bca-divisions/administrative/Pages/minnesota-duty-officer-program.aspx

Site Investigation Goal 2, Milestone 2: Develop the Conceptual Site Model (CSM)

Develop the CSM Action 1: Evaluate Fate and Transport

Many PFAS are resistant to biotic and abiotic degradation except for precursors which can transform into terminal PFAS (final degradation products). They are, therefore, ubiquitous in the environment and subject to long-range environmental transport. Most PFAS can move readily between environmental compartments. The fate and transport of perfluoroalkane sulfonic acids (PFSAs) and perfluoroalkyl carboxylic acids (PFCAs) has been studied in more detail than other PFAS. In general, PFSAs are more strongly sorbed to solid phases (e.g., soil or sediment) than PFCAs. Similarly, longer chain perfluoroalkyl acids (PFAAs), which contain both PFSAs and PFCAs, are more strongly sorbed than the shorter chain PFAAs (ITRC 2022). Generally, PFAAs are relatively mobile in groundwater, tend to associate with the organic carbon fraction in soil and sediment, and can be generated by transformation of volatile precursors (ITRC 2022). Due to their unique properties as surfactants, containing a hydrophilic head and a hydrophobic tail, PFAAs tend to accumulate along interfaces of environmental media such as soil/water, water/air, and water/non-aqueous phase liquid (ITRC 2022). For additional information about the fate and transport of PFAS refer to the ITRC PFAS technical and regulatory guidance document.

It is, therefore, important to consider the fate and transport mechanisms that may result in the migration of PFAS contamination from one medium to another. The following examples highlight the primary migration pathways for PFAS:

Groundwater to surface water/ surface water to groundwater

Because of their high mobility and persistence, PFAS can travel large distances through migration between groundwater and surface water compartments. If there is potential for a surface water to recharge groundwater or groundwater to discharge to surface water, concentration data should be compared to both MPCA surface water quality standards and MDH drinking water values. This ensures that both surface water and groundwater are protected. Typically, groundwater RBVs are more protective because they are developed for the drinking water pathway. However, for bioaccumulative

PFAS, such as PFOS, the surface water RBV is more stringent than the groundwater RBV because it accounts for the fish consumption pathway.

When evaluating the surface water pathway, surface foam samples should be collected when possible. The presence of foam is variable and depends on factors such as seasonal changes and precipitation events. These factors shall be incorporated into the work plan in order to ensure that sampling events occur when foam is most likely to be present.

Soil leaching to groundwater

PFAS present in the unsaturated zone are subject to downward transport during precipitation and irrigation events. Soil concentrations should be evaluated with the use of MPCA's soil leaching values (SLVs) and/or soil reference values (SRVs).

Atmospheric deposition to terrestrial and aquatic environments

Due to the ubiquity of PFAS in the environment, atmospheric deposition directly impacts the occurrence of PFAS in what would be considered background, unpolluted areas. Background concentrations of PFAS therefore represent "ambient" conditions due to atmospheric deposition, even in the absence of a release. Atmospheric deposition may also have occurred from on-site releases as well which can result in several migration pathways to soil, surface water, and groundwater.

Other potential pathways

Subsurface features such as utility lines can provide a preferential pathway for contaminated groundwater. PFAS-contaminated groundwater can infiltrate into sewer lines. PFAS-contaminated wastewater can also exfiltrate into groundwater. In both cases transport along the utility corridor can occur. The history of remediation efforts at a site should also be evaluated. For example, groundwater pump and treat systems may have changed the plume dimensions, or their discharge could have transported the PFAS to other areas.

Develop the CSM Action 2: Source Evaluations

When developing a work plan for site investigations, consider that more than one PFAS source may be present at a site, both spatially and temporally. The Desktop Review should indicate if compositions of PFAS changed during the history of operations, locations of facility areas moved, or fire suppression events occurred. It is also important to consider secondary sources of PFAS at a site, such as: sump, wastewater, or stormwater discharges, irrigation, pesticide applications, imported soils, and applications of biosolids. The source evaluation should consider the age, locations, compositions, quantities, and durations of releases.

If a site is impacted by multiple known or suspected sources, there are forensic tools that can be useful in fingerprinting different classes of PFAS. These tools are described in Section 10.5.1 of the ITRC PFAS guidance: 10 Site Characterization – PFAS — Per- and Polyfluoroalkyl Substances (itrcweb.org).

Complicating the issue of fingerprinting various sources is PFAS precursors. As previously mentioned, PFAS precursors can also transform into terminal PFAS (i.e., final degradation products) such as PFOS, PFOA, and PFHxS. Many PFAS precursors are polyfluorinated PFAS, meaning they are not fully fluorinated, while the terminal PFAS are perflourinated (i.e., fully fluorinated). Of the thousands of PFAS that currently exist, most are thought to be polyfluorinated. Given the information gaps that still exist for most PFAS, there is much uncertainty regarding the extent to which precursor transformation occurs, which environmental compartments represent the majority of the transformations and the relevant rates and pathways, and relevant environmental conditions that affect transformation processes (ITRC 2022). For an illustration of precursors and how they may impact contaminated sites refer to the ITRC *Figure 5-3*. As shown in Table (table from Goal 1, Milestone 1, Action 2), a total oxidizable precursor (TOP) assay can be used to estimate the total precursor content for each terminal degradant. During the TOP assay, precursors are transformed (oxidized) to the end products and the evaluation of pre- and post-TOP assay data offers information on the approximate amount of precursors present in a given sample.

Oftentimes, PFAS may not be the only contaminant released at a site. Consideration needs to be given to how the PFAS source is interacting with other contaminants such as dense and light non-aqueous phase liquids (DNAPLs and LNAPLs). Some research suggests that PFAS partition and accumulate at the NAPL/water interface in both LNAPLs and DNAPLS, possibly resulting in increased retainage and retardation of PFAS where they occur with NAPLs. See ITRC's PFAS guidance *Section 5.2.5*.

Background sources of PFAS are an evolving field of research. Widespread air deposition of PFAS has led to low-level contamination of most environmental media globally. Indoor air sources may also be present due to the numerous household products containing PFAS. Air emission sources of PFAS will be monitored as described in the 2022 PFAS Monitoring Plan. The MPCA will apply knowledge gathered from future research to evaluate how to assess background levels at remediation sites. For more information on background levels, refer to the ITRCs section: 6 Media-Specific Occurrence – PFAS — Per- and Polyfluoroalkyl Substances (itrcweb.org)

Site Investigation Goal 2, Milestone 3: Site investigations

The general principles of site investigation are similar for PFAS as they would be for other identified chemicals of concern in MERLA and RCRA. As noted above, investigation is necessary to define the full extent and magnitude of contamination to either risk-based or site-specific criteria. Site investigation work plan(s) will include the approaches outlined in Milestone 1 but will depend on the type of PFAS source and transport via various media. Please note that site investigations will likely undergo an iterative process. For nuances related to non-responsible parties, refer to the Brownfield section of this document.

Site Investigations Action 1: Hydrogeologic investigation strategies

The geologic and hydrogeologic site setting is a key component of the CSM, particularly since PFAS may extend significantly from a site. An assessment will be site-specific, but an adequate assessment will be one that considers the stratigraphic and lithologic complexity and project objectives.

Effective techniques to meet this need include the application of Environmental Sequence Stratigraphy (ESS) and High-Resolution Site Characterization (HRSC). ITRC has developed guidance on implementing advanced site characterization tools (see https://asct-1.itrcweb.org/).

As noted in ITRC's PFAS guidance, important geochemical parameters include soil characteristics (e.g., fraction of organic carbon (foc) surface charge, cation exchange capacity, grain size, mineralogy, and water content) and groundwater chemistry (e.g., cation and anion concentrations, ionic strength, oxidation-reduction conditions, pH). These data are used toassess transformation, partitioning (including desorption), and migration in groundwater or soil. These and other geochemical data (e.g., total dissolved solids iron, manganese, hardness) can be used to assess the viability of PFAS remedy options should remediation be necessary.

As noted in ITRC's PFAS Site Characterization Considerations and Media-Specific Occurrence fact sheet, investigations also need to account for the potential for secondary sourcing to occur from the following:

- Leaching from the vadose zone to the saturated zone
- Back-diffusion
- Desorption
- Non-aqueous phase liquids (NAPL) dissolution

- Non-site sources
- Atmospheric deposition
- Overland runoff
- Groundwater seepage into surface water or surface water seepage into groundwater
- Subsurface features, including utility lines and drain tiles
- Multicomponent mixtures
- PFAS precursors that may be present

Site Investigations Action 2: Employ use of PFAS-specific tools for site screening or characterization when available.

In addition to traditional sample collection (i.e., discrete samples), there are a number of available technologies to obtain data. While not a comprehensive list, ITRC's PFAS guidance provides some potential options:

- Use of a mobile laboratory that can be used in conjunction with discrete HRSC sampling
- Passive and no-purge samplers, which can significantly reduce the amount of Investigation Derived Waste and resources
- Electrochemical sensors, such as ion selective electrodes (see Rodriguez et al. (2020))
- Passive flux meters and other novel techniques (see Horst et al. 2022).

Site Investigation Goal 3 – Site Management Decisions

Actions 1 and 2 are used to facilitate site management, which is the same for PFAS as it would be for other identified chemicals of concern in MERLA and RCRA. Figure 1-2 of ITRC, 2011, while written in mind for dense non-aqueous phase liquids (DNAPL), lays out the process for an effective site management strategy.

Questions to ask include but are not limited to:

- Is the conceptual site model well understood?
- Are the extent and magnitude of PFAS adequately defined?
- Has the appropriate media been sampled?
- Have the goals of the investigation been met?
- Is the risk to human health and the environment understood? (See Risk Assessment Section)
- Has enough data been collected to determine what the cleanup approach is? Has that been documented? (See Remediation section for information on documenting a cleanup decision)
- If a remediation or mitigation system is installed, is adequate performance monitoring occurring in order to measure progress toward cleanup goals?

If the answer to any of these questions is no, then additional information and/or data collection is necessary before a site can be "closed."

Life Cycle Stage 3: Risk assessment

Goal: to identify and quantify the potential risks PFAS pose to human health and the environment at contaminated sites.

This section is designed to assist parties in properly applying risk-based guidance for evaluating the human health and environmental risk caused by exposure to PFAS-contaminated media. In a risk-based approach, remedial actions are driven by evaluating the contaminated media, exposure pathways, and impacts to current and future receptors. The results from the Site Usage and Site Investigation stage provide information about the presence of PFAS. The absence or presence of PFAS is confirmed through sample collection and analysis. The potential risk is assessed by evaluating several metrics, including but not limited to, site characteristics, exposure pathways to receptors, and analytical data.

> **Note**
> Responsible and voluntary parties are responsible for conducing risk assessments with MPCA guidance and oversight.

It is imperative that users of this guidance understand the exposure scenarios and other assumptions used in developing the risk-based values (RBVs) referenced in this section and have sufficient knowledge of the site to which the values are being applied. A risk characterization will be meaningful only when the RBVs are properly applied, and uncertainties are clearly identified. Individual RBVs may not be adequately protective in situations where multiple contaminants are present (refer to the "Additivity for mixtures assessment" section for more information).

For the purposes of this guidance, the risk assessment process will require a comparison of analytical results to RBVs. When RBVs are not available, the party conducting the risk assessment should work in close coordination with MPCA remediation staff and risk assessors to determine a path forward. This may include strategies such as the use of ambient background values if available, surrogate values, relative potency approaches, etc. A site-specific risk assessment and more active involvement by MPCA remediation staff and risk assessors will be needed in the following cases:

- Risk-based and/or ambient background values are not readily available
- Risk-based and/or ambient background values are exceeded, and a more thorough evaluation is needed
- Complex exposure pathways need to be evaluated (e.g., migration of PFAS into food products)

The risk assessment stage typically follows a site investigation. However, RBVs may be used at numerous stages of a site investigation – for initial screening of the first set of samples and during any subsequent investigations that may need to be completed. Risk assessment is also applicable during the disposal phase, when investigation derived waste (IDW) needs to be characterized to determine appropriate management options.

Risk is determined by combining hazard and exposure, i.e., the inherent danger of a chemical or mixture of chemicals and the likelihood that they will come into contact with or impact a human or environmental receptor. For the purposes of this guidance:

- Hazard is defined as the presence of PFAS at a site
- Exposure is defined by an exposure pathway (existing or future) leading to a receptor having potential contact with the identified contamination.

Risk assessments often make use of RBVs derived by regulatory agencies. An RBV represents an estimate of the contaminant concentration that is not likely to result in an appreciable risk of deleterious effects during a specific exposure duration, usually a lifetime. These values can take into account default or site-specific exposure assumptions. When there is more than one contaminant and/or multiple exposure pathways present, cumulative risk should be considered. For sites with multiple contaminants and a single exposure pathway, RBVs can be used to assess one type of cumulative risk – additive risk. Additive risk is calculated by summing the target cancer risk for carcinogenic contaminants and individual hazard quotients to calculate a hazard index for noncarcinogens with similar health endpoints.

The receptor evaluation conducted during the Site Investigation stage will provide information on human and ecological/environmental receptors within a specific radius from the site that need to be part of the risk assessment. RBVs are typically developed by receptor and environmental media type. Table 1 provides a summary of the media and receptor types that are typically evaluated during the risk assessment stage.

Table 1. Receptors and media to evaluate during risk assessment

	Environmental Media to Evaluate				
Receptor	**Soil**	**Sediment**	**Surface Water[1]**	**Groundwater**	**Soil vapor**
Ecological	X	X	X	N/A	N/A
Human	X	X	X	X	X

1 – PFAS containing foam may be present on surface water; more information is available in the risk-based values section

N/A = not applicable

However, there are additional exposure pathways that may need to be evaluated. Figure 1 provides a generalized conceptual site model illustrating other potential pathways that may need to be evaluated for human and ecological receptors.

