City of Tacoma Environmental Services (Teresa Peterson)

Please see the attached for the City of Tacoma's comments on the Draft Puget Sound Reduction Plan. This is the second of two submittals to submit all of the City's attachments. This second submittal includes attachments 7 through 47 of 47 total.

LINCOLN LOEHR

I submitted comments on the 2018 draft 303(d) list of impaired waters to Ecology on June 4, 2021. I am attaching them here as they are also relevant to the proposed Nutrient General Permit.

P. O. Box 226
Winthrop, WA 98862
June 4, 2021

Washington State Department of Ecology
Jeremy Reiman
PO Box 47600
Olympia, WA 98504-7600
303(d)@ecy.wa.gov

Subject: Comments on proposed 2018 303(d) list of impaired waters

Dear Mr. Reiman,

This comment pertains to all of the marine water category 5 (impaired) listings for dissolved oxygen. The listings are based on 53 year old dissolved oxygen criteria that are not biologically based, are lacking in any identified scientific rationale, are not scientifically defensible, and are not based on credible information and literature for developing and reviewing a surface water quality standard.

The dissolved oxygen criteria do not meet the federal requirements of 40 CFR 131.11, nor do they meet the requirements found in Chapter 2 of WQP Policy 1-11 "Ensuring Credible Data for Water Quality Management". Since Ecology is using non-credible criteria, there is no basis for asserting that the waters are impaired. The 0.2 mg/l change component of the criteria is not biologically based. The listings should be changed to Category 2 (unsure) and notation provided that the listings will be re-evaluated after Ecology goes through a credible process to develop new criteria involving scientific input and public and scientific review. EPA should be involved since they have experience with marine DO criteria development.

I urge Ecology to start with the Marine Dissolved Oxygen Criteria developed by EPA and adopted by three states for Chesapeake Bay, which EPA says "may also apply to other estuarine and coastal systems, with appropriate modifications." There are important considerations in the Chesapeake Bay criteria including differences in depth, duration of exposure (averaging periods), and seasonality that are lacking in our criteria.

To prescribe significant wastewater treatment changes for assumed impairment based on ancient, overly protective, non-credible criteria is essentially malpractice. Ecology likes to assert that they are confident that our criteria are protective. I would agree, but they are also needlessly over-protective and therefore not representative of impairment.

To illustrate the overly protective aspect of the criteria, the Good classification includes a numeric criterion of 5 mg/l which "meet or exceed the requirements for all uses including but not limited to, salmonid migration and rearing; other fish migration, rearing, and spawning; clam, oyster, and mussel rearing and spawning; crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing and spawning." The Excellent quality classification includes a higher numeric criteria of 6 mg/l which meets all the same requirements protected by 5 mg/l. Similarly, the Extraordinary quality classification includes a higher numeric criteria of 7 mg/l which meets all the same requirements protected by 5 mg/l. The only function served by the Excellent and Extraordinary criteria is to be more protective than necessary. When the numeric criteria are crossed, that triggers the natural condition and the human caused decrease of 0.2 mg/l components of the criteria. So, a water with a designated criteria of 7, might be at 6.5 with more than 0.2 mg/l of that attributed to human caused decrease. We currently call that impaired, yet it is still higher than 5 mg/l which our criteria assert protects all uses.

I note that the freshwater dissolved oxygen criteria are similarly flawed, should be changed to Category 2 and notation provided to re-evaluate after a credible process to develop freshwater dissolved oxygen criteria. Ecology could start with EPA's freshwater dissolved oxygen criteria recommendations.

Ecology has asserted that effects levels documented in a 2008 report by Vaquer-Sunyer and Duarte support our criteria and even indicate that our criteria should be more stringent.[1] They further discuss a report by John Davis (1975)[2] as additional information also supporting our criteria. The data reviewed by Davis are also included in the Vaquer-Sunyer and Duarte report, so it isn't additional information. However, Vaquer-Sunyer and Duarte do not give specifics on what effects were measured in different tests. Davis does. Some effects have no significance for the well-being of the tested species, and therefore are not relevant to criteria development or assertions of impairment.

For example, the Ratfish (*Hydrolagus colliei*) is shown as having a DO threshold of 8.54 mg/l. Davis shows that below that threshold, the blood is less than 100% saturated. The Ratfish has large eyes, the better to see with in low light conditions. It lives in deep water in Puget Sound and along the continental shelf and slope along the west coast. In Puget Sound it makes up about 80% of the fish biomass in demersal trawl surveys. It makes up a sizeable percentage of the fish biomass in trawl surveys on the continental shelf as well. The deep water where it resides is substantially lower than 8.54 mg/l. If one was developing water quality criteria for marine dissolved oxygen, studies using blood oxygen saturation of less than 100% as a threshold would not be used. Criteria development has to consider what effects are most relevant to the survival of the species.

Chesapeake Bay states had DO criteria of 5 mg/l as an average and 4 mg/l as a minimum. Those criteria probably did go back to the 1968 Department of Interior water quality criteria recommendations. With help from EPA they developed newer, better criteria that recognized different types of water (surface, deep, bottom, nearshore, heads of tidal inlets) and had different criteria for each. Criteria had averaging periods, seasonality and depth considerations. The biological basis for the criteria were spelled out in detail. The new criteria were less stringent than the old criteria. The EPA recommendations were adopted by the states. The states did not choose to keep their more stringent criteria, which they could have said were more protective.

Sincerely yours,

Lincoln Loehr

---

[1] See power point from May 30, 2018 Nutrient Forum meeting, and also DOE's August 2018 report, Washington State's Marine Dissolved Oxygen Criteria; Application to Nutrient. An Overview of the Purpose and Application of the Criteria in the Surface Water Quality Standards.

[2] John Davis. (1975). Minimal Dissolved Oxygen Requirements of Aquatic Life with Emphasis on Canadian Species: a Review.

HELLER EHRMAN WHITE & McAULIFFE
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ANCHORAGE
LOS ANGELES
PALO ALTO
PORTLAND
SAN FRANCISCO
TACOMA

July 17, 1998

17278-0001

Mr. Jerry Thielen
Rules Coordinator
Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

Re: **Petition to the Department of Ecology to revise the dissolved oxygen standards and to halt dissolved oxygen related TMDL development and implementation until the revisions are complete.**

Dear Mr. Thielen:

In accordance with RCW 34.05.330, and on behalf of the City of Everett, we are submitting the attached petition for adoption of EPA's dissolved oxygen criteria as state water quality standards to replace those presently in rule at WAC 173-201A-030. We believe that there is no known technical basis to support our present standards and that EPA's criteria offer the best technical basis available. This petition carries ramifications to the State's 303(d) List and to the ongoing TMDL activities related to Dissolved Oxygen. We ask that all TMDL activities related to Dissolved Oxygen be curtailed until the state completes adoption of scientifically defensible Dissolved Oxygen standards.

As per RCW 34.05.330, the Department is required to respond to this petition within 60 days, by either (1) denying the petition in writing, stating its reasons for denial and specifically addressing the concerns raised by the petitioner, stating the alternative means by which it will address those concerns, or (2) initiating rulemaking proceedings.

We urge the Department to act on this petition by addressing this issue during the current triennial review of water quality standards.

Sincerely yours,

Tad H. Shimazu

Lincoln C. Loehr

cc: Mr. Tom Fitzsimmons

Petition to the Washington State Department of Ecology
to revise the State's Surface Water Quality Standards
for Dissolved Oxygen
and
to curtail further TMDL development for water bodies
listed for Dissolved Oxygen
until such revisions are completed

The existing Dissolved Oxygen standards are found in WAC 173-201A-030 (see Attachment A). The Dissolved Oxygen standards were adopted on or before 1967 (see Attachment B). At that time there was no EPA criteria document to help summarize the science or to provide a technical basis for the standard. (At that time there was no EPA.)

The state has no records identifying the basis behind the Dissolved Oxygen standards (see Attachment B). The implementation of the present Dissolved Oxygen standards has been simply habitual and unquestioned. The Dissolved Oxygen standards have not been reviewed or revised in any triennial review. Apparently neither the Department of Ecology nor the regulated community have thought to examine or question the Dissolved Oxygen standards in the last 30 years. In this regard, we accept that we all bear some responsibility for this omission.

In accordance with RCW 34.05.330 we petition the Department of Ecology to undergo rulemaking to update the Dissolved Oxygen standards with the objective being to use new science to develop defensible Dissolved Oxygen standards which may be similar to EPA's dissolved oxygen criteria. Our petition is now timely because the state has listed numerous water bodies on the 303(d) list specifically for Dissolved Oxygen. The state is now expending much effort at developing TMDLs because of the Dissolved Oxygen listings. These endeavors are in turn imposing substantial costs on the regulated communities for compliance. Appendix I to the 1998 Section 303(d) List submittal to EPA identifies TMDL activities specific to Dissolved Oxygen for 89 waterbodies (see Attachment C for a listing of those specific waterbodies.) The list presented in Attachment C does not represent all of the waterbodies listed for Dissolved Oxygen. It only represents those for which there have been TMDL activities. There are other listed waterbodies for which Dissolved Oxygen TMDL activities are yet to begin.

Because of the high costs to Ecology to develop TMDLs and the much higher costs to the regulated (and unregulated) community for implementing TMDLs, it is appropriate to examine the standards to assure they are based on scientifically sound and up-to-date technical information. The present Dissolved Oxygen standards are more than 30 years old, lack any identified technical basis and obviously cannot represent current science.

We ask that Ecology halt all Dissolved Oxygen related TMDL developments and implementation until the state adopts scientifically defensible Dissolved Oxygen standard. At the moment, the state has no such standards. We propose that the state could rapidly adopt EPA's freshwater Dissolved Oxygen criteria for both freshwater and saltwater. Alternatively, for saltwater, the state could simply adopt a standard that "the dissolved oxygen concentration shall not at any time be depressed more than 10 percent from that which occurs naturally, as the result of the discharge of oxygen demanding waste materials." This approach is what California uses, and is also in agreement with EPA's freshwater Dissolved Oxygen Criteria. We further ask that DOE immediately amend the 1998 303(d) List that was submitted to EPA to reflect the indefensibility of the present Dissolved Oxygen Standard and to later adjust the 303(d) List when Ecology completes the rulemaking.

The process we are requesting (both the standard revision, the TMDL moratorium and the 303(d) revision) must include a public education component to emphasize that this is needed to correct an old standard that is evidently without basis. The positive benefits should be emphasized. These benefits include 1) our waters are probably not as bad as had been previously indicated 2) both state and local resources may be more available to address other pressing needs instead and 3) a better standard will result.

The EPA Dissolved Oxygen criteria.

EPA published their criteria document in 1986 (see Attachment D), and also included a summary of the criteria in *Quality Criteria for Water, 1986* (also known as the "Goldbook") (see Attachment E). The criteria are specific to the protection of early life stages and other life stages for coldwater organisms and for warmwater organisms. The criteria (in mg/L) are:

Coldwater Criteria	Early Life Stages	Other Life Stages
30 day mean	NA	6.5
7 day mean	9.5(6.5)	NA
7 day mean minimum	NA	5.0
1 day minimum	8.0(5.0)	4.0
Warmwater Criteria		
30 day mean	NA	5.5
7 day mean	6.0	NA
7 day mean minimum	NA	4.0
1 day minimum	5.0	3.0

EPA's criteria include footnotes that explain that

- The early life stage values are water column concentrations recommended to achieve the required intergravel dissolved oxygen concentrations shown in the parentheses. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.
- The 1 day minimum values should be considered as instantaneous concentrations to be achieved at all times.

The EPA criteria also discuss when natural conditions alone create dissolved oxygen concentrations less than 110 percent of the applicable criteria means or minima or both, the minimum acceptable concentration is 90 percent of the natural concentration. Note that this allows a much greater decrease than the State's 0.2 mg/L allowable drop from the natural. Also note that this is in agreement with the state of California's marine water Dissolved Oxygen standard.

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
P.O. Box 47600 • Olympia, Washington 98504-7600
(360) 407-6000 • TDD Only (Hearing Impaired) (360) 407-6006

July 8, 1998

Mr. Lincoln Loehr
Environmental Analyst
Heller, Ehrman, White and McAuliffe
6100 Columbia Center\701 Fifth Avenue
Seattle, WA 98104-7098

Dear Mr. Loehr:

I am writing in response to your June 12 letter concerning our state standards for dissolved oxygen. As I discussed with you on the phone, we do not have supporting information on the technical basis for our existing criteria.

This last year I personally went through all of the files stored at Ecology and downtown in the state central archives. I examined these files with the intent to document the basis for our various water criteria. Little information exists in general regarding the water quality standards. This leaves me with the disappointing conclusion that the archive staff decided these records were not historically critical and had them destroyed. All I found in relation to dissolved oxygen was a comment letter sent by a pulp mill stating the need to allow some human degradation beyond natural levels in marine waters during periods of upwelling.

The existing dissolved oxygen criteria thresholds have existed in the state standards as far back as 1967 and is the oldest copy of the standards in my possession. The criteria has never been expressed other than an absolute threshold value, even though many other criteria have been and continue to include averaging periods. Let me know if you have any further questions or issues needing clarification (360) 407-6477.

Sincerely,

Mark Hicks

Mark Hicks
Water Quality Standards

MPh:mh

Shared.../section/wm/mark/loehr1.doc

STATE OF WASHINGTON

DEPARTMENT OF ECOLOGY

P.O. Box 47600 • Olympia, Washington 98504-7600
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September 16, 1998

Mr. Tad H. Shimazu
Heller Ehrman White & McAuliffe
6100 Columbia Center
701 Fifth Avenue
Seattle, WA 98104-7098

Dear Mr. Shimazu:

Thank you for your July 17, 1998 petition to revise our state's water quality standards for dissolved oxygen. Ecology is required by RCW 34.05.330 to respond to your petition within 60 days by either (1) denying the petition in writing or (2) initiating rule-making proceedings. We have reviewed your petition and find that we must deny your request at this time.

Our denial is based in part on our having already committed to undertake a review of our freshwater dissolved oxygen criteria as part of the current efforts investigating the potential conversion of the standards to a use-based approach. Following completion of these efforts, targeted for December 1999, we will evaluate whether state and agency priorities and the availability of resources allow us to initiate a similar review of our marine criteria.

We also find your request to be inconsistent with our understanding of procedural and technical issues associated with the standards, and the dissolved oxygen criteria in particular, as well as being inconsistent with our overall strategy for the surface water quality standards. For example, you suggest in the petition that our dissolved oxygen criteria are inappropriate due to their age and lack of administrative record. We disagree with your assumption that the age of the criteria and the lack of documentation in state archives indicates these standards lack scientific validity. We also find fault with the assumption that not having conducted a formal review of these criteria since their adoption is the result of an oversight. No basis has been provided to scientifically challenge our existing standards.

You also suggest that we should, and easily could, adopt the guidance values for freshwater dissolved oxygen from the U.S. Environmental Protection Agency's (EPA)

1986 Quality Criteria for Water and apply them to both fresh and marine waters. We disagree with this assumption for several reasons. First, EPA's guidance was developed specifically for fresh waters and did not consider or evaluate use impacts for marine waters. Second, EPA's guidance includes only limited evaluations of impacts to non-fish species and of sub-lethal or cumulative effects. Finally, any criteria change requires a review by the federal fisheries agencies as part of the Endangered Species Act consultative process. Based on the information provided to date by the resource agencies participating in the use-based criteria effort, we doubt whether EPA's 1986 dissolved oxygen criteria would be considered as adequately protective of the salmon species currently listed or proposed for listing as threatened or endangered in Washington waters.

Your petition includes a request that we suspend the development of Total Maximum Daily Loads (TMDLs) for dissolved oxygen until such time as we have adopted new dissolved oxygen criteria. Our existing state standards were developed and adopted in accordance with state rules and regulations and have been approved by EPA consistent with federal regulations and statutes. These regulations and statutes also require that we use them for setting permit limits, for establishing the 303(d) list, and for conducting TMDLs. We cannot legally or in good conscience waive the use of our current dissolved oxygen criteria. The enclosed letter from EPA Region 10 confirms that our current standards are legally binding and are to be used for TMDL development as well for other water pollution control efforts.

Ecology remains fully committed to maintaining accurate and defensible water quality criteria for all parameters, and dissolved oxygen is no exception. In fact, we have made many improvements to the Surface Water Quality Standards rule during the past twenty-five years in order to better protect Washington's waters. These improvements have incorporated new scientific information and advances in our understanding of aquatic systems as well as new state and national environmental policies. Recent improvements in the standards program have included the adoption of nutrient criteria for lakes and refinements to criteria for several metals and toxic chemicals. We are developing language to clarify how the state's antidegradation policy will be implemented and converting the standards to a use-based approach. The use-based approach will allow us to better customize the criteria for temperature, bacteria, dissolved oxygen, and fish habitat in order to protect the specific uses of a waterbody.

After these improvements to the standards are in place, we will need to switch our emphasis from rule development to implementing the nutrient criteria, antidegradation policy, and use-based criteria as part of the agency's watershed approach. We recognize that the standards program is very dynamic and there are many standards issues being discussed at the national level, including new requirements for nutrient criteria and biocriteria. We will, of course, continue to monitor developments on the national level with interest. It may make sense to adopt certain federal proposals in the future.

However, because we believe it is now our highest priority to implement the recent and pending changes to the standards, we do not anticipate initiating further changes to the standards in the foreseeable future.

We encourage you to remain involved with our current efforts to enhance the surface water quality standards, specifically development of an antidegradation implementation plan and conversion of the standards to a use-based approach. Mark Hicks, at (360) 407-6477 in our Water Quality Program, is leading this effort and can provide you with additional information regarding these activities.

Sincerely,

Tom Fitzsimmons
Director

TF:MH:kh
Enclosure

cc: Lincoln Loehr Heller Ehrman White & McAuliffe

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue
Seattle, Washington 98101

SEP 1 4 1998

REPLY TO
ATTN. OF: OW-134

OPTIONAL FORM 99 (7-90)

FAX TRANSMITTAL		# of pages ▸ 2
To Steve Saunders	From Shirley	
Dept./Agency DOE	Phone # 553-8512	
Fax # 407-7162	Fax # -0165	
NSN 7540-01-317-7368 5099-101	GENERAL SERVICES ADMINISTRATION	

Mr. Steve Saunders
Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

Re: Petition to Ecology submitted by Heller Ehrman White & McAuliffe to revise dissolved oxygen standards and to halt related TMDL development

Dear Mr. Saunders:

Thank you for forwarding a copy of the referenced July 17, 1998 petition. We have reviewed this document and find no basis for a favorable response. Washington's Surface Water Quality Standards (WQS) have been adopted by the state as Chapter 173-201A WAC and approved by the Environmental Protection Agency, Region 10 (EPA) in accordance with all applicable state and federal regulations and statutes. This approval includes Washington State's current standards for Dissolved Oxygen.

The petitioners are also requesting that Ecology replace the state's current Dissolved Oxygen criteria with those referenced in EPA's 1986 Quality Criteria for Water (Gold Book). Although we support the general use and adoption of the 1986 criteria, EPA policy as well as federal regulations and statutes encourage states to adopt criteria that are equal to or more protective of existing and designated uses. We believe Ecology's Dissolved Oxygen criteria provide better protection of the uses identified for each of the classifications in Washington's standards than would the single Dissolved Oxygen criteria set forth in the Gold Book. This is particularly true regarding the protection of marine uses in that the Gold Book criteria addresses only the protection of freshwater uses while Ecology has adopted separate criteria for both fresh and marine waters.

Federal Regulations and statutes also require that the approved standards be used as the basis for identifying water quality limited waters, establishing Total Maximum Daily Loads (TMDLs), and permitting decisions. Furthermore, approved standards must be used until such time that revised standards have been formally adopted by the state and approved by EPA. EPA's approval of new or revised standards also includes consultation with the federal resource agencies to ensure adequate protection for listed or threatened species under the federal Endangered Species Act. Therefore, we can not support the petitioner's request to suspend the application of approved standards during reviews of proposed revisions to the standards.

If you have any questions concerning this letter please contact Fletcher G. Shives of my staff at (206) 553-8512.

Sincerely,

[signature] for TH

Timothy Hamlin
Manager, Water Quality Unit

Gordon Holtgrieve

Please see attached file.

SCHOOL OF AQUATIC AND FISHERY SCIENCES
UNIVERSITY of WASHINGTON

August 16, 2021

Eleanor Ott, PSNGP Permit Writer
Department of Ecology
Water Quality Program
PO Box 47600
Olympia, WA 98504-7600

Regarding: Puget Sound Nutrient General Permit

The Scientific Basis for Regulation is Flawed
The Washington State Department of Ecology (hereafter Ecology), intends to implement the Nutrient General Permit on the basis that the state's water quality standard for dissolved oxygen is not being met, due in part to nitrogen discharge from wastewater treatment plants (WWTP). Ecology has used its implementation of the Salish Sea Model (SSM) to determine: a) the dissolved oxygen water quality standard is not being met, and b) WWTP are contributing to this non-compliance. These two factors are the basis for the Nutrient General Permit and, as such, questions about the SSM and the compliance determination process are relevant to the Nutrient General Permit under consideration. As detailed in my letter regarding the Draft Nutrient Permit dated 15 March 2021, I and other independent scientists with relevant expertise have repeatedly and publicly challenged Ecology's assertion that the SSM is sufficiently precise and accurate to determine compliance with the standard. In short, we believe that model uncertainty when predicting current conditions is too large to say that the standard is likely not being met. The response to my letter, provided by Ecology in the General Nutrient Permit Fact Sheet, fails to adequately address the issue of model uncertainty in determining compliance to the standard. *This use of the SSM to determine compliance to the water quality standard needs independent review by qualified scientists without conflicts of interest.*

Public Messaging from Ecology on Puget Sound Water Quality is Misleading and Not Based on Facts
Ecology's recent public messaging campaign that describes "dead zones" in Puget Sound (either current or future) as a meaningful problem for the ecosystem necessitating action[i] is not based on any published study or report. Ecology representatives have been on the record stating that salmon are suffocating because of nutrients from WWTP[ii], yet there is no scientific evidence pointing to low oxygen from nutrients as a cause of salmon mortality in Puget Sound. *Simply put, this public messaging campaign is a dishonest misrepresentation of the impacts WWTP are having on Puget Sound and should be immediately retracted.*

Here are the facts: Between 0.25% and 1% of the volume of Puget Sound is hypoxic[iii] during part of the summer, of which 80% to 85% of this hypoxia is due to natural processes outside of

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human control (Ahmed et al. 2019, MacCready 2019). That means between 0.03% and 0.2% of the Puget Sound is becoming hypoxic due to humans, for part of the year, and actions to reduce nutrients from WWTP will not have a meaningful impact on hypoxia (MacCready 2019).

Effectiveness and Tradeoffs Must be Considered

The Puget Sound Ecosystem faces numerous challenges from myriad of stressors. This reality dictates that proposed solutions must be evaluated both on their likelihood of effecting change and the opportunity costs of actions that will not occur because the proposed policy. Ecology has never considered these critical factors in their decision-making around this issue! Given the high natural variability in dissolved oxygen in Puget Sound, it is a near certainty that there will be no observable change in dissolved oxygen as a result of this policy. Furthermore, because the SSM is a deterministic model, it is an absolute certainty it will indicate a water quality improvement, even if there is not an observable change, because it is written into the model. Will the public accept that the money they have spent on this action does not result in an observable change in dissolved oxygen even if the model says it should be there? *At a minimum, Ecology should detail how the effectiveness of this policy will be evaluated.*

Finally, the list of issues and potential actions to improve the health of Puget Sound is long – far longer than is possible, given available resources. Consideration of tradeoffs and optimization of actions is therefore a must. Recent research by King County suggests that actions to reduce stormwater runoff and improve habitat result in a far greater "bang for the buck" than nutrient reduction.[iv] Ecology must take seriously the reality that resources are limiting and restoration actions must be prioritized. Otherwise, there is the substantial risk that money will be spent on this issue in vain and, even worse, the public will pull their support for future environmental initiatives. *As environmental scientists, engineers and policy-makers, have a responsibility spend the public's money wisely.*

Recommendations

1. Delay implementation of the Nutrient General Permit until it is clear that: a) there is an ecologically meaningful problem as the result of nutrients from WWTP, b) the proposed action will provide ecological benefits to the Puget Sound, and c) critical funds are not better spent on alternative actions with higher likelihoods of success.

2. Revise Ahmed et al. (2019) to include the model uncertainties in a transparent and scientifically-defensible way that specifically includes the range of likely values (i.e., confidence intervals), not just a single number, for each model-generated result. When determining compliance to the dissolved oxygen standard, present the areas deemed to be out of compliance with an associated type I error probability.

3. Conduct a multi-model comparison of Puget Sound water quality, as is the current best practice. There are at least three existing models of water quality for Puget Sound that can easily be compared to one another as a means to assess model uncertainty.

4. Solicit an independent review of the science related to compliance standards and incorporate all relevant suggestions into a new presentation of results. The Washington State Academy of Sciences frequently conducts this type of scientific review for issues of high policy

importance such as this. It is therefore recommended that Ecology requests a full scientific review from the Academy.

5. Publicly retract all statements that suggest "dead zones" are a meaningful problem in Puget Sound that can be corrected by regulating nutrients from WWTP. Furthermore, Ecology should publicly retract all statements that suggest salmon are being impacted by "dead zones" in the Puget Sound (i.e., suffocating). Neither of these statements can be supported by data or modeling.

Sincerely,

Gordon W. Holtgrieve
Associate Professor
School of Aquatic & Fishery Sciences
University of Washington

References Cited

Ahmed, A., Figueroa-Kaminsky, C. Gala, J., Mohamedali, T., Pelletier, G., and McCarthy, S. 2019. Puget Sound Nutrient Source Reduction Project. Volume 1: Model Updates and Bounding Scenarios. Washington State Department of Ecology, Publication 19-03-001.

MacCready, P. 2019. External Review of the Bounding Scenarios Report by Ahmed et al. Obtained by public records request.

Diaz, RJ and R Rosenberg. 2008. Spreading Dead Zones and Consequences for Marine Ecosystems. *Science* 321(5891): 926-929. DOI: 10.1126/science.1156401

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[i] https://ecology.wa.gov/Blog/Posts/June-2021/To-prevent-dead-zones-in-Puget-Sound,-communities

[ii] Puget Sound Partnership Leadership Council Meeting (open to the public) 18 February 2021.

[iii] The term "dead zone" is poorly defined, but at a minimum it implies lethal consequences for marine life due to low oxygen. "Hypoxia"—typically defined as dissolved oxygen less than or equal to 2 mg/L—is a term used to indicate low oxygen that can negatively impact marine life, while mass mortality events are expected to occur at dissolved oxygen values of 0.5 mg/L or less (Diaz and Rosenberg 2008).

[iv] Presentation by Dow Constantine, Abigail Hook, and colleagues at the Puget Sound Partnership Leadership Council Meeting (open to the public) 18 February 2021.

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
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July 8, 1998

Mr. Lincoln Loehr
Environmental Analyst
Heller, Ehrman, White and McAuliffe
6100 Columbia Center\701 Fifth Avenue
Seattle, WA 98104-7098

Dear Mr. Loehr:

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Sincerely,

Mark Hicks

Mark Hicks
Water Quality Standards

MPh:mh

Treatment Technology Review and Assessment

Association of Washington Business
Association of Washington Cities
Washington State Association of Counties

December 4, 2013

500 108th Avenue NE
Suite 1200
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(425) 450-6200

04594

Table of Contents

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Acronyms

Acronym	Definition
AACE	Association for the Advancement of Cost Engineering
AOP	advanced oxidation processes
AWB	Association of Washington Businesses
BAC	biological activated carbon
BAP	benzo(a)pyrene
BOD	biochemical oxygen demand
BTU	British thermal unit
CEPT	Chemically-enhanced primary treatment
cf	cubic feet
CIP	clean in place
CRITFC	Columbia River Inter-Tribal Fish Commission
Ecology	Washington Department of Ecology
EPA	U.S. Environmental Protection Agency
FCR	fish consumption rate
g/day	grams per day
GAC	granular activated carbon
gal	gallon
gfd	gallons per square foot per day
GHG	greenhouse gas
gpd	gallons per day
gpm	gallons per minute
GWh	giga watt hours
HDR	HDR Engineering, Inc.
HHWQC	human health water quality criteria
HRT	hydraulic residence time
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
KWh/MG	kilowatt-hours per million gallons
lb	pound
MBR	membrane bioreactor
MCL	maximum contaminant level
MF	microfiltration
mgd	million gallons per day
mg/L	milligrams per liter
MMBTU	million British thermal units
MWh/d	megawatt-hours per day
NF	nanofiltration
ng/L	nanograms per liter
NPDES	National Pollutant Discharge Elimination System
NPV	net present value
O&M	operations and maintenance
ODEQ	Oregon Department of Environmental Quality
PAC	powdered activated carbon
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyls
PE	population equivalents
PIX	potable ion exchange

Acronym	Definition
ppm	parts per million
RO	reverse osmosis
SDWA	Safe Drinking Water Act
sf	square feet
SGSP	salinity gradient solar pond
SRT	solids retention time
Study Partners	Association of Washington Businesses/Association of Washington Cities and Washington State Association of Counties consortium
TDS	total dissolved solids
TMDL	total maximum daily load
TSS	total suspended solids
UF	ultrafiltration
µg/L	micrograms per liter
USDA	U.S. Department of Agriculture
UV	ultraviolet
WAC	Washington Administrative Code
WAS	waste activated sludge
WLA	waste load allocation
WWTP	wastewater treatment plant
ZLD	zero liquid discharge

Executive Summary

This study evaluated treatment technologies potentially capable of meeting the State of Washington Department of Ecology's (Ecology) revised effluent discharge limits associated with revised human health water quality criteria (HHWQC). HDR Engineering, Inc. (HDR) completed a literature review of potential technologies and an engineering review of their capabilities to evaluate and screen treatment methods for meeting revised effluent limits for four constituents of concern: arsenic, benzo(a)pyrene (BAP), mercury, and polychlorinated biphenyls (PCBs). HDR selected two alternatives to compare against an assumed existing baseline secondary treatment system utilized by dischargers. These two alternatives included enhanced secondary treatment with membrane filtration/reverse osmosis (MF/RO) and enhanced secondary treatment with membrane filtration/granulated activated carbon (MF/GAC). HDR developed capital costs, operating costs, and a net present value (NPV) for each alternative, including the incremental cost to implement improvements for an existing secondary treatment facility.

Currently, there are no known facilities that treat to the HHWQC and anticipated effluent limits that are under consideration. Based on the literary review, research, and bench studies, the following conclusions can be made from this study:

- Revised HHWQC based on state of Oregon HHWQC (2001) and U.S. Environmental Protection Agency (EPA) "National Recommended Water Quality Criteria" will result in very low water quality criteria for toxic constituents.
- There are limited "proven" technologies available for dischargers to meet required effluent quality limits that would be derived from revised HHWQC.
    - Current secondary wastewater treatment facilities provide high degrees of removal for toxic constituents; however, they are not capable of compliance with water quality-based National Pollutant Discharge Elimination System (NPDES) permit effluent limits derived from the revised HHWQC.
    - Advanced treatment technologies have been investigated and candidate process trains have been conceptualized for toxics removal.
        - Advanced wastewater treatment technologies may enhance toxics removal rates; however, they will not be capable of compliance with HHWQC-based effluent limits for PCBs. The lowest levels achieved based on the literature review were between <0.00001 and 0.00004 micrograms per liter (µg/L), as compared to a HHWQC of 0.0000064 µg/L.
        - Based on very limited performance data for arsenic and mercury from advanced treatment information available in the technical literature, compliance with revised criteria may or may not be possible, depending upon site specific circumstances.
            - Compliance with a HHWQC for arsenic of 0.018 µg/L appears unlikely. Most treatment technology performance information available in the literature is based on drinking water treatment applications targeting a much higher Safe Drinking Water Act (SDWA) maximum contaminant level (MCL) of 10 µg/L.
            - Compliance with a HHWQC for mercury of 0.005 µg/L appears to be potentially attainable on an average basis, but perhaps not if effluent limits are structured on a maximum monthly, maximum weekly or maximum daily basis. Some secondary treatment facilities attain average effluent mercury levels of 0.009 to 0.066 µg/L. Some treatment facilities with effluent filters attain average effluent mercury levels of 0.002 to 0.010 µg/L. Additional

advanced treatment processes are expected to enhance these removal rates, but little mercury performance data is available for a definitive assessment.

- Little information is available to assess the potential for advanced technologies to comply with revised BAP criteria. A municipal wastewater treatment plant study reported both influent and effluent BAP concentrations less than the HHWQC of 0.0013 ug/L (Ecology, 2010).

  - Some technologies may be effective at treating identified constituents of concern to meet revised limits while others may not. It is therefore even more challenging to identify a technology that can meet all constituent limits simultaneously.
  - A HHWQC that is one order-of-magnitude less stringent could likely be met for mercury and BAP; however, it appears PCB and arsenic limits would not be met.

- Advanced treatment processes incur significant capital and operating costs.
  - Advanced treatment process to remove additional arsenic, BAP, mercury, and PCBs would combine enhancements to secondary treatment with microfiltration membranes and reverse osmosis or granular activated carbon and increase the estimated capital cost of treatment from $17 to $29 in dollars per gallon per day of capacity (based on a 5.0-million-gallon-per-day (mgd) facility).
  - The annual operation and maintenance costs for the advanced treatment process train will be substantially higher (approximately $5 million - $15 million increase for a 5.0 mgd capacity facility) than the current secondary treatment level.
- Implementation of additional treatment will result in additional collateral impacts.
  - High energy consumption.
  - Increased greenhouse gas emissions.
  - Increase in solids production from chemical addition to the primaries. Additionally, the membrane and GAC facilities will capture more solids that require handling.
  - Increased physical space requirements at treatment plant sites for advanced treatment facilities and residuals management including reverse osmosis reject brine processing.
- It appears advanced treatment technology alone cannot meet all revised water quality limits and implementation tools are necessary for discharger compliance.
  - Implementation flexibility will be necessary to reconcile the difference between the capabilities of treatment processes and the potential for HHWQC driven water quality based effluent limits to be lower than attainable with technology

Table ES-1 indicates that the unit NPV cost for baseline conventional secondary treatment ranges from $13 to $28 per gallon per day of treatment capacity. The unit cost for the advanced treatment alternatives increases the range from the low $20s to upper $70s on a per gallon per-day of treatment capacity. The resulting unit cost for improving from secondary treatment to advanced treatment ranges between $15 and $50 per gallon per day of treatment capacity. Unit costs were also evaluated for both a 0.5 and 25 mgd facility. The range of unit costs for improving a 0.5 mgd from secondary to advanced treatment is $60 to $162 per gallon per day of treatment capacity. The range of unit costs for improving a 25 mgd from secondary to advanced treatment is $10 to $35 per gallon per day of treatment capacity.

Table ES-1. Treatment Technology Costs in 2013 Dollars for a 5-mgd Facility

Alternative	Total Construction Cost, 2013 dollars ($ Million)	O&M Net Present Value, 2013 dollars ($ Million)***	Total Net Present Value, 2013 dollars ($ Million)	NPV Unit Cost, 2013 dollars ($/gpd)
Baseline (Conventional Secondary Treatment)*	59 - 127	5 - 11	65 - 138	13 - 28
Incremental Increase to Advanced Treatment - MF/RO	48 - 104	26 - 56	75 - 160	15 - 32
Advanced Treatment - MF/RO**	108 - 231	31 - 67	139 - 298	28 - 60
Incremental Increase to Advanced Treatment - MF/GAC	71 - 153	45 - 97	117 - 250	23 - 50
Advanced Treatment - MF/GAC	131 - 280	50 - 108	181 - 388	36 - 78

* Assumed existing treatment for dischargers. The additional cost to increase the SRT to upwards of 30-days is about $12 - 20 million additional dollars in total project cost for a 5 mgd design flow.

** Assumes zero liquid discharge for RO brine management, followed by evaporation ponds. Other options are available as listed in Section 4.4.2.

*** Does not include the cost for labor.

mgd=million gallons per day
MG=million gallons
MF/RO=membrane filtration/reverse osmosis
MF/GAC=membrane filtration/granulated activated carbon
O&M=operations and maintenance
Net Present Value = total financed cost assuming a 5% nominal discount rate over an assumed 25 year equipment life.

Costs presented above are based on a treatment capacity of 5.0 mgd, however, existing treatment facilities range dramatically across Washington in size and flow treated. The key differences in cost between the baseline and the advanced treatment MF/RO are as follows:

- Larger aeration basins than the baseline to account for the longer SRT (>8 days versus <8 days).
- Additional pumping stations to pass water through the membrane facilities and granulated activated carbon facilities. These are based on peak flows.
- Membrane facilities (equipment, tanks chemical feed facilities, pumping, etc.) and replacement membrane equipment.
- Granulated activated carbon facilities (equipment, contact tanks, pumping, granulated activated carbon media, etc.)
- Additional energy and chemical demand to operate the membrane and granulated activated carbon facilities
- Additional energy to feed and backwash the granulated activated carbon facilities.
- Zero liquid discharge facilities to further concentrate the brine reject.
    - Zero liquid discharge facilities are energy/chemically intensive and they require membrane replacement every few years due to the brine reject water quality.
- Membrane and granulated activated carbon media replacement represent a significant maintenance cost.

- Additional hauling and fees to regenerate granulated activated carbon off-site.

The mass of pollutant removal by implementing advanced treatment was calculated based on reducing current secondary effluent discharges to revised effluent limits for the four pollutants of concern. These results are provided in Table ES-2 as well as a median estimated unit cost basis for the mass of pollutants removed.

Table ES-2. Unit Cost by Contaminant for a 5-mgd Facility Implementing Advanced Treatment using Membrane Filtration/Reverse Osmosis

Component	PCBs	Mercury	Arsenic	BAPs
Required HHWQC based Effluent Quality (µg/L)	0.0000064	0.005	0.018	0.0013
Current Secondary Effluent Concentration (µg/L)	0.002	0.025	7.5	0.006
Total Mass Removed (lbs) over 25 year Period	0.76	7.6	2,800	1.8
Median Estimated Unit Cost (NPV per total mass removed in pounds over 25 years)	$290,000,000	$29,000,000	$77,000	$120,000,000

µg/L=micrograms per liter
lbs=pounds
NPV=net present value

Collateral adverse environmental impacts associated with implementing advanced treatment were evaluated. The key impacts from this evaluation include increased energy use, greenhouse gas production, land requirements and treatment residuals disposal. Operation of advanced treatment technologies could increase electrical energy by a factor of 2.3 to 4.1 over the baseline secondary treatment system. Direct and indirect greenhouse gas emission increases are related to the operation of advanced treatment technologies and electrical power sourcing, with increases of at least 50 to 100 percent above the baseline technology. The energy and air emission implications of advanced treatment employing granulated activated carbon construction of advanced treatment facilities will require additional land area. The availability and cost of land adjacent to existing treatment facilities has not been included in cost estimates, but could be very substantial. It is worthwhile noting residual materials from treatment may potentially be hazardous and their disposal may be challenging to permit. Costs assume zero liquid discharge from the facilities.

1.0 Introduction

Washington's Department of Ecology (Ecology) has an obligation to periodically review waterbody "designated uses" and to modify, as appropriate, water quality standards to ensure those uses are protected. Ecology initiated this regulatory process in 2009 for the human health-based water quality criteria (HHWQC) in Washington's *Surface Water Quality Standards* (Washington Administrative Code [WAC] 173-201A). HHWQC are also commonly referred to as "toxic pollutant water quality standards." Numerous factors will influence Ecology's development of HHWQC. The expectation is that the adopted HHWQC will be more stringent than current adopted criteria. National Pollutant Discharge Elimination System (NPDES) effluent limits for permitted dischargers to surface waters are based on U.S. Environmental Protection Agency (EPA) and state guidance. Effluent limits are determined primarily from reasonable potential analyses and waste load allocations (WLAs) from total maximum daily loads (TMDLs), although the permit writer may use other water quality data. Water quality-based effluent limits are set to be protective of factors, including human health, aquatic uses, and recreational uses. Therefore, HHWQC can serve as a basis for effluent limits. The presumption is that more stringent HHWQC will, in time, drive lower effluent limits. The lower effluent limits will require advanced treatment technologies and will have a consequent financial impact on NPDES permittees. Ecology anticipates that a proposed revision to the water quality standards regulation will be issued in first quarter 2014, with adoption in late 2014.

The Association of Washington Businesses (AWB) is recognized as the state's chamber of commerce, manufacturing and technology association. AWB members, along with the Association of Washington Cities and Washington State Association of Counties (collectively referred to as Study Partners), hold NPDES permits authorizing wastewater discharges. The prospect of more stringent HHWQC, and the resulting needs for advanced treatment technologies to achieve lower effluent discharge limits, has led this consortium to sponsor a study to assess technology availability and capability, capital and operations and maintenance (O&M) costs, pollutant removal effectiveness, and collateral environmental impacts of candidate technologies.

The "base case" for the study began with the identification of four nearly ubiquitous toxic pollutants present in many industrial and municipal wastewater discharges, and the specification of pollutant concentrations in well-treated secondary effluent. The pollutants are arsenic, benzo(a)pyrene (BAP), mercury and polychlorinated biphenyls (PCBs), which were selected for review based on available monitoring data and abundant presence in the environment. The purpose of this study is to review the potential water quality standards and associated treatment technologies able to meet those standards for four pollutants.

A general wastewater treatment process and wastewater characteristics were used as the common baseline for comparison with all of the potential future treatment technologies considered. An existing secondary treatment process with disinfection at a flow of 5 million gallons per day (mgd) was used to represent existing conditions. Typical effluent biochemical oxygen demand (BOD) and total suspended solids (TSS) were assumed between 10 and 30 milligrams per liter (mg/L) for such a facility and no designed nutrient or toxics removal was assumed for the baseline existing treatment process.

Following a literature review of technologies, two advanced treatment process options for toxics removal were selected for further evaluation based on the characterization of removal effectiveness from the technical literature review and Study Partners' preferences. The two tertiary treatment options are microfiltration membrane filtration (MF) followed by either reverse osmosis (RO) or granular activated carbon (GAC) as an addition to an existing secondary treatment facility.

The advanced treatment technologies are evaluated for their efficacy and cost to achieve the effluent limitations implied by the more stringent HHWQC. Various sensitivities are examined, including for less stringent adopted HHWQC, and for a size range of treatment systems. Collateral environmental impacts associated with the operation of advanced technologies are also qualitatively described.

2.0 Derivation of the Baseline Study Conditions and Rationale for Selection of Effluent Limitations

2.1 Summary of Water Quality Criteria

Surface water quality standards for toxics in the State of Washington are being updated based on revised human fish consumption rates (FCRs). The revised water quality standards could drive very low effluent limitations for industrial and municipal wastewater dischargers. Four pollutants were selected for study based on available monitoring data and abundant presence in the environment. The four toxic constituents are arsenic, BAP, mercury, and PCBs.

2.2 Background

Ecology is in the process of updating the HHWQC in the state water quality standards regulation. Toxics include metals, pesticides, and organic compounds. The human health criteria for toxics are intended to protect people who consume water, fish, and shellfish. FCRs are an important factor in the derivation of water quality criteria for toxics.

The AWB/City/County consortium (hereafter "Study Partners") has selected four pollutants for which more stringent HHWQC are expected to be promulgated. The Study Partners recognize that Ecology probably will not adopt more stringent arsenic HHWQC so the evaluation here is based on the current arsenic HHWQC imposed by the National Toxics Rule. Available monitoring information indicates these pollutants are ubiquitous in the environment and are expected to be present in many NPDES discharges. The four pollutants include the following:

- Arsenic
  - Elemental metalloid that occurs naturally and enters the environment through erosion processes. Also widely used in batteries, pesticides, wood preservatives, and semiconductors. Other current uses and legacy sources in fungicides/herbicides, copper smelting, paints/dyes, and personal care products.
- Benzo(a)pyrene (BAP)
  - Benzo(a)pyrene is a polycyclic aromatic hydrocarbon formed by a benzene ring fused to pyrene as the result of incomplete combustion. Its metabolites are highly carcinogenic. Sources include wood burning, coal tar, automobile exhaust, cigarette smoke, and char-broiled food.
- Mercury
  - Naturally occurring element with wide legacy uses in thermometers, electrical switches, fluorescent lamps, and dental amalgam. Also enters the environment through erosion processes, combustion (especially coal), and legacy industrial/commercial uses. Methylmercury is an organometallic that is a bioaccumulative toxic. In aquatic systems, an anaerobic methylation process converts inorganic mercury to methylmercury.
- Polychlorinated Biphenyls (PCBs)
  - Persistent organic compounds historically used as a dielectric and coolant in electrical equipment and banned from production in the U.S. in 1979. Available information indicates continued pollutant loadings to the environment as a byproduct from the use of some pigments, paints, caulking, motor oil, and coal combustion.

2.3 Assumptions Supporting Selected Ambient Water Quality Criteria and Effluent Limitations

Clean Water Act regulations require NPDES permittees to demonstrate their discharge will "not cause or contribute to a violation of water quality criteria." If a "reasonable potential analysis" reveals the possibility of a standards violation, the permitting authority is obliged to develop "water quality-based effluent limits" to ensure standards achievement. In addition, if ambient water quality monitoring or fish tissue assessments reveal toxic pollutant concentrations above HHWQC levels, Ecology is required to identify that impairment ("303(d) listing") and develop corrective action plans to force reduction in the toxic pollutant discharge or loading of the pollutant into the impaired water body segment. These plans, referred to as total maximum daily loads (TMDLs) or water cleanup plans, establish discharge allocations and are implemented for point discharge sources through NPDES permit effluent limits and other conditions.

The effect of more stringent HHWQC will intuitively result in more NPDES permittees "causing or contributing" to a water quality standards exceedance, and/or more waterbodies being determined to be impaired, thus requiring 303(d) listing, the development of TMDL/water cleanup plans, and more stringent effluent limitations to NPDES permittees whose treated wastewater contains the listed toxic pollutant.

The study design necessarily required certain assumptions to create a "baseline effluent scenario" against which the evaluation of advanced treatment technologies could occur. The Study Partners and HDR Engineering, Inc (HDR) developed the scenario. Details of the baseline effluent scenario are presented in Table 1. The essential assumptions and rationale for selection are presented below:

- Ecology has indicated proposed HHWQC revisions will be provided in first quarter 2014. A Study Partners objective was to gain an early view on the treatment technology and cost implications. Ecology typically allows 30 or 45 days for the submission of public comments on proposed regulations. To wait for the proposed HHWQC revisions would not allow sufficient time to complete a timely technology/cost evaluation and then to share the study results in the timeframe allowed for public involvement/public comments.
- Coincident with the issuance of the proposed regulation, Ecology has a statutory obligation to provide a Significant Legislative Rule evaluation, one element of which is a "determination whether the probable benefits of the rule are greater than its probable costs, taking into account both the qualitative and quantitative benefits and costs and the specific directives of the statute being implemented" (RCW 34.05.328(1)(d)). A statutory requirement also exists to assess the impact of the proposed regulation to small businesses. The implication is that Ecology will be conducting these economic evaluations in fourth quarter 2013 and early 2014. The Study Partners wanted to have a completed technology/cost study available to share with Ecology for their significant legislative rule/small business evaluations.
- The EPA, Indian tribes located in Washington, and various special interest groups have promoted the recently promulgated state of Oregon HHWQC (2011) as the "model" for Washington's revisions of HHWQC. The Oregon HHWQC are generally based on a increased FCR of 175 grams per day (g/day) and an excess cancer risk of 10^{-6}. While the Study Partners do not concede the wisdom or appropriateness of the Oregon criteria, or the selection of scientific/technical elements used to derive those criteria, the Study Partners nevertheless have selected the Oregon HHWQC as a viable "starting point" upon which this study could be based.

- The scenario assumes generally that Oregon's HHWQC for ambient waters will, for some parameters in fact, become effluent limitations for Washington NPDES permittees. The reasoning for this important assumption includes:
    - The state of Washington's NPDES permitting program is bound by the *Friends of Pinto Creek vs. EPA* decision in the United States Court of Appeals for the Ninth Circuit (October 4, 2007). This decision held that no NPDES permits authorizing new or expanded discharges of a pollutant into a waterbody identified as impaired; i.e., listed on CWA section 303(d), for that pollutant, may be issued until such time as "existing dischargers" into the waterbody are "subject to compliance schedules designed to bring the (waterbody) into compliance with applicable water quality standards." In essence, any new/expanded discharge of a pollutant causing impairment must achieve the HHWQC at the point of discharge into the waterbody.
    - If a waterbody segment is identified as "impaired" (i.e., not achieving a HHWQC), then Ecology will eventually need to produce a TMDL or water cleanup plan. For an existing NPDES permittee with a discharge of the pollutant for which the receiving water is impaired, the logical assumption is that any waste load allocation granted to the discharger will be at or lower than the numeric HHWQC (to facilitate recovery of the waterbody to HHWQC attainment). As a practical matter, this equates to an effluent limit established at the HHWQC.
    - Acceptance of Oregon HHWQC as the baseline for technology/cost review also means acceptance of practical implementation tools used by Oregon. The HHWQC for mercury is presented as a fish tissue methyl mercury concentration. For the purposes of NPDES permitting, however, Oregon has developed an implementation management directive which states that any confirmed detection of mercury is considered to represent a "reasonable potential" to cause or contribute to a water quality standards violation of the methyl mercury criteria. The minimum quantification level for total mercury is presented as 0.005 micrograms per liter (µg/L) (5.0 nanograms per liter (ng/L)).
    - The assumed effluent limit for arsenic is taken from EPA's *National Recommended Water Quality Criteria* (2012) (inorganic, water and organisms, 10^{-6} excess cancer risk). Oregon's 2011 criterion is actually based on a less protective excess cancer risk (10^{-4}). This, however, is the result of a state-specific risk management choice and it is unclear if Washington's Department of Ecology would mimic the Oregon approach.
    - The assumption is that no mixing zone is granted such that HHWQC will effectively serve as NPDES permit effluent limits. Prior discussion on the impact of the Pinto Creek decision, 303(d) impairment and TMDL Waste Load Allocations processes, all lend support to this "no mixing zone" condition for the parameters evaluated in this study.
- Consistent with Ecology practice in the evaluation of proposed regulations, the HHWQC are assumed to be in effect for a 20-year period. It is assumed that analytical measurement technology and capability will continue to improve over this time frame and this will result in the detection and lower quantification of additional HHWQC in ambient water and NPDES dischargers. This knowledge will trigger the Pinto Creek/303(d)/TMDL issues identified above and tend to pressure NPDES permittees to evaluate and install advanced treatment technologies. The costs and efficacy of treatment for these additional HHWQC is unknown at this time.

Other elements of the Study Partners work scope, as presented to HDR, must be noted:

- The selection of four toxic pollutants and development of a baseline effluent scenario is not meant to imply that each NPDES permittee wastewater discharge will include those pollutants at the assumed concentrations. Rather, the scenario was intended to represent a composite of many NPDES permittees and to facilitate evaluation of advanced treatment technologies relying on mechanical, biological, physical, chemical processes.
- The scalability of advanced treatment technologies to wastewater treatment systems with different flow capacities, and the resulting unit costs for capital and O&M, is evaluated.
- Similarly, a sensitivity analysis on the unit costs for capital and O&M was evaluated on the assumption the adopted HHWQC (and effectively, NPDES effluent limits) are one order-of-magnitude less stringent than the Table 1 values.

Table 1: Summary of Effluent Discharge Toxics Limits

Constituent	Human Health Criteria based Limits to be met with no Mixing Zone (µg/L)	Basis for Criteria	Typical Concentration in Municipal Secondary Effluent (µg/L)	Typical Concentration in Industrial Secondary Effluent (µg/L)	Existing Washington HHC (water + org.), NTR (µg/L)
PCBs	0.0000064	Oregon Table 40 Criterion (water + organisms) at FCR of 175 grams/day	0.0005 to 0.0025[b,c,d,e,f]	0.002 to 0.005[i]	0.0017
Mercury	0.005	DEQ IMD[a]	0.003 to 0.050[h]	0.010 to 0.050[h]	0.140
Arsenic	0.018	EPA National Toxics Rule (water + organisms)[k]	0.500 to 5.0[j]	10 to 40[j]	0.018
Benzo(a)Pyrene	0.0013	Oregon Table 40 Criterion (water + organisms) at FCR of 175 grams/day	0.00028 to 0.006[b,g]	0.006 to1.9	0.0028

[a] Oregon Department of Environmental Quality (ODEQ). Internal Management Directive: Implementation of Methylmercury Criterion in NPDES Permits. January 8, 2013.
[b] Control of Toxic Chemicals in Puget Sound, Summary Technical Report for Phase 3: Loadings from POTW Discharge of Treated Wastewater, Washington Department of Ecology, Publication Number 10-10-057, December 2010.
[c] Spokane River PCB Source Assessment 2003-2007, Washington Department of Ecology, Publication No. 11-03-013, April 2011.
[d] Lower Okanogan River Basin DDT and PCBs Total Maximum Daily Load, Submittal Report, Washington Department of Ecology, Publication Number 04-10-043, October 2004.
[e] Palouse River Watershed PCB and Dieldrin Monitoring, 2007-2008, Wastewater Treatment Plants and Abandoned Landfills, Washington Department of Ecology, Publication No. 09-03-004, January 2009
[f] A Total Maximum Daily Load Evaluation for Chlorinated Pesticides and PCBs in the Walla Walla River, Washington Department of Ecology, Publication No. 04-03-032, October 2004.
[g] Removal of Polycyclic Aromatic Hydrocarbons and Heterocyclic Nitrogenous Compounds by A POTW Receiving Industrial Discharges, Melcer, H., Steel, P. and Bedford, W.K., Water Environment Federation, 66th Annual Conference and Exposition, October 1993.
[h] Data provided by Lincoln Loehr's summary of WDOE Puget Sound Loading data in emails from July 19, 2013.
[i] NCASI memo from Larry Lefleur, NCASI, to Llewellyn Matthews, NWPPA, revised June 17, 2011, summarizing available PCB monitoring data results from various sources.
[j] Professional judgment, discussed in August 6, 2013 team call.
[k] The applicable Washington Human Health Criteria cross-reference the EPA National Toxics Rule, 40 CFR 131.36. The EPA arsenic HHC is 0.018 ug/L for water and organisms.

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3.0 Wastewater Characterization Description

This section describes the wastewater treatment discharge considered in this technology evaluation. Treated wastewater characteristics are described, including average and peak flow, effluent concentrations, and toxic compounds of concern.

3.1 Summary of Wastewater Characterization

A general wastewater treatment process and wastewater characteristics were developed as the common baseline to represent the existing conditions as a starting point for comparison with potential future advanced treatment technologies and improvements. A secondary treatment process with disinfection at a flow of 5 mgd as the current, baseline treatment system for existing dischargers was also developed. Typical effluent biochemical oxygen demand (BOD) and total suspended solids (TSS) were assumed between 10 to 30 mg/L from such a facility and no nutrient or toxics removal was assumed to be accomplished in the existing baseline treatment process.

3.2 Existing Wastewater Treatment Facility

The first step in the process is to characterize the existing wastewater treatment plant to be evaluated in this study. The goal is to identify the necessary technology that would need to be added to an existing treatment facility to comply with revised toxic pollutant effluent limits. Rather than evaluating the technologies and costs to upgrade multiple actual operating facilities, the Study Partners specified that a generalized municipal/industrial wastewater treatment facility would be characterized and used as the basis for developing toxic removal approaches. General characteristics of the facility's discharge are described in Table 2.

Table 2. General Wastewater Treatment Facility Characteristics

Average Annual Wastewater Flow, mgd	Maximum Month Wastewater Flow, mgd	Peak Hourly Wastewater Flow, mgd	Effluent BOD, mg/L	Effluent TSS, mg/L
5.0	6.25	15.0	10 to 30	10 to 30

mgd=million gallons per day
mg/L=milligrams per liter
BOD=biochemical oxygen demand
TSS=total suspended solids

In the development of the advanced treatment technologies presented below, the capacity of major treatment elements are generally sized to accommodate the maximum month average wastewater flow. Hydraulic elements, such as pumps and pipelines, were selected to accommodate the peak hourly wastewater flow.

The general treatment facility incorporates a baseline treatment processes including influent screening, grit removal, primary sedimentation, suspended growth biological treatment (activated sludge), secondary clarification, and disinfection using chlorine. Solids removed during primary treatment and secondary clarification are assumed to be thickened, stabilized, dewatered, and land applied to agricultural land. The biological treatment process is assumed to be activated sludge with a relatively short (less than 10-day) solids retention time. The baseline secondary treatment facility is assumed not to have processes dedicated to removing nutrients or toxics. However, some coincident removal of toxics will occur during conventional treatment.

3.3 Toxic Constituents

As described in Section 2.3, the expectation of more stringent HHWQC will eventually trigger regulatory demands for NPDES permittees to install advanced treatment technologies. The Study Group and HDR selected four specific toxic pollutants reflecting a range of toxic constituents as the basis for this study to limit the constituents and technologies to be evaluated to a manageable level.

The four toxic pollutants selected were PCBs, mercury, arsenic, and BAP, a polycyclic aromatic hydrocarbon (PAH). Mercury and arsenic are metals, and PCBs and PAHs are organic compounds. Technologies for removing metals and organic compounds are in some cases different. Key information on each of the compounds, including a description of the constituent, the significance of each constituent, proposed HHWQC, basis for the proposed criteria, typical concentration in both municipal and industrial secondary effluent, and current Washington state water quality criteria, are shown in Table 1. It is assumed that compliance with the proposed criteria in the table would need to be achieved at the “end of pipe” and Ecology would not permit a mixing zone for toxic constituents. This represents a “worst–case,” but a plausible assumption about discharge conditions.

4.0 Treatment Approaches and Costs

4.1 Summary of Treatment Approach and Costs

Two advanced treatment process options for toxics removal for further evaluation based on the characterization of removal effectiveness from the technical literature review and Study Group preferences. The two tertiary treatment options are microfiltration MF followed by either RO or GAC as an addition to an existing secondary treatment facility. Based on the literature review, it is not anticipated that any of the treatment options will be effective in reducing all of the selected pollutants to below the anticipated water quality criteria. A summary of the capital and operations and maintenance costs for tertiary treatment is provided, as well as a comparison of the adverse environmental impacts for each alternative.

4.2 Constituent Removal – Literature Review

The evaluation of treatment technologies relevant to the constituents of concern was initiated with a literature review. The literature review included a desktop search using typical web-based search engines, and search engines dedicated to technical and research journal databases. At the same time, HDR's experience with the performance of existing treatment technologies specifically related to the four constituents of concern, was used in evaluating candidate technologies. A summary of the constituents of concern and relevant treatment technologies is provided in the following literature review section.

4.2.1 Polychlorinated Biphenyls

PCBs are persistent organic pollutants that can be difficult to remove in treatment. PCB treatment in wastewater can be achieved using oxidation with peroxide, filtration, biological treatment or a combination of these technologies. There is limited information available about achieving ultra-low effluent PCB concentrations near the 0.0000064 µg/L range under consideration in the proposed rulemaking process. This review provides a summary of treatment technology options and anticipated effluent PCB concentrations.

Research on the effectiveness of ultraviolet (UV) light and peroxide on removing PCBs was tested in bench scale batch reactions (Yu, Macawile, Abella, & Gallardo 2011). The combination of UV and peroxide treatment achieved PCB removal greater than 89 percent, and in several cases exceeding 98 percent removal. The influent PCB concentration for the batch tests ranged from 50 to 100 micrograms per liter (µg/L). The final PCB concentration (for the one congener tested) was <10 µg/L (10,000 ng/L) for all tests and <5 µg/L (5,000 ng/L) for some tests. The lowest PCB concentrations in the effluent occurred at higher UV and peroxide doses.

Pilot testing was performed to determine the effectiveness of conventional activated sludge and a membrane bioreactor to remove PCBs (Bolzonella, Fatone, Pavan, & Cecchi 2010). EPA Method 1668 was used for the PCB analysis (detection limit of 0.01 ng/L per congener). Influent to the pilot system was a combination of municipal and industrial effluent. The detailed analysis was for several individual congeners. Limited testing using the Aroclor method (total PCBs) was used to compare the individual congeners and the total concentration of PCBs. Both conventional activated sludge and membrane bioreactor (MBR) systems removed PCBs. The effluent MBR concentrations ranged from <0.01 ng/L to 0.04 ng/L compared to <0.01 ng/L to 0.88 ng/L for conventional activated sludge. The pilot testing showed that increased solids retention time (SRT) and higher mixed liquor suspended solids concentrations in the MBR system led to increased removal in the liquid stream.