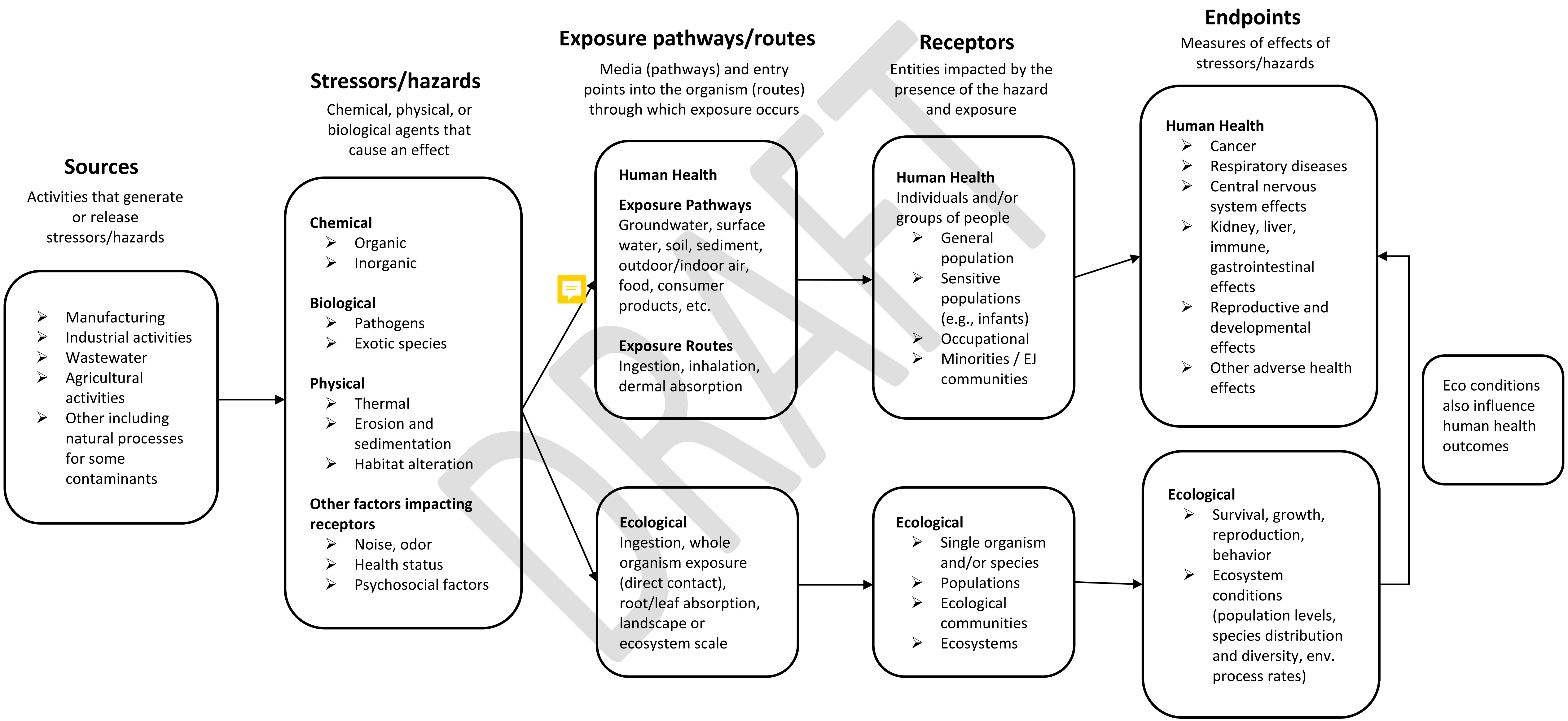
RBVs may not be available for all pathways in Figure 1; a site-specific risk assessment would be required in those cases. A site-specific risk assessment requires close coordination between MPCA remediation staff, MPCA risk assessors, and the party conducting the risk assessment. A site-specific risk assessment is also required when evaluating complex exposure pathways (e.g., migration of PFAS into food products). Complex exposure pathways are best evaluated through a forward risk calculation method, which more easily allows for the calculation of aggregate (single contaminant aggregated through multiple exposure pathways) and cumulative risk (multiple contaminants through multiple exposure pathways) (ITRC 2015, USEPA 2003). For more information on the forward risk calculation method refer to the Interstate Technology and Regulatory Council (ITRC 2015).

Risk assessments should include an uncertainty analysis with a brief discussion of the possible sources of uncertainty that could affect the conclusions of the assessment. To the extent that it is known, the uncertainty analysis should describe whether the uncertainty is due to:

- Incomplete knowledge of the site (e.g., unidentified hot spot) or receptors,
- Incomplete data from the scientific literature or other information sources (e.g., lack of toxicity information for some contaminants), or
- From the effects of natural, unquantified variability (e.g., natural fluctuation in moisture content of soil).

The discussion should also indicate whether the uncertainty has a biased impact on the risk characterization results (e.g., leading to an over- or under-estimation of risk) and, if possible, the magnitude of the effect.

Figure 1. Generalized conceptual site model (adapted from USEPA 2003)



Risk-based values

Table 2 provides a summary of PFAS RBVs currently available in Minnesota for assessing risks to human and ecological health. Human health vapor intrusion screening values have not been developed for the PFAS listed in **Error! Reference source not found.** as these PFAS are considered to be of low volatility a t environmentally relevant pH conditions.

It is important that users of the RBVs listed in Table 2 understand their applicability, the exposure assumptions that were used to derive the values and the uncertainties present. The technical support/guidance documents available for each set of values should be reviewed prior to using the values during risk assessments (Table 2).

Each set of human health RBVs is derived using target or acceptable risk levels. In Minnesota, these are defined as follows:

- **For carcinogenic chemicals** the acceptable risk level is a total or cumulative excess lifetime cancer risk (ELCR) not to exceed 1 in 100,000 (i.e., 1×10^{-5}) for chronic exposure. In other words, the acceptable risk level is a maximum of one additional case of cancer per 100,000 chronically exposed individuals above background cancer rates in the general population. If there are multiple carcinogens present, the cumulative cancer risk is determined by summing the ELCRs of individual contaminants with a carcinogenic endpoint.
- **For noncarcinogenic chemicals** the acceptable risk level is a noncancer chronic risk not to exceed a hazard quotient (HQ) of 1 per contaminant and a hazard index (HI) of 1 for multiple contaminants with similar health endpoints. The HQ is determined by dividing the site contaminant exposure concentration by the contaminant RBV. The HI is determined by adding the HQs for contaminants that share a similar toxicological endpoint.
- More information about calculating HI and cumulative ELCR is provided under the “Additivity for mixtures assessment” section.

Currently, only noncancer RBVs are available for PFAS. As more information becomes available about the carcinogenicity of certain PFAS, cancer values may be derived in the future. To evaluate ecological receptors, RBVs may be derived in a variety of ways depending on the environmental media and organisms being evaluated and may include values for wildlife (avian or mammalian), plants (terrestrial or aquatic), aquatic organisms (invertebrates, fish), etc. As specified in Table 2, some PFAS ecological RBVs are available but should be chosen in coordination with MPCA remediation staff and eco risk assessor.

Note

RBVs should not be interpreted as default cleanup values. In establishing remedial/cleanup goals, risk managers need to consider additional lines of evidence. Refer to the Remediation life cycle stage.

Due to the unique properties of PFAS, there may be additional situations that warrant evaluation, such as the presence of foam on surface waterbodies. There are no RBVs to evaluate human or ecological contact with foam. Because there is considerable uncertainty in evaluating PFAS foam exposures quantitatively, the MPCA strongly supports the MDH’s ongoing messaging to the public to avoid any contact with foam. Foams are typically not stable and can intermittently form and dissipate. Both natural organic and PFAS-containing foams pose risks to people and pets from ingestion. Signage may be useful in areas that are swimmable or have public access beaches and are known to have PFAS-containing foam or support conditions for foam formation. In some cases, wildlife may be exposed to PFAS through surface water foams. This exposure could be from direct ingestion of the foam or from ingesting other animals (like insects) that interact with foam or the high-concentration surface water microlayer (air-water boundary).

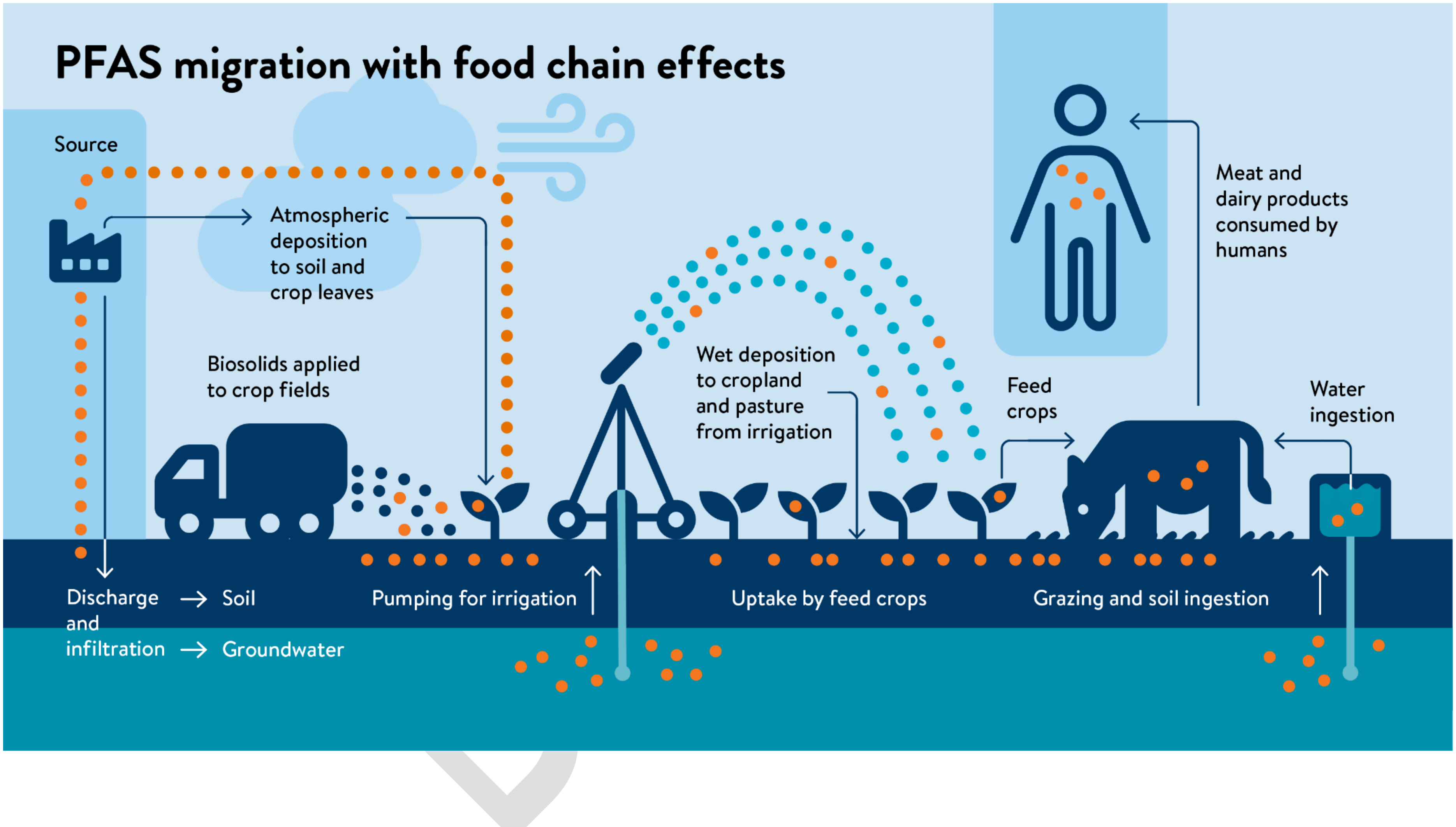
PFAS are also subject to long-range environmental transport and readily migrate between environmental media. Several migration pathways are discussed in the Site Investigation – Fate and Transport section. These migration pathways can all contribute to widespread PFAS contamination, which in addition to impacting human and ecological receptors through direct exposures to the contaminated media, can lead to impacts through food chain exposures such as through human/animal consumption of plant/animal products (Figure 2). For example, animals consuming contaminated water or ingesting contaminated soil or plant matter may lead to PFAS building up in their tissues. In addition to a potential direct risk to the animal, this also represents another exposure pathway for humans who consume animal products such as meat, milk, offal, eggs, and fish. Figure 2 represents an example of a complicated exposure pathway with food chain effects. Other potential migration pathways may need to be considered and evaluated on a site-specific basis.

Table 2. Summary of available PFAS RBVs

		Human Health				Ecological
Per- and polyfluoroalkyl substances	**PFAS**	**Surface Water and Fish Tissue [1]**	**Groundwater [2]**	**Soil [3]**	**Soil leaching pathway [4]**	**All relevant pathways**
Perfluorobutanoic acid / perfluorobutanoate	PFBA	Site-specific WQC available	MDH short-term, subchronic and chronic value available	MPCA SRV available	MPCA SLV in development	Some screening values are available – work with MPCA remediation staff and eco risk assessor
Perfluorobutane sulfonic acid / Perfluorobutane sulfonate	PFBS	Site-specific WQC available	MDH short-term, subchronic, and chronic value available	MPCA SRV available	MPCA SLV in development	
Perfluorohexane sulfonic acid / Perfluorohexane sulfonate	PFHxS	Site-specific WQC available	MDH short-term, subchronic and chronic value available	MPCA SRV available	MPCA SLV in development	
Perfluorohexanoic acid / Perfluorohexanoate	PFHxA	Site-specific WQC available	MDH short-term, subchronic and chronic value available	MPCA SRV available	MPCA SLV in development	
Perfluorooctanoic acid / Perfluorooctanoate	PFOA	Site-specific WQC available	MDH short-term, subchronic and chronic value available	MPCA SRV available	MPCA SLV in development	
Perfluorooctane sulfonic acid / Perfluorooctane sulfonate	PFOS	Site-specific WQC available	MDH short-term, subchronic and chronic value available	MPCA SRV available	MPCA SLV in development	
Hexafluoropropylene Oxide Dimer Acid	HFPO-DA	Not available	USEPA drinking water health advisory	MPCA SRV available	MPCA SLV in development	
Additional Information		Available on site-specific WQC webpage	MDH values available through the MDH Water Guidance Values table USEPA PFAS drinking water health advisories fact sheet	Available in the SRV spreadsheet Sediment RBVs are derived on a site-specific basis	Available in the SLV spreadsheet	
Other PFAS or exposure pathways		Work with MPCA remediation staff and risk assessors				

1 – Refer to the MPCA WQS website, Minn R. 7050, and Minn R. 7052 for more information on water quality standards and site-specific criteria. Site-specific WQC are applicable to specific waterbodies, refer to Appendix B on the site-specific WQC webpage for a list of waterbodies where WQC apply.
2 – Refer to the MDH 2008/2009 SONAR which explains the current methodology used to derive groundwater values. The USEPA has developed drinking water health advisories for four PFAS including PFOS, PFOA, GenX, and PFBS. MDH values may be used preferentially if available.
3 – Refer to the MPCA SRV technical support document and background threshold value evaluation document for more information.
4 – Refer to the MPCA soil leaching value (SLV) guidance document for more information.

Figure 2. PFAS release to the environment with a complex exposure pathway



Risk evaluation

Potential risks to human and ecological receptors should be estimated by comparing site sample concentrations to the applicable RBVs and/or ambient background values, if available and applicable. Refer to the "Ambient background concentration" section for more information on ambient background.

In general, if the contaminant concentration is equal to or less than the RBV (i.e., individual HQ or cumulative HI ≤ 1 and individual or cumulative ELCR ≤ 1 x 10-5), the contaminant does not present an unacceptable human health or ecological risk. If, however, the RBVs are exceeded this indicates that there may be potential for risk and further evaluation is warranted. Initial data collections/site investigation may not always be done in a way that best lends itself to risk assessment (for example, too few samples may have been collected). Therefore, further evaluation often means additional sample collection to better characterize the extent of contamination and risk. Some RBVs, such as the MPCA SRVs, can be adjusted during these later stages of site investigation if the initial values have been exceeded and site-specific information is available for refinements. Other values, such as the MDH groundwater values, are typically not adjusted and an exceedance may mean that response actions, such as replacement or treatment of a drinking water supply, are warranted.

For PFAS that bioaccumulate in fish tissue, such as PFOS, fish consumption can be a significant source of exposure. When evaluating PFAS impacted surface water, fish sampling may be needed in addition to surface water sampling. If a water quality standard, water quality criterion, or other screening level designed to protect fish consumers is exceeded in surface water, fish sampling is recommended to determine if the compound is bioaccumulating in edible fish at a level that may pose a risk to human health.

During risk evaluation, it is important that exposure areas and representative exposure point concentrations (EPCs) are appropriately defined and used. An exposure area is the location of potential contact between a human or ecological receptor and a release of contaminants. An exposure area is defined relative to a given pathway and exposure route, and may correspond to a single location, especially in the case of water wells or surface water, an entire site, or some portion of the site. An exposure area may or may not correspond to the extent of contamination at the site, a source area proper, or a source area with an associated plume. An exposure area may extend beyond property lines.

Based on the pattern of contamination (e.g., location and magnitude of hot spots) and current and planned site activity, it is necessary to determine whether the site conditions or the focus of investigation requires definition of multiple exposure areas and grouping of associated data to estimate the EPC to be used in the evaluation. It may be necessary to group data by depth or location or as a function of time. EPCs can represent both single analytical results, such as a maximum contaminant concentration, or a calculated value based on grouped results, such as by calculating a 95% upper confidence limit (UCL) of the mean of multiple samples. Many of the RBV technical support/guidance documents specify how site data are to be handled prior to comparison to RBVs. This information should be reviewed prior to establishing EPCs. Refer to Table 2 for links to relevant documents.

To that end, it is important that the data collected have been collected in a manner consistent with the risk assessment being performed and the RBVs being used. The following data issues are frequently encountered:

- Non-detect results,
- Estimated results, often denoted with a "J" data qualifier, and

- Detection and reporting limits higher than RBVs.

If analytically feasible, detection and reporting limits should always be below the RBVs used in the risk assessment to ensure that non-detects do not exceed RBVs. If sufficiently low detection limits cannot be achieved, this should be discussed in the uncertainty analysis. Estimated results (e.g., “J” qualified results) that are typically defined as being between the method detection limit and the limit of quantitation (may be called a reporting limit) can be used as any other detected result in the risk assessment. Estimated results should always be appropriately qualified/flagged in laboratory reports and data summaries. The Kaplan Meier (KM) method available through USEPA’s ProUCL software is recommended for evaluating non-detect data when appropriate (i.e., assuming appropriate data quality and the method is appropriate for the dataset in question). For example, the SRV technical support document recommends the KM method for calculating a 95% UCL of the mean for censored datasets with non-detect frequency of less than or equal to 80 percent if it’s needed for a specific exposure area. Non-detect results should not be used in additivity calculations. If non-detect results have the potential to impact the additivity calculation this should be discussed in the uncertainty analysis.

PFAS precursors

Due to the uncertainty surrounding PFAS precursors, it is recommended that any precursors identified at a site are screened using RBVs for their terminal products, if available. This would be considered most health protective given how much is unknown about precursor degradation. Refer to the footnote for a list of resources that can help with identifying PFAS precursors and terminal products.[1]

Stepwise process

Follow the steps below during risk evaluation. Refer to Figure 3 outlining the major decision points.

Depending on the individuals or communities impacted it may be important to account for variations in cultural practices. For example, certain communities might be eating more fish/game that could be contaminated with PFAS than others or engaging in cultural practices that use resources in ways that could increase exposure. This information should be identified during the data and information gathering stage (Step 1). If the individuals or communities being evaluated are likely to have greater exposure to PFAS than what is represented by the default exposure assumptions used in developing RBVs, then a site-specific risk assessment may be needed (Step 9). Consult with MPCA if this is the case.

Step 1. Gather data and all relevant information needed for the assessment. This includes but is not limited to:

- Site information/characteristics
- Analytical data/results
- Conceptual site model outlining the exposure pathways and current and/or future potentially impacted receptors

[1] Information from Environment and Climate Change Canada for PFOS and precursors: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/ecological-screening-report-sulfonate/appendix-1.html
PFOA and precursors (Table 2): https://ec.gc.ca/ese-ees/default.asp?lang=En&n=370AB133-1

Information from Germany’s REACH restriction proposal for PFHxA (see Final BD annex, section B.4.1.2): https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18323a25d

Information from the Stockholm Convention on PFHxS and PFBS precursors: http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-POPRC13FU-REF-PFHxS-20171027.En.pdf

- Applicable RBVs[2]

Step 2. Confirm that all data have been properly QA/QC'ed and that enough samples have been collected for the assessment. This will depend on the RBVs being used.

Step 3. Determine the EPCs. This may be a maximum contaminant concentration, or a calculated value based on grouped data such as a 95% UCL of the mean.

Step 4. Compare the EPCs to the applicable RBVs[2] from **Error! Reference source not found.** a nd calculate HQs and ELCRs.

> **Step 4a.** When more than one contaminant is detected and additivity needs to be considered at the screening level (e.g., for groundwater and surface water), perform additivity calculations (i.e., calculate an HI for noncarcinogens and a cumulative ELCR for carcinogens). Refer to the "Additivity for mixtures assessment" section for more information.

Step 5. If RBVs are not exceeded (i.e., HQ or HI ≤ 1 and individual or cumulative ELCR ≤ 1×10^{-5}) then the risk is below RBVs/unacceptable thresholds. If RBVs are exceeded (i.e., HQ or HI > 1 and individual or cumulative ELCR > 1×10^{-5}) then assume there is potential for risk and further evaluation may be needed. Proceed to Step 5a and 6.

> **Step 5a.** Consider if remedial actions can be taken to address the potential risk. Refer to the Remediation Stage for options.

Step 6. Determine if and to what extent additional site investigation is needed. Conduct additional sampling and collect more data as appropriate.

> **Step 6a.** Determine if site-specific adjustments can be made to the RBVs being used. For soil, site-specific information can be used to refine the RBVs if appropriate.

Step 7. Perform steps 2, 3, 4, and 4a incorporating the new information – data from additional sampling events and/or site-specific information used to adjust RBVs.

Step 8. If RBVs are still exceeded, determine what remedial actions can be taken to address the potential risk. Refer to the Remediation Stage for options. If remedial actions cannot be selected yet due to insufficient information or determinations of risk, proceed to Step 9.

Step 9. Conduct a detailed site-specific risk assessment. Work with MPCA remediation staff and risk assessors on next steps. A site-specific risk assessment at this stage may need to incorporate complex exposure pathways. A forward risk assessment should be conducted to properly aggregate all applicable exposure pathways (ITRC 2015).

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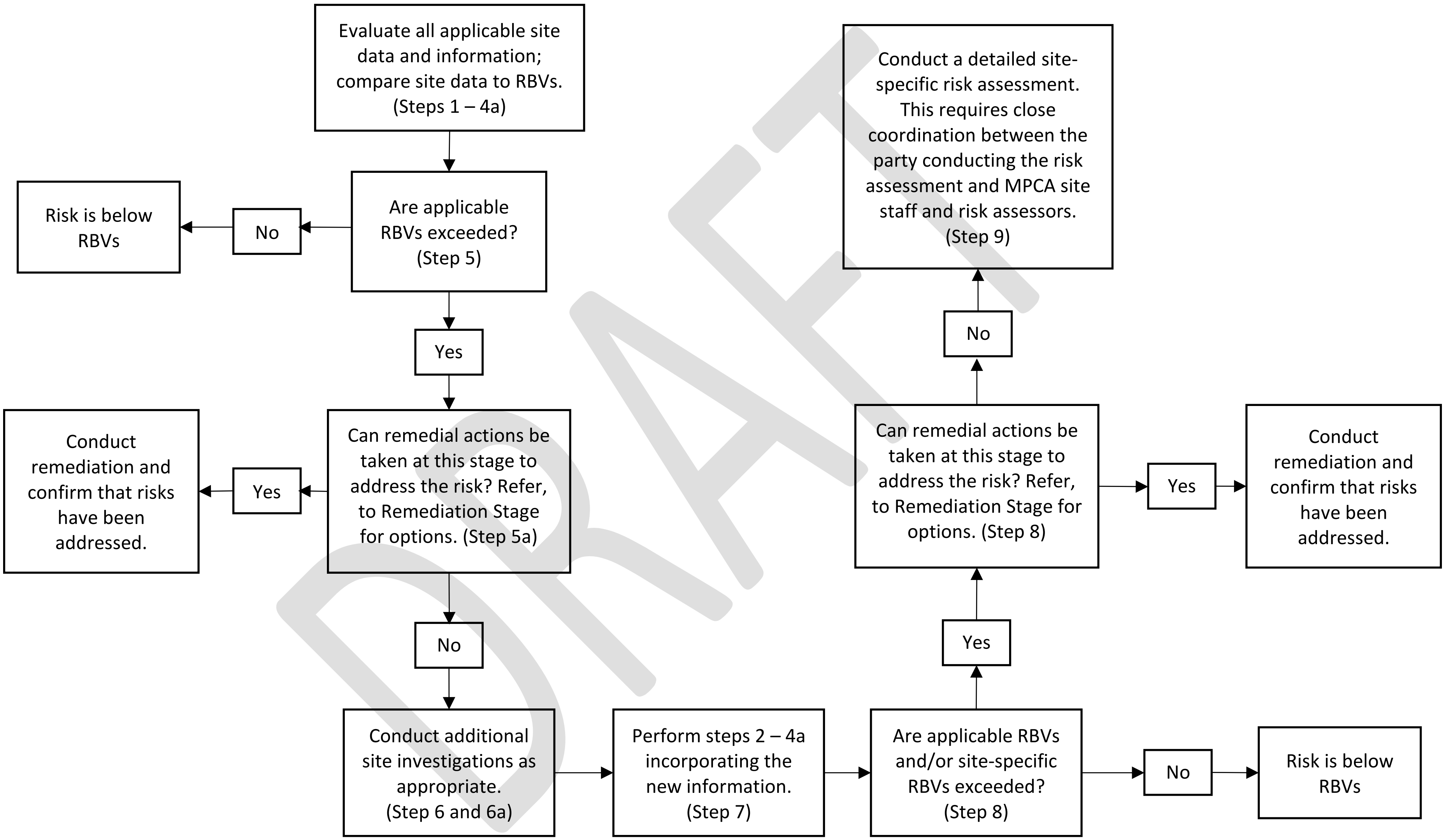
[2] Applicable RBVs are selected based on the presence of an exposure pathway to a current or future receptor – human or ecological. For example, if receptors may come into contact with contaminated groundwater and soil, then groundwater and soil RBVs need to be used to evaluate risk.

Figure 3. Flowchart of decision points during risk evaluation



Additivity for mixtures assessment

Contaminants in combination (i.e., more than one contaminant present in a particular medium) may cause adverse effects that would not be predicted by evaluating each contaminant separately. Therefore, when multiple contaminants are detected at a site, additive risk (a type of cumulative risk) may need to be evaluated. The USEPA uses additive risk as a reasonable approach to mixtures assessment given what is unknown about how chemicals interact in the body (e.g., there may be synergistic, antagonistic, or additive effects). Additivity is evaluated by an HI for noncarcinogens and a cumulative ELCR for carcinogens. The HI is expressed as the sum of the ratios of the measured concentration of each contaminant to its respective RBV. If the calculated HI for a particular endpoint exceeds 1, this may indicate that there is potential for risk and further evaluation is warranted. Similarly, cumulative ELCR is expressed as the sum of the individual contaminant ELCRs.

Other mixtures assessments, such as a PFAS relative potency factors (RPF) method, may be developed in the future by USEPA or other regulatory agencies. MPCA may adopt a federally or state developed RPF method in the future.