Bench scale studies were completed to test the effectiveness of GAC and biological activated carbon (BAC) for removing PCBs (Ghosh, Weber, Jensen, & Smith 1999). The effluent from the

GAC system was 800 ng/L. The biological film in the BAC system was presumed to support higher PCB removal with effluent concentrations of 200 ng/L. High suspended sediment in the GAC influent can affect performance. It is recommended that filtration be installed upstream of a GAC system to reduce solids and improve effectiveness.

Based on limited available data, it appears that existing municipal secondary treatment facilities in Washington state are able to reduce effluent PCBs to the range approximately 0.10 to 1.5 ng/L. It appears that the best performing existing municipal treatment facility in Washington state with a microfiltration membrane is able to reduce effluent PCBs to the range approximately 0.00019 to 0.00063 µg/L. This is based on a very limited data set and laboratory blanks covered a range that overlapped with the effluent results (blanks 0.000058 to 0.00061 µg/L).

Addition of advanced treatment processes would be expected to enhance PCB removal rates, but the technical literature does not appear to provide definitive information for guidance. A range of expected enhanced removal rates might be assumed to vary widely from level of the reference microfiltration facility of 0.19 to 0.63 ng/L.

Summary of PCB Technologies

The literature review revealed there are viable technologies available to reduce PCBs **but no research was identified with treatment technologies capable of meeting the anticipated human health criteria based limits for PCB removal**. Based on this review, a tertiary process was selected to biologically reduce PCBs and separate the solids using tertiary filtration. Alternately, GAC was investigated as an option to reduce PCBs, although it is not proven that it will meet revised effluent limits.

4.2.2 Mercury

Mercury removal from wastewater can be achieved using precipitation, adsorption, filtration, or a combination of these technologies. There is limited information available about achieving ultra-low effluent mercury concentrations near the 5 ng/L range under consideration in the proposed rulemaking process. This review provides a summary of treatment technology options and anticipated effluent mercury concentrations.

Precipitation (and co-precipitation) involves chemical addition to form a particulate and solids separation, using sedimentation or filtration. Precipitation includes the addition of a chemical precipitant and pH adjustment to optimize the precipitation reaction. Chemicals can include metal salts (ferric chloride, ferric sulfate, ferric hydroxide, or alum), pH adjustment, lime softening, or sulfide. A common precipitant for mercury removal is sulfide, with an optimal pH between 7 and 9. The dissolved mercury is precipitated with the sulfide to form an insoluble mercury sulfide that can be removed through clarification or filtration. One disadvantage of precipitation is the generation of a mercury-laden sludge that will require dewatering and disposal. The mercury sludge may be considered a hazardous waste and require additional treatment and disposal at a hazardous waste site. The presence of other compounds, such as other metals, may reduce the effectiveness of mercury precipitation/co-precipitation. For low-level mercury treatment requirements, several treatment steps will likely be required in pursuit of very low effluent targets.

EPA compiled a summary of facilities that are using precipitation/co-precipitation for mercury treatment (EPA 2007). Three of the full-scale facilities were pumping and treating groundwater and the remaining eight facilities were full-scale wastewater treatment plants. One of the pump and treat systems used precipitation, carbon adsorption, and pH adjustment to treat groundwater to effluent concentrations of 300 ng/L.

Adsorption treatment can be used to remove inorganic mercury from water. While adsorption can be used as a primary treatment step, it is frequently used for polishing after a preliminary treatment step (EPA 2007). One disadvantage of adsorption treatment is that when the adsorbent is saturated, it either needs to be regenerated or disposed of and replaced with new adsorbent. A common adsorbent is GAC. There are several patented and proprietary adsorbents on the market for mercury removal. Adsorption effectiveness can be affected by water quality characteristics, including high solids and bacterial growth, which can cause media blinding. A constant and low flow rate to the adsorption beds increases effectiveness (EPA 2007). The optimal pH for mercury adsorption on GAC is pH 4 to 5; therefore, pH adjustment may be required.

EPA compiled a summary of facilities that are using adsorption for mercury treatment (EPA 2007). Some of the facilities use precipitation and adsorption as described above. The six summarized facilities included two groundwater treatment and four wastewater treatment facilities. The reported effluent mercury concentrations were all less than 2,000 ng/L (EPA 2007).

Membrane filtration can be used in combination with a preceding treatment step. The upstream treatment is required to precipitate soluble mercury to a particulate form that can be removed through filtration. According to the EPA summary report, ultrafiltration is used to remove high-molecular weigh contaminants and solids (EPA 2007). The treatment effectiveness can depend on the source water quality since many constituents can cause membrane fouling, decreasing the effectiveness of the filters. One case study summarized in the EPA report showed that treatment of waste from a hazardous waste combustor treated with precipitation, sedimentation, and filtration achieved effluent mercury concentrations less than the detection limit of 200 ng/L.

Bench-scale research performed at the Oak Ridge Y-12 Plant in Tennessee evaluated the effectiveness of various adsorbents for removing mercury to below the NPDES limit of 12 ng/L and the potential revised limit of 51 ng/L (Hollerman et al. 1999). Several proprietary adsorbents were tested, including carbon, polyacrylate, polystyrene, and polymer adsorption materials. The adsorbents with thiol-based active sites were the most effective. Some of the adsorbents were able to achieve effluent concentrations less than 51 ng/L but none of the adsorbents achieved effluent concentrations less than 12 ng/L.

Bench-scale and pilot-scale testing performed on refinery wastewater was completed to determine treatment technology effectiveness for meeting very low mercury levels (Urgun-Demirtas, Benda, Gillenwater, Negri, Xiong & Snyder 2012) (Urgun-Demirtas, Negri, Gillenwater, Agwu Nnanna & Yu 2013). The Great Lakes Initiative water quality criterion for mercury is less than 1.3 ng/L for municipal and industrial wastewater plants in the Great Lakes region. This research included an initial bench scale test including membrane filtration, ultrafiltration, nanofiltration, and reverse osmosis to meet the mercury water quality criterion. The nanofiltration and reverse osmosis required increased pressures for filtration and resulted in increased mercury concentrations in the permeate. Based on this information and the cost difference between the filtration technologies, a pilot-scale test was performed. The 0.04 um PVDF GE ZeeWeed 500 series membranes were tested. The 1.3 ng/L water quality criterion was met under all pilot study operating conditions. The mercury in the refinery effluent was predominantly in particulate form which was well-suited for removal using membrane filtration.

Based on available data, it appears that existing municipal treatment facilities are capable of reducing effluent mercury to near the range of the proposed HHWQC on an average basis. Average effluent mercury in the range of 1.2 to 6.6 ng/L for existing facilities with secondary treatment and enhanced treatment with cloth filters and membranes. The Spokane County plant data range is an average of 1.2 ng/L to a maximum day of 3 ng/L. Addition of advanced treatment processes such as GAC or RO would be expected to enhance removal rates. Data from the West Basin treatment facility in California suggests that at a detection limit of 7.99 ng/L mercury is not detected in the effluent from this advanced process train. A range of expected enhanced removal rates from the advanced treatment process trains might be expected to ranged from meeting the proposed standard at 5 ng/L to lower concentrations represented by the Spokane County performance level (membrane filtration) in the range of 1 to 3 ng/L, to perhaps even lower levels with additional treatment. For municipal plants in Washington, this would suggest that effluent mercury values from the two advanced treatment process alternatives might range from 1 to 5 ng/L (0.001 to 0.005 µg/L) and perhaps substantially better, depending upon RO and GAC removals. It is important to note that industrial plants may have higher existing mercury levels and thus the effluent quality that is achievable at an industrial facility would be of lower quality.

Summary of Mercury Technologies

The literature search revealed limited research on mercury removal technologies at the revised effluent limit of 0.005 µg/L. Tertiary filtration with membrane filters or reverse osmosis showed the best ability to achieve effluent criteria less than 0.005 µg/L.

4.2.3 Arsenic

A variety of treatment technologies can be applied to capture arsenic (Table 3). Most of the information in the technical literature and from the treatment technology vendors is focused on potable water treatment for compliance with a Safe Drinking Water Act (SDWA) maximum contaminant level (MCL) of 10 µg/L. The most commonly used arsenic removal method for a wastewater application (tertiary treatment) is coagulation/ flocculation plus filtration. This method by itself could remove more than 90 to 95 percent of arsenic. Additional post-treatment through adsorption, ion exchange, or reverse osmosis is required for ultra-low arsenic limits in the 0.018 µg/L range under consideration in the proposed rulemaking process. In each case it is recommended to perform pilot-testing of each selected technology.

Table 3: Summary of Arsenic Removal Technologies[1]

Technology	Advantages	Disadvantages
Coagulation/filtration	• Simple, proven technology • Widely accepted • Moderate operator training	• pH sensitive • Potential disposal issues of backwash waste • As^{+3} and As^{+5} must be fully oxidized
Lime softening	• High level arsenic treatment • Simple operation change for existing lime softening facilities	• pH sensitive (requires post treatment adjustment) • Requires filtration • Significant sludge operation
Adsorptive media	• High As^{+5} selectivity • Effectively treats water with high total dissolved solids (TDS)	• Highly pH sensitive • Hazardous chemical use in media regeneration • High concentration SeO_4^{-2}, F^-, Cl^-, and SO_4^{-2} may limit arsenic removal

Table 3: Summary of Arsenic Removal Technologies[1]

Technology	Advantages	Disadvantages
Ion exchange	• Low contact times • Removal of multiple anions, including arsenic, chromium, and uranium	• Requires removal of iron, manganese, sulfides, etc. to prevent fouling • Brine waste disposal
Membrane filtration	• High arsenic removal efficiency • Removal of multiple contaminants	• Reject water disposal • Poor production efficiency • Requires pretreatment

[1]Adapted from WesTech

The removal of arsenic in activated sludge is minimal (less than 20 percent) (Andrianisa et al. 2006), but biological treatment can control arsenic speciation. During aerobic biological process As (III) is oxidized to As (V). Coagulation/flocculation/filtration removal, as well as adsorption removal methods, are more effective in removal of As(V) vs. As (III). A combination of activated sludge and post-activated sludge precipitation with ferric chloride (addition to MLSS and effluent) results in a removal efficiency of greater than 95 percent. This combination could decrease As levels from 200 µg/L to less than 5 µg/L (5,000 ng/L) (Andrianisa et al. 2008) compared to the 0.018 µg/L range under consideration in the proposed rulemaking process.

Data from the West Basin facility (using MF/RO/AOP) suggests effluent performance in the range of 0.1 to 0.2 µg/L, but it could also be lower since a detection limit used there of 0.15 µg/l is an order of magnitude higher than the proposed HHWQC. A range of expected enhanced removal rates might be assumed to equivalent to that achieved at West Basin in 0.1 to 0.2 µg/L range.

Review of Specific Technologies for Arsenic Removal

Coagulation plus Settling or Filtration

Coagulation may remove more than 95 percent of arsenic through the creation of particulate metal hydroxides. Ferric sulfite is typically more efficient and applicable to most wastewater sources compared to alum. The applicability and extent of removal should be pilot-tested, since removal efficiency is highly dependent on the water constituents and water characteristics (i.e., pH, temperature, solids).

Filtration can be added after or instead of settling to increase arsenic removal. Example treatment trains with filtration are shown in Figures 1 and 2, respectively.

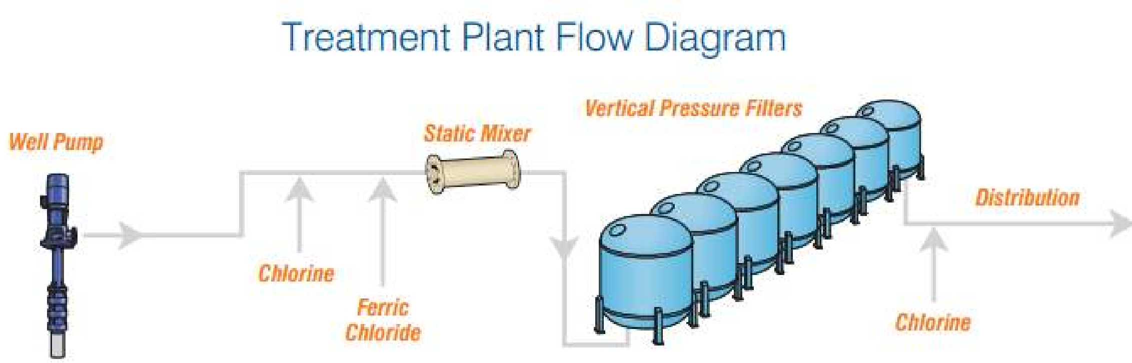

Figure 1. Water Treatment Configuration for Arsenic Removal (WesTech)

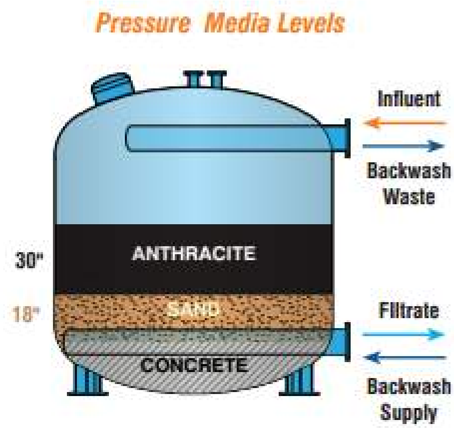

Figure 2. WesTech Pressure Filters for Arsenic Removal

One system for treatment of potable water with high levels of arsenic in Colorado (110 parts per million [ppm]) consists of enhanced coagulation followed by granular media pressure filters that include anthracite/silica sand/garnet media (WesTech). The arsenic levels were reduced to less than the drinking water MCL, which is 10 µg/L (10,000 ng/L). The plant achieves treatment by reducing the pH of the raw water to 6.8 using sulfuric acid, and then adding approximately 12 to 14 mg/L ferric sulfate. The water is filtered through 16 deep bed vertical pressure filters, the pH is elevated with hydrated lime and is subsequently chlorinated and fed into the distribution system.
(http://www.westechinc.com/public/uploads/global/2011/3/Fallon%20NV%20Installation%20ReportPressureFilter.pdf).

Softening (with lime)

Removes up to 90 percent arsenic through co-precipitation, but requires pH to be higher than 10.2.

Adsorption processes

Activated alumina is considered an adsorptive media, although the chemical reaction is an exchange of arsenic ions with the surface hydroxides on the alumina. When all the surface hydroxides on the alumina have been exchanged, the media must be regenerated. Regeneration consists of backwashing, followed by sodium hydroxide, flushing with water and neutralization with a strong acid. Effective arsenic removal requires sufficient empty bed contact time. Removal efficiency can also be impacted by the water pH, with neutral or slightly acidic conditions being considered optimum. If As (III) is present, it is generally advisable to increase empty bed contact time, as As (III) is adsorbed more slowly than As (V). Alumina dissolves slowly over time due to contact with the chemicals used for regeneration. As a result, the media bed is likely to become compacted if it is not backwashed periodically.

Granular ferric hydroxide works by adsorption, but when the media is spent it cannot be regenerated and must be replaced. The life of the media depends upon pH of the raw water, the concentrations of arsenic and heavy metals, and the volume of water treated daily. Periodic backwashing is required to prevent the media bed from becoming compacted and pH may need to be adjusted if it is high, in order to extend media life. For maximum arsenic removal, filters operate in series. For less stringent removal, filters can operate in parallel.

One type of adsorption media has been developed for application to non-drinking water processes for arsenic, phosphate and for heavy metals removal by sorption (Severent Trent Bayoxide® E IN-20). This granular ferric oxide media has been used for arsenic removal from mining and industrial wastewaters, selenium removal from refinery wastes and for phosphate polishing of municipal wastewaters. Valley Vista drinking water treatment with Bayoxide® E IN-20 media achieves removal from 31-39 µg/L (31,000-39,000 ng/L) to below 10 µg/L MCL (http://www.severntrentservices.com/News/Successful_Drinking_Water_Treatment_in_an_Arsenic__Hot_Spot__nwMFT_452.aspx).

Another adsorptive filter media is greensand. Greensand is available in two forms: as glauconite with manganese dioxide bound ionically to the granules and as silica sand with manganese dioxide fused to the granules. Both forms operate in pressure filters and both are effective. Greensand with the silica sand core operates at higher water temperatures and higher differential pressures than does greensand with the glauconite core. Arsenic removal requires a minimum concentration of iron. If a sufficient concentration of iron is not present in the raw water, ferric chloride is added.

WesTech filters with greensand and permanganate addition for drinking water systems can reduce As from 15-25 µg/L to non-detect. Sodium hypochlorite and/or potassium permanganate are added to the raw water prior to the filters. Chemical addition may be done continuously or intermittently, depending on raw water characteristics. These chemicals oxidize the iron in the raw water and also maintain the active properties of the greensand itself. Arsenic removal is via co-precipitation with the iron.

Ion Exchange

Siemens offers a potable ion exchange (PIX) arsenic water filtration system. PIX uses ion exchange resin canisters for the removal of organic and inorganic contaminants, in surface and groundwater sources to meet drinking water standards.

Filtronics also uses ion exchange to treat arsenic. The technology allows removal for below the SWDA MCL for potable water of 10 µg/L (10,000 ng/L).

Reverse osmosis

Arsenic is effectively removed by RO when it is in oxidative state As(V) to approximately 1,000 ng/L or less (Ning 2002).

Summary of Arsenic Technologies

The current state of the technology for arsenic removal is at the point where all the processes target the SWDA MCL for arsenic in potable water. Current EPA maximum concentration level for drinking water is 10 ug/l; much higher than 0.0018 µg/L target for arsenic in this study. The majority of the methods discussed above are able to remove arsenic to either EPA maximum contaminant level or to the level of detection. The lowest detection limit of one of the EPA approved methods of arsenic measurements is 20 ng/l (0.020 µg/l) (Grosser, 2010), which is comparable to the 0.018 µg/L limit targeted in this study.

4.2.1 Polycyclic Aromatic Hydrocarbons

BAP During Biological Treatment

During wastewater treatment process, BAP tends to partition into sludge organic matter (Melcer et al. 1993). Primary and secondary processing could remove up to 60 percent of incoming PAHs and BAP in particular, mostly due to adsorption to sludge (Kindaichi et al., NA, Wayne et al. 2009). Biodegradation of BAP is expected to be very low since there are more than five benzene rings which are resistant to biological degradation. Biosurfactant addition to biological process could partially improve biodegradation, but only up to removal rates of 50 percent (Sponza et al. 2010). Existing data from municipal treatment facilities in Washington state have influent and effluent concentrations of BAP of approximately 0.30 ng/L indicating that current secondary treatment has limited effectiveness at BAP removal.

Methods to Enhance Biological Treatment of BAP

Ozonation prior to biological treatment could potentially improve biodegradability of BAP (Zeng et al. 2000). In the case of soil remediation, ozonation before biotreatment improved biodegradation by 70 percent (Russo et al. 2012). The overall removal of BAP increased from 23 to 91 percent after exposure of water to 0.5 mg/L ozone for 30 minutes during the simultaneous treatment process and further to 100 percent following exposure to 2.5 mg/L ozone for 60 minutes during the sequential treatment mode (Yerushalmi et al. 2006). In general, to improve biodegradability of BAP, long exposure to ozone might be required (Haapea et al. 2006).

Sonication pre-treatment or electronic beam irradiation before biological treatment might also make PAHs more bioavailable for biological degradation..

Recent studies reported that a MBR is capable of removing PAHs from wastewater (Rodrigue and Reilly 2009; Gonzaleza et al. 2012). None of the studies listed the specific PAHs constituents removed.

Removal of BAP from Drinking Water

Activated Carbon

Since BAP has an affinity to particulate matter, it is removed from the drinking water sources by means of adsorption, such as granular activated carbon (EPA). Similarly, Oleszczuk et al. (2012) showed that addition of 5 percent activated carbon could remove 90 percent of PAHs from the wastewater.

Reverse Osmosis

Light (1981) (referenced by Williams, 2003) studied dilute solutions of PAHs, aromatic amines, and nitrosamines and found rejections of these compounds in reverse osmosis to be over 99 percent for polyamide membranes. Bhattacharyya et al. (1987) (referenced by Williams, 2003) investigated rejection and flux characteristics of FT30 membranes for separating various pollutants (PAHs, chlorophenols, nitrophenols) and found membrane rejections were high (>98 percent) for the organics under ionized conditions.

Summary of BAP Technologies

Current technologies show that BAP removal may be 90 percent or greater. The lowest detection limit for BAP measurements is 0.006 µg/L, which is also the assumed secondary effluent BAP concentration assumed for this study. If this assumption is accurate, it appears technologies may exist to remove BAP to a level below the proposed criteria applied as an effluent limit of 0.0013 µg/L; however, detection limits exceed this value and it is impossible to know this for certain. A municipal wastewater treatment plant study reported both influent and effluent BAP concentrations less than the HHWQC of 0.0013 ug/L (Ecology, 2010).

4.3 Unit Processes Evaluated

Based on the results of the literature review, a wide range of technologies were evaluated for toxic constituent removal. A listing of the technologies is as follows:

- Chemically enhanced primary treatment (CEPT): this physical and chemical technology is based on the addition of a metal salt to precipitate particles prior to primary treatment, followed by sedimentation of particles in the primary clarifiers. This technology has been shown to effectively remove arsenic but there is little data supporting the claims. As a result, the chemical facilities are listed as optional.

- Activated sludge treatment (with a short SRT of approximately 8 days or less): this biological technology is commonly referred to as secondary treatment. It relies on converting dissolved organics into solids using biomass. Having a short SRT is effective at removing degradable organics referred to as BOD compounds for meeting existing discharge limits. Dissolved constituents with a high affinity to adsorb to biomass (e.g., metals, high molecular weight organics, and others) will be better removed compared to smaller molecular weight organics and recalcitrant compounds which will have minimal removal at a short SRT.
- Enhanced activated sludge treatment (with a long SRT of approximately 8 days or more): this technology builds on secondary treatment by providing a longer SRT, which enhances sorption and biodegradation. The improved performance is based on having more biomass coupled with a more diverse biomass community, especially nitrifiers, which have been shown to assist in removal of some of the more recalcitrant constituents not removed with a shorter SRT (e.g., lower molecular weight PAHs). There is little or no data available on the effectiveness of this treatment for removing BAP.

  Additional benefits associated with having a longer SRT are as follows:

  - Lower BOD/TSS discharge load to receiving water
  - Improved water quality and benefit to downstream users
  - Lower effluent nutrient concentrations which reduce algal growth potential in receiving waters
  - Reduced receiving water dissolved oxygen demand due to ammonia removal
  - Reduced ammonia discharge, which is toxic to aquatic species
  - Improved water quality for habitat, especially as it relates to biodiversity and eutrophication
  - Secondary clarifier effluent more conditioned for filtration and disinfection
  - Greater process stability from the anaerobic/anoxic zones serving as biological selectors
- Coagulation/Flocculation and Filtration: this two-stage chemical and physical process relies on the addition of a metal salt to precipitate particles in the first stage, followed by the physical removal of particles in filtration. This technology lends itself to constituents prone to precipitation (e.g., arsenic).
- Lime Softening: this chemical process relies on increasing the pH as a means to either volatilize dissolved constituents or inactivate pathogens. Given that none of the constituents being studied are expected to volatilize, this technology was not carried forward.
- Adsorptive Media: this physical and chemical process adsorbs constituents to a combination of media and/or biomass/chemicals on the media. There are several types of media, with the most proven and common being GAC. GAC can also serve as a coarse roughing filter.
- Ion Exchange: this chemical technology exchanges targeted constituents with a resin. This technology is common with water softeners where the hard divalent cations are

exchanged for monovalent cations to soften the water. Recently, resins that target arsenic and mercury removal include activated alumina and granular ferric hydroxides have been developed. The resin needs to be cleaned and regenerated, which produces a waste slurry that requires subsequent treatment and disposal. As a result, ion exchange was not considered for further.

- Membrane Filtration: This physical treatment relies on the removal of particles larger than the membranes pore size. There are several different membrane pore sizes as categorized below.
  - Microfiltration (MF): nominal pore size range of typically between 0.1 to 1 micron. This pore size targets particles, both inert and biological, and bacteria. If placed in series with coagulation/flocculation upstream, dissolved constituents precipitated out of solution and bacteria can be removed by the MF membrane.
  - Ultrafiltration (UF): nominal pore size range of typically between 0.01 to 0.1 micron. This pore size targets those solids removed with MF (particles and bacteria) plus viruses and some colloidal material. If placed in series with coagulation/flocculation upstream, dissolved constituents precipitated out of solution can be removed by the UF membrane.
  - Nanofiltration (NF): nominal pore size range of typically between 0.001 to 0.010 micron. This pore size targets those removed with UF (particles, bacteria, viruses) plus colloidal material. If placed in series with coagulation/flocculation upstream, dissolved constituents precipitated out of solution can be removed by the NF membrane.
- MBR (with a long SRT): this technology builds on secondary treatment whereby the membrane (microfiltration) replaces the secondary clarifier for solids separation. As a result, the footprint is smaller, the mixed liquor suspended solids concentration can be increased to about 5,000 – 10,000 mg/L, and the physical space required for the facility reduced when compared to conventional activated sludge. As with the activated sludge option operated at a longer SRT, the sorption and biodegradation of organic compounds are enhanced in the MBR process. The improved performance is based on having more biomass coupled with a more diverse biomass community, especially nitrifiers which have been shown to assist in removal of persistent dissolved compounds (e.g., some PAHs). There is little or no data available on effectiveness at removing BAP. Although a proven technology, MBRs were not carried further in this technology review since they are less likely to be selected as a retrofit for an existing activated sludge (with a short SRT) secondary treatment facility. The MBR was considered to represent a treatment process approach more likely to be selected for a new, greenfield treatment facility. Retrofits to existing secondary treatment facilities can accomplish similar process enhancement by extending the SRT in the activated sludge process followed by the addition of tertiary membrane filtration units.
- RO: This physical treatment method relies on the use of sufficient pressure to osmotically displace water across the membrane surface while simultaneously rejecting most salts. RO is very effective at removing material smaller than the size ranges for the membrane filtration list above, as well as salts and other organic compounds. As a result, it is expected to be more effective than filtration and MBR methods described above at removing dissolved constituents. Although effective, RO produces a brine reject water that must be managed and disposed.

- Advanced Oxidation Processes (AOPs): this broad term considers all chemical and physical technologies that create strong hydroxyl-radicals. Examples of AOPs include Fenton's oxidation, ozonation, ultraviolet/hydrogen peroxide (UV-H2O2), and others. The radicals produced are rapid and highly reactive at breaking down recalcitrant compounds. Although effective at removing many complex compounds such as those evaluated in this study, AOPs does not typically have as many installations as membranes and activated carbon technologies. As a result, AOPs were not carried forward.

Based on the technical literature review discussed above, a summary of estimated contaminant removal rated by unit treatment process is presented in Table 4.

Table 4. Contaminants Removal Breakdown by Unit Process

Unit Process	Arsenic	BAP	Mercury	Polychlorinated Biphenyls
Activated Sludge Short SRT	No removal	Partial Removal by partitioning		80% removal; effluent <0.88 ng/L
Activated Sludge Long SRT	No removal	Partial removal by partitioning and/or partially biodegradation; MBR could potentially remove most of BAP		>90% removal with a membrane bioreactor, <0.04 ng/L (includes membrane filtration)
Membrane Filtration (MF)	More than 90 % removal (rejection of bound arsenic)	No removal	<1.3 ng/L	>90% removal with a membrane bioreactor, <0.04 ng/L (includes membrane filtration)
Reverse Osmosis (RO)	More than 90% removal (rejection of bound arsenic and removal of soluble arsenic)	More than 98% removal		
Granular Activated Carbon (GAC)	No removal, removal only when carbon is impregnated with iron	90 % removal	<300 ng/L (precipitation and carbon adsorption) <51 ng/L (GAC)	<800 ng/L Likely requires upstream filtration
Disinfection	--	--	--	--

4.4 Unit Processes Selected

The key conclusion from the literature review was that there is limited, to no evidence, that existing treatment technologies are capable of simultaneously meeting all four of the revised discharge limits for the toxics under consideration. Advanced treatment using RO or GAC is expected to provide the best overall removal of the constituents of concern. It is unclear whether these advanced technologies are able to meet revised effluent limits, however these processes may achieve the best effluent quality of the technologies reviewed. This limitation in the findings is based on a lack of an extensive dataset on treatment removal effectiveness in the technical literature for the constituents of interest at the low levels relevant to the proposed criteria, which approach the limits of reliable removal performance for the technologies. As Table 4 highlights, certain unit processes are capable of removing a portion, or all, of the removal requirements for each technology. The removal performance for each constituent will vary from facility to facility and require a site-specific, detailed evaluation because the proposed criteria are such low concentrations. In some cases, a facility may only have elevated concentrations of a single constituent of concern identified in this study. In other cases, a discharger may have elevated concentrations of the four constituents identified in this study, as well as others not identified in this study but subject to revised water quality criteria. This effort is intended to describe a planning level concept of what treatment processes are required to comply with discharge limits for all four constituents. Based on the literature review of unit processes above, two different treatment trains were developed for the analysis that are compared against a baseline of secondary treatment as follows:

- Baseline: represents conventional secondary treatment that is most commonly employed nationwide at wastewater treatment plants. A distinguishing feature for this treatment is the short solids residence time (SRT) (<8 days) is intended for removal of BOD with minimal removal for the toxic constituents of concern.
- Advanced Treatment – MF/RO: builds on baseline with the implementation of a longer SRT (>8 days) and the addition of MF and RO. The longer SRT not only removes BOD, but it also has the capacity to remove nutrients and a portion of the constituents of concern. This alternative requires a RO brine management strategy which will be discussed in sub-sections below.
- Advanced Treatment – MF/GAC: this alternative provides a different approach to advanced treatment with MF/RO by using GAC and avoiding the RO reject brine water management concern. Similar to the MF/RO process, this alternative has the longer SRT (>8 days) with the capacity to remove BOD, nutrients, and a portion of the toxic constituents of concern. As a result, the decision was made to develop costs for both advanced treatment options.

A description of each alternative is provided in Table 5. The process flowsheets for each alternative are presented in Figure 3 to Figure 5.

4.4.1 Baseline Treatment Process

A flowsheet of the baseline treatment process is provided in Figure 3. The baseline treatment process assumes the current method of treatment commonly employed by dischargers. For this process, water enters the headworks and undergoes primary treatment, followed by conventional activated sludge (short SRT) and disinfection. The solids wasted in the activated sludge process are thickened, followed by mixing with primary solids prior to entering the anaerobic digestion process for solids stabilization. The digested biosolids are dewatered to produce a cake and hauled off-site. Since the exact process for each interested facility in Washington is unique, this baseline treatment process was used to establish the baseline capital and O&M costs. The baseline costs will be compared against the advanced treatment alternatives to illustrate the magnitude of the increased costs and environmental impacts.

Table 5. Unit Processes Description for Each Alternative

Unit Process	Baseline	Advanced Treatment – MF/RO	Advanced Treatment - GAC
Influent Flow	5 mgd	5 mgd	5 mgd
Chemically Enhanced Primary Treatment (CEPT); Optional	--	• Metal salt addition (alum) upstream of primaries	• Metal salt addition (alum) upstream of primaries
Activated Sludge	• Hydraulic Residence Time (HRT): 6 hrs • Short Solids Residence Time (SRT): <8 days	• Hydraulic Residence Time (HRT): 12 hrs (Requires more tankage than the Baseline) • Long Solids Residence Time (SRT): >8 days (Requires more tankage than the Baseline)	• Hydraulic Residence Time (HRT): 12 hrs (Requires more tankage than the Baseline) • Long Solids Residence Time (SRT): >8 days (Requires more tankage than the Baseline)
Secondary Clarifiers	Hydraulically Limited	Solids Loading Limited (Larger clarifiers than Baseline)	Solids Loading Limited (Larger clarifiers than Baseline)
Microfiltration (MF)	--	Membrane Filtration to Remove Particles and Bacteria	Membrane Filtration to Remove Particles and Bacteria
Reverse Osmosis (RO)	--	Treat 50% of the Flow by RO to Remove Metals and Dissolved Constituents. Sending a portion of flow through the RO and blending it with the balance of plant flows ensures a stable non-corrosive, non-toxic discharge.	--
Reverse Osmosis Brine Reject Mgmt	--	Several Options (All Energy or Land Intensive)	--
Granular Activated Carbon (GAC)	--	--	Removes Dissolved Constituents
Disinfection	Not shown to remove any of the constituents	Not shown to remove any of the constituents	Not shown to remove any of the constituents

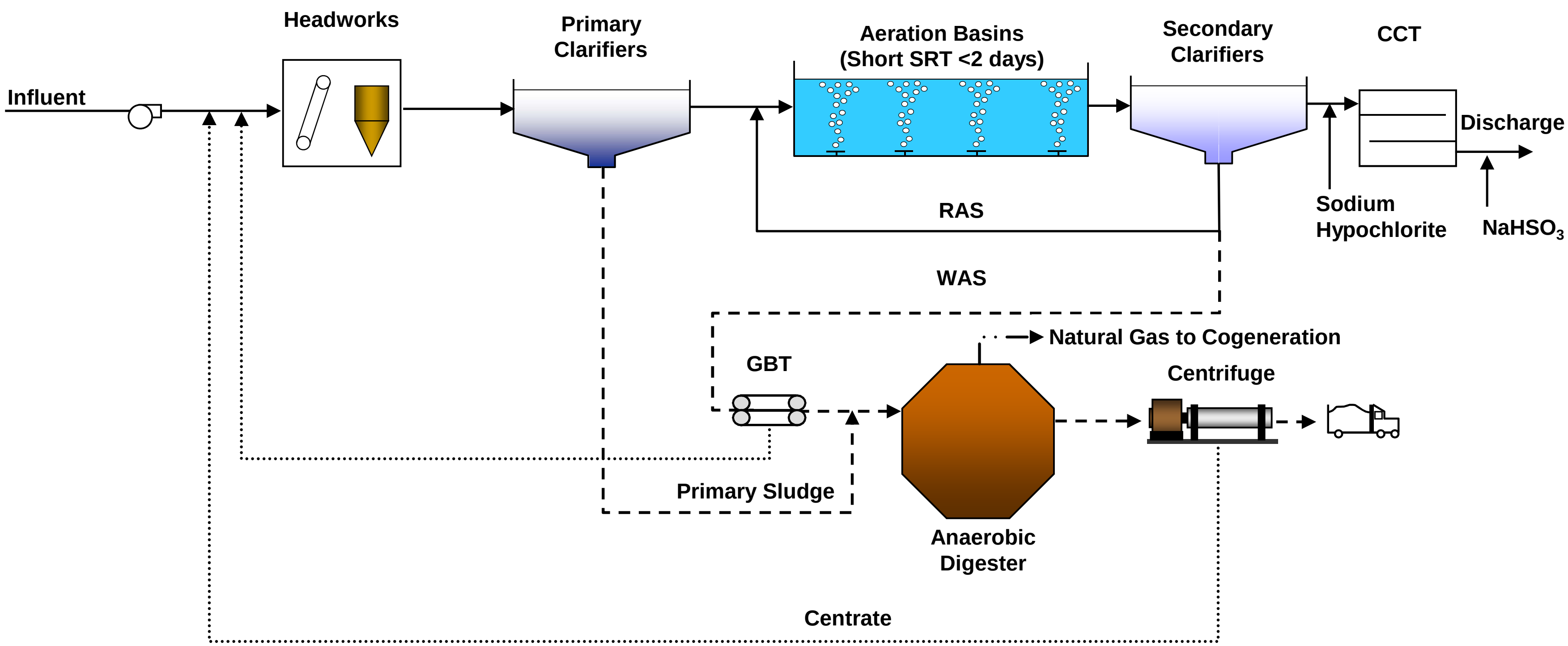

Figure 3. Baseline Flowsheet – Conventional Secondary Treatment

4.4.2 Advanced Treatment – MF/RO Alternative

A flowsheet of the advanced treatment – MF/RO alternative is provided in Figure 4. This alternative builds on the baseline secondary treatment facility, whereby the SRT is increased in the activated sludge process, and MF and RO are added prior to disinfection. The solids treatment train does not change with respect to the baseline. Additionally, a brine management strategy must be considered.

The RO process concentrates contaminants into a smaller volume reject stream. Disposing of the RO reject stream can be a problem because of the potentially large volume of water involved and the concentration of contaminants contained in the brine. For reference, a 5 mgd process wastewater flow might result in 1 mgd of brine reject requiring further management. The primary treatment/handling options for RO reject are as follows:

- Zero liquid discharge
- Surface water discharge
- Ocean discharge
- Haul and discharge to coastal location for ocean discharge
- Sewer discharge
- Deep well injection
- Evaporate in a pond
- Solar pond concentrator

Many of the RO brine reject management options above result in returning the dissolved solids to a “water of the state” such as surface water, groundwater, or marine waters. Past rulings in Washington State have indicated that once pollutants are removed from during treatment they are not to be re-introduced to a water of the state. As a result, technologies with this means for disposal were not considered viable options for management of RO reject water in Washington.

Zero Liquid Discharge

Zero liquid discharge (ZLD) is a treatment process that produces a little or no liquid brine discharge but rather a dried residual salt material. This process improves the water recovery of the RO system by reducing the volume of brine that must be treated and disposed of in some manner. ZLD options include intermediate treatment, thermal-based technologies, pressure driven membrane technologies, electric potential driven membrane technologies, and other alternative technologies.

Summary

There are many techniques which can be used to manage reject brine water associated with RO treatment. The appropriate alternative is primarily governed by geographic and local constraints. A comparison of the various brine management methods and potential costs are provided in Table 6.

Of the listed options, ZLD was considered for this analysis as the most viable approach to RO reject water management. An evaporation pond was used following ZLD. The strength in this combination is ZLD reduces the brine reject volume to treat, which in turn reduces the required evaporation pond footprint. The disadvantage is that evaporation ponds require a substantial amount of physical space which may not be available at existing treatment plant sites. It is also important to recognize that the greenhouse gas (GHG) emissions vary widely for the eight brine management options listed above based on energy and chemical intensity.

Table 6. Brine Disposal Method Relative Cost Comparison

Disposal Method	Description	Relative Capital Cost	Relative O&M Cost	Comments
Zero Liquid Discharge (ZLD)	Further concentrates brine reject for further downstream processing	High	High	This option is preferred as an intermediate step. This rationale is based on the reduction in volume to handle following ZLD. For example, RO reject stream volume is reduced on the order of 50-90%.
Surface Water Discharge	Brine discharge directly to surface water. Requires an NPDES permit.	Lowest	Lowest	Both capital and O&M costs heavily dependent on the distance from brine generation point to discharge. Not an option for nutrient removal.
Ocean Discharge	Discharge through a deep ocean outfall.	Medium	Low	Capital cost depends on location and availability of existing deep water outfall.
Sewer Discharge	Discharge to an existing sewer pipeline for treatment at a wastewater treatment plant.	Low	Low	Both capital and O&M costs heavily dependent on the brine generation point to discharge distance. Higher cost than surface water discharge due to ongoing sewer connection charge. Not an option for wastewater treatment.
Deep Well Injection	Brine is pumped underground to an area that is isolated from drinking water aquifers.	Medium	Medium	Technically sophisticated discharge and monitoring wells required. O&M cost highly variable based on injection pumping energy.
Evaporation Ponds	Large, lined ponds are filled with brine. The water evaporates and a concentrated salt remains.	Low – High	Low	Capital cost highly dependent on the amount and cost of land.
Salinity Gradient Solar Ponds (SGSP)	SGSPs harness solar power from pond to power an evaporative unit.	Low – High	Lowest	Same as evaporation ponds plus added cost of heat exchanger and pumps. Lower O&M cost due to electricity production.
Advanced Thermal Evaporation	Requires a two-step process consisting of a brine concentrator followed by crystallizer	High	Highest	Extremely small footprint, but the energy from H_2O removal is by far the most energy intensive unless waste heat is used.

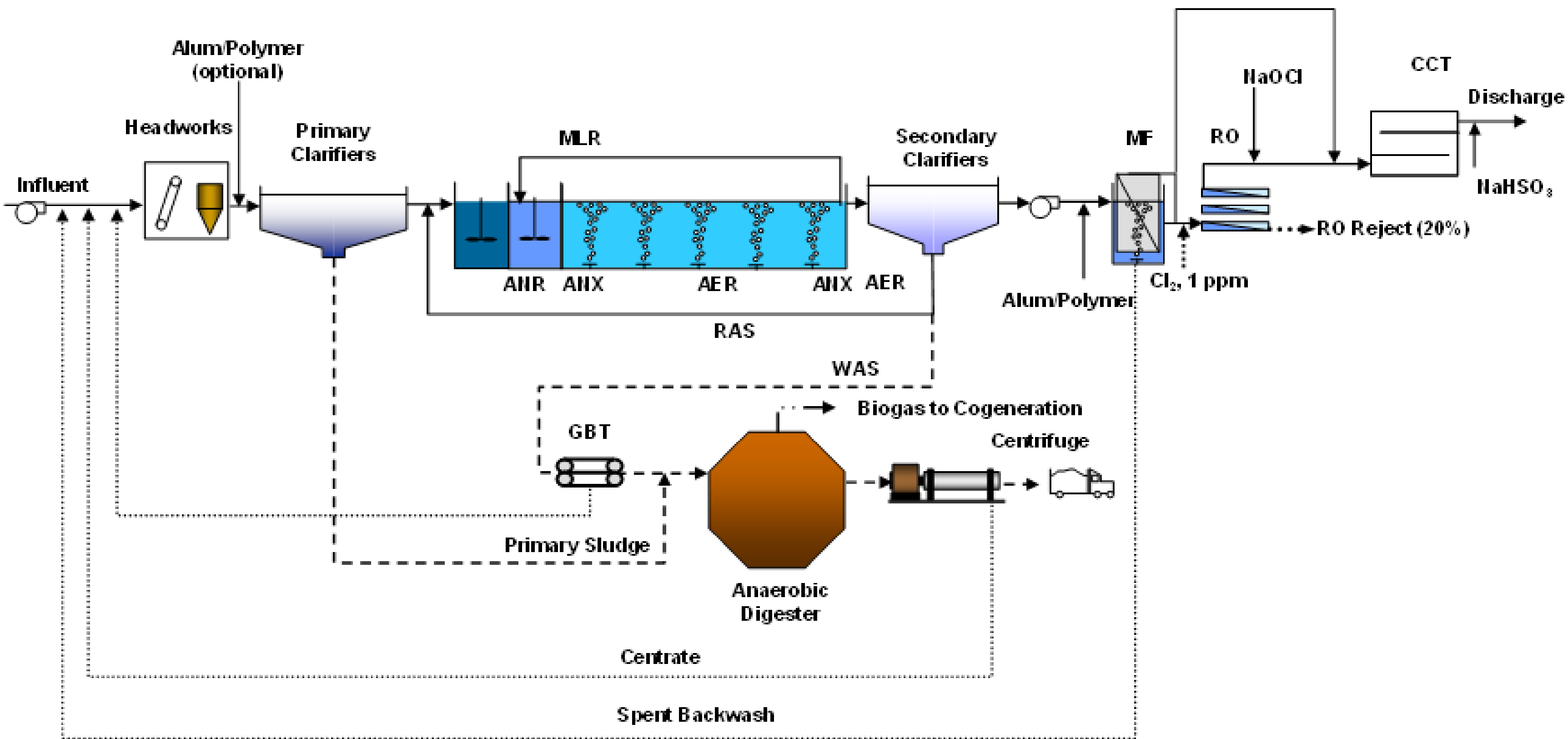

Figure 4. Advanced Treatment Flowsheet – Tertiary Microfiltration and Reverse Osmosis

4.4.3 Advanced Treatment – MF/GAC Alternative

A flowsheet of the advanced treatment – MF/GAC alternative is provided in Figure 5. Following the MF technology, a GAC contactor and media are required.

This alternative was developed as an option that does not require a brine management technology (e.g., ZLD) for comparison to the MF/RO advanced treatment alternative. However, this treatment alternative does require that the GAC be regenerated. A baseline secondary treatment facility can be retrofitted for MF/GAC. If an existing treatment facility has an extended aeration lagoon, the secondary effluent can be fed to the MF/GAC. The longer SRT in the extended aeration lagoon provides all the benefits associated with the long SRT in an activated sludge plant as previously stated:

- Lower BOD/TSS discharge load
- Higher removal of recalcitrant constituents and heavy metals
- Improved water quality and benefit to downstream users
- Less downstream algal growth
- Reduced receiving water dissolved oxygen demand due to ammonia removal
- Reduced ammonia discharge loads, which is toxic to several aquatic species
- Improved water quality for habitat, especially as it relates to biodiversity and eutrophication
- Secondary clarifier effluent more conditioned for filtration and disinfection
- Greater process stability from the anaerobic/anoxic zones serving as a selector

If an existing treatment facility employs a high rate activated sludge process (short SRT) similar to the baseline, it is recommended that the activated sludge process SRT be increased prior to the MF/GAC unit processes. The longer SRT upstream of the MF is preferred to enhance the membrane flux rate, reduce membrane biofouling, increase membrane life, and reduce the chemicals needed for membrane cleaning.

The key technical and operational challenges associated with the tertiary add-on membrane filtration units are as follows:

- The membrane filtration technology is a proven and reliable technology. With over 30 years of experience, it has made the transition in recent years from an emerging technology to a proven and reliable technology.
- Membrane durability dependent on feed water quality. The water quality is individual facility specific.
- Membranes are sensitive to particles, so upstream screening is critical. The newer generations of membranes have technical specifications that require a particular screen size.
- Membrane area requirements based on peak flows as water must pass through the membrane pores. Additionally, membranes struggle with variable hydraulic loading. Flow equalization upstream can greatly reduce the required membrane surface area and provide uniform membrane loading.

- Membrane tanks can exacerbate any foam related issues from the upstream biological process. Foam entrapment in the membrane tank from the upstream process can reduce membrane filtration capacity and in turn result in a plant-wide foam problem.
- Reliable access to the membrane modules is key to operation and maintenance. Once PLC is functionary properly, overall maintenance requirements for sustained operation of the system are relatively modest.
- The membranes go through frequent membrane relaxing or back pulse and a periodic deep chemical clean in place (CIP) process.
- Sizing of membrane filtration facilities governed by hydraulic flux. Municipal wastewaters have flux values that range from about 20 to 40 gallons per square foot per day (gfd) under average annual conditions. The flux associated with industrial applications is wastewater specific.

Following the MF is the activated carbon facilities. There are two kinds of activated carbon used in treating water: powdered activated carbon (PAC) and GAC. PAC is finely-ground, loose carbon that is added to water, mixed for a short period of time, and removed. GAC is larger than PAC, is generally used in beds or tanks that permit higher adsorption and easier process control than PAC allows, and is replaced periodically. PAC is not selective, and therefore, will adsorb all active organic substances making it an impractical solution for a wastewater treatment plant. As a result, GAC was considered for this analysis. The type of GAC (e.g., bituminous and subbituminous coal, wood, walnut shells, lignite or peat), gradation, and adsorption capacity are determined by the size of the largest molecule/ contaminant that is being filtered (AWWA, 1990).

As water flows through the carbon bed, contaminants are captured by the surfaces of the pores until the carbon is no longer able to adsorb new molecules. The concentration of the contaminant in the treated effluent starts to increase. Once the contaminant concentration in the treated water reaches an unacceptable level (called the breakthrough concentration), the carbon is considered "spent" and must be replaced by virgin or reactivated GAC.

The capacity of spent GAC can be restored by thermal reactivation. Some systems have the ability to regenerate GAC on-site, but in general, small systems haul away the spent GAC for off-site regeneration (EPA 1993). For this study, off-site regeneration was assumed.

The basic facilities and their potential unit processes included in this chapter are as follows:

- GAC supply and delivery
- Influent pumping
    - Low head feed pumping
    - High head feed pumping (assumed for this study as we have low limits so require high beds)
- Contactors and backwash facilities
    - Custom gravity GAC contactor
    - Pre-engineered pressure GAC contactor (Used for this study)
    - Backwash pumping
- GAC transport facilities
    - Slurry pumps
    - Eductors (Used for this study)

- Storage facilities
  - Steel tanks
  - Concrete tanks (Used for this study; larger plants would typically select concrete tanks)
- Spent carbon regeneration
  - On-site GAC regeneration
  - Off-Site GAC regeneration

Following the MF is the GAC facility. The GAC contactor provides about a 12-min hydraulic residence time for average annual conditions. The GAC media must be regenerated about twice per year in a furnace. The constituents sorbed to the GAC media are removed during the regeneration process. A typical design has full redundancy and additional storage tankage for spent and virgin GAC. Facilities that use GAC need to decide whether they will regenerate GAC on-site or off-site. Due to challenges associated with receiving air emission permits for new furnaces, it was assumed that off-site regeneration would be evaluated.

The key technical and operational challenges associated with the tertiary add-on GAC units are as follows:

- Nearest vendor to acquire virgin GAC – How frequently can they deliver virgin GAC and what are the hauling costs?
- Contactor selection is typically based on unit cost and flow variation. The concrete contactor is typically more cost effective at higher flows so it was used for this evaluation. The pre-engineered pressure contactor can handle a wider range of flows than a concrete contactor. Additionally, a pressure system requires little maintenance as they are essentially automated
- Periodical contactor backwashing is critical for maintaining the desired hydraulics and control biological growth
- Eductors are preferred over slurry pumps because they have fewer mechanical components. Additionally, the pump with eductors is not in contact with the carbon, which reduces wear.
- Off-site GAC regeneration seems more likely due to the challenges with obtaining an air emissions permit.

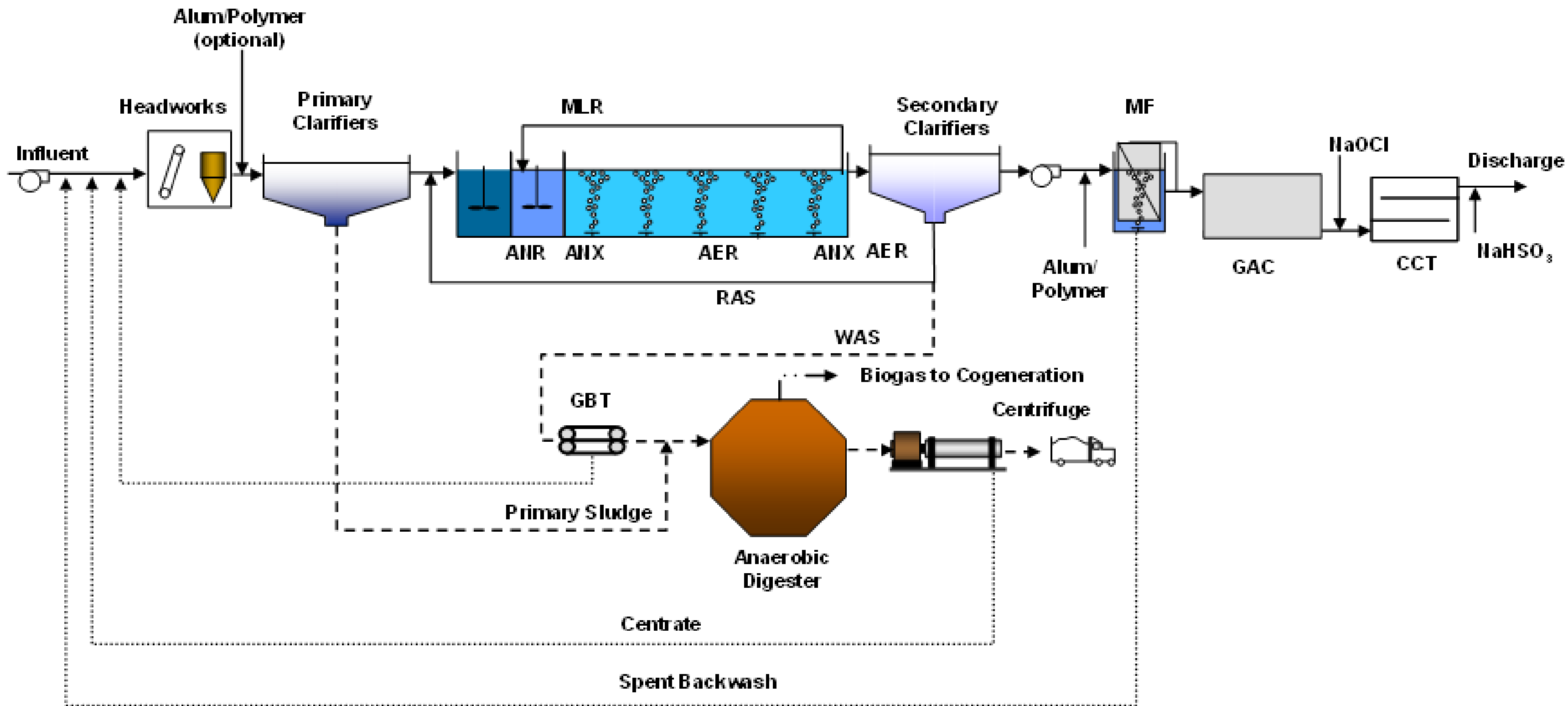

Figure 5. Advanced Treatment Flowsheet – Tertiary Microfiltration and Granular Activated Carbon

4.5 Steady-State Mass Balance

HDR used its steady-state mass balance program to calculate the flows and loads within the candidate advanced treatment processes as a means to size facilities. The design of wastewater treatment facilities are generally governed by steady-state mass balances. For a steady-state mass balance, the conservation of mass is calculated throughout the entire wastewater treatment facility for defined inputs. Dynamic mass balance programs exist for designing wastewater facilities, but for a planning level study such as this, a steady state mass balance program is adequate. A dynamic program is generally used for detailed design and is site-specific with associated requirements for more detailed wastewater characterization.

The set of model equations used to perform a steady-state mass balance are referred to as the model. The model equations provide a mathematical description of various wastewater treatment processes, such as an activated sludge process, that can be used to predict unit performance. The program relies on equations for each unit process to determine the flow, load, and concentration entering and leaving each unit process.

An example of how the model calculates the flow, load, and concentration for primary clarifiers is provided below. The steady-state mass balance equation for primary clarifiers has a single input and two outputs as shown in the simplified Figure 6. The primary clarifier feed can exit the primary clarifiers as either effluent or sludge. Solids not removed across the primaries leave as primary effluent, whereas solids captured leave as primary sludge. Scum is not accounted for.

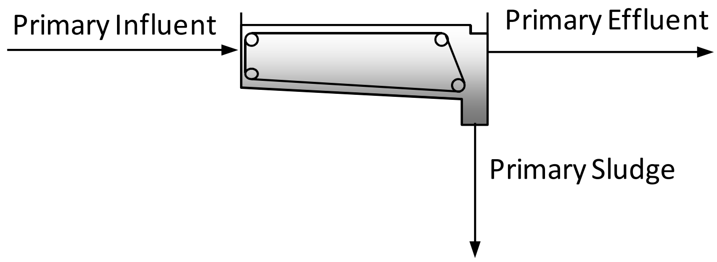

Figure 6. Primary Clarifier Inputs/Outputs

The mass balance calculation requires the following input:

- Solids removal percentage across the primaries (based on average industry accepted performance)
- Primary solids thickness (i.e., percent solids) (based on average industry accepted performance)

The steady-state mass balance program provides a reasonable first estimate for the process performance, and an accurate measure of the flows and mass balances at various points throughout the plant. The mass balance results were used for sizing the facility needs for each alternative. A listing of the unit process sizing criterion for each unit process is provided in Appendix A. By listing the unit process sizing criteria, a third-party user could redo the analysis and end up with comparable results. The key sizing criteria that differ between the baseline and treatment alternatives are as follows:

- Aeration basin mixed liquor is greater for the advanced treatment alternatives which in turn requires a larger volume
- The secondary clarifiers are sized based on hydraulic loading for the baseline versus solids loading for the advanced treatment alternatives

- The MF/GAC and MF/RO sizing is only required for the respective advanced treatment alternatives.

4.6 Adverse Environmental Impacts Associated with Advanced Treatment Technologies

The transition from the baseline (conventional secondary treatment) to either advanced treatment alternatives has some environmental impacts that merit consideration, including the following:

- Land area for additional system components (which for constrained facility sites, may necessitate land acquisition and encroachment into neighboring properties with associated issues and challenges, etc.).
- Increased energy use and atmospheric emissions of greenhouse gases and criteria air contaminants associated with power generation to meet new pumping requirements across the membrane filter systems (MF and RO) and GAC.
- Increased chemical demand associated with membrane filters (MF and RO).
- Energy and atmospheric emissions associated with granulated charcoal regeneration.
- RO brine reject disposal. The zero liquid discharge systems are energy intensive energy and increase atmospheric emissions as a consequence of the electrical power generation required for removing water content from brine reject.
- Increase in sludge generation while transitioning from the baseline to the advanced treatment alternatives. There will be additional sludge captured with the chemical addition to the primaries and membrane filters (MF and RO). Additionally, the GAC units will capture more solids.
- Benefits to receiving water quality by transitioning from a short SRT (<2 days) in the baseline to a long SRT (>8 days) for the advanced treatment alternatives (as previously stated):
    - Lower BOD/TSS discharge load
    - Higher removal of recalcitrant constituents and heavy metals
    - Improved water quality and benefit to downstream users
    - Reduced nutrient loadings to receiving waters and lower algal growth potential
    - Reduced receiving water dissolved oxygen demand due to ammonia removal
    - Reduced ammonia discharge loads, which is toxic to aquatic species
    - Improved water quality for habitat, especially as it relates to biodiversity and eutrophication
    - Secondary clarifier effluent better conditioned for subsequent filtration and disinfection
    - Greater process stability from the anaerobic/anoxic zones serving as a biological selectors

HDR calculated GHG emissions for the baseline and advanced treatment alternatives. The use of GHG emissions is a tool to normalize the role of energy, chemicals, biosolids hauling, and fugitive emissions (e.g., methane) in a single unit. The mass balance results were used to quantify energy demand and the corresponding GHG emissions for each alterative. Energy demand was estimated from preliminary process calculations. A listing of the energy demand for each process stream, the daily energy demand, and the unit energy demand is provided in Table 7. The advanced treatment options range from 2.3 to 4.1 times greater than the baseline. This large increase in energy demand is attributed to the energy required to pass water through the membrane barriers and/or the granular activated carbon. Additionally, there is energy required to handle the constituents removed as either regenerating the GAC or handling the RO brine reject water. This additional energy required to treat the removed constituents is presented in Table 7.

Table 7. Energy Breakdown for Each Alternative (5 mgd design flow)

Parameter	Units	Baseline	Advanced Treatment – MF/GAC	Advanced Treatment – MF/RO
Daily Liquid Stream Energy Demand	MWh/d	11.6	23.8	40.8
Daily Solids Stream Energy Demand	MWh/d	-1.6	-1.1	-1.1
Daily Energy Demand	MWh/d	10.0	22.7	39.7
Unit Energy Demand	kWh/MG Treated	2,000	4,500	7,900

MWh/d = megawatt hours per day
kWh/MG = kilowatt hours per million gallons

Details on the assumptions used to convert between energy demand, chemical demand and production, as well as biologically-mediated gases (i.e., CH4 and N2O) and GHG emissions are provided in Appendix B.

A plot of the GHG emissions for each alternative is shown in Figure 7. The GHG emissions increase from the baseline to the two advanced treatment alternatives. The GHG emissions increase about 50 percent with respect to baseline when MF/GAC is used and the GHG emissions increase over 100 percent with respect to baseline with the MF/RO advanced treatment alternative.

The MF/GAC energy demand would be larger if GAC regeneration was performed on-site. The GHG emissions do not include the energy or air emissions that result from off-site GAC regeneration. Only the hauling associated with moving spent GAC is included. The energy associated with operating the furnace would exceed the GHG emissions from hauling spent GAC.

The zero liquid discharge in the MF/RO alternative alone is comparable to the Baseline. This contribution to increased GHG emissions by zero liquid discharge brine system highlights the importance of the challenges associated with managing brine reject.