Groundwater

The methods used to derive MDH groundwater/drinking water values specify that additive risk is to be evaluated (Minn. R. 4717.7870). Most RBVs have health endpoint(s) associated with various exposure durations. These endpoints are organs (e.g., liver, kidney), organ systems (e.g., reproductive), or other health outcomes (e.g., developmental effects) that have the potential to be adversely impacted by the contaminant. To calculate additivity for groundwater exposure, the MDH developed and maintains an additivity calculator that is available through their website. For simplicity, MDH refers to both cancer and noncancer additive risk as a health risk index.

Additivity should be assessed for all contaminants that are detected, not just for contaminants that are close to exceeding an RBV and not just for PFAS. There may be situations where no single contaminant approaches an RBV but when all detected contaminants are assessed for additive risk the risk index may exceed 1, which would indicate that there is potential for risk.

Surface water

Similarly, the methods used to derive MPCA surface water quality standards or criteria include additive risk considerations (Minn. R. 7050.0222, subp. 7, item D). For water quality standards currently in rule, additivity can only be assessed for carcinogens (human health based) or for acutely toxic conditions (aquatic life based). However, the surface water RBVs for PFAS are based on chronic noncancer effects for which additivity can and should be evaluated. The health endpoints associated with the PFAS site-specific WQC as well as an explanation of the additivity calculation is provided in these technical support documents:

- PFOS WQC technical support document
- PFOA, PFHxS, PFHxA, PFBA, and PFBS WQC technical support document

The PFAS WQC are site-specific and only apply to the waterbodies listed in the appendices to these technical support documents:

- PFOS Appendix B: Application to specific waterbodies
- PFOA, PFHxS, PFHxA, PFBA, and PFBS Appendix B: Application to specific waterbodies

The appendices can be updated to include additional waterbodies. If there is a surface waterbody that needs to be evaluated for PFAS contamination, but it is not listed in the above linked appendices, remediation staff should contact WQS unit staff so they can assess whether the WQC can be applied to the waterbody in question and update the appendices if deemed appropriate.

Soil

As a matter of policy, SRVs are developed using a relative source contribution (RSC) factor of 0.2 and are considered to be reasonably protective of additive effects at the screening level for most sites. The RSC applied to SRVs is a modifying factor that adjusts the HQ downward. Adjusting the HQ downward as a way of accounting for potential additive effects at the screening level is also recommended by the USEPA (USEPA 2022). For soil, additivity is assessed on a site-specific, as-needed basis. A modified SRV spreadsheet allowing for the calculation of additivity is available and can be requested from MPCA.

Risk-based values from other sources and data poor PFAS

To evaluate human health risk, MPCA preferentially recommends RBVs, and toxicity values developed by Minnesota state agencies (e.g., MDH or MPCA values). However, there is not enough toxicity information for the majority of PFAS to derive RBVs; therefore, Minnesota-derived values may not be available for all PFAS of interest. When RBVs are not available for certain PFAS, the PFAS contaminants should be clearly identified (name, detection frequency and magnitude) and discussed in the uncertainty portion of the risk assessment. RBVs may be available from other sources, such as the federal government, that may be used in certain situations. For example, if a site cleanup is being led by the USEPA, preference may be given to values developed by the USEPA.

When Minnesota RBVs are not available and values are available from other sources, such as the federal government or other state governments, it may be appropriate to determine the toxicity values used in developing those RBVs. MPCA and MDH can review the toxicity information used in developing other RBVs and determine if a Minnesota RBV can be derived. Toxicity values are commonly developed by the USEPA, Agency for Toxic Substances and Disease Registry (ATSDR), California EPA (CalEPA), Environment and Climate Change Canada, and the European Chemicals Agency's REACH program.

If no toxicity information is available for a PFAS of interest, other approaches will need to be considered. MDH is already exploring surrogate and other approaches for characterizing toxicity for PFAS with no or limited toxicological information. As toxicity values become available for additional PFAS from MDH or other sources (USEPA, ATSDR, CalEPA, etc.), MPCA will evaluate, and if appropriate, incorporate this information and develop human health RBVs for use during site investigations and risk assessments. Additionally, parties conducting the risk assessment should suggest approaches for selecting toxicity values if no value is available for the PFAS of interest and should work closely with MPCA remediation staff and risk assessors. The following are options, in order of preference:

- Surrogate toxicity values
  - This is a common practice when dealing with data-poor contaminants. MDH has used the surrogate approach in the past (circa 2006) when not enough toxicity information was available at the time to derive groundwater RBVs for certain PFAS such as PFBA and PFHxS. Chemical-specific RBVs were derived once toxicity data became available.
- RPF approach
- Surrogate toxicity values may also be used for a group of data-poor PFAS by selecting one PFAS with existing toxicity information as a group representative. Grouping may be

considered based on similar toxicities and potencies, and/or based on structural and physicochemical similarities.

Additionally, the following resources may help with identifying relevant information for data-poor PFAS:

- USEPA CompTox Chemicals Dashboard
  - Includes information on physicochemical properties, environmental fate and transport, exposure, usage, in vivo toxicity, and in vitro bioassays.
- PFAS-TOX Database
  - Database of relevant toxicity studies for "less well studied" PFAS (excluding PFOS and PFOA which have been studied extensively).

To evaluate ecological risk, MPCA often recommends federal or other state RBVs as deemed appropriate. The availability of RBVs is likely to grow in the future. As outlined in **Error! Reference s ource not found.**, there are some screening values available, but they should be selected in consultation with MPCA remediation staff and eco risk assessor.

Ambient background concentrations

Background concentration refers to the concentration of a chemical that is ubiquitous and consistently present in the environment and would be present even if the site of concern did not exist. PFAS are subject to long-range transport and are often detected in areas far away from point sources. The MPCA has prepared a technical memo describing ambient background PFAS concentrations in various media (MPCA 2023d). This memo is informational only and should not be used to set cleanup levels at remediation sites. Ambient background can be defined as the concentration of a contaminant in water, soil or other media that is the sum of the naturally occurring background concentration (if applicable) and the contaminant levels that have been introduced from diffuse or non-point sources by general anthropogenic activity not associated with industrial, commercial, or agricultural activities (DWER 2021). Given that PFAS are manmade, there is no natural background for these contaminants.

When more information about the toxicity of a contaminant becomes available, it is often necessary to update or recalculate existing RBVs. This often means that RBVs become more stringent/protective especially if it is found that the contaminant is toxic at lower levels than previously understood. Given that there is still much to learn about PFAS toxicity, it is possible that certain RBVs may fall below PFAS ambient background concentrations in the future. Site-specific background should be determined at sites where ambient background concentrations may need to be used during risk assessments.

Note that it must be assumed that detected PFAS are present above ambient background concentrations unless it can be otherwise demonstrated. Generally, it is necessary to collect samples from appropriate off-site locations and apply statistical methods (if applicable) to determine whether site PFAS concentrations are consistent with or above ambient background concentrations. Published ambient background levels may not be representative of Minnesota conditions and may not be comparable to the data obtained at the site (e.g., different soil type, variations in sampling and analytical techniques, etc.). Thus, the assessor should not use any list of published ambient background levels which has not been specifically recommended or approved by the MPCA.

Ambient background samples should be collected in locations that are relatively undisturbed and unlikely to have been affected by point sources. For PFAS, ambient background samples should be obtained at locations where the only potential PFAS source is atmospheric deposition, with no proximal PFAS point sources. The sampling location should be based upon similarity of the site conditions to the background area conditions. Enough samples must be taken to allow a meaningful comparison of ambient background concentrations to site concentrations. This will depend on the environmental media being evaluated. Determination of site-specific PFAS ambient background should be done in close coordination with MPCA.

For soil, the following resources may be useful for determining ambient background concentrations:

- USEPA guidance for developing soil background concentrations for Superfund sites
  - While the document was developed for Superfund, the guidance is a useful resource for any site where background concentrations may need to be determined.
- ITRC information on establishing soil background for risk assessments

Life Cycle Stage 4: PFAS Remediation

The remediation life cycle stage focuses on selecting and implementing remedies at contaminated Superfund sites, cooperative responsible party sites, or brownfields sites. Remedy selection begins after a thorough site investigation and risk assessment have been completed, and it has been determined that an unacceptable risk exists at the site. Using the site investigation data, remedial alternatives are developed that protect public health and the environment and can reduce the identified risk to an acceptable level.

***Goal:* Address PFAS contamination source to mitigate the identified risk(s) to human health and the environment through remedial activities.** Remedial activities include but are not limited to the treatment, destruction, or removal of PFAS-impacted environmental media, and/or engineering or institutional controls. The remedy selection process is discussed in the *Draft Guidelines Remedy Selection* (MPCA, 1998) guidance document and can be used to address PFAS and other contamination.

Actions:

Risk management

Risk management utilizes the information gained during risk assessments but is considered a separate process. Risk assessment establishes whether a risk is present and if possible, the range or magnitude of that risk while risk management uses the results of a risk assessment and integrates it with other lines of information such as economic, technology, legal and other factors to reach a decision regarding the best management strategy for a site and response to address the risk. Purely health based RBVs, for example, do not take into consideration information such as the cost or feasibility of treatment; therefore, they represent only one line of information/evidence to consider during site cleanups. Risk managers also use the information gained from a risk assessment to communicate risk to stakeholders and affected communities. Risk-based values (RBVs, discussed in detail in the Risk Assessment section), along with ambient levels, detection limits or analytical limitations, technology limitations (e.g., using values derived based on best available treatment technology), economic/cost considerations, and other factors should be considered when establishing remedial/cleanup goals, including:

- Current/future site usage
- Results of risk assessment
- Remediation options
- Other information/lines of evidence

Remedy selection

This section is not a comprehensive remedy selection guidance. The purpose of this section is to provide an overview of some unique factors to consider when evaluating and selecting remedies related to PFAS contaminant releases. Determining when an unacceptable risk is present and when response actions are needed related to PFAS are addressed in previous chapters of this document.

PFAS uncertainties and remedy considerations

Due to the complex nature of PFAS contaminants and because regulations and treatment technologies for PFAS in environmental media are still evolving, it is prudent to use caution in implementing long-term remedies (ITRC, 2022). For additional information, see the Uncertainty Analysis portion of the Risk Assessment section. Some of the characteristics of PFAS that warrant special consideration when evaluating and implementing remedies for these contaminants include:

- Very high degree of permanence and resistance to degradation in most settings.
- Strong tendency for cross-media contamination due to the recalcitrant, stable nature, and mobility of many PFAS including their ability to move between air, soil, groundwater, leachate, and surface water.
- Tendency for some PFAS to bioaccumulate in plants, animals, and human tissue.
- Rapidly developing knowledge regarding toxicity, and physical fate and transport properties.
- Uncertainty due to rapidly developing regulations and limited disposal options for contaminated media.
- Stable and surfactant nature of PFAS making many treatment technologies ineffective, including those that rely on contaminant volatilization or bioremediation (ITRC, 2022).

The complex chemistry of PFAS also makes understanding and effectively managing or remediating these contaminants challenging. There are numerous PFAS compounds including metabolites of originally released compounds and precursors to PFAS chemical detected in the environment. Information on physical and chemical properties and toxicity for many of these compounds is very limited.

Analytical methods are only available for a relatively small number of PFAS and may only be able to identify and quantify a portion of PFAS chemicals where releases may consist of a complex mixture of many compounds including precursors to shorter chain PFAS detected downstream. This can make characterizing source areas and meeting cleanup objectives difficult.

Due to these uncertainties and the ability of many PFAS contaminants to persist in the environment and to travel long distance in surface water and groundwater, protection of drinking water sources and human health should be prioritized as a primary response action objective when evaluating potential remedial alternatives. At some sites, it might be reasonable to take short-term site stabilization actions with the intent of applying more robust and cost-effective technologies as these are developed (ITRC, 2022). At the same time, remedies involving more complete cleanups, or providing permanent destruction might be greater preference in some situations given these factors.

MPCA Remediation Division general remedy selection policy

The primary missions of the MPCA Remediation Division programs are to protect human health, public welfare, and the environment by conducting or overseeing investigations and response actions related to releases of hazardous substances and pollutants to the environment in order to return land to economic or other beneficial use under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Minnesota Environmental Response and Liability Act (MERLA, including the Land Recycling Act). Responding to releases of PFAS contaminants into the environment falls under this authority.

In accordance with MERLA, remedy decisions also may incorporate concepts of cost-effectiveness, pollution prevention, and natural resources damages. The MPCA Remediation Division mission supports evaluation of potential remedies ranging from those that thoroughly destroy contaminants to those that include the use of engineering controls and institutional controls, depending upon site specific circumstances (MPCA, 1998).

MN remedy selection process

The remedy selection process follows site characterization and a risk assessment where it has been determined that an unacceptable risk exists at the site and response actions are needed. Information about the nature and extent of the releases along with site characterization data are used to construct a conceptual site model and to develop potential remedial alternatives designed to protect public health and welfare and the environment (MPCA, 1998).

The remedy selection process can vary depending on the size and complexity of the site (including the extent of contamination and impacted receptors), and if the cleanup work is being conducted and funded by a responsible or voluntary party. The remedy selection process for state remediation sites is described in the Draft Guidelines Remedy Selection, Minnesota Pollution Control Agency Site Remediation Section (MPCA, 1998). This guidance document includes a description of appropriate variations for streamlining or abbreviating the process based on the size and complexity of the project.

A Remedial Investigation/Feasibility Study (RI/FS) process is often used for remediation projects to investigate a release and to evaluate potential remedial actions. The RI/FS is used to develop a conceptual site model and response action objectives and to screen and evaluate potential remedial alternatives.

For PFAS sites, even for small sites being remediated by a responsible party (RP) or voluntary party (VP), special consideration must be given to the long term-persistence and mobility of PFAS and the limited options for remediation and disposal. At some sites, it might be reasonable to take interim response actions (discussed later in this section) with the intent of applying more robust and cost-effective technologies as these are developed (ITRC, 2022) . For PFAS sites, a primary objective is to reduce or eliminate migration of contaminants into groundwater or surface water and protection of drinking water.

For remediation sites the following balancing criteria and other considerations must be evaluated when selecting a remedy. These are described in detail in the MPCA Remedy Selection Guidance Document (MPCA, 1998) and MPCA Generic RFRA (MPCA, 1998).