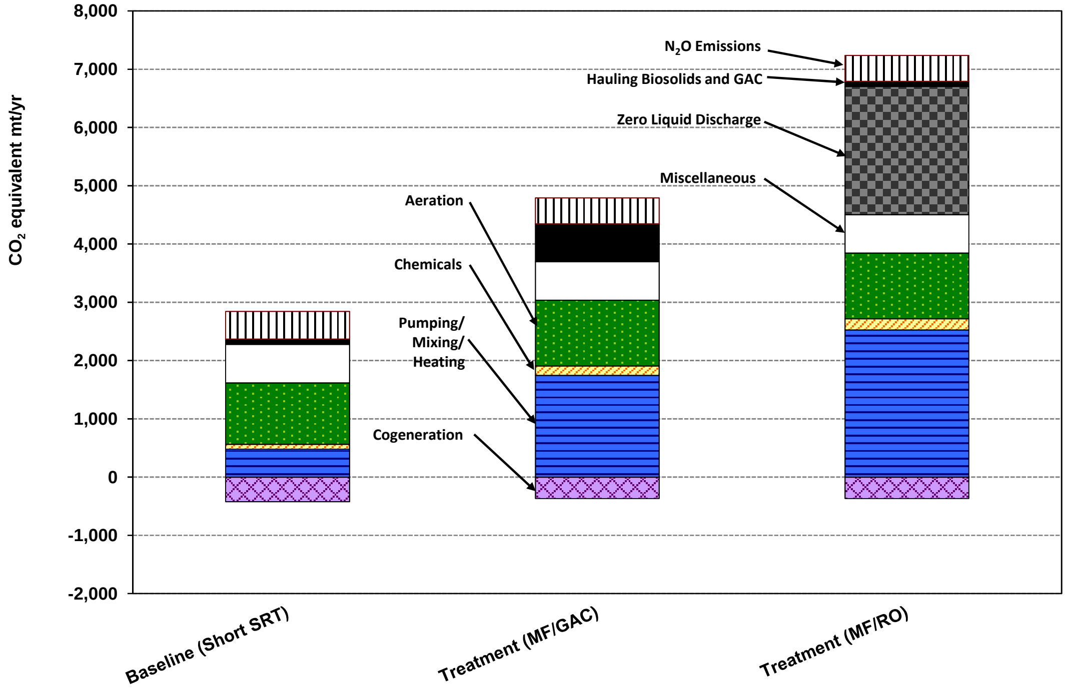

Figure 7. Greenhouse Gas Emissions for Each Alternative

The use of GHG emissions as a measure of sustainability does not constitute a complete comparison between the baseline and advanced treatment alternatives. Rather, it is one metric that captures the impacts of energy, chemical demand and production, as well as biologically-mediated gases (i.e., CH_4 and N_2O). The other environmental impacts of advanced treatment summarized in the list above should also be considered in decision making beyond cost analysis.

4.7 Costs

Total project costs along with the operations and maintenance costs were developed for each advanced treatment alternative for a comparison with baseline secondary treatment.

4.7.1 Approach

The cost estimates presented in this report are planning level opinions of probable construction costs for a nominal 5 mgd treatment plant design flow representing a typical facility without site specific details about local wastewater characteristics, physical site constraints, existing infrastructure, etc. The cost estimates are based on wastewater industry cost references, technical studies, actual project cost histories, and professional experience. The costs presented in this report are considered planning level estimates. A more detailed development of the advanced treatment process alternatives and site specific information would be required to further refine the cost estimates. Commonly this is accomplished in the preliminary design phase of project development for specific facilities following planning.

The cost opinion includes a range of costs associated with the level of detail used in this analysis. Cost opinions based on preliminary engineering can be expected to follow the Association for the Advancement of Cost Engineering (AACE International) Recommended Practice No. 17R-97 Cost Estimate Classification System estimate Class 4. A Class 4 estimate is based upon a 5 to 10 percent project definition and has an expected accuracy range of -30 to +50 percent and typical end usage of budget authorization and cost control. It is considered an "order-of-magnitude estimate." The life-cycle costs were prepared using the net present value (NPV) method.

The cost associated for each new unit process is based on a unit variable, such as required footprint, volume, demand (e.g., lb O_2/hr), and others. This approach is consistent with the approach developed for the EPA document titled "Estimating Water Treatment Costs: Volume 2-Cost Curves Applicable to 1 to 200 mgd Treatment Plants" dated August 1979. The approach has been updated since 1979 to account for inflation and competition, but the philosophy for estimating costs for unit processes has not changed. For example, the aeration system sizing/cost is governed by the maximum month airflow demand. Additionally, the cost associated constructing an aeration basin is based on the volume. The cost considers economies of scale.

The O&M cost estimates were calculated from preliminary process calculations. The operations cost includes energy and chemical demand. For example, a chemical dose was assumed based on industry accepted dosing rates and the corresponding annual chemical cost for that particular chemical was accounted for. The maintenance values only considered replacement equipment, specifically membrane replacement for the Advanced Treatment Alternatives.

4.7.2 Unit Cost Values

The life-cycle cost evaluation was based on using the economic assumptions shown in Table 8. The chemical costs were based on actual values from other projects. To perform detailed cost evaluations per industry, each selected technology would need to be laid out on their respective site plan based on the location of the existing piping, channels, and other necessary facilities.

Table 8. Economic Evaluation Variables

Item	Value
Nominal Discount Rate	5%
Inflation Rate:	
General	3.5%
Labor	3.5%
Energy	3.5%
Chemical	3.5%
Base Year	2013
Project Life	25 years
Energy	$0.06/kWh
Natural Gas	$0.60/therm
Chemicals:	
Alum	$1.1/gal
Polymer	$1.5/gal
Hypochlorite	$1.5/gal
Salt	$0.125/lb
Antiscalant	$12.5/lb
Acid	$0.35/lb
Deionized Water	$3.75/1,000 gal
Hauling:	

Table 8. Economic Evaluation Variables

Item	Value
Biosolids Hauling Distance	100 miles (one way)
Biosolids Truck Volume	6,000 gal/truck
Biosolids Truck Hauling	$250/truck trip
GAC Regeneration Hauling Distance	250 miles (round trip)
GAC Regeneration Truck Volume	$20,000 lb GAC/truck
GAC Regeneration Truck Hauling	Included in cost of Virgin GAC

kWh= kilowatt hours; lbs=pounds; GAC=granulated activated carbon; gal=gallon

4.7.3 Net Present Value of Total Project Costs and Operations and Maintenance Cost in 2013 Dollars

An estimate of the net present value for the baseline treatment process and the incremental cost to implement the advanced treatment alternatives is shown in Table 9. The cost for the existing baseline treatment process was estimated based on new construction for the entire conventional secondary treatment process (Figure 3). The incremental cost to expand from existing baseline secondary treatment to advanced treatment was calculated by taking the difference between the baseline and the advanced treatment alternatives. These values serve as a benchmark for understanding the prospective cost for constructing advanced treatment at the planning level of process development.

Table 9. Treatment Technology Total Project Costs in 2013 Dollars for a 5 mgd Facility

Alternative	Total Construction Cost, 2013 dollars ($ Million)	O&M Net Present Value, 2013 dollars ($ Million)*	Total Net Present Value, 2013 dollars ($ Million)	NPV Unit Cost, 2013 dollars ($/gpd)
Baseline (Conventional Secondary Treatment)*	59 - 127	5 - 11	65 – 138	13 - 28
Advanced Treatment – MF/RO**	108 - 231	31 - 67	139 - 298	28 - 60
Advanced Treatment – MF/GAC	131 - 280	50 - 108	181 - 388	36 - 78
Incremental Increase to Advanced Treatment MF/RO	48 - 104	26 - 56	75 - 160	15 - 32
Incremental Increase to Advanced Treatment MF/GAC	71 - 153	45 - 97	117 - 250	23 - 50

* The additional cost to increase the SRT to upwards of 30-days is about $12 - 20 million additional dollars in total project cost for a 5 mgd design flow
** Assumes zero liquid discharge for RO brine management, followed by evaporation ponds. Other options are available as listed in Section 4.4.2.
O&M=operations and maintenance; MF/RO=membrane filtration/reverse osmosis; MF/GAC=membrane filtration/granulated activated carbon; gpd=gallons per day

4.7.4 Unit Cost Assessment

Costs presented above are based on a treatment capacity of 5.0 mgd, however, existing treatment facilities range dramatically across Washington in size and flow treated. Table 9 indicates that the unit capital cost for baseline conventional secondary treatment for 5.0 mgd ranges between $13 to 28 per gallon per day of treatment capacity. The unit cost for the advanced treatment alternatives increases the range from the low $20s to upper $70s on a per-gallon per-day of capacity. The increase in cost for the advanced treatment alternatives is discussed in the sub-sections below.

Advanced Treatment MF/RO

The advanced treatment MF/RO alternative has a total present worth unit cost range of $28 to $60 million in per gallon per day of capacity. This translates to an incremental cost increase with respect to the baseline of $15 to $32 million dollars in per gallon per day treatment capacity. The key differences in cost between the baseline and the advanced treatment MF/RO are as follows:

- Larger aeration basins than the baseline to account for the longer SRT (<8 days versus >8 days).
- Additional pumping stations to pass water through the membrane facilities (MF and RO). These are based on peak flows.
- Membrane facilities (MF and RO; equipment, tanks chemical feed facilities, pumping, etc.) and replacement membrane equipment.
- Additional energy and chemical demand to operate the membrane facilities (MF and RO) and GAC.
- Zero liquid discharge facilities to further concentrate the brine reject.
- Zero liquid discharge facilities are energy/chemically intensive and they require membrane replacement every few years due to the brine reject water quality.
- An evaporation pond to handle the brine reject that has undergone further concentration by zero liquid discharge.

The advanced treatment MF/RO assumes that 100 percent of the flow is treated by MF, followed by 50 percent of the flow treated with RO. Sending a portion of flow through the RO and blending it with the balance of plant flows ensures a stable water to discharge. The RO brine reject (about 1.0 mgd) undergoes ZLD pre-treatment that further concentrates the brine reject to about 0.1-0.5 mgd. The recovery for both RO and ZLD processes is highly dependent on water quality (e.g., silicate levels).

ZLD technologies are effective at concentrating brine reject, but it comes at a substantial cost ($17.5 per gallon per day of ZLD treatment capacity of brine reject). The zero liquid discharge estimate was similar in approach to the demonstration study by Burbano and Brandhuber (2012) for La Junta, Colorado. The ability to further concentrate brine reject was critical from a management standpoint. Although 8 different options were presented for managing brine reject in Section 4.4.2, none of them is an attractive approach for handling brine reject. ZLD provides a viable pre-treatment step that requires subsequent downstream treatment. Evaporation ponds following ZLD were used for this study. Without ZLD, the footprint would be 3-5 times greater.

Roughly 30 acres of evaporation ponds, or more, may be required to handle the ZLD concentrate, depending upon concentrator effectiveness, local climate conditions, residuals accumulation, residual removal, etc. Precipitation throughout Washington is highly variable which can greatly influence evaporation pond footprint. The approach for costing the evaporation pond was in accordance with Mickley et al. (2006) and the cost was about $2.6 million.

Recent discussions with an industry installing evaporation ponds revealed that they will use mechanical evaporators to enhance evaporation rates. The use of mechanical evaporators was not included in this study, but merits consideration if a facility is performing a preliminary design that involves evaporation ponds. The mechanical evaporators have both a capital costs and annual energy costs.

Advanced Treatment MF/GAC

The advanced treatment MF/GAC alternative has a total present worth unit cost range of $36 to $78 million in per gallon per day capacity. This translates to an incremental cost increase with respect to the baseline of $23 to $50 million dollars on a per gallon per day of treatment capacity basis. The key differences in cost between the baseline and the advanced treatment MF/GAC are as follows:

- Larger aeration basins than the baseline to account for the longer SRT (<8 days versus >8 days).
- Additional pumping stations to pass water through the MF membrane and GAC facilities. These are based on peak flows.
- GAC facilities (equipment, contact tanks, pumping, GAC media, etc.)
- Additional energy to feed and backwash the GAC facilities.
- GAC media replacement was the largest contributor of any of the costs.
- Additional hauling and fees to regenerate GAC off-site.

The advanced treatment MF/GAC assumes that 100 percent of the flow is treated by MF, followed by 100 percent of the flow treated with GAC. The GAC technology is an established technology. The costing approach was in accordance with EPA guidelines developed in 1998.

The critical issue while costing the GAC technology is whether a GAC vendor/regeneration facility is located within the region. On-site regeneration is an established technology with a furnace.

However, there are several concerns as listed in Section 4.4.3:

- Ability to obtain an air emissions permit
- Additional equipment to operate and maintain
- Energy and air emissions to operate a furnace on-site
- Operational planning to ensure that furnace is operating 90-95 percent of the time. Otherwise, operations is constantly starting/stopping the furnace which is energy intensive and deleterious to equipment
- If not operated properly, the facility has the potential to create hazardous/toxic waste to be disposed

If located within a couple hundred miles, off-site regeneration is preferred. For this study, off-site regeneration was assumed with a 250-mile (one-way) distance to the nearest vendor that can provide virgin GAC and a regeneration facility.

Incremental Treatment Cost

The difference in costs between the baseline and the advanced treatment alternatives is listed in Table 10. The incremental cost to retrofit the baseline facility to the advanced treatment was calculated by taking the difference between the two alternatives. These values should serve as a planning level benchmark for understanding the potential cost for retrofitting a particular facility. The incremental cost is unique to a particular facility. Several reasons for the wide range in cost in retrofitting a baseline facility to advanced treatment are summarized as follows:

- Physical plant site constraints. A particular treatment technology may or may not fit within the constrained particular plant site. A more expensive technology solution that is more compact may be required. Alternately, land acquisition may be necessary to enlarge a plant site to allow the addition of advanced treatment facilities. An example of the former is stacking treatment processes vertically to account for footprint constraints. This is an additional financial burden that would not be captured in the incremental costs presented in Table 10.
- Yard piping. Site specific conditions may prevent the most efficient layout and piping arrangement for an individual facility. This could lead to additional piping and pumping to convey the wastewater through the plant. This is an additional financial burden that would not be captured in the incremental costs presented in Table 10.
- Pumping stations. Each facility has unique hydraulic challenges that might require additional pumping stations not captured in this planning level analysis. This is an additional financial burden that would not be captured in the incremental costs presented in Table 10.

A cursory unit cost assessment was completed to evaluate how costs would compare for facilities with lower (0.5 mgd) and higher capacity (25 mgd), as presented in Table 10. Capital costs were also evaluated for a 0.5 mgd and 25 mgd facility using non-linear scaling equations with scaling exponents. The unit capital cost for baseline conventional secondary treatment for 0.5 mgd and 25 mgd is approximately $44 and $10 per gallon per day of treatment capacity, respectively. The incremental unit costs to implement an advanced treatment retrofit for 0.5 mgd would range between $30 to $96 per gallon per day of treatment capacity and would be site and discharger specific. The incremental unit costs to implement an advanced treatment retrofit for 25 mgd would range between $10 to 35 per gallon per day of treatment capacity and would be site and discharger specific. The larger flow, 25 mgd, is not as expensive on a per gallon per day of treatment capacity. This discrepancy for the 0.5 and 25 mgd cost per gallon per day of treatment capacity is attributed to economies of scale. Cost curve comparisons (potential total construction cost and total net present value) for the baseline and the two tertiary treatment options (MF/RO and MF/GAC) are shown in Figure 8 and Figure 9 between the flows of 0.5 and 25 mgd. It is important to note that while the economies of scale suggest lower incremental costs for the larger size facilities, some aspects of the advanced treatment processes may become infeasible at larger capacities due to factors such as physical space limitations and the large size requirements for components such as RO reject brine management.

Table 10. Treatment Technology Total Project Costs in 2013 Dollars for a 0.5 mgd Facility and a 25 mgd Facility

Alternative	Total Construction Cost, 2013 dollars ($ Million)	O&M Net Present Value, 2013 dollars ($ Million)*	Total Net Present Value, 2013 dollars ($ Million)	NPV Unit Cost, 2013 dollars ($/gpd)
0.5 mgd:				
Baseline (Conventional Secondary Treatment)	15 - 32	0.5 - 1.1	15 - 33	31 - 66
Advanced Treatment – MF/RO**	27 - 58	3.2 - 6.8	30 - 65	60 - 130
Advanced Treatment – MF/GAC	33 - 70	5 - 10.8	38 - 81	76 - 162
Incremental Increase to Advanced Treatment MF/RO	12 - 26	2.7 - 5.7	15 - 32	30 - 64
Incremental Increase to Advanced Treatment MF/GAC	18 - 38	4.6 - 9.8	22 - 48	45 - 96
25 mgd:				
Baseline (Conventional Secondary Treatment)	156 - 335	25 - 54	182 - 389	7 - 16
Advanced Treatment – MF/RO**	283 - 606	157 - 336	440 - 942	18 - 38
Advanced Treatment – MF/GAC	343 - 735	252 - 541	595 - 1276	24 - 51
Incremental Increase to Advanced Treatment MF/RO	127 - 272	131 - 281	258 - 553	10 - 22
Incremental Increase to Advanced Treatment MF/GAC	187 - 401	226.9 - 486	414 - 887	17 - 35

* Does not include the cost for labor.
** Assumes zero liquid discharge for RO brine management, followed by evaporation ponds. Other options are available as listed in Section 4.4.2.
MF/RO=membrane filtration/reverse osmosis
MF/GAC=membrane filtration/granulated activated carbon
O&M=operations and maintenance
gpd=gallons per day

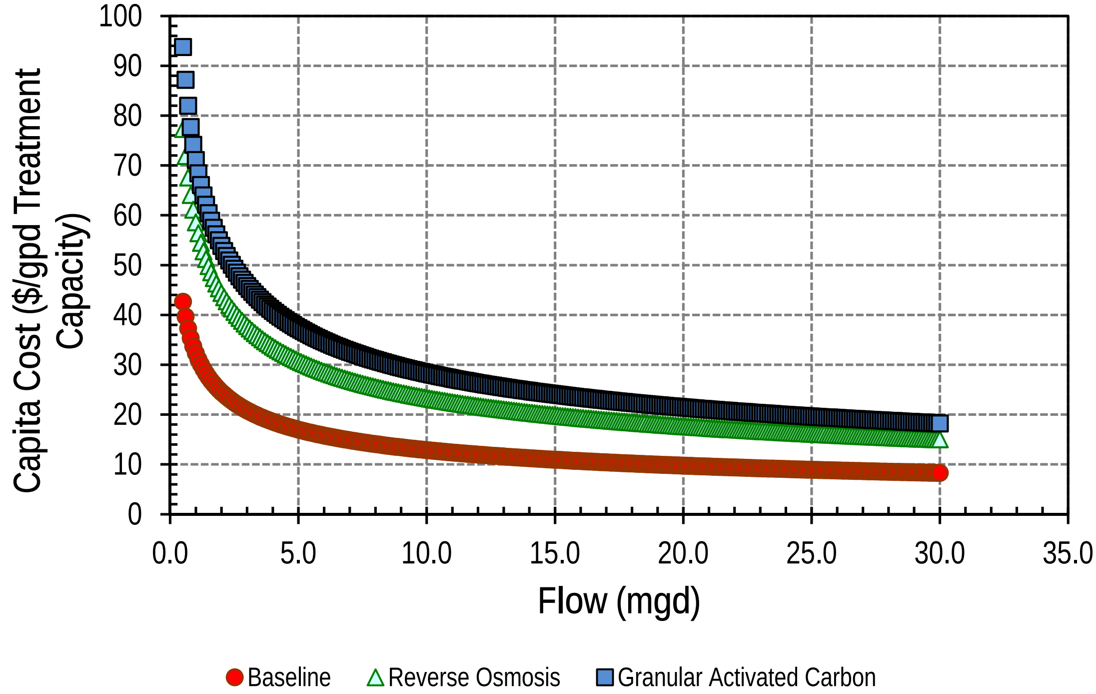

Figure 8: Capital Cost Curve Comparison for Baseline Treatment, MF/RO, and MF/GAC

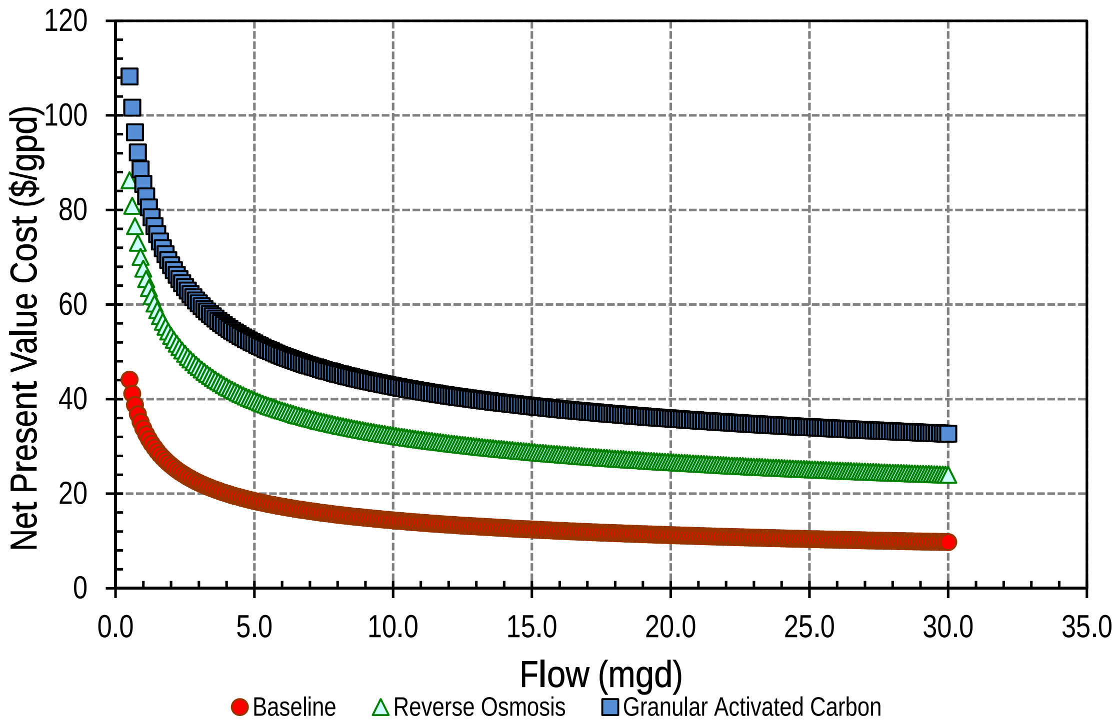

Figure 9: NPV Cost Curve Comparison for Baseline Treatment, MF/RO, and MF/GAC

4.8 Pollutant Mass Removal

An estimate of the projected load removal for the four constituents of concern was developed and is presented in Table 11. The current secondary effluent and advanced treatment effluent data is based on the only available data to HDR and is from municipal treatment plant facilities. Data is not available for advanced treatment facilities such as MF/RO or MF/GAC. Due to this lack of data, advanced treatment using MF/RO or MF/GAC was assumed to remove an additional zero to 90 percent of the constituents presented resulting in the range presented in Table 11. It is critical to note these estimates are based on limited data and are presented here simply for calculating mass removals. Current secondary effluent for industrial facilities would likely be greater than the data presented here and as a result, the projected effluent quality for industrial facilities would likely be higher as well. Based on the limited actual data from municipal treatment facilities, Table 11 indicates that mercury and BAP effluent limits may potentially be met using advanced treatment at facilities with similar existing secondary effluent quality.

Table 11. Pollutant Mass Removal by Contaminant for a 5 mgd Facility

Component	PCBs	Mercury	Arsenic	BAP
Required HHWQC based Effluent Quality (µg/L)	0.0000064	0.005	0.018	0.0013
Current Secondary Effluent Concentration (µg/L)*	0.0015	0.025	7.5	0.00031
Projected Effluent Quality (µg/L) from Advanced Treatment (MF/RO or MF/GAC)*	0.000041 – 0.00041	0.00012 – 0.0012	0.38 – 3.8	0.000029 - 0.00029
Mass Removed (mg/d)**	21 - 28	451 - 471	71,000 – 135,000	0.4 – 5.0
Mass Removed (lb/d)**	0.000045 – 0.000061	0.00099 – 0.0010	0.16 – 0.30	0.0000010 – 0.0000012

* Based on or estimated for actual treatment plant data from municipal facilities. Data sets are limited and current secondary effluent for industrial facilities would likely be greater than the data presented here.
** 1 lb = 454,000 mg
HHWQC=human health-based water quality criteria
MF/RO=membrane filtration/reverse osmosis
MF/GAC=membrane filtration/granulated activated carbon
µg/L=micrograms per liter
mg/d=milligrams per day
lb/d=pounds per day

Unit costs were developed based on required mass removal from a 5 mgd facility for each of the four constituents of concern to reduce discharges from current secondary effluent quality to the assumed required effluent quality (HHWQC). It important to note that this study concludes it is unclear if existing technology can meet the required effluent quality, however, the information presented in Table 12 assumes HHWQC would be met for developing unit costs. The unit costs are expressed as dollars in NPV (over a 25 year period) per pound of constituent removed over the same 25 year period using advanced treatment with MF/RO. The current secondary effluent quality data presented are based on typical secondary effluent quality expected for a municipal/industrial discharger. Table 12 suggests unit costs are most significant in meeting the PCB, mercury, and PAH required effluent quality.

Table 12. Unit Cost by Contaminant for a 5 mgd Facility Implementing Advanced Treatment using MF/RO

Component	PCBs	Mercury	Arsenic	PAHs
Required HHWQC based Effluent Quality (µg/L)	0.0000064	0.005	0.018	0.0013
Current Secondary Effluent Concentration (µg/L)*	0.002	0.025	7.5	0.006
Total Mass Removed (lbs) over 25-year Period	0.76	7.6	2,800	1.8
Unit Cost (NPV per total mass removed in pounds over 25 years)	$290,000,000	$29,000,000	$77,000	$120,000,000

*Derived from data presented in Table 3.
**Based on assumed 25-year NPV of $219,000,000 (average of the range presented in Table 10) and advanced treatment using MF/RO.
NPV=net present value
HHWQC=human health-based water quality criteria
µg/l=micrograms per liter

4.9 Sensitivity Analysis

The ability of dischargers to meet a HHWQC one order of magnitude less stringent (than HHWQC presented in Table 3 and used in this report) was considered. The same advanced treatment technologies using MF/RO or MF/GAC would still be applied to meet revised effluent quality one order-of-magnitude less stringent despite still not being able to meet less stringent effluent limits. As a result, this less stringent effluent quality would not impact costs. Based on available data, it appears the mercury and BAP limits would be met at a less stringent HHWQC. PCB effluent quality could potentially be met if advanced treatment with RO or GAC performed at the upper range of their projected treatment efficiency. It does not appear the less stringent arsenic HHWQC would be met with advanced treatment. It is important to note that a discharger's ability to meet these less stringent limits depends on existing secondary effluent characteristics and is facility specific. Facilities with higher secondary effluent constituent concentrations will have greater difficulty meeting HHWQC.

5.0 Summary and Conclusions

This study evaluated treatment technologies potentially capable of meeting revised effluent discharge limits associated with revised HHWQC. HDR completed a literature review of potential technologies and engineering review of their capabilities to evaluate and screen treatment methods for meeting revised effluent limits for four constituents of concern: arsenic, BAP, mercury, and PCBs. HDR selected two alternatives to compare against a baseline, including enhanced secondary treatment, enhanced secondary treatment with MF/RO, and enhanced secondary treatment with MF/GAC. HDR developed capital costs, operating costs, and a NPV for each alternative, including the incremental cost to implement from an existing secondary treatment facility.

The following conclusions can be made from this study.

- Revised HHWQC based on state of Oregon HHWQC (2001) and EPA "National Recommended Water Quality Criteria" will result in very low water quality criteria for toxic constituents.
- There are limited "proven" technologies available for dischargers to meet required effluent quality limits that would be derived from revised HHWQC.
  - Current secondary wastewater treatment facilities provide high degrees of removal for toxic constituents; however, they will not be capable of compliance with water quality-based NPDES permit effluent limits derived from revised HHWQC.
  - Advanced treatment technologies have been investigated and candidate process trains have been conceptualized for toxics removal.
    - Advanced wastewater treatment technologies may enhance toxics removal rates, however they will not be capable of compliance with HHWQC based effluent limits for PCBs. The lowest levels achieved based on the literature review were between <0.00001 and 0.00004 µg/L, as compared to a HHWQC of 0.0000064 µg/L.
    - Based on very limited performance data for arsenic and mercury from advanced treatment information available in the technical literature, compliance with revised criteria may or may not be possible, depending upon site specific circumstances.
      - Compliance with a HHWQC for arsenic of 0.018 µg/L appears unlikely. Most treatment technology performance information available in the literature is based on drinking water treatment applications targeting a much higher SDWA MCL of 10 µg/L.
      - Compliance with a HHWQC for mercury of 0.005 µg/L appears to be potentially attainable on an average basis but perhaps not if effluent limits are structured on a maximum monthly, weekly or daily basis. Some secondary treatment facilities attain average effluent mercury levels of 0.009 to 0.066 µg/L. Some treatment facilities with effluent filters attain average effluent mercury levels of 0.002 to 0.010 µg/L. Additional advanced treatment processes are expected to enhance these removal rates, but little mercury performance data is available for a definitive assessment.
    - Little information is available to assess the potential for advanced technologies to comply with revised benzo(a)pyrene criteria. A municipal wastewater treatment plant study reported both influent and effluent BAP concentrations less than the HHWQC of 0.0013 ug/L (Ecology, 2010).

- Some technologies may be effective at treating identified constituents of concern to meet revised limits while others may not. It is therefore even more challenging to identify a technology that can meet all constituent limits simultaneously.
- A HHWQC that is one order-of-magnitude less stringent could likely be met for mercury and PAHs however it appears PCB and arsenic limits would not be met.