- **Required balancing criteria:**
    - Short Term Risk
    - Long-Term Effectiveness
    - Project Implementability
    - Cost Effectiveness
    - Community Participation
- **Other required considerations**
    - Compliance with Regulation
    - Planned Use of the Property
    - Institutional Controls

This same general framework must be used for state remediation sites with PFAS contamination. The unique characteristics of PFAS chemicals, such as their persistence in the environment, mobility in water, complex chemistry, and limited options for treatment and disposal should also be evaluated.

The remedy selection process for remediation sites with federal oversight and/or funding, such EPA led National Priorities List (NPL) superfund sites or Great Lakes National Program Office (GLNPO) led sediment remediation sites must be consistent with the remedy selection process as described in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) and CERCLA. The 1990 NCP at 55 FR **8719-2.3** describes how the detailed analysis of alternatives is to be performed using these criteria. Chapter 7 of the “Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA” (EPA, 1988) provides further detail on the process.

For remediation projects that are being led or funded by the federal government, the remedy selection process must be consistent with the detailed remedy selection approach described in the NCP and CERCLA. Some of the primary steps included in the federal superfund remedy selection process under CERCLA include:

- Remedial Investigation/Feasibility Study (RI/FS)
  - Remedial Investigation and Risk Assessments
  - Development of Response Action Objectives
  - RI/FS Detailed Analysis of Remedial Alternatives using comparative analysis of nine standard threshold and balancing criteria
  - Selection and Development of Proposed Plan
  - Public Notice of Proposed Plan
  - Evaluation and Implementation of Modifying Criteria
  - Issuing Record of Decision and Public Notice

State of MN Streamlined Remedy Selection Options

The remedy selection process for state remediation sites is described in Draft Guidelines Remedy Selection, Minnesota Pollution Control Agency Site Remediation Section (MPCA, 1998). This guidance document includes a description of appropriate variations for streamlining or abbreviating the process based on the size and complexity of the project.

A streamlined selection approach is appropriate at smaller and less complex cleanup sites where:

- The volume of contaminated media is low
- A proven effective treatment is available
- The impacted area is small and confined to one or a small number of properties. Off-site migration is not occurring, and off-site receptors are not impacted
- The remedy is non-controversial and has little or no impact on the surrounding community
- The cleanup is being conducted and paid for by a responsible or voluntary party
- The remedy is acceptable to the RP/VP

For simple remedies such as this, only a brief Remedial Action Plan (RAP) may be needed to describe how the remedial action will be conducted for MPCA staff review and approval.

A more comprehensive remedy selection process that more closely follows all steps in the MPCA Remedy Selection Guidance Document (MPCA, 1998) should be used for non-federal sites with more significant volumes of contaminated material, more complex technical issues, and/or have land use or other community issues that must be addressed. Two or more remedial options are generally evaluated to assess the effectiveness and cost of the different strategies and to provide alternatives in addressing the broader issues posed by t these types of sites. When evaluation of more than one remedial alternative is performed, the MPCA recommends conducting a focused feasibility Study (FFS) following the MPCA Remedy Selection Guidance Document (MPCA, 1998) or the remedy selection process outlined in CERCLA (EPA, 1997) to compare remedies and to document the selection process.

The FFS describes the remedial alternatives, evaluates each alternative in relation to balancing criteria, and provides the rationale for selection of the proposed remedy. With the FFS, the remedial alternatives or combination of alternatives that meet the needs of the RP/VP, MPCA, and the community can be selected.

Complex and state fund financed sites: The most complicated state RP/VP and state fund-financed sites may require a higher level of evaluation and documentation and stakeholder and public participation in order to select a remedy. These sites may have numerous areas and/or types of contamination, off-site contaminant migration impacted receptors and greater community-related concerns.

A more comprehensive remedy selection using an RI/FS process consistent with EPA remedy selection guidance (EPA) is typically used at larger more complex sites, sites listed on the MN Permanent List of

Priorities (PLP), sites NPL sites, or other sites under federal oversight by the EPA superfund program or Department of Defense (DoD). Examples of situations where a comprehensive remedy selection process generally adhering to the traditional Superfund remedy selection process as outlined in the NCP is required or is appropriate include:

- State-lead sites where the MPCA is conducting the site investigation and cleanup because there is no identified or viable RP to do so. In these cases, the MPCA generally adheres to the traditional Superfund remedy selection process as outlined in the NCP to maximize the opportunity for recovery of MPCA's costs from RPs at a future date under federal Superfund law (42 U.S.C. § 9607(4)(A)) The actions taken by the MPCA must be "not inconsistent" with the NCP.
- When an RP/VP wishes to ensure their ability to pursue a cost recovery action under federal Superfund law. For example, an RP/VP may choose to begin site investigation and cleanup even though there are other persons that are legally responsible for participating in the costs of site investigation and/or cleanup but are unwilling to do so. In this case, in order to pursue a future cost recovery action under federal Superfund law (42 U.S.C. § 9607(4)(B)), the RP/VP should follow a RI/FS process that is "consistent with" the NCP.
- In cases where the MPCA uses its authority to issue a Request for Response Action (RFRA) to an RP, the MPCA may require the RP to follow the RI/FS remedy selection process. The MPCA must issue a RFRA and a Determination of Inadequate Response (DIR) if it intends to spend state Superfund money for site cleanup where the RPs are unwilling or unable to do so.

Detailed information about the traditional RI/FS remedy selection process can be found in Attachments A and B to the MPCA's Generic RFRA (MPCA, 1998).

Interim response actions

In some cases, interim response actions may be needed to eliminate unacceptable risk to human health in a timely manner. For example, interim response actions may be needed if unacceptable levels of PFAS are found in drinking water, or if a spill or direct release of PFAS occurs.

Should environmental conditions require corrective measures to immediately reduce unacceptable risks to human health or the environment, the Agency may require an Interim Response Action (IRA) prior to or parallel with the RI/RA process (Ref.). The purpose of an IRA is to provide an expedited response which will reduce or eliminate the identified unacceptable risk. While an IRA may take any number of forms, further discussion is warranted on two specific scenarios that are particularly relevant to PFAS.

First, IRAs may be required in case of a release or imminent release of PFAS or PFAS-containing substance. While IRAs of this nature are not unique to PFAS, note that an intentional release of PFAS-containing AFFF as a fire suppressant (i.e., consistent with the product's intended use) may also require an IRA similar in scope to a spill response. Within this context, an IRAs may likely include soil excavation to reduce human risks via direct soil contact and/or to reduce total PFAS mass and mobility.

Second, given the mobility of PFAS in groundwater, IRAs may be required in case of current or imminent human health risks via drinking water wells. In the case of private drinking water wells, the presumptive IRA may include providing alternative water sources or point of use/point of entry treatment (POUT/POET). Proposed POUT/POET systems for IRAs will be evaluated by the Agency for system effectiveness (i.e., ability to meet the relevant risk threshold), the technology maturity and feasibility, cost-effectiveness, and other criteria where appropriate. The following POUT/POET treatment options are known to be effective at removing PFAS from drinking water when properly installed and maintained:

- **Reverse osmosis** systems use energy to push water through a membrane that stops many contaminants while allowing water to pass. Reverse osmosis systems are more practical as a POUT system than a POET system
- **Granular activated carbon filtration** systems pass water through a bed or cartridge of activated carbon, which is known to have a high adsorption affinity for many PFAS.
- **Ion exchange resins** for PFAS removal is a newer technology relative to reverse osmosis and activated carbon. However, it too has become well-established. Effective PFAS-selective resins are now commercially available.

All POUT/POET systems require regular maintenance. At the time of writing, only granular activated carbon POUT/POET technologies have been applied in MPCA-approved PFAS IRAs.

Documenting a cleanup decision

State listed Superfund sites, (i.e., sites on the permanent list of priorities (PLP), which includes both non-cooperative responsible parties and fund-financed sites) have a Minnesota Decision Document (MDD) per Minn. Stat. § 115B.17. This presents the selected cleanup action(s) and cleanup levels. Sites with a cooperative responsible party do not have an MDD. Instead, the cleanup decision is presented in a Remedial Action Plan and/or in a Response Action Plan (RAP) that is approved by MPCA staff.

MDDs and RAPs contain the following information

- A statement of purpose
- A description of the problem, including site history, investigations conducted, and extent and magnitude of contamination
- A description of response actions already completed
- Documents that have been reviewed
- An Evaluation of Response action alternatives. This includes information found from the FFS or CMS.
- A description of the RAOs and what the cleanup levels are
- A description of the selected remedy
- SMART goals (ITRC 2011)

Remedies achieve the following three performance standards:

- Protect human health and the environment based on reasonably anticipated land use(s), both now in the future
- Achieve media-specific cleanup objectives that address media cleanup levels (chemical concentrations), points of compliance (where cleanup levels should be achieved), and remediation time frames (time to implement the remedy and achieve cleanup levels at the point of compliance)
- Remediate the source(s) of releases to eliminate or reduce further releases to the environment

MDDs also have an opportunity for public input prior to finalization; the document is typically available for a 30-day comment period. MPCA staff take received comments into consideration for deciding the final remedy.

For RCRA corrective action sites, a Cooperative Action Agreement (CAA) is similar to the RAP and MDD. However, it is not a required document. Instead, these sites follow MN 7045 which outlines hazardous waste management rules.

Sites on the national list of priorities (NPL) have a Record of Decision (ROD) but this document does not cover RODs. For more information, please visit EPA's website.

Milestone: Assess remedial technologies

Data on remedial approaches for PFAS are emerging and remain an area of continuous learning. As the fate and transport of PFAS are better understood and technologies are updated, the available options may increase. Due to the nature of PFAS contaminants being stable and surfactants, it has been documented that many existing treatment technologies (e.g., volatilization or bioremediation) are generally inadequate for effective PFAS treatment (ITRC, 2022). As a result, there has been focused attention from the environmental community to develop new technologies or innovative combinations of existing technologies for PFAS treatment. To date, approaches to PFAS treatment have included sequestration/separation technologies that remove or bind PFAS, as well as technologies that are focused on transformation and/or destruction of PFAS (ITRC, 2022). The types of technologies currently being evaluated as candidates for PFAS treatment include but are not limited to the following:

- Separation
    - Flocculation/Coagulation
    - Membrane Filtration
    - Sorption
    - Stabilization
    - Thermal Desorption
- Transformation/Destruction
    - Biodegradation
    - Redox Manipulation
    - Thermal Destruction

Additional information regarding specific examples of remediation technologies within each of the above referenced technology types is included in Table of Liquid Treatment Technologies and Table of Solid Treatment Technologies. The tables do not present a complete list of all available technologies but are provided as examples of the types of technologies currently being evaluated for PFAS treatment.

Due to the heterogeneity of contaminated sites across Minnesota, combined with the constantly evolving body of scientific literature regarding PFAS treatment, specific treatment technologies are listed here to serve as information only. Any remediation decisions should be evaluated on a case-by-case basis using professional judgement and the most up-to-date information. The referenced tables are intended to provide an overview of PFAS treatment technologies including a brief description of the technology, the maturity of the technology and general advantages and disadvantages of each. The information presented is based solely on published literature and/or guidance as of the date of this published guidance. Considering that many non-measurable PFAS can be present and the probability of converting these non-measurable PFAS into measurable target PFAS is still largely unknown, this document provides screening-level technology selection guidance based on the current understanding of target PFAS treatment technologies, their applicability, published literature and/or guidance, maturity, and technical effectiveness for removal of PFAS in water/liquid and solids.

As PFAS treatment technologies are evolving rapidly, any evaluation of PFAS treatment technology should not be limited to a review of this guidance document and should include a review of other technical publications (i.e., ITRC Treatment Technologies [12 Treatment Technologies – PFAS — Per- and Polyfluoroalkyl Substances (itrcweb.org)]), guidance documents, state and federal regulations, and consultation with technology service providers, as applicable.

Remedy selection for sites impacted with PFAS in Minnesota will follow existing MPCA guidance that requires the evaluation of alternatives using the balancing criteria previously described. As with any contaminant, evaluation of PFAS treatment technologies should include consideration of defined remedial action objectives, a well understood conceptual site model (CSM), site-specific PFAS characteristics, occurrence of co-contaminants, geochemistry and other factors as detailed by the ITRC.

The appropriate method for addressing PFAS contamination at a given site will be evaluated through completion of the feasibility study. As noted, the maturity of treatment technologies varies and while some technologies have demonstrated effectiveness in field demonstrations, the MPCA will likely require additional testing and documentation through completion of subsequent focused feasibility studies, treatability studies, pilot studies and/or bench tests prior to approval of emerging treatment technologies. Public acceptance of any selected approach will be determined during the public comment period of the decision document.

Type		Technology Description	Technology Examples[1]	Advantages	Disadvantages	Waste Consideration	Technology Maturity
SEPARATION TECHNOLOGIES	**Coagulation/ Flocculation**	Approach utilizes coagulation and flocculation methods in succession to remove suspended solids from liquid. The first step 'coagulation' involves addition of a coagulent (chemical or electrical) to the water that serves to destabilize the colloids (small particles) that are in suspension allowing them to group together. Flocculation is the process in which a polymeric substance is added to the water as it is slowly mixed to facilitate 'clumping' of smaller/fine particles into larger "floc" that can subsequently be separated from the water. The flocs are typically removed from water via filtration or sedimentation. Coagulation and flocculation is intended to reduce PFAS concentrations through removal of solids from suspension under the assumption that the suspended solids contain or have PFAS sorbed to their surfaces.	Chemical Coagulation (alum, ferric salts, polyaluminum chlorides, polymeric coagulents)	- Conventional technology. - Widespread use in traditional water/wastewater treatment. - Ease of scalability. - Potential for use in pre-treatment.	- Potentially ineffective for low level contamination - Potential limitation as initial or pre-treatment technology. - Will likely require polishing.	Solids dewatering and disposal	**Developing**
			Electrocoagulation	- Documented use in water/wastewater treatment. - Potential for use in pre-treatment.	- Potentially ineffective for low level contamination - Potential limitation as initial or pre-treatment technology. - Will likely require polishing. - Higher energy consumption.	Solids dewatering and disposal	**Developing**
	Foam Fractionation	Foam fractionation is the process by which PFAS are adsorbed onto the surface of bubbles rising through water. When exposed to the air-water interface, the bubbles form foam containing PFAS that can subsequently be separated. The separated foam can then be "collapsed" or concentrated for additional treatment.	Foam Fractionation	- Coupling separation with destructive approaches (e.g., ozofractionation) can enhance treatment. - Removal of long-chain PFAS	- Needs testing at various sites; - Removal efficiency depends on foam depth, ionic strength of solution, and aeration rates. - Low removal efficiency of short-chain PFAS.	Generates PFAS concentrated wastewater that requires additional treatment/disposal	**Developing**
	Sorption	Sorption technologies utilize two mechanisms (adsorption or ion exchange) to remove PFAS from water. Adsorption is a physical mass transfer process that use forces to bind PFAS to adsorptive media such as granular activated carbon. Ion exchange works for PFAS treatment through exchanging ions of the same charge. Ion exchange targets the functional end of the PFAS molecule and in exchange releases a benign ion (such as chloride) into the water in its place. Sorption technologies have been used for both in situ and ex situ water treatment applications; however, most in situ applications are still considered developing technologies.	Granular activated carbon (GAC)	- Conventional technology with regulatory acceptance. - Demonstrated effectiveness for both short- and long-chain PFAS. - Design flexibility to increase removal. - Simple operation. - Multiple vendors. - Off-site reactivation/regeneration available for PFAS.	- Need to evaluate breakthrough of different PFAS; faster breakthrough times for shorter chain versus longer chain PFAS under certain influent and other conditions. - Cost increases relative to influent concentrtions. - Challenges of co-contamination/competitive adsorption. - Presence of precursors and other PFAS not analyzed for may increase GAC loading and accelerate changeout frequencies and associated cost. - No destruction of PFAS, unless the GAC is reactivated. - Pretreatment may be required.	Spent activated carbon must be removed for offsite disposal, or reactivation / regeneration.	**Mature**
			Colloidal activated carbon (In Situ)	- Applied to eliminate migration and potential exposure to PFAS. - No operation and maintenance. - No waste generated. - Longevity projected to be Multiple decades with single injection. - Can be reapplied. - Highly sustainable with very low carbon footprint.	- PFAS contaminants are immobilized, not destroyed. - Presence of co-contamination may reduce efficacy of media.	None	**Developing**
			Anionic exchange resins (AEX or IX)	-Higher demonstrated loading capacity for PFAS versus activated carbon. - Design flexibility to increase removal. - Simple to operate without regeneration. - On-site solvent-brine regeneration is commercially available.	- Possible faster breakthrough times for shorter chain versus longer chain PFAS under certain influent and other conditions. - Virgin media costs twice as much as activated carbon, but less media replacement is needed. - Removal efficiencies are compound specific. - Payback for on-site regeneration may be long, but requires cost-benefit compared to GAC dur to higher loading capacities. - PFAS not destroyed unless resins are incinerated.	Spent resin must be removed for off-site disposal or on-site regeneration. Solvent-brine, which is flammable, is only demonstrated solution for on-site regeneration. On-site destruction technologies for concentrated regeneration brine are currently under development.	**Mature**
			Biochar	- Possible alternative to GAC. - effectiveness increases with surface area.	- Only proven effective on ultrapure water. - Natural organic matter reduces effectiveness. - Slow reaction kinetics.	Off-site disposal required for spent biochar.	**Developing**
SEPARATION TECHNOLOGIES	**Membrane Filtration (Separation)**	Pressure-driven technologies that utilize semipermeable membrane filters or membrane filters with nanosized pores to physically filter out PFAS molecules from water.	Reverse osmosis	- Established technology.	- Demonstrated for drinking water applications only	Generates a high volume (~10% of flow) of concentrate (reject water) that must be managed.	**Mature**
			Nanofiltration	- Established technology.		Generates a concentrate that must be managed.	**Developing**
			Ultrafiltration	- Low pressure filtration process - Applicable under wide range of pH (2 to 13 SU)	- May require pretreatment. - Temperature affects water density and viscosity, which directly corresponds to flow rate across filter membranes. - Insufficient data to demonstrate efficacy		**Developing**
TRANSFORMATION TECHNOLOGIES	**Redox Manipulation**	Redox manipulation includes multiple subcategories including chemical oxidation and reduction technologies. Chemical oxidation includes the delivery of liquid, slurry or gaseous oxidants from a reactive oxidant to the target PFAS. This technology essentially decomposes PFAS through introduction of additives, light, sound, or electricity to highly reactive, oxidative, or reductive species.	Light (UV/solvated electrons, Photolysis/photochemical oxidation, Photocatalytic treatment with BOHP/BiPO4, UV irradiation (hydrated electron) with electrochemical reduction)	PFAS Compounds almost completely destroyed under specific conditions. Photocatalytic treatment with BOHP/BiPO4, UV irradiation (hydrated electron) with electrochemical reduction are Energy-efficient compared to other UV only treatment systems.	- Certain methods do not work well under various conditions (acidic, high temperature, high reductant dosage, and high solution pH). - Energy intensive.	No waste generated, but incomplete reactions may produce PFAAs.	**Developing**
			Redox additives (Catalyzed hydrogen peroxide based systems, activated persulfate, ozone based, zero valent iron)	- Scalable - Energy efficient - Potential to combine with other technologies	- May result in production of less reactive PFAS species. - Does not treat all PFAS. - pH and temprature dependent	No waste generated, but incomplete reactions may produce PFAAs.	**Developing**
			Electrochemical	- Degradation is not affected by dissolved organic carbon. - Can be combined with other treatment technologies. - Demonstrated to be effective for treatment of short chiain, long-chain PFAAs as well as PFAA precursors in remediation-derived waste streams	- May consume high energy - High cost of electrodes, limited scalability. - Limited full-scale applications for any contaminant types.	No waste generated, but incomplete reactions may produce PFAAs.	**Developing**
			Plasma	- Effectively degrades PFAS ina short time period. - Environmentally friendly - no demand on pressure or temperature and does not require significant input of chemicals. - Degradation rate not affected by co-contaminants.	- Higher cost - Some conversion of longer chain to shorter chain PFAS	No waste generated, but incomplete reactions may produce PFAAs.	**Developing**
			Sonochemical Oxidation/Ultrasound	- PFAS are thermally destroyed and hydroxyl radicals are generated for destruction of cocontaminants. - Demonstrated in bench studies.	- Rate of reaction decreases above certain power level. - Inorganics such as bicarbonate decrease reaction rate. - High energy requirement.	No waste generated, but incomplete reactions may produce PFAAs.	**Developing**
	Biodegradation	Degradation and transformation of PFAS through biochemical processes through the introduction of certain strains of bacteria, fungi, or species of flora to the contaminated water.	Fungal/Bacterial Enzymes	- Green solution if proven effective - Process would likely be effective on organic cocontaminants. - Variety of carbon sources could be biostimulants for co-metabolism	- Limited evidence of effectiveness. - May be sensitive to environmental changes (e.g., temperature, pH).	None	**Developing**
			Phytoremediation	- Green solution if demonstrated effective.	- Limited evidence of effectiveness.	None	**Developing**

Type		Technology Description	Example Technology	Advantages	Disadvantages	Waste Consideration	Technology Maturity
SEPARATION TECHNOLOGIES	Sorption and Stabilization	Sorption and stabilization are intended to reduce the potential for PFAS to leach or migrate from the surface of the impacted soil into groundwater. A variety of materials have been used to bind PFAS compounds including Portland cement, activated carbon, kaolinite clay and others. The materials are used to cement the subsurface materials and solidify/stabilize the PFAS and render it immobile. Technology is highly dependent on site-specific considerations such as PFAS concentrations, soil type, moisture content, treatment objectives, etc. Changing conditions following stabilization may also result in additional leaching from immobilized media. Long term monitoring plans are highly recommended to evaluate effectiveness of stabilization technologies.	Stabilization (Soil Mixing)	- Basic implementation technology (soil mixing etc.) with proven results for other contaminants of concern. - Mature technology with use at full-scale	- PFAS contamination not treated or destroyed - Effectiveness will vary depending on soil type and chemistry. - Changes in site conditions (ph, ionic strength etc.) may result in leaching from immobilized media. - Effectiveness evaluated through long-term monitoring programs	None	Mature
			Natural minerals (iron oxide, high iron sand, clay)	- Enhance sorption by modifying surface. - Adsorption isotherms vary for various minerals.	- PFAS contamination not treated or destroyed - Effectiveness will vary depending on soil type and chemistry. - Changes in site conditions (ph, ionic strength etc.) may result in leaching from immobilized media. - Effectiveness evaluated through long-term monitoring programs	Sorbed media	Developing
			Surface-modified clay	- High affinity for a variety of PFAS - Commercially available media.	- PFAS contamination not treated or destroyed - Effectiveness will vary depending on soil type and chemistry. - Changes in site conditions (ph, ionic strength etc.) may result in leaching from immobilized media. - Effectiveness evaluated through long-term monitoring programs	Ex situ stabilized soil	Developing
	Thermal Desorption	Utilizes high temperatures to remove PFAS from soil surface through the process of desorption and separates the PFAS into a vapor phase that can then be captured.	Thermal desorption, in situ and ex situ capture	Can remove other volatile co-contaminants	Due to high heat demand, in situ treatment may not be cost-effective. May have potential to be applied as an in-situ technology.	Air emissions	Developing
	Soil Sieving/ Washing	Physically removes PFAS from the surface of soil after its been fractionated by grain size.	Separates soil by size fractionation and then removes PFAS from contaminated fraction by washing.	- Accepted remedial technology for a wide range of contaminants.	- Relatively high cost and energy intensive. -Requires use of washing solvents that require treatment/disposal. -Efficacy of washing solvents needs further evaluation/site-specific testing.	Wastewater	Mature
DESTRUCTION TECHNOLOGIES	Soil Sieving/Washing with Advanced Oxidative Process (AOP)	A multi-step treatment approach using a combination of soil washing, foam fractionation and AOP to treat the resultant wastewater. PFAS from the surface of fractionated soil is removed through washing. The soil wash rinsate water is then subject to foam fractionation to concentrate the PFAS. The concentrate generated by foam fractionation is then treated using highly oxidative species through the incorporation of various additives (dissolved ozone, sodium persulfate, food-grade phosphatebased buffers, and dilute hydrogen peroxide).	Soil Washing/Treatment using innovative approaches of combining technologies to separate and then treat/destroy PFAS.	- Effective for PFAS and co-contaminants. - Treatment of waste intended to result in complete destruction of all waste streams.	- Complex treatment process with multiple steps. - High cost and energy intensive	None	Developing
	Thermal Destruction	Utilizes high temperatures to degrade PFAS compounds sorbed to the surface of soil.	Off-site incineration	- Proven technology. - Applicable to all PFAS	- High energy consumption and associated cost. - Uncertainty in complete destruction due to potential for air emissions.	Air emissions	Mature
	Excavation and Disposal	Remove PFAS from locations where it poses a threat to human health or the environment and relocate it to a qualified landfill.	Excavation and Disposal	- Proven technology. - Applicable to all PFAS	- Possible contribution to PFAS in landfill leachate. - Regulatory acceptance may be subject to change. - Landfills may be changing acceptance rules for PFAS impacted waste.	Excavated material needs offsite disposal	Mature

Notes: Technology examples presented do not represent all technologies currently in development. Refer to ITRC for additional technologies and the recent information.

Life Cycle Stage 5: Site closure & Institutional controls

Site closure

The criteria used to determine eligibility for site closure for a PFAS release are the same as for other types of hazardous substances. For a responsible party or state-led investigation, the full extent and magnitude of PFAS contamination must be defined and any necessary remediation or risk management actions completed, on both the source property and other off-site affected properties. Closure for a PFAS release at a responsible party site is provided by a No Action or No Further Action Determination.

For a non-responsible party enrolled in the Brownfield Program, site closure options are more varied, depending on the type of assurance letter requested. In all cases, potential on-site risk from exposure to PFAS-impacted media must be managed. It's important to note that closure of a brownfield site does not necessarily mean that the PFAS release is being closed. If the brownfield site investigation identifies the potential for off-site receptors to be at risk from PFAS contamination, the Brownfield Program will refer the PFAS release to the MPCA's Site Assessment Program for further evaluation and risk assessment. For additional information about PFAS decisions at non-responsible party sites, refer to the Brownfield section of this document.

The site closure process may establish certain obligations such as the ongoing operation, monitoring, or maintenance of a remedy to ensure continued protectiveness of human health and the environment. The MPCA uses institutional controls, when appropriate, as part of the closure process to ensure that current and future property owners are aware of residual contamination at the site and comply with site-specific activity restrictions and affirmative obligations. For any site, if an institutional control is required as part of the response action, the institutional control must be recorded with the appropriate county office and a copy of the recorded institutional control submitted to the MPCA before site closure will be granted.

What are institutional controls?

Institutional controls are legal or administrative controls imposed on properties to protect cleanup work and avoid exposure to any remaining contamination. Institutional controls may limit how the property is used, restrict certain activities at the site, such as disturbing soil or extracting groundwater, or impose affirmative obligations, such as operating a treatment system or maintaining a vertical clean soil buffer over deeper residual contamination. Institutional controls are not intended to be a sole remedy but are often part of the overall remedy. A description of the types of institutional controls most often used by the MPCA and supporting templates can be found on the MPCA's Cleanup Guidance and Assistance webpage insert link.

When will MPCA require an institutional control for PFAS?

The criteria used to determine the need for an institutional control for PFAS contamination are the same as for other types of hazardous substances:

- If environmental conditions at the time of site closure require activity restrictions and/or affirmative obligations to protect human health or the environment, then an Environmental Covenant and Easement (ECE) will be required. The ECE will require submittal of an annual compliance letter or report to document that the property owner is complying with the activity restrictions and/or affirmative obligations listed in the ECE.