- Advanced treatment processes incur significant capital and operating costs.
  - Advanced treatment process to remove additional arsenic, benzo(a)pyrene, mercury, and PCBs would combine enhancements to secondary treatment with microfiltration membranes, reverse osmosis, and granular activated carbon and increase the estimated capital cost of treatment from $17 to $29 in dollars per gallon per day of capacity (based on a 5.0 mgd facility).
  - The annual operation and maintenance costs for the advanced treatment process train will be substantially higher (approximately $5 million - $15 million increase for a 5.0 mgd capacity facility) than the current secondary treatment level.
- Implementation of additional treatment will result in additional collateral impacts.
  - High energy consumption.
  - Increased greenhouse gas emissions.
  - Increase in solids production from chemical addition to the primaries. Additionally, the membrane and GAC facilities will capture more solids that require handling.
  - Increased physical space requirements at treatment plant sites for advanced treatment facilities and residuals management including reverse osmosis reject brine processing.
- It appears advanced treatment technology alone cannot meet all revised water quality limits and implementation tools are necessary for discharger compliance.
  - Implementation flexibility will be necessary to reconcile the difference between the capabilities of treatment processes and the potential for HHWQC driven water quality based effluent limits to be lower than attainable with technology

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7.0 Appendices

- Appendix A - Unit Process Sizing Criteria
- Appendix B - Greenhouse Gas Emissions Calculation Assumptions

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APPENDIX A - UNIT PROCESS SIZING CRITERIA

Table A-1. Unit Processes Sizing Criteria for Each Alternative

Unit Process	Units	Baseline Treatment	Advanced Treatment	Comment
Influent Pumping Station	unitless	3 Times Ave Flow	3 Times Ave Flow	This is peaking factor used to size the pumps (peak flow:average flow)
Alum Dose for CEPT (optional)	mg/L	20	20	This is the metal salt upstream of the primaries
Primary Clarifiers	gpd/sf	1000	1000	This is for average annual flows
Primary Solids Pumping Station	unitless	1.25 Times Ave Flow	1.25 Times Ave Flow	This is peaking factor used to size the pumps (maximum month flow:average flow)
Aeration System Oxygen Uptake Rate (OUR)	mg/L/hr	25	25	Average annual OUR is used in tandem with mixed liquor to determine the required aeration basin volume (the limiting parameter governs the activated sludge basin volume)
Aeration Basin Mixed Liquor	mg/L	1250	2500	Average annual mixed liquor is used in tandem with OUR (see next row) to determine the required aeration basin volume (the limiting parameter governs the activated sludge basin volume)
Secondary Clarifiers Hydraulic Loading	gpd/sf	650	--	Only use for Baseline as clarifiers governed hydraulically with short SRT (<2 days)
Secondary Clarifiers Solids Loading	lb/d/sf	--	24	Only use for Advanced Treatment as clarifiers governed by solids with long SRT (>8 days)
Return Activated Sludge (RAS) Pumping Station	unitless	1.25 Times Ave Flow	1.25 Times Ave Flow	RAS must have capacity to meet 100% influent max month Flow. The influent flow is multiplied by this peaking factor to determine RAS pumping station capacity.
Waste Activated Sludge (WAS) Pumping Station	gpm	1.25 Times Ave Flow	1.25 Times Ave Flow	WAS must have capacity to meet max month WAS flows. The average annual WAS flow is multiplied by this peaking factor to determine WAS pumping station capacity.
Microfiltration (MF) Flux	gfd	--	25	Based on average annual pilot experience in Coeur D'Alene, ID
MF Backwash Storage Tank	unitless	--	1.25	Storage tanks must have capacity to meet maximum month MF backwash flows. The average annual MF backwash volume is multiplied by this peaking factor to determine required volume.

Table A-1. Unit Processes Sizing Criteria for Each Alternative

Unit Process	Units	Baseline Treatment	Advanced Treatment	Comment
MF Backwash Pumps	unitless	--	1.25	Backwash pumps must have capacity to meet maximum month MF backwash flows. The average annual MF backwash flow is multiplied by this peaking factor to determine required flows.
Reverse Osmosis (RO)	gallon per square foot per day (gfd)	--	10	
RO Reject	%	--	20	This represents the percentage of feed flow that is rejected as brine
Chlorination Dose	mg/L	15	15	
Chlorination Storage Capacity	days	14	14	
Chlorine Contact Tank	min	30	30	This is for average annual conditions.
Dechlorination Dose	mg/L	15	15	
Dechlorination Storage Capacity	days	14	14	
Gravity Belt Thickener	gpm/m	200	200	This is for maximum month conditions using the 1.25 peaking factor from average annual to maximum month
Anaerobic Digestion	Hydraulic residenc e time (HRT)	18	18	This is for average annual conditions
Dewatering Centrifuge	gpm	120	120	This is for maximum month conditions using the 1.25 peaking factor from average annual to maximum month

gpd=gallons per day; sf=square feet; gpm=gallons per minute

Appendix B – Greenhouse Gas Emissions Calculation Assumptions

The steady state mass balance results were used to calculate GHG emissions. The assumptions used to convert between energy demand, chemical demand and production, as well as biologically-mediated gases (i.e., CH4 and N2O) and GHG emissions are provided in Table B-1. The assumptions are based on EPA (2007) values for energy production, an adaptation of the database provided in Ahn et al. (2010) for N2O emissions contribution, Intergovernmental Panel on Climate Change (IPCC) (2006) for fugitive CH4 emissions, and various resources for chemical production and hauling from production to the wastewater treatment plant (WWTP). Additionally, the biogas produced during anaerobic digestion that is used as a fuel source is converted to energy with MOP8 (2009) recommended waste-to-energy values.

Table B-1. Greenhouse Gas Emissions Assumptions

Parameters	Units	Value	Source
N_2O to CO_2 Conversion	lb CO_2/lb N_2O	296	IPCC, 2006
CH_4 to CO_2 Conversion	lb CO_2/lb CH_4	23	IPCC, 2006
Energy Production			
CO_2	lb CO_2/MWh	1,329	USEPA (2007)
N_2O	lb N_2O/GWh	20.6	USEPA (2007)
CH_4	lb CO_2/GWh	27.3	USEPA (2007)
Sum Energy Production	lb CO_2/MWh	1336	USEPA (2007)
GHGs per BTU Natural Gas			
CO_2	lb CO_2/MMBTU Natural Gas	52.9	CA Climate Action Registry Reporting Tool
N_2O	lb N_2O/MMBTU Natural Gas	0.0001	CA Climate Action Registry Reporting Tool
CH_4	lb CO_2/MMBTU Natural Gas	0.0059	CA Climate Action Registry Reporting Tool
Sum Natural Gas		53.1	CA Climate Action Registry Reporting Tool
Non-BNR N_2O Emissions	g N_2O/PE/yr	32	Ahn et al. (2010)
BNR N_2O Emissions	g N_2O/PE/yr	30	Ahn et al. (2010)
Biogas Purity	% Methane	65	WEF, 2009
Biogas to Energy	BTU/cf CH4	550	WEF, 2009
Digester Gas to Electrical Energy Transfer Efficiency	%	32	HDR Data

Table B-1. Greenhouse Gas Emissions Assumptions

Parameters	Units	Value	Source
Chemical Production			
Alum	lb CO_2/lb Alum	0.28	SimaPro 6.0 - BUWAL250, Eco-indicator 95
Polymer	lb CO_2/lb Polymer	1.18	Owen (1982)
Sodium Hypochlorite	lb CO_2/lb Sodium Hypochlorite	1.07	Owen (1982)
Building Energy Efficiency	kBTU/sf/yr	60	Calif. Commercial End-Use Survey (2006)
Hauling Distance		-	
Local	miles	100	-
Hauling Emissions			
Fuel Efficiency	miles per gallon	8	
CO_2	kg CO_2/gal diesel	10.2	CA Climate Action Registry Reporting Tool
N_2O	kg N_2O/gal diesel	0.0001	CA Climate Action Registry Reporting Tool
CH_4	kg CH_4/gal diesel	0.003	CA Climate Action Registry Reporting Tool
Sum Hauling Fuel	kg CO_2/gal diesel	10.2	CA Climate Action Registry Reporting Tool

GWh = Giga Watt Hours
MWh = Mega Watt Hours
MMBTU = Million British Thermal Units
BTU = British Thermal Unit
PE = Population Equivalents
kBTU/sf/yr = 1,000 British Thermal Units per Square Foot per Year
cf = cubic feet
lb = pound
kg = kilogram
gal = gallon

Tacoma
City of Tacoma
Environmental Services Department

August 16, 2021

Eleanor Ott, PSNGP Permit Writer
Department of Ecology, Water Quality Program
PO Box 47600
Olympia, WA 98504-7600

Dear Ms. Ott:

City of Tacoma, Environmental Services Department (Environmental Services) appreciates the opportunity to comment on the Department of Ecology's (Ecology) draft Puget Sound Nutrient General Permit (Permit) and draft Fact Sheet. Environmental Services operates two wastewater treatment facilities: the North End Treatment Plant No. 3, a 7.2 MGD, facility, and the Central Treatment Plant, a 60 MGD facility. Both facilities discharge secondary effluent to Commencement Bay.

The City of Tacoma is an advocate for clean water and Environmental Services is committed to the protection of Puget Sound and making meaningful progress towards water quality goals. This commitment has been demonstrated through our voluntary acceptance of our responsibility to clean up the Thea Foss waterway and the over 50 million dollars the City has put towards this effort. Environmental Services recognizes that it is important to address the growing challenge of nutrient over-enrichment in Puget Sound to ensure that science-based and effective controls are put in place to address all sources of pollution. Environmental Services has demonstrated its support of a scientific approach to protecting Puget Sound by, among other things, providing the funding for the establishment of the Salish Sea Modeling Center. Environmental Services is also a founding member of the Puget Sound Clean Water Alliance; an organization dedicated to analyzing peer-reviewed, scientific, environmental, and economic data and using it to develop regional strategies aimed at both protecting and enhancing Puget Sound.

Environmental Services provides the following comments and questions regarding the draft Permit and Fact Sheet:

COMMENT NO. 1: THE GENERAL PERMIT IS NOT THE RIGHT TOOL

Ecology's process of developing the Permit has revealed several facts that do not support issuance of nutrient controls in a general permit.

A general permit is available as an alternative to an individual permit when Ecology determines that the dischargers are more appropriately controlled under a general permit. This determination must be made in accordance with the governing regulations. As discussed more fully below, a general permit is appropriate only when a defined category of dischargers have the same or substantially similar types of operations, wastes, effluent limits or operating conditions, and require similar monitoring. The Fact Sheet states, "A general permit is designed to provide coverage for a group of related facilities or operations of a specific industry type or group of industries.

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It is appropriate when the discharge characteristics are sufficiently similar, and a standard set of permit requirements can effectively provide environmental protection and comply with ***water quality standards*** for discharges." See Fact Sheet, Page 12. Likewise, the NPDES Permit Writers' Manual explains that, "a facility that otherwise qualifies for a general permit may opt to apply for an individual permit." NPDES Permit Writers' Manual, Section 4.4, at 4-12. Ecology has not explained when and how it made the determination that a general permit was appropriate, what process it followed, what criteria, facts and information were taken into consideration when it made this determination and how each of the criteria were met.

Ecology's NPDES permit regulations provide in pertinent part as follows:

> (2) The director may issue general permits to cover categories of dischargers for geographic areas as described under subsection (3) of this section. The area shall correspond to existing geographic or political boundaries . .....
> (3) General permits may be written to cover the following within a described area:
> (a) Stormwater sources; or
> (b) Categories of dischargers that meet all of the following requirements:
> (i) Involve the same or substantially similar types of operations;
> (ii) Discharge the same or substantially similar types of wastes;
> (iii) Require the same or substantially similar effluent limitations or operating conditions, and require similar monitoring; and
> (iv) In the opinion of the director are more appropriately controlled under a general permit than under individual permits.

WAC 173-226-050(2) & (3); See also, 40 C.F.R. § 122.28(a)(1). Requirements (b)(i) – (iv) are written in the conjunctive, meaning that each requirement must be met for the category of dischargers subject to the Permit. The NPDES Permit Writers' Manual explains that,

> In deciding whether to develop a general permit, permitting authorities consider whether
>
> - A large number of facilities will be covered.
> - The facilities have similar production processes or activities.
> - The facilities generate similar pollutants.
> - Whether uniform WQBELs (where necessary) will appropriately implement water quality standards.

The above requirements appropriately limit the use of a general permit to those circumstances in which the selected category of dischargers are engaged in substantially similar operations and types of discharges. As noted in the NPDES Permit Writers' Manual, ". . . using a general permit ensures consistent permit conditions for comparable facilities." See, NPDES Permit Writers' Manual, Section 3.1.2, Page 3-2. Clearly, as explained below and as acknowledged by Ecology, the facilities are not comparable and the Permit conditions are not consistent.

First, several of the dischargers proposed to be covered under this Permit are not marine dischargers. The Permit itself recognizes this. Ecology has not explained how or why it is appropriate to include some non-marine dischargers in the Permit.

Second, a category of dischargers governed by a general permit must be within a designated geographical area. See, WAC 173-226-020(13).[1] The federal regulations (made applicable to Ecology pursuant to 40 C.F.R § 123.25 and 122.1(a)(2)) provide further clarification regarding what should be considered a geographic area for coverage,

> (a) Coverage. The Director may issue a general permit in accordance with the following:
>
> (1) . . . The area should correspond to existing geographic or political boundaries such as:
>
> (i) Designated planning areas under sections 208 and 303 of CWA;
>
> (ii) Sewer districts or sewer authorities;
>
> (iii) City, county, or State political boundaries;
>
> (iv) State highway systems;
>
> (v) Standard metropolitan statistical areas as defined by the Office of Management and Budget;
>
> (vi) Urbanized areas as designated by the Bureau of the Census according to criteria in 30 FR 15202 (May 1, 1974); or
>
> (vii) Any other appropriate division or combination of boundaries.

40 CFR §§ 122.28(a)(1) & 123.25.

The included non-marine discharges are not located in the same geographic area as the marine dischargers. Ecology has not explained why or how the geographic area for the non-marine dischargers is rationally or appropriately included in the same geographic area as the marine dischargers.

Third, because the dischargers do not have similar production processes or activities, the requirements of the Permit are not uniform in application. The Permit has been constructed to recognize that larger facilities have a different impact than smaller facilities and therefore are subject to different requirements. For example, larger facilities are required to update their planning documents annually, monitor more frequently and implement "optimization", while smaller facilities are only required to create optimization plans. Additionally, the Total Inorganic Nitrogen (TIN) Action Levels are effluent limits individualized for each plant. As noted in the NPDES Permit Writers' Manual, the general permit is not intended to be applied where "*uniform"* water quality based effluent limitations (WQBELs) will not appropriately implement water quality standards. See, NPDES Permit Writers' Manual, Section 3.1.2, Page 3-2.

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[1] (13) "General permit" means a permit that covers multiple dischargers of a point source category within a designated geographical area, in lieu of individual permits being issued to each discharger.

Likewise, the planning requirements in the Permit recognize that each facility is unique in its process and its discharge and cannot be subject to the same general requirements. There is no one size fits all solution and each plant must create their own planning and engineering documents to address the operating conditions of that plant. The wastewater treatment plants (WWTPs) have different technologies and processes for treatment that should be addressed under individual permits, not a general permit. A general permit is not a suitable or appropriate regulatory control when the dischargers, as they are here, are substantively dissimilar.

The Fact Sheet likewise recognizes the lack of similarity among the dischargers in its description of Ecology's "evolving" all known available and reasonable treatment technology (AKART) concept. The Fact Sheet states:

> The prevalence of 303(d) listings related to depleted dissolved oxygen levels from increased levels of nitrogen and phosphorus requires Ecology to reconsider the basis of AKART for domestic WWTPs. It is apparent that the agency must start to consider refining what constitutes AKART for this treatment category. The AKART provision needs evaluation on a case-by-case basis given its direct ties to economic impact. What constitutes AKART at one facility may be different at the next. This is especially true when considering the size differences between WWTPs, available space for expansion at the existing location, costs of additional treatment processes, the rate payer base and any identified hardship that may exist due to the median household income in the community.

See Fact Sheet, at 18. Ecology thus acknowledges that each facility is unique and requires an individualized evaluation to determine the appropriate nutrient controls. It stands to reason that these controls should be in individual permits. Indeed, in recognition of the lack of similarity among the plants included in the Permit, Ecology exempts one facility from the substantive requirements of the Permit. Ecology does not explain how or why inclusion of dischargers that are not the same or substantively the same satisfies the requirements of Ecology's own regulations and the federal regulations applicable to general permits.

Fourth, for the WWTP operators the major advantage of a general permit is that it might better facilitate a collaborative approach to nutrient management through effluent trading. However, Ecology's statement in the Fact Sheet that an effluent trading program would require waste load allocations for each individual facility negates any benefit that a general permit might provide in establishing such a program since there are no waste load allocations or final WQBELs in the Permit. Ecology does not explain how an effluent trading program would be feasible without waste load allocations of a final WQBEL in the Permit.

Finally, the prevalence of 303(d) listings related to depleted dissolved oxygen levels from increased levels of nitrogen and phosphorus requires Ecology to reconsider the basis of AKART for domestic WWTPs. It is apparent that the agency must start to consider refining what constitutes AKART for this treatment category. The AKART provision needs evaluation on a case-by-case basis given its direct ties to economic impact to each of the operators.

Recently, the Court of Appeals reiterated that the term 'reasonable' in the AKART standard limits Ecology to require a treatment system that is both technically and economically feasible.

Nw. Envtl. Advocates v Dep't of Ecology, 2021 Wash. App. LEXIS 1558, 2021 WL 2556573; citing to, *Puget Soundkeeper All. v Dep't of Ecology*, 102 Wn. App. 783, 793 (2000). What constitutes AKART at one facility will necessarily be different at the next. This is especially true when considering the size differences between WWTPs, available space for expansion at the existing location, costs of additional treatment processes, the rate payer base and any identified hardship that may exist due to the median household income in the community. Ecology has not explained how use of the general permit to regulate nutrients rather than the use of individual permits will ensure compliance with AKART.

COMMENT NO. 2: THE GENERAL PERMIT IS AN UNAUTHORIZED SECOND PERMIT FOR A SINGLE DISCHARGE

Ecology is proposing two mandatory permits, an individual permit and a general permit, to regulate a single discharge. The general permit coverage requirement proposed by Ecology conflicts with state and federal law regarding concurrency of a general and individual permits and constitutes an unlawful modification of the Tacoma's expired but administratively continued individual permits.

Ecology states that the Permit "supersedes effluent requirements related to total inorganic nitrogen in the individual NPDES permits with the exception of ammonia effluent limitations developed for control of ammonia toxicity." Fact Sheet, at 13. Ecology also states that the "permit supplements the individual NDPES permits held by the dischargers proposed for coverage." Fact Sheet, at 34.

These statements indicate that Nitrogen limits in individual permits still apply but are superseded by the Permit except under certain circumstances and that the Permit adds conditions not contained in the individual permits. This is not only confusing but in direct conflict with the Clean Water Act (CWA) which does not allow more than one permit for a single discharge, does not allow an individual permit to be amended through a general permit, and does not allow enforcement actions to be taken under the CWA when an operator is in compliance with an individual permit. Additionally, for dischargers operating under an administratively extended individual permit like Tacoma, coverage under the Permit will, by operation of law, extinguish the individual permit.

State NPDES permit programs authorized under the CWA are required to conform to the provisions of 33 USC § 1342 and guidelines for establishing state NPDES programs. 33 USC § 1342(c)(2). All state programs must be administered in accordance with the program requirements enumerated at 40 CFR § 123.25. 40 CFR §§ 122.1(a)(2) & 123.5. The program requirements made applicable to state programs include EPA regulations for general permits under 40 CFR § 122.28. Finally, the 2018 Memorandum of Agreement between the EPA and Ecology (2018 MOA) provides that Ecology will issue and administer general permits in accordance with State regulations and requirements consistent with 40 CFR § 122.28 (hereafter referred to as the "General Permit Regulations"). Ecology's' decision to require dischargers identified in the Permit to apply for coverage under the Permit conflicts with the provisions of 40 CFR § 122.28, the 2018 MOA and the CWA.

The EPA general permit regulations provide that general permits shall be written to cover one or more categories or subcategories of discharges or facilities not covered by individual permits. See, 40 CFR §122.28(a)(1). This provision does not contemplate or allow a general permit to operate concurrently with an individual permit. This is made clear in the same regulations which provide that, if a discharger is excluded from coverage under a general permit because the discharger already has an individual permit, the discharger may request that the individual permit be revoked in order to be covered under the general permit. 40 CFR § 122.28(a)(3)(G)(4)(v). Thus, to be covered by a general permit, the individual permit must be revoked.

Likewise, the application requirements for individual permits provide that any person discharging pollutants is required to apply for an individual permit unless that discharger is covered by a general permit. 40 CFR 122.21(a). And, if an individual NPDES permit is issued to a discharger already covered by a general permit, the general permit will be automatically terminated on the effective date of the individual permit. 40 CFR § 122.28(a)(3)(G)(4)(iv). The applicable EPA regulations do not provide for or allow concurrent coverage under both a general and individual permit. The same is true for Ecology's regulations.

Ecology's general permit program, at chapter 173-226 WAC, defines the term general permit as a permit that covers multiple dischargers of a point source category within a designated geographic area, in lieu of individual permits being issued to each discharger. WAC 173-226-020. Like the EPA regulations that Ecology's program must conform to, a general permit is an alternative to coverage under an individual permit. Ecology's regulations mirror the EPA regulations by providing that when an individual permit is issued to a discharger, the applicability of the general permit to that discharger is automatically terminated. In other words, there cannot be concurrent coverage. Further, a precondition to issuance of a general permit is a finding by Ecology that the category of dischargers to be covered are more appropriately controlled under a general permit than under individual permits. WAC 173-226-050(3)(b)(iv).[2] Again, the regulations establish that coverage must be under a general permit or an individual permit, but not both. Ecology has not explained its authority to require the operators to be subject to the Permit to be contemporaneously subject to the conditions of their individual permits and the Permit. Nor has Ecology explained why the individual permits for those operators subject to administratively extended permits will not terminate by operation of law upon coverage under the Permit, or why the Permit will not terminate by operation of law for those operators covered under an individual permit.

The Permit coverage requirement is also unenforceable. The permit shield contained in the CWA, 33 U.S.C. § 1342(k)) provides that compliance with the terms and conditions of a permit is deemed to be compliance with the CWA. The permit shield is also embodied in the Federal NPDES regulations.

> . . . [C]ompliance with a permit during its term constitutes compliance, for purposes of enforcement, with sections 301,302,306,307, 318, 403 and 405 (a)-(b) of CWA.

40 CFR § 122.5.

Accordingly, compliance with the terms of an individual permit is deemed to be compliance with the CWA. Ecology has not identified a provision in the CWA and its implementing regulations, or the State Water Pollution Control Act and its implementing regulations, that authorize Ecology to require coverage under a general permit for a discharger already covered by an individual

[2] See also WAC 173-226-070(2)(a)(i) providing that where water quality-based effluent limitations shall be incorporated into a general permit if, among other things, Ecology determines that the use of a general permit rather than individual permits is appropriate.

permit. In the absence of such authority, Ecology cannot require any of the covered dischargers to apply for coverage under the Permit or take enforcement action if they fail to do so.

The Permit will also operate to modify the conditions of the individual permit in violation of the procedures set forth in the CWA and its implementing regulations for a permit modification. As noted above, Ecology has stated that the Permit will supersede effluent requirements related to TIN in the individual NPDES permits and that the Permit will supplement the individual NPDES permits. Fact Sheet, at 13, 34. In effect, the Permit will operate as a modification of the individual permit because it purports to modify the discharger's obligations under the individual permit. In other words, certain actions which were deemed to be compliance with the CWA under the terms and conditions of the individual permit, will no longer be deemed compliance with the CWA under the Permit. Ecology has not explained its authority to modify the terms and conditions of an individual permit through coverage under a concurrent general permit and has not explained its authority to impose conditions through a general permit that would vitiate the permit shield of the individual permit.

Modifications of permits are governed by 40 CFR §§ 122.62 & 124.5, made applicable to Ecology pursuant to 40 CFR § 123.25. A permit modification requires that Ecology find that cause exists for a modification. 40 CFR § 122.62. Assuming cause exists, permit modifications (other than minor modifications) must conform to the process set forth at 40 CFR § 124. 40 CFR § 122.63. Ecology has not followed this process for modification of Tacoma's obligations under its individual NPDES permits. Accordingly, issuance of the Permit cannot operate to modify any of the terms and conditions of the individual permits issued to Tacoma. Nor can issuance of the Permit alter the provisions under the CWA, and implementing regulations, establishing that compliance by Tacoma with the terms and conditions of its existing permits constitutes compliance with the CWA.

Finally, even if Ecology has such authority, issuance of the Permit would by operation of law result in termination of the Tacoma individual permits pursuant to WAC 173-226-200(5) and for some jurisdictions, would result in immediate termination of the general permit pursuant to WAC 173-226-080(3); WAC 173-226-200(7). Termination of the individual permit as required under WAC 173-226-200(5), would violate the anti-backsliding provisions of 33 USC 1342(0) and 40 CFR 122.44(I) because the effluent limits in the individual permits would not be included in the Permit. The absence of those limits would constitute permit conditions and effluent limits that are less stringent than the terminated individual permits. Ecology's action to require coverage under the Permit would therefore violate the state NPDES permit program, the CWA and the 2018 MOA. Ecology has not explained how or why these provisions would be inoperative with respect to the Permit.

<u>Questions:</u>

- In response to comments, can Ecology explain how EPA and Ecology regulations precluding coverage under an individual and a general permit for the same discharge do not apply to the proposed permit?

- In response to comments, can Ecology also explain for individual permits that are currently under administrative extension, whether the administrative extension will expire as provided in WAC 173-226-300(5) ("…continuation of an expired individual permit, pursuant to WAC 173-220-180(5), shall terminate upon coverage by the general permit.")?

- In response to comments, can Ecology explain whether coverage under the general permit will be mandatory or voluntary?

<u>COMMENT NO. 3: THE SSM DOES NOT HAVE THE PRECISION TO PREDICT WATER QUALITY (DO) IMPAIRMENTS</u>

Ecology is misusing the Salish Sea Model (SSM) to drive an ineffective general permit. Using models to calculate wasteload allocations is entirely different from using models to predict the impact of nitrogen discharges on dissolved oxygen (DO) levels. Ecology's own guidance on water quality assessments requires the use of actual data to establish a water quality impairment for DO. Water Quality Policy 1-11 Chapter 1, at 50 (Ecology 2020)(Pub. No. 18-10-035). The SSM would be extremely useful in designing strategies for reducing impacts for various sources of Nitrogen. It is completely inappropriate for assessing water quality. Models have been used to predict DO in a waterbody and even to help calculate wasteload allocations. In these cases they have been compared against water quality samples not as Ecology has done here, by simply comparing the results of two hypothetical model runs. No model, not the SSM or the Chesapeake Bay or the San Francisco Bay model, has the precision to estimate 0.2 mg/L difference between two model runs. Indeed, the 2019 bounding scenarios report includes an assessment of the Mean Square Error (MSE) of the SSM. The MSE indicates that DO levels can be predicted within an error of 0.8 mg/L, an error rate that is nearly an order of magnitude greater than 0.2mg/L standard. Thus the SSM cannot determine if the water quality standard is being met. Ecology has presented no evidence of near field, or localized, impacts. If Ecology believes the model is capable of predicting far field impacts, that information should be used in constructing individual permits.

The Fact Sheet, at 31, states that following review, "Ecology will use the draft Puget Sound Nutrient Reduction Plan (NRP) to assign the applicable allocations, possibly at the basin level." If the ultimate outcome of the SSM is to derive waste load allocations, Ecology should use the TMDL process, not a general permit to regulate individual permit strategies. Ecology incorrectly claims that the "benefits of this alternative restoration plan approach include achieving cleaner water more quickly than a traditional TMDL and improved opportunities for stakeholder input throughout the document development." *Id.* This is clearly not the case. Assuming there is an impairment, Ecology's process does nothing to address the problem for at least five years when WQBELs are supposed to be established. A TMDL approach would more precisely (and probably more accurately) identify where the impairments are so that a more targeted strategy including effluent limits and non-point source reductions could be employed sooner.

The proposed process takes a sledge hammer approach that will have a minor, if any, effect everywhere and a major impact nowhere.

Ecology cites the 2019 Bounding Scenarios Report to support a conclusion that Puget Sound is impaired due to low DO. Ecology has not explained its reasoning or process for how it determined that there is a reasonable potential to exceed water quality standards. EPA guidance refers to the model selection decision tool (MSDT) available in the Nutrient Management Toolbox (NMT), a process which requires the permit writer to go through a series of steps to determine which modeling approach is best to use in a reasonable potential analysis. Neither the Fact Sheet nor the Permit give any indication that Ecology has gone through the proper steps to select the correct model and used the correct procedures to perform a reasonable potential analysis. A conclusion of reasonable potential to exceed a water quality (nutrient) standard requires Ecology to link nutrient loads to ecological response indicators for purposes of developing nutrient criteria or setting allowable load based response. This requires Ecology to identify the dominant habitat and ecological responder. Ecology has not done this and in fact has used a blanket approach that evaluates all of Puget Sound including shallow embayments and depths greater than 30 meters and lumps them together. Ecology has failed to identify the ecological responder as wells as the dominant habitat of the ecological responder.

COMMENT NO. 4: ECOLOGY HAS NOT PROVIDED ADEQUATE INFORMATION FOR A MEANINGFUL COMMENT ON THE REASONABLE POTENTIAL ANALYSIS THAT FORMS THE BASIS FOR THE GENERAL PERMIT

EPA and Ecology regulations require sufficient information to evaluate and comment on the basis for a NPDES permit. This information must be set forth in a draft Fact Sheet that is available for public review at the time a draft NPDES permit is issued for public comment. In the case of the Permit, Ecology has relied entirely on the 2019 Bounding Scenarios Report and the SSM model runs described therein. The Fact Sheet and report lack sufficient information for Tacoma to comment on the reasonable potential determination.

Tacoma made several requests to Ecology to obtain documentation on the assumptions and values that were used in the Bounding Scenarios Report SSM. Despite receiving thousands of pages of documents there is no documentation by Ecology of the values that were inputted to the SSM. Tacoma cannot determine, for example, how the inputs assigned its plants or any other plants were calculated. There is no document that can be identified that explains this information. Likewise, and again despite repeated requests, there is no documentation of how the model results were processed. The Bounding Scenarios Report provides a single set of figures that depict models cells that apparently fall below the applicable DO standard. It is impossible to determine from this generalized information what exact cells fall into this category, which layers of the cell were deemed impaired, and the duration of such impairment.

It appears from Ecology presentations that many, if not most, of the cells that Ecology deems to be impaired in the Bounding Scenarios Report and for the purposes of the reasonable potential analysis for the Permit were from modeled results in the deepest of ten layers for each cell in the SSM. This is contrary to the DO water quality standard under WAC 173-201A-210(d)(iii) where the standard must be applied to the “dominant aquatic habitat.” Since the standards are based on salmon habitat, there is no basis for finding an impairment or interpreting the model results from deep layers in the model cells to make a reasonable potential determination.

Likewise, Ecology’s WQP 1-11 is clear that data, or in this case model results, should not be used “if a water column meets the criterion except at depths close to the sediment interface.” WQP 1-11, Ch. 1, Page 50. Ecology’s own policy states that it is not appropriate to attribute a criterion exceedance to the data since “DO levels near the sediment interface are naturally depleted in certain waters.” WQP 1-11, Ch. 1, Page 51.

Tacoma has been attempting to reverse engineer the SSM runs done by Ecology for the bounding scenarios report. This effort is compounded by the fact that Ecology did the modelling internally, with no documentation, and without any external peer review. Tacoma cannot provide meaningful comments on the reasonable potential analysis forming the basis for the Permit without completing this work.