- If no specific activity restriction or action is needed but notice of residual contamination on the property is warranted, then an Affidavit concerning real property contaminated with hazardous substances will be required.

A list of MPCA remediation sites with institutional controls and an interactive map that shows their location can be found on the Minnesota Geospatial Commons website: https://gisdata.mn.gov/dataset/env-institutional-controls.

For widespread groundwater contamination that poses a potential risk to public health, the MPCA may request the Minnesota Department of Health to establish a Special Well and Boring Construction Area (aka “well advisory”). The well advisory area provides for controls on the drilling of water supply wells to prevent exposure to groundwater contamination.

Cross-cutting area: Brownfield Program considerations for PFAS

Overview

The Voluntary Investigation and Cleanup (VIC) program provides technical assistance to promote the investigation, cleanup and redevelopment of brownfield properties contaminated with hazardous substances, pollutants, and contaminants. Unlike the Superfund program, which requires a responsible party to addresses the full extent and magnitude of a release, including off-site impacts, the VIC program works with non-responsible parties who generally focus on potential exposure to on-site contamination as related to a specific development plan. Parties that enroll in the VIC program are responsible for addressing potential risk associated with their proposed actions relative to on-site contamination in order to receive technical assistance and/or liability assurances letters.

Sites are typically enrolled in the VIC program as part of the redevelopment or property transfer process. Past and/or current use(s) of the property should be examined to determine the potential for PFAS contamination. For a VIC site, the need for PFAS sampling and analysis is not triggered solely by the discovery that PFAS may be a contaminant of concern at a site. Additional considerations that trigger the need for PFAS sampling at a VIC site include whether site activities will create an exposure pathway relative to PFAS contamination or cause PFAS contamination to spread, whether the VIC applicant wants PFAS to be included in an identified release for a specific media, and the type of assurance letter requested.

If PFAS compounds are detected at a site and pose a risk to human health or the environment, based on the current or planned property use, then appropriate remedial and/or risk management strategies are necessary to mitigate that risk. Consistent with assurances issued for other hazardous substances, pollutants, and contaminants, an institutional control may be required for PFAS-contaminated media at the site to prevent disturbance or future exposure to PFAS contamination.

Site usage

How do I know if PFAS are potential contaminants of concern at a brownfield site?

A thorough Phase I Environmental Site Assessment (Phase I ESA) and a knowledge of the types of industries/practices associated with potential PFAS use are essential for determining whether PFAS are potential contaminants of concern at a brownfield site. The following general criteria provide a framework for evaluating whether a brownfield site may be impacted by a PFAS release. For a more detailed explanation, refer to the "Desktop Review" section at the beginning of this document.

- On-site or nearby industrial operations or practices that are likely to have used PFAS
- Proximity to a current or former dump or landfill
- Proximity to known PFAS contamination

Evaluation of property use should include consideration of industry categories and practices that are commonly linked to the use, storage, or disposal of PFAS. Given the widespread use of PFAS in the manufacturing sector, the list of possibilities is lengthy. A more comprehensive list of industry categories and practices that may use, store, or dispose of PFAS can be found in Annex I.

Site investigation

When is testing for PFAS necessary at a brownfield site?

For a VIC site, the need for PFAS sampling and analysis is not triggered solely by the discovery that PFAS may be a contaminant of concern at a site. Additional considerations that trigger the need for PFAS sampling include whether site activities will create an exposure pathway relative to PFAS contamination or cause PFAS contamination to spread, whether the VIC applicant wants PFAS to be included in an identified release for a specific media, and the type of assurance letter requested.

It depends on the site activities. Every party enrolled in the VIC program must manage risk to human health and the environment that may stem from their proposed actions. If PFAS are potential contaminants of concern at a brownfield site and if the proposed actions may create a potential exposure pathway for PFAS or cause the contamination to spread, then testing for PFAS is required to identify and manage potential risk. Example scenarios include but are not limited to the following:

- An on-site water supply well may create a drinking water exposure pathway
- An on-site irrigation well may mobilize PFAS-impacted groundwater and contaminate soil
- A stormwater infiltration pond may leach PFAS-impacted soil and/or mobilize a PFAS plume
- A greenspace area may create a soil exposure pathway, if site soil is impacted due to on-site use of PFAS, PFAS-impacted runoff from an adjoining property, or aerial deposition of PFAS from a nearby industry.
- Planned off-site reuse of soil may spread PFAS contamination to another property

It depends on the desired scope of liability protection. The liability protection provided in a No Association Determination letter is limited to a specific identified release as documented by sampling results. If PFAS are potential contaminants of concern at a brownfield site, then testing for PFAS is recommended for voluntary parties who wish to obtain liability protection for PFAS, even if their proposed actions would not create a potential exposure pathway or cause the contamination to spread.

***It depends on the type of assurance letter*.** A voluntary party enrolled in the VIC program can choose which assurance letter(s) to pursue. Different assurance letters have different technical requirements regarding the scope of the site investigation. For example, a Certificate of Completion requires a thorough investigation for all potential contaminants of concern in all applicable media, whereas a No Action Letter might be limited to a single media or a specific type of contaminant. For additional information on the types of assurance letters offered by the VIC Program, see the MPCA's Brownfield Program Services guidance document.

***It depends on the landfill*.** In some circumstances, a landfill may request PFAS sampling of soil before accepting it for disposal. Voluntary parties should contact their chosen landfill prior to site redevelopment to confirm the landfill's data needs.

What about ambient background concentrations?

While PFAS are known to be widespread in the environment, information regarding ambient background concentrations of PFAS in Minnesota's soil, groundwater, and surface water is not currently widely available. Identification of PFAS as a potential contaminant of concern at a brownfield site, for the purpose of this guidance, is based on the presence of an on-site or nearby potential source of PFAS. MPCA's recently completed white paper indicates that ambient background concentrations of PFAS in soil (e.g., from diffuse or non-point sources) are not expected to be present at concentrations that pose a risk to receptors, based on information currently available. For a more detailed discussion of this topic, refer to the "Ambient background concentrations" section of this document.

There is no expectation that PFAS testing be conducted at a brownfield site in the absence of a potential source. If a voluntary party chooses to sample for PFAS in the absence of a potential source, the detected PFAS compounds could be included, as appropriate, in an identified release for an assurance letter. Because PFAS are not naturally occurring compounds, any detections of PFAS, even if attributable to ambient background concentrations, would be evaluated to determine the need for remediation or risk mitigation.

Which specific PFAS compounds should be analyzed?

For any given analytical method, all analytes included in the method will be analyzed by the laboratory. The MPCA requires that all data generated by the analysis be reported. Please refer to the PFAS analytical guidance on the MPCA's website for information about analytical methods.

Risk assessment. The risk assessment should evaluate existing conditions and proposed actions to identify potential on-site exposure or interaction with PFAS-impacted media, using the same risk assessment tools that are used for other types of contaminants.

- Use soil reference values (SRVs) to assess direct contact with soil. Refer to the SRV spreadsheet and SRV technical support document on the MPCA's website.
- Use soil leaching values (SLVs) to assess the soil-to-groundwater leaching pathway. Refer to the Soil Leaching Pathway Spreadsheet and supporting guidance on the MPCA's website. Note that site screening SLVs are based on typical precipitation rates and would not be applicable to areas of concentrated infiltration, such as a stormwater infiltration pond.
- Consider aspects of the development plan that could mobilize PFAS contamination, such as use of an on-site well for irrigation or increased point-source infiltration from a stormwater pond.

Remediation. If the risk assessment identifies a potential risk to human health or the environment at the site from PFAS-impacted media, based on the current or planned future use, then appropriate remedial and/or risk management strategies are necessary to mitigate that risk. See the Remediation section of this guidance for appropriate technologies for PFAS-impacted soil and groundwater. See the Disposal section of this guidance for information about managing PFAS-containing waste.

For a brownfield site, risk management may entail changing certain aspects of the development plan to avoid creating an exposure pathway or to avoid disturbing PFAS-impacted soil or groundwater. For example:

- Relocating the stormwater infiltration pond or choosing a different type of stormwater management system to avoid leaching of PFAS-impacted soil and/or mobilization of PFAS-impacted groundwater due to enhanced stormwater infiltration.
- Choosing a building design that minimizes excavation of PFAS-impacted soil during construction to reduce soil disposal challenges.
- Sealing an on-site water supply or irrigation well to avoid potential exposure to and mobilization of PFAS-impacted groundwater

Site closure. Closure of a brownfield site occurs when the conditions/requirements of any VIC assurance letters issued for the site have been met and any required institutional control has been filed with the county.

Cross-cutting area: Disposal of PFAS contaminated materials & Investigation derived waste

Goal: Determine that PFAS-containing waste is properly characterized and managed. PFAS are classified as a hazardous waste under MERLA due to their potential to be a hazard to human health or the environment. Despite this definition, PFAS are not listed as hazardous waste under the federal Resource Conservation and Recovery Act (RCRA) law.

Waste materials are produced during the site investigation and remediation life cycle stages. The need to dispose of PFAS-impacted materials may be present during other stages. This section applies to all life-cycle stages and cross-cutting areas. Impacted environmental media require proper storage, transport, and disposal to minimize potential risks to human health and the environment.

Definition: PFAS-impacted materials include but are not limited to environmental media, equipment, and rinse water, associated with a PFAS site investigation, remedial activities, or implementation of site institutional controls. These materials may be potentially impacted or known to be impacted.

Actions:

Action 1: Characterize waste

During this stage, the potential risk to human health and the environment associated with the investigation derived waste (IDW) is determined. Samples of each media type will be assessed for PFAS. The process is similar to the Site Investigation stage where samples of each media type are collected to evaluate the presence of PFAS.

Prior to sample collection, ensure that potentially impacted waste materials are stored on-site in appropriate containers. The MPCA PFAS Sampling Guide (https://www.pca.state.mn.us/sites/default/files/p-eao2-27.pdf) outlines specific types of storage materials for potentially impacted media including:

- Aqueous media (e.g., drinking water, surface water and groundwater)
- Solid matrices (e.g., sediment and soil):
- Biological matrices (e.g., fish tissue)

Sample collection procedures are described in the Site Investigation section and outlined in the MPCA Sampling Guidance (https://www.pca.state.mn.us/sites/default/files/p-eao2-27.pdf). Ensure that the representative samples collected from IDW are:

- Media-specific
- Sufficient number to accurately represent the materials
- Appropriate type

Appropriate analytical methods for each media type will be used to identify PFAS presence. See Table 1 in the Site Investigation section for a list of methods. Analytical results will be used to evaluate potential risk to receptors through a comparison against existing screening criteria for PFAS. Screening criteria may also be used as *de minimus* concentrations for hazardous wastes. Screening criteria include applicable ambient concentrations for media such as soil and surface water. Screening criteria are available for groundwater, drinking water, soil and leaching values. See the Risk Assessment section for additional details on processes for determining whether waste has been impacted by PFAS. If it is determined that the on-site IDW has been impacted, remedial approaches will be identified.

Action 2: Evaluate need for on-site treatment

If analytical results indicate that PFAS values exceed ambient or health-based values, on-site treatment methods will ensure that the site is not re-exposed to contamination. On-site remedial options allow the mitigation of potential harm to human health and/or the environment. Materials used to treat the impacted media will also require appropriate waste management. The Remediation section provides additional information about current methods and technologies.

Action 3: Identify appropriate disposal options

If IDW cannot be treated on-site or the impacted media must be moved off-site, then a federal hazardous waste designation will require that transportation processes follow RCRA guidelines. Criteria for acceptance at a landfill includes the following:

- Subtitle D landfills (dependent on the facilities Industrial Solid Waste Management Plan)
- Subtitle C landfills (this option is applicable once PFAS are federally designated as RCRA hazardous waste)
- Incineration

Action 4: Ensure liability remains with appropriate party

Ensure that liability for the appropriate management of the IDW remains with the party that generated the waste.

Cross-cutting area: Communications

Goal: MPCA will communicate decisions and findings to relevant stakeholders in a community. It will also be expected that RPs communicate their actions and decisions to all stakeholders and locally affected communities. When possible, it is ideal to proactively communicate with residents, business owners, and other adjacent property owners to share information about site activities. There can be a tendency and temptation to delay formal communication until "all the facts are known." With more complete information, staff hope to be better positioned to answer and address questions from community members. Unfortunately, sampling and site investigations can be lengthy and time-consuming processes. Failure to proactively communicate can create a communications vacuum where misinformation can be spread as residents become concerned because they "haven't heard anything."

- *Desktop review:* Throughout the determination of whether a site will be evaluated for the presence of a PFAS release, preparations will begin for future communications. This includes identifying stakeholders and parties involved. The groundwork for future communications should be detailed and prepared for the site investigation stage.
- *Site investigation:* A determination should be made when community notification will occur. Identify past and present work and relay this information to pertinent stakeholders. Ensure the site is listed properly on the WIMN webpage and contact information is correctly displayed for community outreach. Communications should be timely and transparent. Site closure should be communicated to all relevant stakeholders and updated on the WIMN webpage. If a site continues to the Risk Assessment stage, communications must evolve along with the on-site and off-site investigation work.
- *Risk assessment:* Risk should be communicated to all potential receptors identified with present data and known risks. Ensure transparency and accessibility to information. Ensure that translation and interpretation services are available if a non-English speaking community is identified. Solicit community feedback and input. Communications should evolve with community response and feedback.
- *Remediation:* Provide all relevant stakeholders with information on mitigation and remedial measures. Identify details on what actions are being taken and communicate any maintenance requirements (bottled water delivery, GAC filter changeouts, etc.) Present long-term solutions if there are interim mitigation efforts.
- *Site closure:* Ensure all stakeholders are informed of site closure. Update relevant webpages (WIMN, site-specific webpage, etc.). Communicate any longer-term investigation or monitoring work planned. Provide a full breakdown of what the problem was, what the solutions have been, and the data to support site closure.
- *Disposal:* Have resources available for PFAS disposal options. This requires up to date information to be sought out and shared. PFAS disposal will likely be a moving target with options evolving. Stay up to date and communicate updates as they are understood.
- *Brownfield assurances:* Ensure off-site impacts are being assessed and addressed upon discovery of contaminants on Brownfield sites. Evaluate and communicate both on-site and off-site remedial activities and mitigation efforts.