Questions:

- In response to comments, can Ecology disclose how it processed it the results from the SSM modeling to make impairment determinations used in its reasonable potential analysis?

- In response to comments, can Ecology explain the extent of cells deemed out of compliance with DO standards based solely on model results in the deepest layer of a cell?

- In response to comments, can Ecology explain if WQP 1-11 represents the current interpretation and application of the marine DO water quality standard?

- In response to comments, can Ecology explain if it has adopted a new DO standard in the manner in which it has processed and applied the results from the SSM described in the Bounding Scenario Report?

COMMENT NO. 5: A TMDL WOULD BE THE MORE EFFECTIVE APPROACH TO MAINTAINING AND IMPROVING WATER QUALITY

Assuming there is an impairment, Ecology's proposed process does nothing to address the problem for at least five years when WQBELs may be established. A TMDL approach would more precisely and probably more accurately identify where the impairments are so that a targeted strategy including WQBELs and non-point source reductions could be employed. In addition a TMDL approach would more likely result in waste load allocations that would provide reasonable assurance that water quality standards will be achieved. The proposed process takes a sledge hammer approach that will have a minor, if any, effect everywhere and a major effect nowhere.

COMMENT NO. 6: THE DRAFT NARRATIVE WATER QUALITY-BASED EFFLUENT LIMITS (WQBELS) DO NOT CONTROL DISCHARGES AS NECESSARY TO MEET APPLICABLE WATER QUALITY STANDARDS FOR DO

As Ecology admits it does not have the data to determine if this Permit will control discharges in a manner that will result in meeting water quality standards. Ecology has further determined that current levels of TIN in WWTP effluent are causing or contributing to violations of the DO standards in Puget Sound. See Fact Sheet, Page 30. Ecology has not proposed a monitoring program that adequately measures DO in the “impaired” water bodies. Without this data there is no way to tell whether the proposed actions in the Permit have any impact on DO.

Questions:

- In response to comments, can Ecology explain whether discharges from a facility at or below the total inorganic nitrogen action levels in Condition S4.B will cause or contribute to a violation of water quality standards?

- In response to comments, can Ecology explain how the proposed permit narrative effluent limits will meet water quality standards for DO?

- In response to comments, can Ecology explain whether a facility in full compliance with the permit and discharging total inorganic nitrogen at or below

action levels in Condition S4.B will be meeting water quality standards for dissolved oxygen? Can Ecology explain the basis for its answer to this question?

COMMENT NO. 7: THE ACTION LEVEL CALCULATION DATA SET IS TOO SMALL

Ecology recognizes that most facilities did not have adequate data sets to represent the Nitrogen discharge from the facilities covered under the Permit. Ecology developed a calculation tool for ALo that uses a nonparametric method called "bootstrapping" to calculate the annual load from facility data.

Bootstrapping disregards the underlying problem that Ecology does not have a data set that accurately represents nitrogen discharges from the covered operators. In addition, some operators had only quarterly data which Ecology extrapolated in an illogical attempt to represent the variability. Using extrapolated data in the bootstrapping calculation destroys what little statistical validity existed in the bootstrapping analysis. The action level that Ecology is using is an annual total load of TIN. The bootstrapping analysis is based on monthly averages. The confidence interval calculated, that is the basis for the action levels, is based on the estimated monthly mean not the annual load. This greatly exaggerates the precision of this estimate and could result in a high probability of immediate exceedances of the action level. Tacoma estimates that it has a one in five chance of exceeding the action level in the first year of the Permit.

There is no way that meaningful confidence intervals for annual loads can be calculated from monthly data, particularly if the extrapolation and bootstrapping have been used to artificially increase the sample size. Ecology should design and require a sampling program for each plant to more precisely estimate current nitrogen discharges before setting effluent limits or action levels. Ecology should defer setting action levels until more data is collected.

Additionally, Ecology's reference for Bootstrapping in the bibliography is not reliable.

Bootstrapping (statistics). (2021, May 7). In *Wikipedia.*
https://en.wikipedia.org/w/index.php?title=Bootstrapping_(statistics)&oldid=1021858475) [11]

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<u>COMMENT NO. 8: ALTERNATIVE RATE STRUCTURES ARE NOT LEGAL UNDER STATE LAW OR THE WASHINGTON STATE CONSTITUTION</u>

Ecology has recognized that the financial impact of the costs of treatment can create an unreasonable burden upon communities served by wastewater treatment plants. See, *Northwest Environmental Advocates v State*, 2021 Wash. App. LEXIS 1558 (2021). Overburdened communities will bear a significant and disproportionate burden of the cost of compliance with the Permit.

While the City appreciates Ecology's effort to address environmental justice by requiring an affordability assessment, the assessment will do nothing to address the disparate impact of the cost burden of the Permit upon communities of color, Tribes, indigenous communities, and low income populations. State law does not allow dischargers to create rate classifications based upon ability to pay, except as authorized pursuant to RCW 74.38.070 for low-income citizens. See, RCW Chapters 35.67 and 35.92. Tacoma already has a program for rate reductions under this statute. All other rate classifications must be based upon the cost of service and must be allocated equitably based upon service received. See generally, *King County Water Dist. No. 75 v Seattle*, 89 Wn. 2d 890, 903 (1978). A utility has a duty to fix rates that are just and reasonable and not unduly discriminatory. *Faxe v Grandview*, 48 Wn. 2d 342, 347 (1956).

Rates must comply with Article 1 § 12 of the State Constitution which requires that rates be non-discriminatory, meaning that rates apply alike to all persons within a class, and that there must be a reasonable ground for creation of different rate classifications. *Faxe*, 89 Wn. 2d at 348. Rate classifications under state law are based upon such factors as cost of service, the character of the service furnished, or the quantity or amount received. *Faxe*, 89 Wn. 2d at 349-350. State law sets for the criteria in Chapter 35.67 and 35.92 RCW. Neither state law nor the state constitution allow rate classifications based upon an affordability assessment with the exception of low income rate reductions authorized under state law and which are already being implemented. Accordingly, the concept of a study and proposal for rate alternatives only serves to create false hope that the enormous impact of funding the cost of treatment can be more equitably distributed. Further, it will not address the reasonableness of the overall costs of compliance to be borne by all of the rate payers.

<u>Question:</u>

- In response to comments, can Ecology explain what assessment Ecology has made to address environmental justice impacts from the proposed permit?

- **In response to comments, can Ecology explain how the requested report will be used to regulate NPDES permits for publically owned WWTPs?**

COMMENT NO. 9: ADAPTIVE MANAGEMENT

Tacoma supports an adaptive management approach, however the Permit does not include the basic tenet of adaptive management. Adaptive management is based off of the Deming Cycle of plan, do, study, act.

Determine Management Objectives:

Ecology's stated management objective for the first Permit is to "prevent the dissolved oxygen problem in Puget Sound from getting any worse." To that end, Ecology's key desired outcome would be to prevent DO levels from declining throughout Puget Sound. The key performance indicator would be DO.

The problem is that there is no provision in the Permit that requires DO to be measured or to use that data in determining the success or failure of any actions taken. The performance provisions in the Permit are limited to the total nitrogen loading from the WWTPs. Presumably this data will be used to do additional model runs that will tell us that DO conditions have improved. But without actual measurements of DO all we will know is that we have successfully manipulated the model. A robust monitoring program designed to detect improvements in DO levels is absolutely essential to a successful adaptive management program.

The ultimate management objective of the Permit is to improve DO conditions in Puget Sound. Assuming that limiting TIN loads from marine dischargers will actually have a meaningful impact on DO impairment, Ecology should use the first Permit cycle to collect the data necessary to inform the strategies for accomplishing the ultimate objective. Rather than write plans that may never be implemented or implement strategies that will, at best, maintain the status quo, Ecology should use the first Permit cycle to develop strategies and actions that most efficiently and effectively achieve target DO levels.

Implement Strategies and Actions to Achieve Objectives:

Ecology's timeframes for implementation are far too short. Once a strategy has been selected and appropriate metrics determined, baseline data must be collected to determine the nominal state before implementation of the strategy. If we don't know where we began, how will we know how far we have travelled or if there has been any meaningful benefit from reduction of nutrient loads from marine dischargers? Measurement of the effectiveness of a strategy is the basis of adaptive management. Collecting baseline data can take months. Actually implementing the strategy can take months to years depending on the amount of construction involved and the difficulty in optimizing the process change. Finally the action must proceed for a long enough period of time that any differences can be reliably measured.

Evaluate Management Effectiveness:

The time required for data collection, strategy development and implementation suggest long term objectives rather than short term, first Permit cycle, objectives should be the focus of adaptive management.

COMMENT NO. 10: CONDITION S3 – COMPLIANCE WITH STANDARDS

The Permit provides as follows:

> A. Discharges must not cause or contribute to a violation of surface water quality standards (Chapter 173-201A WAC), sediment management standards (Chapter 173-204 WAC), and human health-based criteria in the Federal water quality criteria applicable to Washington (40 CFR Part 135.45). This Permit does not authorize discharge in violation of water quality standards.

Permit, Condition S3.A

Ecology has determined that WWTPs discharges are causing or contributing to violations of the DO standards in Puget Sound. Fact Sheet, at 30. Indeed Ecology has determined that excess nutrients discharged from WWTPs in one location cumulatively contribute to DO impairments in other locations due to the water exchange that occurs between basins. *Id.* Based on these determinations compliance with the conditions of Permit will not result in meeting water quality standards putting dischargers in immediate violation of Condition S3.A of the Permit. Accordingly, the Permit will not meet the requirements of the CWA because compliance with the permit will not result in meeting water quality standards.

Questions:

- In response to comments, can Ecology explain the scope of the prohibition in Condition S3 in the permit? Does the prohibition only apply to TIN?

> **- In response to comments, can Ecology explain the basis for its presumption that compliance with permit conditions will result in compliance with water quality standards?**
>
> **- In response to comments, can Ecology explain whether discharges from a facility at or below the total inorganic nitrogen action levels in Condition S4.B will cause or contribute to a violation of water quality standards?**
>
> **- In response to comments, can Ecology explain the basis for its presumption in Condition S3 that compliance with permit conditions will result in compliance with water quality standards?**
>
> **- In response to comments, can Ecology explain whether discharges from a facility at or below the total inorganic nitrogen action levels in Condition S4.B will cause or contribute to a violation of water quality standards?**
>
> **- In response to comments, can Ecology explain whether the reasonable potential determination in the Draft Fact Sheet, at 30, constitutes site specific information for each facility covered under the permit that the facility has a discharge that is causing or contributing to a violation of water quality standards?**

COMMENT NO. 11: S4.A APPLICABILITY OF NARRATIVE EFFLUENT LIMITS

Condition S4 does not meet the requirements under 40 CFR §§ 122.44(d) and (k) for establishing narrative effluent limits. Effluent limits means any restriction, prohibition, or specification established by the Ecology in a permit on:

> . . . (a) Quantities, rates, percent removals, and/or concentrations of physical, chemical, or biological characteristics of wastes which are discharged into waters of the state; and (b) Management practices relevant to the prevention or control of such waste discharges.

WAC 173-221-030.

When Ecology has determined that there exists a reasonable potential for a discharger to cause, or contribute to an excursion above any water quality standard for a particular pollutant, the Permit must contain effluent limits for that pollutant. See, 40 CFR § 112.4(d). Best management practices may be used in lieu of a numeric effluent limit when numeric effluent limitations are infeasible. 40 CFR § 122.44(k)(3). Best management practices (BMPs) means,

> . . . schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of ''waters of the United States.'' BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

See, 40 CFR § 122.2

Ecology acknowledges in the Fact Sheet that under 40 CFR § 122.44 the Permit must contain effluent limits to control pollutants which have the reasonable potential to cause an excursion above water qualities standards. Fact Sheet, at 33. As noted above, Ecology has stated in the Fact Sheet that it has determined that domestic wastewater discharges may cause or contribute to a violation of water quality standards for DO. See, Fact Sheet, at 34. If Ecology stands by this determination, numeric WQBELs are required to be included in the Permit. See, 40 CFR § 122.44(d). The Permit does not meet the requirements of 40 CFR § 122.44(d) for the following reasons.

As noted above, narrative effluent limits may be used in lieu of a numeric effluent limit when numeric effluent limits are infeasible. 40 CFR § 122.4(k)(3). However, Ecology has acknowledged that not only is it feasible to establish numeric water quality limits, it plans to do so in the second iteration of the Permit. Fact Sheet, at 33.[3] The fact that it will take more time to perform additional model runs to establish numeric effluent limits does not mean that it is infeasible to do so. Accordingly, the Permit does not meet the requirements of 40 CFR § 122.44(k)(3). The Permit also fails to comply with NPDES permit regulations because it does not require actions that will result in meeting water quality standards. 40 § CFR 122.44(k)(4). At best the Permit will require compliance with actions levels that Ecology has determined are causing violations of the DO water quality standard throughout Puget Sound.

Table 4 (Condition S4) sets forth what are labeled "Narrative Effluent Limitations for Dominant TIN Loaders" that include three items: (1) monitoring and reporting, (2) nitrogen optimization plan, and (3) a nutrient reduction evaluation. The Permit and Fact Sheet do not explain how these narrative effluent limitations will result in compliance with water quality standards as required under EPA and Ecology regulations.

In *Washington Dairy Federation v. Department of Ecology*, 2021 WL 2660024, *13, __ Wn. App. ____ (Div. II June 29, 2021) (citing WAC 173-226-100(1)(j)(ii)), the court ruled that with NPDES Ecology must "issue a fact sheet that includes an explanation of how the permits meet groundwater and surface water quality standards."

<u>Questions:</u>

- In response to comments, can Ecology explain how these narrative effluent limitations will result in compliance with DO water quality standards?

- In response to comments, can Ecology explain whether a facility in full compliance with the permit and discharging total inorganic nitrogen at or below action levels in Condition S4.B will be meeting water quality standards for dissolved oxygen? Can Ecology explain the basis for its answer to this question?

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[3] "Ecology continues to review model results from the first year of optimization scenarios and scope future model runs through the Puget Sound Nutrient Forum. Additional model runs will be defined in 2021 to further quantify far and near field effects of wastewater discharges to marine waters along with the anthropogenic nutrient loads from Puget Sound watershed. Once Ecology can establish a nutrient loading capacity that meets DO criteria in the marine waters of Puget Sound, allocations that will lead to numeric WQBELs can be established. The NRP will include draft allocations for point sources and watershed inflows. After internal and external review, the allocations will be finalized and numeric WQBELs will no longer be infeasible. It is anticipated that for the second iteration of this permit the approach will shift to working towards compliance with those numeric limits." Fact Sheet, at 33.

COMMENT NO. 12: TIN ACTION LEVELS

Table 5 in the Permit includes "action levels" for TIN applicable to some WWTPs.

Questions:

- In response to comments, can Ecology explain how the actions levels were calculated?

- In response to comments, can Ecology explain the basis and information that were used to derive the action levels?

- In response to comments, can Ecology explain if the actions levels were calculated at a level to achieve compliance with DO water quality standards?

COMMENT NO. 13: CONDITION S4.A NITROGEN OPTMIZATION PLAN AND REPORT

Condition S4.A requires a permittee to develop and implement a Nitrogen Optimization Plan and apply an adaptive management approach at the WWTP. Ecology has not adequately defined what optimization means and how an operator can determine if it has optimized or how Ecology or a third party will determine if the operator has optimized. The Permit defines "optimization" as a BMP resulting in the refinement of WWTP operations that lead to improved effluent water quality and/or treatment efficiencies. By Ecology's own admission, optimization does not have a large impact on the perceived DO impairment. A more effective measure would be to put effort into determining WQBELs and begin planning design and construction of facilities that would actually have a significant impact on DO impairment, assuming there is an impairment.

Nitrogen Optimization Plan and Report. If a plant initially optimizes for maximum Nitrogen removal and then exceeds the Action Level, the Permit does not explain what adaptive management strategies are available since the WWTPs have presumably already optimized for maximum nitrogen removal.

Ecology's requirement that optimization strategies be planned and implemented in under a year is unrealistic. The facility must select a strategy, define metrics, measure the baseline data, and implement the strategy and then using the selected metrics determine if the strategy works. It is not feasible to complete this work within one year.

Question:

- In response to comments, can Ecology explain if a plant initially optimizes for maximum nitrogen removal but exceeds the action level, then what adaptive management strategies are left since they have presumably already optimized for maximum nitrogen removal?

COMMENT NO. 14: CONDITION S4.C NITROGEN OPTIMIZATION PLAN AND REPORT

Condition S4.C.1.b requires that the nitrogen optimization plan determine the optimization goal(s) for the WWTP. It is not clear from this language what goal or goals should be considered other than maximizing nitrogen removal. In the same section of the Permit Ecology allows the plan to exclude any strategy that would exceed a one year timeframe. There are no strategies for optimizing nitrogen removal at Tacoma facilities that can be developed, tested, modelled, and implemented in under a year.

In Condition S4.C.2.a.iv requires documentation of any impacts to the overall treatment performance as a result of process changes. Ecology does not explain how a facility, or how Ecology, will address potential negative impacts from optimization to overall treatment performance. It is not clear if a facility may violate its individual permit if negative impacts result from implementing optimization efforts, or whether negative impacts from optimization will be addressed in modified or reissued individual permits. It is not clear if optimization strategies that will have negative impacts to overall treatment performance must be considered.

Condition A4.C.2.b.i requires a load evaluation by March 31 each year to determine the facility's annual average TIN concentration and load from the reporting period. Since there will only be one year of data in year two of the Permit, it is impossible to calculate an annual loading average.

Condition S4.C.3.b requires identification of strategies for reducing TIN from new multi-family/dense residential developments and commercial buildings. The Fact Sheet does not explain or provide any guidance on what strategies should be considered under this condition of the Permit.

Condition S4.D.1.c requires, when a facility exceeds its action level, it must include in its next Annual Report a proposed approach to reduce the annual effluent nitrogen level by 10 percent. The Permit does not explain how a facility can be capable of obtaining an additional 10 percent reduction in loading if it has already reduced nitrogen loading to the maximum extent under the Permit.

The Fact Sheet, at 44, cites two EPA Case Studies on Implementing Low-Cost Modifications to Improve Nutrient Reduction at Wastewater Treatment Plants (2015) as a resource for evaluating alternatives for optimizing nitrogen reductions at activated sludge plants. The EPA study concluded that most opportunities for optimization were only found in facilities with existing BNR capabilities. The EPA document does not apply to the Tacoma facilities and Ecology has cited no other guidance for optimization alternatives.

The Fact Sheet, at 47, suggests that facilities evaluate strategies for reducing nitrogen loading including increasing production volumes of reclaimed water (if applicable to the facility), implementing side stream treatment for a portion of return flows from solids treatment, reducing influent nitrogen loads, alternative effluent disposal options and any other intermediate treatment alternative which results in decreased nitrogen loads into Puget Sound prior to major facility upgrades. All of these alternatives require substantial capital investment or growth moratoria. This is contrary to the previous statement that substantial capital investment would not be part of the optimization program.

Questions:

- In response to comments, can Ecology explain how a facility can document the exclusion of optimization strategies under this section?

- In response to comments, can Ecology explain whether Condition S4.C.1.b applies to consideration of an additional 10 percent reduction – namely, that a

facility does not need to consider optimization strategies that exceed a reasonable implementation cost or timeframe that exceeds one year?

- In response to comments, can Ecology explain the consequence to a facility if there are no optimization strategies that can reasonably be implemented to reduce nitrogen loading by an additional 10 percent within five years?

- In response to comments, can Ecology explain whether a facility will be in violation of the permit where there are no reasonably available optimization strategies to achieve a 10 percent reduction in annual nitrogen loading?

COMMENT NO. 15: CONDITION S4.E NUTRIENT REDUCTION EVALUATION

Condition S4.E.2 states that a facility must submit an "approvable" nutrient reduction evaluation report. There is no regulatory standard for nutrient reduction evaluation report and no basis for a permittee to know what might constitute an approvable or unapprovable evaluation. The Permit states that the nutrient reduction evaluation must include an AKART analysis. Since Ecology has determined, and the state courts have affirmed, that BNR and other tertiary treatment technology are not AKART for Puget Sound WWTPs, it is assumed that these technologies do not have to be considered in the evaluation. The Permit and Fact Sheet do not provide any explanation or basis for considering these types of treatment technologies as AKART.

Condition S4.E.3 of the Permit requires consideration of treatment technologies to achieve an effluent concentration of 3 mg/L. The Permit and fact sheet do not explain the basis for this requirement and how this requirement applies in the context of the Condition S4.E.2 AKART evaluation. It is assumed that a facility does not need to include an evaluation of any technology that would not constitute AKART.

Question:

- In response to comments, can Ecology explain what specifically constitutes an "approvable" Nutrient Reduction Evaluation?

- In response to comments, can Ecology explain the basis for inclusion of a requirement to evaluate treatment technologies to achieve TIN effluent concentrations of 3 mg/L?

COMMENT NO. 16: CONDITION S4.E.5.C IS VAGUE

Condition S4.E.5.c requires an environmental justice review and affordability assessment for what "overburdened communities" can afford to pay for the wastewater utility. There is no explanation as to what constitutes an overburdened community or how to determine what a member of an overburdened community can afford to pay for the wastewater utility. It is not clear the basis on which Ecology is asking for this information. There are no regulatory standards under Ecology regulations for the assessment and there is no basis for a facility under the state constitution or state statutes to vary the utility rates of its customers based on environmental justice. This is an assessment that Ecology should undertake on its own initiative prior to issuance of the Permit.

COMMENT NO. 17: CONDITION G25 BYPASS PROHIBITED

General Condition G25 imposes a bypass prohibition that directly modifies the administratively extended individual permits for the Tacoma facilities. This is a clear violation of federal and state regulations and case law that prohibit the modification of expired and administratively extended permits. This condition cannot lawfully be included in a general permit applicable to the Tacoma facilities.

COMMENT NO. 18: SEPA COMPLIANCE

Ecology should withdraw its SEPA determination for the Permit and prepare an environmental impact statement. Ecology acknowledges that a "modification of permit coverage for physical alterations, modifications, or additions to the wastewater treatment process that are substantially different from the original design and/or expands the existing treatment footprint requires State Environmental Policy Act (SEPA) compliance." Ecology is incorrect, however, in concluding that optimization does not require additional SEPA review. The draft Fact Sheet, at 47, suggests that facilities evaluate strategies for reducing nitrogen loading including increasing production volumes of reclaimed water, if applicable to the facility, implementing side stream treatment for a portion of return flows from solids treatment, reducing influent nitrogen loads, alternative effluent disposal options and any other intermediate treatment alternative which results in decreased nitrogen loads into Puget Sound prior to major facility upgrades." All of these alternatives will require substantial capital investment or some sort of growth moratoria by Tacoma.

The Tacoma facilities were not designed for de-nitrification and the optimization alternatives proposed by Ecology will require modifications that subject the Permit to SEPA review under an environmental impact statement.

Additionally, condition S4.C.3.b requires identification of strategies for reducing TIN from new multi-family/dense residential developments and commercial buildings. This condition requires Tacoma to propose development regulations that would trigger SEPA review. See, WAC 365-196-620 (Adoption of comprehensive plans and development regulations are "actions" as defined under SEPA. Counties and cities must comply with SEPA when adopting new or amended comprehensive plans and development regulations.)

Regardless of the applicability of any SEPA exemption, Ecology is also required to assess the potential climate impacts from the optimization requirements and the evaluation of treatment technologies, particularly treatment technologies that can achieve an effluent concentration of TIN at 3 mg/L. These alternatives will have a profound impact on energy consumption at the Tacoma facilities. *See Washington Dairy Federation v. Department of Ecology,* 2021 WL 2660024, *23 ___ Wn. App. ____ (Div. II June 29, 2021) (Ecology must consider climate change impacts in issuing a NPDES permit).

COMMENT NO. 19: PERMIT LIMITS BASED ON CURRENT TIN LOADING CONFLICT WITH TACOMA'S OBLIGATION TO PROVIDE WASTEWATER SERVICES WITH THE SERVICE AREAS OF ITS FACILITIES

Ecology has improperly based numeric effluent action levels on calculated levels of TIN loading from flow data and nitrogen concentration data in recent years. Tacoma is obligated under the Growth Management Act to accept and facilitate growth within the applicable urban growth boundaries. Associated with this obligation is the parallel requirement under its NPDES permits to maintain sufficient capacity to provide wastewater treatment within the service areas of its two facilities. This is a permit condition in both of the individual NPDES permits issued by Ecology and a requirement that is reflected in the general facility plans and engineering documents generated by Tacoma under WAC 173-240-050 and WAC 173-240-060. By adopting an effluent limit based on current loading and concentrations Ecology will be denying Tacoma any ability to provide for anticipated growth or leave the City in violation of its individual permits. Moreover, Ecology is locking in effluent limitations that fail to consider the permitted design flows for its facilities and that may be irrevocable under state and federal water quality anti-backsliding regulations. This is a critical issue that should compel Ecology to abandon the Permit until it has completed a DO TMDL for Puget Sound and is able to address nitrogen issues in individual NPDES permits.

Questions:

- In response to comments, can Ecology explain why it has not considered design flows and the need to maintain treatment capacity in setting effluent limitations in the permit?

- In response to comments, can Ecology explain whether the general permit will supersede and modify the obligations in the individual Tacoma permits to maintain treatment capacity within the service areas of the facilities?

- In response to comments, can Ecology explain whether, based on the general permit, the department will now consider void those portions of Tacoma's general sewer plan and engineering reports that are based on providing and maintaining wastewater treatment capacity within the respective service areas of its two facilities?

- In response to comments, can Ecology explain how it has evaluated the likelihood that Tacoma will have to put building moratoria in place to meet the proposed effluent limitations?

- In response to comments, can Ecology explain how it has evaluated the impact of the effluent limitations on the ability to develop low and moderate income housing?

- In response to comments, can Ecology explain how it has evaluated the potential environmental justice concerns that will result from reduced access to affordable housing?

- In response to comments, can Ecology explain how it has evaluated the applicability of anti-backsliding regulations to the proposed effluent limitations?

Thank you for this opportunity to comment on the Puget Sound Nutrient General Permit. We trust our comments are useful. If you have any questions or would like additional information please contact Daniel C. Thompson, Ph.D at 253 502-2191 dthompso@cityoftacoma.org.

Sincerely

Michael P. Slevin III, P.E.

Michael P. Slevin III, P.E.
Environmental Services Director

POLLUTION CONTROL HEARINGS BOARD
STATE OF WASHINGTON

KING COUNTY, Appellant, v. WASHINGTON STATE DEPARTMENT OF ECOLOGY, Respondent.	Case No. 21-083 **DECLARATION OF CHRISTIE TRUE**

1. My name is Christie True. I make this Declaration in support of the County's Motion to Stay.

2. I am over the age of eighteen (18) and declare the following facts are true to the best of my recollection, and that I have personal knowledge of the same.

3. I am the Director of King County's Department of Natural Resources and Parks. In that capacity, I oversee, and am responsible for the County's operation of its wastewater treatment plants ("WWTPs" or "Plants"), including King County's Brightwater Plant, its South Plant, its Vashon Plant, and its West Point Plant. The WWTPs and their operations, including the costs of compliance with regulatory requirements and permit, are funded by fees that the County charges to users of the WWTPs.

4. Each of these Plants is currently regulated by an individual National Pollutant Discharge Elimination System ("NPDES") permit issued by the Department of Ecology

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("Ecology") as follows: Brightwater is covered by #WA0032247, which expires on February 28, 2023; South is covered by #WA00295810, which expired on July 31, 2020 but which has been administratively extended; West Point is covered by #WA00029181, which expired on January 31, 2020 but which has been administratively extended; and Vashon is covered by #WA022527, which expires on February 28, 2022 but which I anticipate will be administratively extended. Copies of these individual permits are attached to the County's Motion to Stay.

5. Ecology issued the Puget Sound Nutrient General Permit ("PSNGP" or "Permit") on December 1, 2021, which becomes effective on January 1, 2022. Although the County's four WWTPs are already covered by existing individual NPDES permits, the PSNGP requires the County to apply for coverage for these four WWTPs under the PSNGP by March 1, 2022. The PSNGP applies to discharges of nutrients from the WWTPs and will simultaneously regulate the WWTPs along with their existing individual NPDES permits. King County has appealed the PSNGP and now moves to stay its effectiveness as to the County's four WWTPs.

6. The PSNGP requires the County to immediately begin complying with a number of onerous requirements, including (i) additional sampling, monitoring, and reporting requirements for each of the County's WWTP's dischargers, including monitoring for Total Inorganic Nitrogen ("TIN"); (ii) developing and implementing for each of the WWTPs a Nitrogen Optimization Plan to maximize nitrogen removal; (iii) compliance with assigned TIN discharge "action levels" established under Condition S4.D of the Permit for each of the County's individual WWTPs, or alternatively, compliance with the cumulative or "bubbled" action level assigned to the County's three Plants classified by the Permit as "dominant dischargers"; and (iv) compliance with the PSNGP's generic prohibitions on causing or contributing to a violation of surface water quality standards, sediment management standards, and human health-based water quality criteria. These immediate obligations will require a significant amount of staff and outside consultant time and effort and will cost the County *tens of*

millions of dollars in the next two years, in addition to continuing to comply with all the requirements of the WWTPs' individual NPDES permits, which will remain fully in effect.

7. More specifically, the PSNGP now requires the County to begin enhanced monitoring of the influent and effluent at each of its four WWTPs as well as monthly permit required DMR reporting. Conditions S7.A, S7.C. That will involve additional sampling and sample transport, analytical testing and associated lab practices, documentation and reporting, and the need to purchase additional equipment. This will also require the County to hire two new staffers. The total cost of this additional sampling, monitoring, and recording will be about $350,000 annually.