Cross-cutting area: Environmental Justice

The MPCA Environmental Justice Framework lays out strategies for equitable decision-making https://www.pca.state.mn.us/sites/default/files/p-gen5-05.pdf. The primary goal of the framework is to identify and address disproportionate impacts of pollution on lower income Minnesotans and people of color and to ensure that communities have opportunities for meaningful involvement in decisions that impact them. A mechanism for achieving this is the iterative evaluation of progress through an assessment of successes and failures. These goals are strongly associated with communication. Therefore, the actions for the two cross-cutting areas are jointly presented. The Environmental Justice Cross-Cutting Area requires that we consider communication strategies by first identifying the needs of a group or community. Items to consider include relevance of information, potential barriers (language, internet access), and cultural perceptions to overcome. These considerations will be addressed during a site's initial entry into the program.

Currently available criteria for identifying an environmental justice (EJ) community include Tribal Areas, tracts with over 50% people of color, and tracts with over 40% of households earning under 185% of the federal poverty level. An EJ map and link to the EPA Environmental Justice Screening Tool is available at the following link: https://www.pca.state.mn.us/about- mpca/environmental-justice.

- *Desktop review*: First and foremost a determination should be made of a site's EJ status. Identify whether the site is in or adjacent to an area that meets one or multiple EJ criteria. EJ data should be fully encompassed and understood during the site usage stage. EJ community contacts should also be identified and understood in case of movement to site investigation.
- *Site investigation:* A point of contact for each individual EJ community near a site should be identified. EJ information should coincide with community outreach and communications. Considerations should be made to specific EJ impacts such as more frequent consumption of fish and game or other EJ specific situations.
- *Risk assessment*: Sites within EJ areas should be assessed for risk of contaminants other than PFAS as well as historical investigations or data gaps that may have been missed in prior risk assessments. Risk assessment provides an opportunity to reevaluate EJ areas for issues that were previously overlooked.
- *Remediation:* Ensure all community members requiring mitigation or remediation are contacted and communicated with. If EJ community members are unable to be reached via initial communications, ensure additional effort is put forth to contact all community members impacted.
- *Site closure*: Ensure that all impacted EJ areas have been assessed and fully remediated or mitigated prior to site closure. Engage with the community to explain the full life cycle of a site and the reason for site closure. Complete a final review of investigatory data to evaluate the need for additional EJ work.
- *Disposal:* Ensure PFAS disposal is properly addressed within EJ areas. Furthermore, ensure PFAS disposal locations do not have a negative impact on EJ areas. Disposal locations should be evaluated for proper disposal methods, and environmental impacts should be evaluated and addressed at disposal sites.
- *Brownfield assurances*: EJ areas should not be overlooked when assessing offsite risk to Brownfield sites. Each Brownfield site should be assessed for site usage and EJ status. Further investigation should take place if necessary.

Resources

The resources and references used for each section are listed below.

Desktop review

Phase I Environmental Site Assessment

ASTM E1527-21: Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process (astm.org) Information about industrial practices associated with the generation, use, storage and/or disposal of PFAS are available in the following:

- Appendix F of MPCA's PFAS Monitoring Plan includes the NAICS codes associated with PFAS use or release that were originally scoped into the plan. https://www.pca.state.mn.us/sites/default/files/p-gen1-22b.pdf
    - The complete list of North American Industrial Classification System (NAICS) codes is available at https://www.census.gov/naics/
    - Results from PFAS testing at closed landfills are available at https://www.pca.state.mn.us/air-water-land-climate/pfas-and-closed-landfills.
        - MPCA has published resources on PFAS use and release from key industry sectors. These are available at https://www.pca.state.mn.us/air-water-land-climate/pfas-studies-and-reportsThere are reviews of PFAS uses by industry in the scientific literature: Historical and current usage of per- and polyfluoroalkyl substances (PFAS): A literature review: https://onlinelibrary.wiley.com/doi/10.1002/ajim.23362
        - An overview of the uses of per- and polyfluoroalkyl substances (PFAS): https://pubs.rsc.org/en/content/articlelanding/2020/EM/D0EM00291G
    - Interstate Technology Regulatory Council (ITRC) has published resources:
    - Best Practices for Traditional Ecological Knowledge: https://edm-1.itrcweb.org/traditional-ecological-knowledge-home/
    - PFAS use and release to the environment.
        - Use: https://pfas-1.itrcweb.org/2-5-pfas-uses/
        - Release: https://pfas-1.itrcweb.org/2-6-pfas-releases-to-the-environment/#2_6_3
- Online databases and mapping applications provide information on the proximity of a site to known or potential PFAS sources:
    - MDH Interactive Dashboard for PFAS in Drinking Water : https://www.health.state.mn.us/communities/environment/water/pfasmap.html
    - What's in My Neighborhood: https://www.pca.state.mn.us/data/whats-my-neighborhood
    - MPCA Groundwater Contamination Atlas: https://www.pca.state.mn.us/data/minnesota-groundwater-contamination-atlas
    - MPCA Biosolids land application sites : https://gisdata.mn.gov/dataset/env-land-application-sites

Site investigation

Available guidance and results from site-specific sampling show that PFAS contamination may be present in drinking, ground, and surface water; soil, sediment, and debris; and soil vapor and ambient air. The following are a list of resources for the collection and analysis of PFAS in the differing matrices.

- General Investigation Guidance:
  - MPCA. 1998. Draft Guidelines Risk Based Site Characterization and Sampling Guidance. Minnesota Pollution Control Agency. 1998. https://www.pca.state.mn.us/sites/default/files/sitechar.pdf
  - ITRC. 2022. Technical Resources for Addressing Environmental Releases of Per- and Polyfluoroalkyl Substances (PFAS). Washington, D.C.: Interstate Technology & Regulatory Council. PFAS — Per- and Polyfluoroalkyl Substances (itrcweb.org)
  - Shultz, M., R. Cramer, C. Plank, H. Levine, AND K. Ehman. 2017. *Best Practices for Environmental Site Management: A Practical Guide for Applying Environmental Sequence Stratigraphy to Improve Conceptual Site Models*. U.S. Environmental Protection Agency, Washington DC. https://cfpub.epa.gov/si/si_public_record_report.cfm?dir https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=341373&Lab=NRMRL
  - USEPA. Contaminated Site Clean-Up Information (CLU-In). https://clu-in.org/characterization/technologies/hrsc/index.cfm
- Field Sampling Methodology:
  - MPCA. 2022. Guidance for Per- and Polyfluoroalkyl Substances (PFAS): Sampling. Minnesota Pollution Control Agency. January 2022. https://www.pca.state.mn.us/sites/default/files/p-eao2-27.pdf.
  - MPART. 2023. PFAS Sampling Guidance. Michigan PFAS Action Response Team. 2023. https://www.michigan.gov/pfasresponse/investigations/sampling-guidance

- Analytical Methodology:
  - Several laboratories across North America provide EPA-approved analytical methods for environmental media that will be sampled at sites within the Remediation program.
    - MDH accredited laboratories that perform PFAS analysis can be found at the Minnesota Department of Health Environmental Laboratory Accreditation Program (MNELAP) website.
  - MPCA. 2022. Guidance for Per- and Polyfluoroalkyl Substances (PFAS): Analytical. Minnesota Pollution Control Agency. October 2022. https://www.pca.state.mn.us/sites/default/files/p-eao2-28.pdf
  - Additional analytical methods for evaluating the presence of PFAS:
    - Non-targeted analyses. Additional information is available at the EPA : https://www.epa.gov/water-research/pfas-analytical-methods-development-and-sampling-research
    - The use of total organic fluorine (TOF) analysis may provide general information about the presence of oxidizable PFAS. https://pfas-1.itrcweb.org/11-sampling-and-analytical-methods/

Risk assessment

DWER. 2021. Guideline – Assessment and management of contaminated sites. Government of Western Australia, Department of Water and Environmental Regulation. November 2021. https://www.der.wa.gov.au/images/documents/your-environment/contaminated-sites/guidelines/Assessment_and_management_of_contaminated_sites.pdf.

ITRC. 2015. Decision Making at Contaminated Sites: Issues and Options in Human Health Risk Assessment. RISK-3. Washington, D.C.: Interstate Technology & Regulatory Council, Risk Assessment Team. https://projects.itrcweb.org/risk-3/Default.htm#2.%20Use%20of%20Risk%20Assessment.htm.

ITRC. 2022. Soil Background and Risk Assessment. Washington, D.C.: Interstate Technology & Regulatory Council. https://sbr-1.itrcweb.org/.

ITRC. 2022. Technical Resources for Addressing Environmental Releases of Per- and Polyfluoroalkyl Substances (PFAS). Washington, D.C.: Interstate Technology & Regulatory Council, June 2022. https://pfas-1.itrcweb.org/.

MDH. 2008. Statement of Need and Reasonableness. Minnesota Department of Health, July 2008. https://www.leg.mn.gov/archive/sonar/SONAR-03733.pdf#page=2.

MDH. 2022. Human Health-Based Water Guidance Table. Minnesota Department of Health. https://www.health.state.mn.us/communities/environment/risk/guidance/gw/table.html.

MPCA. 2013. Soil Leaching Values. Minnesota Pollution Control Agency, May 2013. https://www.pca.state.mn.us/sites/default/files/c-r1-04.pdf.

MPCA. 2020. Water Quality Standards Technical Support Document: Human Health Protective Water Quality Criteria for Perfluorooctane Sulfonate (PFOS). Minnesota Pollution Control Agency, December 2020. https://www.pca.state.mn.us/sites/default/files/wq-s6-61a.pdf.

MPCA. 2021. Soil Background Threshold Value Evaluation. Minnesota Pollution Control Agency, April 2021. https://www.pca.state.mn.us/sites/default/files/c-r1-08.pdf.

MPCA. 2022. Soil Reference Value Technical Support Document. Minnesota Pollution Control Agency, April 2022. https://www.pca.state.mn.us/sites/default/files/c-r1-05.pdf.

MPCA. 2023a. Water Quality Standards Technical Support Document: Human Health Protective Water Quality Criteria for Perfluorooctane Sulfonate (PFOS): Application to Specific Water bodies, Appendix B. Minnesota Pollution Control Agency, January 2023. https://www.pca.state.mn.us/sites/default/files/wq-s6-61b.pdf.

MPCA. 2023b. Water Quality Standards: Human Health Protective Water Quality Criteria for Per- and Polyfluoroalkyl Substances (PFAS). Minnesota Pollution Control Agency, January 2023. https://www.pca.state.mn.us/sites/default/files/wq-s6-63.pdf.

MPCA. 2023c. Water Quality Standards: Human Health Protective Water Quality Criteria for Per- and Polyfluoroalkyl Substances (PFAS), Appendix B. Minnesota Pollution Control Agency, January 2023. https://www.pca.state.mn.us/sites/default/files/wq-s6-63a.pdf.

MPCA. 2023d. PFAS ambient background concentrations. Minnesota Pollution Control Agency, May 2023. https://www.pca.state.mn.us/sites/default/files/tdr-g1-25.pdf.

USEPA. 2003. Framework for Cumulative Risk Assessment. Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, D.C. May 2003. EPA/630/P-02/001F. https://www.epa.gov/sites/default/files/2014-11/documents/frmwrk_cum_risk_assmnt.pdf.

USEPA. 2022. Regional Screening Levels (RSLs) - User's Guide. U.S. Environmental Protection Agency, https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide.

Remediation

- Remedial Approaches for PFAS can be found on the ITRC website: 12 Treatment Technologies – PFAS — Per- and Polyfluoroalkyl Substances (itrcweb.org)
- MPCA. 1998. Draft Guidelines Risk Based Site Characterization and Sampling Guidance. Minnesota Pollution Control Agency. 1998. https://www.pca.state.mn.us/sites/default/files/sitechar.pdf
- Minnesota Legislature. Chapter 115B, Environmental Response and Liability Act. 1983. Office of the Revisor of Statutes. https://www.revisor.mn.gov/statutes/cite/115B.01
- Rules of Thumb for Superfund Remedy Selection, United States Environmental Protection Agency, (EPA 540-R-97-013 OSWER 93655.0-69 PB97-963301 (August, 1997): https://www.epa.gov/superfund/Key Principles of Superfund-Remedy-Selection
- Quick Reference Fact Sheet: A Guide to Selecting Superfund Remedial Actions, United States Environmental Protection Agency, Office of Solid Waste and Emergency Response (Directive: 9355.0-27FS (April, 1990): https://semspub.epa.gov/work/HQ/174406.pdf
- Interstate Technology and Regulatory Council (ITRC). 2022. Treatment Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS): Treatment Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS) (itrcweb.org)
- Interstate Technology and Regulatory Council (ITRC). 2022. PFAS Technical and Regulatory Guidance Document and Fact Sheets PFAS-1, Section 12, Treatment Technologies.: Treatment Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS) (itrcweb.org)
- Interstate Technology and Regulatory Council (ITRC). 2018. Remediation Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS)pfas_fact_sheet_remediation_3_15_18.pdf (itrcweb.org)
- ITRC (Interstate Technology & Regulatory Council). 2018. *LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies*. LNAPL-3. Washington, D.C.: Interstate Technology & Regulatory Council. LNAPL Update Team. https://lnapl-3.itrcweb.org.

Annex I

Industries and industrial practices associated with the generation, use, storage, or disposal of PFAS:

- Airports
- Building and construction materials
- Chemicals and chemical products
- Cleaning products
- Cleaning and treatment services
- Commercial printing
- Defense sites
- Electronics and electrical components
- Industrial machinery
- Leather and textiles
- Medical products
- Metal plating and finishing
- Paints, coating, and varnishes
- Paper mills and paper products
- Petroleum refining and products
- Plastics, resin, and rubber
- Scrapyards
- Properties where aqueous film forming foam (AFFF) was used
- Waste disposal and treatment