8. In addition to the enhanced monitoring, reporting and record keeping required under Conditions S7.A and S7.C described in ¶ 7 of this declaration, the PSNGP immediately requires the County to begin developing, preparing, and implementing a "Nitrogen Optimization Plan and Report" for each of the WWTPs pursuant to Conditions S4.C. and S6.B of the Permit. Because domestic wastewater treatment plants are not currently designed to remove nitrogen, the purposes of these optimization requirements are to "maximiz[e] nitrogen removal from the existing treatment plant[s] to stay below the calculated action level[s] "applicable to the three "dominant" WWTPs (South Plant, Brightwater, and West Point) and to "maximiz[e] nitrogen removal from" the "small" WWTP (Vashon). Conditions S4.C, S6.B. The Permit emphasizes that **"the Permittee must begin the actions described in this section immediately upon permit coverage."** *Id.* (emphasis in original). Condition S4.C.1.c requires the County to identify viable optimization strategies for each "dominant" WWTP owned and operated by the County, and to select **by July 1, 2022** at least one optimization strategy for implementation. Condition S6.B.1.b requires the County to identify the optimization strategy selected for implementation at the "small" WWTP by **December 31, 2022.**

9. To comply with Conditions S4.C. and S6.B the County must 1) select optimization strategies by July 1, 2022, and December 31, 2022, respectively, and 2) implement

the selected optimization strategies and submit annual reports beginning in March 2023. The County will have to dedicate 7 of its current staff to this effort on a full-time basis. To backfill these staff, the County will have to hire new employees. The labor costs associated with this requirement alone are estimated to be $700,000 for the first two years for optimization planning and $1,200,000 for optimization implementation in the same two years. The County will also have to hire outside consultants to assist with these optimization planning efforts at an expense of approximately $500,000 for the first two years. The County will have increased operating and maintenance costs associated with optimization, which are estimated to be $950,000 annually. The capital cost to implement the selected optimization strategies (e.g., install new equipment) is estimated at $5,000,000 a year per plant. Because the WWTPs and their operations are funded by fees charged to the users of the WWTPs, the County's ratepayers will ultimately bear the costs of complying with the PSNGP.

10. The County is also required to immediately *implement* the selected optimization strategy identified under Condition S4.C.1. and then document the implementation of the selected optimization strategy for each Plant by March 3, 2023. Condition S4.C.2. The immediate implementation of the PSNGP optimization requirement will adversely affect the ability of the County to complete other major capital project upgrades currently scheduled. More specifically, the immediate optimization requirements imposed by the PSNGP will have a cascading negative effect across the County's capital program resulting in the reassignment of project managers, engineers, operations staff, and construction managers. It will result in the delay of capital projects are needed to increase system reliability, maintain system capacity, reduce overflows, and maintain permit compliance. As an example of a critically impacted program, King County's West Point Capital Improvement Program ("the Program") has over $600,000,000 of active and planned projects to improve the reliability of the West Point Treatment Plant. Staff currently assigned to the Program will now need to be reassigned to comply with the PSNGP. This will result in the deferral of projects that are badly needed at

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West Point to improve reliability. This increases the risk of equipment failures and may result in an increase in plant bypasses, secondary treatment bypasses, increased risks to worker safety, and ultimately, to harm to the environment.

11. Additionally, immediate implementation of nitrogen optimization strategies at each WWTP has the real potential to create externalities that are not intended, including causing the Plant to violate a provision of its individual NPDES permit. For example, South Plant operates under NPDES Waste Discharge Permit No. WA0029581 which includes a pH limit and a prohibition on the bypass of sewage around the secondary treatment process. Operating South Plant to biologically remove nitrogen will likely result in a violation of both these requirements due to reduced flow capacity and the existing configuration of the treatment plant. Condition S1.A of the NPDES Waste Discharge Permit No. WA0029581.

12. If, as a result of compliance with Condition S4.C, the County determines that the Plant's annual TIN load exceeds its assigned action load (or, if applicable, the County's cumulative or "bubbled" load for all three dominant discharging Plants), then the County must proceed to take the corrective actions identified in Condition S4.D. Based on the County's data -- used by Ecology for development of the PSNGP-- the current discharge of total inorganic nitrogen (TIN) in effluent from any of the three dominant County dischargers demonstrate that the action levels, or bubbled action level, are likely to be exceeded within the first permit cycle.

13. Condition S4.D requires the County, if it exceeds its action level, to document why that happened and to identify what corrective actions will be needed to get the Plants below the action level. It must also, with the next annual report, submit a strategy to reduce the annual effluent load by *at least 10% below the action level* assigned to the individual plants or the bubbled action level for the three "dominant" plants. Condition S4.D.2. This "strategy" must be in the form of an engineering report that includes a summary of treatment alternatives considered, basic design information and influent characterization, a description of the proposed treatment approach and anticipated results from implementing that approach and have the

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signature and certification of a licensed professional engineer. An engineering report sufficient to comply with the permit is estimated to cost $5,000,000 for each plant. As indicated in paragraph 10 of this Declaration, this will result in a cascading effect, delaying critical capital improvements already in the planning phase.

14. The County's election of the type of coverage must be made in the Notice of Application (NOI) process by or before March 1, 2022, before any substantive planning information can be developed to assist making an informed decision on the optimal path to Permit compliance. If the County elects Permit coverage under individual action levels for the three WWTPs, it estimates that it likely will trigger the S4.D.2. corrective action obligation to develop an abbreviated engineering report to document the actions necessary to reduce nitrogen by 10% of the action level. This Condition of the Permit is expected to be triggered on or before July 1, 2022 at its West Point Plant (even if that Plant discharges at or below its assigned action level), because the County currently knows of no "viable optimization strategies" for that Plant. *See* Condition S4.C.1.b. This could result in an extensive and stranded planning and design effort.

15. If the County exceeds an action level two years in a row, or for a third year during the permit term, the County must implement the strategy proposed in the abbreviated engineering report under a schedule negotiated with Ecology. Condition S4.D.2.a. If the County elects Permit coverage with the bubbled action level, the relatively lower optimization capacity at the West Point WWTP described above would contribute to a probability of exceeding the bubbled action level. Consequently, the County would need to identify a strategy to reduce nitrogen to 10% below the total bubbled action level which would likely require actions be implemented at two or three of the County's regional WWTPs. Should that happen, whether at any of the County's individual WWTPs, or to the 3 County WWTPs classified as "dominant dischargers" cumulatively (if the County choses to approach compliance on the basis of the "bubbled action level"), the County will be forced to prepare a combined engineering report at a cost of

$9,000,000, and spend up to $88,000,000 for an individual treatment plant or $176,000,000 for the bubbled action level in implementing capital improvements to meet the draconian corrective action required by Condition S4.D.2.a. As explained more fully in ¶ 17 below, the investments in corrective actions could result in extensive stranded assets.

16. The County must immediately begin implementation of Condition S4.C.3 that includes, but is not limited to, "…investigate opportunities to reduce influent TIN loads from septage handling practices, commercial, dense residential and industrial sources and submit documentation with the annual report." While the County has limited institutional control over these matters, it accepts septage at the South Plant facility, has delegated authority for industrial waste pretreatment permits for all three regional plant customers, and has some land-use regulation role for unincorporated areas of the service area. Thus, the County must devote resources to work with stakeholders with direct roles in these matters, and develop and ensure compliance with the condition, including, but not limited to, 34 local sewer agencies, community engagement, local limit development, and permit writing. The County estimates that it will cost it a minimum of approximately $600,000 annually to provide the staffg needed to meet this requirement of the PSNGP.

17. The County will be irreparably harmed if the PSNGP is not stayed because the efforts outlined above that are required of the County to comply with the PSNGP will be for naught. Although Ecology is requiring the County to spend tens of millions of dollars to immediately evaluate, optimize, and modify its existing treatment systems, it is also requiring permittees to determine how each of their WWTPs will comply with a 3 mg/l TIN discharge limit as part of the required "Nutrient Reduction Evaluation" required under Condition S4.E.3. Through this requirement, Ecology is signaling that it intends to impose a 3 mg/L TIN discharge limit in the future, or perhaps an even more stringent limit, once it determines what constitutes all known and reasonable methods of treatment technology ("AKART") for domestic wastewater treatment plants that discharge nutrients to the Salish Sea, and once it determines what numeric

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water quality-based effluent limits are necessary for the County's four WWTPs to meet applicable dissolved oxygen water quality standards.

18. To meet TIN discharge limits as low as 3 mg/L at the County's four WWTPs, the County will have to employ tertiary treatment processes. For that to happen, the County will have to build new WWTPs because its existing plants were not built to remove TIN and cannot be retrofitted to accommodate tertiary treatment.

19. This means that if the PSNGP is not stayed, the County will be forced to take all the measures described in ¶¶ 6-16 herein and spend tens of millions of ratepayer dollars in the process, only to have that significant expenditure wasted when the County is forced to build new WWTPs that employ aggressive tertiary treatment methods.

20. In addition to the above, the County runs the risk of having to face an Ecology enforcement action or citizen suit filed under section 505 of the Clean Water Act ("CWA") and potential liability as a result of internally inconsistent provisions under Condition S3 of the PSNGP that render the County susceptible to being charged with discharging amounts of TIN that violate the CWA. On the one hand, Condition S3.A prohibits permittees from violating water quality standards ("WQS"), including the dissolved oxygen ("DO") standard at issue in this Appeal. On the other hand, Condition S3.B presumes that the very discharges that Ecology has authorized elsewhere in the PSNGP comply with the DO WQS. The inconsistencies between these two provisions put the County's four WWTPs at risk of immediate legal jeopardy.

21. More specifically, the Permit presumes that permittees are in compliance with the Permit and with applicable WQS so long as the permittee strictly complies with the Permit. The PSNGP establishes "TIN action levels" (Condition S3.B) for each dominant WWTP discharger that Ecology claims were established at current discharge levels. As described above, the PSNGP requires the dominant dischargers to discharge at or below those TIN action levels. *See generally*, Conditions S3, S4, and if those action levels are exceeded, to take appropriate corrective action.

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22. Yet, at the same time, Ecology decided to issue the PSNGP and to make it immediately applicable to the County's four WWTPs, because Ecology has concluded that the current TIN discharges from the 58 covered WWTPs are causing or contributing to potential violations of the DO WQS. *See* Fact Sheet at 32-33 (explaining that modeling demonstrates that TIN collectively discharged from domestic wastewater treatment plants contributes to low dissolved oxygen concentrations in Puget Sound that do not meet water quality criteria). In other words, Ecology has concluded that "all wastewater discharges to the greater Puget Sound area containing nitrogen cumulatively contribute to existing DO impairments meeting the threshold for reasonable potential under 40 C.F.R. 122.44(d)(1)(iii)" Fact Sheet at 32.

23. In short, under Condition S3, Ecology has both authorized and prohibited the same discharge, rendering the County, and for that matter, all dischargers covered under the Permit, susceptible to potential liability for discharging nitrogen in amounts that the County has concluded violate the DO WQS.

24. Although the County firmly disagrees with and has appealed Ecology's conclusion that each of its four Plants are currently causing or contributing to a violation of the DO WQS (*see* Notice of Appeal at section I), Ecology's foundational premise for issuing the PSNGP and the inconsistent provisions of Condition S3 expose the County to the *immediate* prospect of potential liability under the Permit. Not only do Ecology's "reasonable potential" findings conflict with Condition S3.B and raise concerns that the Permit does not ensure compliance with WQS, they also expose the County to potential citizen suits under the CWA, 33 U.S.C. § 1365. This includes potential penalties up to $56,460 per day for allegedly discharging nutrients in a manner that violates WQS, even if the County strictly complies with the optimization planning requirements and its assigned action levels.

25. For all these reasons, together with those explained more fully in the County's stay motion, the County is being irreparably harmed by having to immediately comply with the

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PSNGP. The Board should stay the Permit's effect while it considers—and until it resolves—the County's Appeal.

I declare under penalty of perjury that the foregoing is true and correct.

12/27/2021

Executed on December __, 2021 in Seattle, Washington

DocuSigned by:

1BD15B1B73AE4A0...

Christie True
Director, King County Dept. of Natural Resources

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CERTIFICATE OF SERVICE

I, Lynn A. Stevens, certify and declare:

I am over the age of 18 years, make this Declaration based upon personal knowledge, and am competent to testify regarding the facts contained herein.

On December 28, 2021, I served true and correct copies of the document to which this certificate is attached on the following persons in the manner listed below:

The Department of Ecology
Appeals Coordinator
300 Desmond Drive SE
Lacey, WA 98503
[ ] Via Facsimile
[■] Via U.S. Mail
[■] Via Legal Messenger
[ ] Via Federal Express

Bob Ferguson
Washington State Attorney General
Office of the Attorney General
Ecology Division
1125 Washington Street, SE
Olympia, WA 98501
[ ] Via Facsimile
[■] Via U.S. Mail
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The Pollution Control Hearings Board
1111 Israel Rd. SW, Ste 301
Tumwater, WA 98501
eluho@eluho.wa.gov
[ ] Via Facsimile
[■] Via U.S. Mail
[■] Via Email
[ ] Via Federal Express

I certify under penalty of perjury pursuant to the laws of the State of Washington that the foregoing is true and correct.

SIGNED on December 28, 2021 at Seattle, Washington.

Lynn A. Stevens

POLLUTION CONTROL HEARINGS BOARD
STATE OF WASHINGTON

KING COUNTY, Appellant, v. WASHINGTON STATE DEPARTMENT OF ECOLOGY, Respondent.	Case No. 21-083 **KING COUNTY'S MOTION FOR STAY**

I. INTRODUCTION

King County ("County") moves the Pollution Control Hearings Board ("Board") for a stay of the effect of the Department of Ecology's ("Ecology") issuance of the Puget Sound Nutrient General Permit ("PSNGP" or "Permit") as it applies to the County. The Permit regulates the discharge of nutrients, including total inorganic nitrogen ("TIN"), from publicly owned domestic wastewater treatment plants ("WWTPs") to the Washington waters of the Salish Sea. Fact Sheet for the Puget Sound Nutrient General Permit ("Fact Sheet") at 2. The PSNGP requires the County, by March 1, 2022, to apply for coverage under the PSNGP for its four WWTPs that discharge to Puget Sound: the Brightwater, South, Vashon, and West Point WWTPs.

The Board should grant the stay because the County is likely to succeed on the merits of the appeal and because the PSNGP will cause the County irreparable harm if the stay is not granted. The County is likely to succeed on the merits for the reasons set forth in the County's

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Notice of Appeal. These reasons include but are not limited to the PSNGP's inconsistency with the federal Clean Water Act ("CWA"), 33 U.S.C. §§ 1251-1387, and state law by requiring the County to apply for and obtain coverage under the PSNGP when the County's WWTP discharges are already authorized and regulated under individual National Pollutant Discharge Elimination System ("NPDES") permits; by simultaneously regulating these discharges under both the PSNGP and the WWTPs' individual permits; and by effectively modifying the County's four individual NPDES permits without complying with permit modification procedures and requirements.

In addition, the County is likely to succeed on the merits of its challenge to PSNGP Condition S3, which is arbitrary, internally inconsistent, and contrary to the CWA. PSNGP Condition S3.A prohibits permittees from causing or contributing to violations of water quality standards, and Ecology has concluded that the current nutrient discharges from all 58 WWTPs that are subject to the PSNGP are contributing to violations of the water quality standards for dissolved oxygen in Puget Sound. Fact Sheet at 32-33. Condition S3.B, however, authorizes permittees to continue discharging at their current levels as long as they comply with the other provisions of the PSNGP. Obviously, the permittees' current nutrient discharges cannot be both compliant and non-compliant with the PSNGP at the same time. Moreover, there is no legal basis for this internally inconsistent provision because it is neither an effluent limit nor any other NPDES permit condition authorized by the CWA or state law. The only effect of Condition S3 is to immediately subject the County and other PSNGP permittees to potential liability, including CWA penalties as high as $56,460 per day per violation. *See* 33 U.S.C. § 1319(d); 40 C.F.R. § 19.4.

The County will also suffer irreparable harm if the Board does not stay the PSNGP. The PSNGP requires the County to immediately devote thousands of hours of employee time, vast amounts of County resources, and tens of millions of ratepayers' dollars to immediately begin complying with the PSNGP's treatment system "optimization" and other requirements.

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Compliance with these requirements will also cause the County to forgo or delay upgrades to existing WWTPs that are needed to maintain system reliability, prevent wastewater from bypassing treatment systems, and improve treatment performance. In addition, the treatment system optimization measures required by the PSNGP are likely to cause the County to violate the conditions of its WWTPs' individual NPDES permit conditions.

Furthermore, the requirements of the PSNGP are likely to be for naught. PSNGP Condition S4.E requires all WWTPs designated as "dominant," including three of the four County WWTPs, to prepare an evaluation report to demonstrate how the County will achieve a seasonal TIN effluent limit of 3 milligrams per liter ("mg/L"), based on Ecology's belief that dischargers subject to the PSNGP will ultimately need to meet that or an even more stringent TIN effluent limit. To achieve a limit that low, the County will be required to employ tertiary treatment, which none of its existing WWTPs can be retrofitted to employ. This means that the County would have to build new WWTPs, thereby wasting the tens of millions of dollars that the PSNGP will require it to invest in "optimizing" its current WWTPs.

This Motion is supported by the accompanying Declaration of Christie True, King County's Director of Natural Resources. A copy of the PSNGP and its accompanying Fact Sheet were filed in support of the County's Notice of Appeal, which has been filed contemporaneously with this Motion.

II. FACTS

A. The PSNGP

Ecology issued the PSNGP on December 1, 2021. The Permit becomes effective on January 1, 2022, and expires on December 31, 2026. The Permit, which is a general NPDES permit issued pursuant to the CWA and RCW 90.48, applies to discharges of nutrients from the 58 WWTPs identified in the Permit that discharge directly to the Washington waters of the Salish Sea, including Puget Sound. *See* PSNGP Cover Page, Condition S1.A.

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The Permit *requires* the County to apply for coverage under the Permit by March 1, 2022, for each of its four WWTPs that discharge to Puget Sound. Condition S2.A. But each of these WWTPs is already fully authorized to discharge treated wastewater to Puget Sound, including the nutrients contained in the wastewater, by individual NPDES permits issued by Ecology. Specifically, the County's Brightwater WWTP is authorized to discharge "treated domestic wastewater to Puget Sound" by individual NPDES permit number WA0032247 (attached as Ex. A), its South WWTP is authorized to discharge "treated municipal wastewater to the Puget Sound" by individual NPDES permit number WA0029581 (attached as Ex. B), its West Point WWTP is authorized to discharge "treated municipal wastewater" to Puget Sound by individual NPDES permit number WA0029181 (attached as Ex. C), and its Vashon WWTP is authorized to discharge "treated domestic wastewater to the Puget Sound" by individual NPDES permit number WA022527 (attached as Ex. D).[1]

Because the County cannot "opt out" of coverage under the PSNGP, discharges from each of the four County WWTPs will be simultaneously regulated by both the PSNGP and the WWTP's individual NPDES permit.

B. PSNGP Requirements

The PSNGP requires the County to immediately begin complying with a number of onerous requirements, including but not limited to the following: Conditions S7 and S9 require additional sampling, monitoring, and reporting requirements for each of the County's WWTPs, including monitoring for TIN. Conditions S4.C and S6.B require developing and implementing for each of the WWTPs a Nitrogen Optimization Plan to maximize nitrogen removal. Condition S4.B establishes annual TIN discharge "action levels" for the three County WWTPs

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[1] The individual NPDES permit for the Brightwater WWTP expires on February 28, 2023. The individual NPDES permits for the South WWTP and West Point WWTP expired on July 31, 2020, and January 31, 2020, respectively, but they remain in effect pending Ecology's final action on the County's timely and pending permit renewal applications. *See* WAC 173-220-180(5). The individual NPDES permit for the Vashon WWTP expires on February 28, 2022, but will remain in effect thereafter until Ecology takes final action on the County's timely and pending permit renewal application. *See id.*

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designated by the PSNGP as "dominant" TIN dischargers, which Ecology asserts are based on their current TIN discharge levels. Condition S4.D requires the County to take various corrective actions if these action levels are not met. Condition S4.E requires a Nutrient Reduction Evaluation for the County's three dominant WWTPs to identify treatment technologies that provide "all known, available, and reasonable methods of prevention, control, and treatment" ("AKART") for nitrogen on an annual basis and to achieve a TIN discharge concentration of 3 mg/L on a seasonal (April through October) basis. Condition S6.C requires an AKART analysis for nitrogen removal for the County's Vashon WWTP. In addition, Condition S3.A prohibits causing or contributing to a violation of surface water quality standards.

C. Effects on the County

As detailed in the accompanying Declaration of Christie True, the PSNGP imposes immediate and substantial obligations on the County. Satisfying these obligations will require a significant amount of staff and outside consultant time and effort and will cost the County *tens of millions of dollars in the next two years*, in addition to continuing to comply with all the requirements of its WWTPs' individual NPDES permits, which will remain fully in effect. True Decl. ¶ 6.

Compliance with the PSNGP's enhanced monitoring and reporting requirements will immediately require the County to hire two new staffers and incur other costs of about $350,000 annually. True Decl. ¶ 7.

Compliance with the PSNGP's Nitrogen Optimization Plan requirements will require the County to immediately begin developing, preparing, and implementing the plans for each of its WWTPs. PSNGP Condition S4.C.1.c requires the County to identify and select viable optimization strategies for each of its three "dominant" WWTPs by July 1, 2022, and Condition S6.B.1.b requires the County to identify the optimization strategy selected for its Vashon WWTP by December 31, 2022. True Decl. ¶ 8. The County estimates that developing and implementing

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these plans will result in labor and outside consulting costs totaling $2.4 million for the first two years. *See* True Decl. ¶ 9. In addition, the County will have increased operating and maintenance costs associated with optimization, which are estimated to be $950,000 annually, and it estimates that the capital cost to implement the selected optimization strategies (*e.g.,* installing new equipment) to be $5 million a year per plant. *Id.*

The immediate implementation of the PSNGP optimization requirement will adversely affect the ability of the County to complete other major capital project upgrades currently scheduled. True Decl. ¶ 10. This will have a cascading negative effect across the County's capital program, including the reassignment of project managers, engineers, operations staff, and construction managers, which will delay ongoing capital projects that are needed to increase system reliability, maintain system capacity, reduce overflows, and maintain compliance with the County's individual NPDES permits. *Id.* This increases the risk of equipment failures and may result in an increase in plant bypasses, secondary treatment bypasses, increased risks to worker safety, and, ultimately, harm to the environment. *Id.* Furthermore, the immediate implementation of nitrogen optimization strategies at each WWTP has the potential to cause other changes in the quality of the wastewater discharged from the WWTPs, and violations of the discharge limits in the WWTPs individual NPDES permits. True Decl. ¶ 11.

These efforts and expenses are ultimately also likely to be for naught. PSNGP Condition S4.E requires the County to determine how each of the three dominant WWTPs will achieve a seasonal TIN discharge concentration of 3 mg/l because Ecology expects that future iterations of the PSNGP will include equally or even more stringent TIN discharge limits. True Decl. ¶ 17. Achieving TIN discharge limits as low as 3 mg/L will require tertiary treatment processes. True Decl. ¶ 18. For that to happen, the County will have to build new WWTPs because its existing plants were not built to remove TIN and cannot be retrofitted to accommodate tertiary treatment. *Id.* This means that if the PSNGP is not stayed, the County will be forced to take all the measures described above, and spend tens of millions of ratepayers'

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dollars in the process, only to have that significant expenditure wasted when the County is forced to build new WWTPs that employ aggressive tertiary treatment methods. True Decl. ¶ 19.

III. ARGUMENT

A. Standard for Stay

Pursuant to WAC 371-08-415, the Board may stay the effect of the PSNGP. The County makes a *prima facie* case for a stay if it "demonstrates *either* a likelihood of success on the merits of the appeal *or* irreparable harm." WAC 371-08-415(4) (emphasis added). Upon such a demonstration, the Board must grant the stay unless Ecology demonstrates either (i) "[a] substantial probability of success on the merits" or (ii) a "[l]ikelihood of success and an overriding public interest which justifies denial of the stay." WAC 371-08-415(4)(a)-(b). Likelihood of success on the merits "does not require the moving party to demonstrate that it will conclusively win on the merits, but only that there are questions 'so serious … as to make them fair ground for litigation and thus for more deliberative investigation.'" *Airport Communities Coal. v. Ecology*, PCHB No. 01-160 (Order Granting Motion to Stay Effectiveness of Section 401 Certification) (Dec. 17, 2001) (ellipsis in original; citation omitted). "The evaluation of the likely outcome on the merits is based on a sliding scale that balances the comparative injuries that the parties and non-parties may suffer if a stay is granted or denied." *Id.* The moving party's showing of likelihood of success on the merits need not be as strong where the non-moving party would suffer little or no harm. *Id.* The Board, after granting or denying a stay request, shall "expedite the hearing and decision on the merits," unless otherwise stipulated by the parties. WAC 371-08-415(5).

B. The County Has a Likelihood of Success on the Merits

The Board reviews the terms of an NPDES permit to determine if it is "invalid in any respect," and whether it is consistent with applicable legal requirements. WAC 371-08-540(2); *Puget Soundkeeper All. v. Ecology*, PCHB No. 15-050 (Order Granting Respondents' Motion for Summary Judgment, Jan. 6, 2016).

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As described in detail below, the PSNGP is invalid in multiple respects and is not consistent with either state or federal regulations. Accordingly, the County is likely to succeed on the merits, and the PSNGP must be stayed.

1. *Federal and State NPDES Permit Regulations Prohibit Ecology from Requiring Coverage Under a General NPDES Permit*

Each of the County's four WWTPs have coverage under individual NPDES permits. Exhibit A-D. Yet, PSNGP Condition S2 *requires* the County to apply for and obtain coverage under the PSNGP for each of its four WWTPs. For the 58 WWTPs listed in the PSNGP, including the County's four WWTPs, coverage under the PSNGP is *mandatory*. This *mandatory* general permit coverage is contrary to both the federal regulations implementing the CWA and Ecology's own regulations.

The federal regulations explicitly prohibit Ecology from developing general permits that cover the same discharges that are authorized by individual permits. 40 C.F.R. § 122.28(a)(1) ("The general permit shall be written to cover one or more categories or subcategories of discharges … *except those covered by individual permits*…." (emphasis added)). If Ecology assigns general NPDES permit coverage to a discharger that does not have permit coverage, the discharger must be allowed to request an individual permit. *See id.* § 122.28(b)(2)(vi). And even a discharger that has obtained coverage under a general permit may request to be excluded from coverage under the general permit by applying for and obtaining an individual NPDES permit. *Id.* § 122.28(b)(3)(iii) ("Any owner or operator authorized by a general permit may request to be excluded from the coverage of the general permit by applying for an individual permit."); *id.* § 122.28(b)(3)(iv).

The federal regulations are permissive in that they allow, but do not require, a discharger covered by an individual permit to apply for coverage under a general permit. *Id.* § 122.28(b)(3)(v) ("A source excluded from a general permit solely because it already has an individual permit *may* request that the individual permit be revoked, and that it be covered by the

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general permit." (emphasis added)). But the regulations do not allow Ecology to mandate coverage under a general permit. Instead, as the U.S. Environmental Protection Agency ("EPA") explained in the final rule promulgating the general permit regulations, "individual permittees can request to be covered by [a] general permit, and vice versa." Final Rule, National Pollutant Discharge Elimination System; Revision of Regulations, 44 Fed. Reg. 32,854, 32,874 (June 7, 1979).

Ecology's own regulations allow dischargers to choose to be regulated under a general permit. WAC 173-226-200(1) ("[A]ll dischargers *who desire to be covered* under the general permit shall notify the department of that fact…." (emphasis added)). Where a discharger has chosen to be covered under a general permit, the regulations specifically allow that discharger to subsequently "request to be excluded from coverage under the general permit by applying for and being issued an individual permit." WAC 173-226-080(3). If the discharger requests to be excluded from the general permit, "[t]he director *shall* either issue an individual permit or deny the request with a statement explaining the reason for denial." *Id.* (emphasis added); *see also* WAC 173-226-240(4) (same). "When an individual permit is issued to a discharger otherwise subject to a general permit, the applicability of the general permit to that permittee is automatically terminated on the effective date of the individual permit." WAC 173-226-080(4).

In direct contravention of the regulations, which allow dischargers discretion whether to apply for coverage under a general permit or apply for individual permit coverage, and which expressly prohibit requiring coverage under a general permit for a discharger already covered by an individual permit, the PSNGP *mandates* that the 58 listed WWTPs apply for and obtain coverage under the PSNGP for the same discharges that are already covered by their individual NPDES permits. Condition S2.A; Fact Sheet at 13 (listing "[d]ischargers that must apply for coverage under this … general permit"). Each of the four County WWTPs has an individual NPDES permit that authorizes discharges of treated wastewater subject to the conditions of those permits, including discharges of the nutrients that would be authorized by the PSNGP. Because

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the PSNGP violates these regulations, it is invalid insofar as it requires the listed facilities, including the County's four WWTPs, to apply for and obtain coverage under it.

2. *Federal and State NPDES Permit Regulations Prohibit Ecology from Regulating the Same Discharge Under Both a General and an Individual NPDES Permit*

The PSNGP is similarly unlawful because the nutrient discharges that it would authorize and regulate would simultaneously be authorized and regulated by the 58 facilities' individual NPDES permits, including those for the four County WWTPs. Ecology's Fact Sheet explains that

> Ecology currently issues individual NPDES permits to municipal wastewater treatment plants. The PSNGP addresses the discharge of nutrient pollution from POTWs that hold an existing, individual NPDES permit.

Fact Sheet at 2. The individual NPDES permits for the County's four WWTPs comprehensively regulate the discharge of effluent from the County's WWTPs by setting effluent limitations along with requirements related to monitoring, recordkeeping, reporting, design, operations, and maintenance, among others. The PSNGP imposes additional monitoring, recordkeeping, and reporting requirements on the County while purporting to authorize discharges of nutrients—something that is *already authorized* by the individual permit for each of the County's WWTPs. Yet, the PSNGP does not fully authorize discharges from the County's WWTPs; it only purports to authorize nutrient discharges, so the County cannot terminate the individual NPDES permits upon obtaining coverage under the PSNGP, as required by the regulations. Instead, the County must maintain its individual NPDES permits even after obtaining coverage under the PSNGP. This mandatory dual permit coverage is contrary to both EPA's and Ecology's regulations.

Both EPA and Ecology's regulations prescribe a binary system where discharges are covered either by an individual permit or by a general permit. WAC 173-226-020 ("No pollutants shall be discharged to waters of the state from any point source, except as authorized by an individual permit … *or* as authorized through coverage under a general permit…."

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(emphasis added)). The federal regulations explicitly prohibit writing a general permit for dischargers covered by an individual permit. 40 C.F.R. § 122.28(a)(1) ("The general permit shall be written to cover one or more categories of discharges … except those covered by individual permits….").

The regulations provide that "[w]hen an individual NPDES permit is issued to an owner or operator otherwise subject to a general NPDES permit, the applicability of the general permit to the individual NPDES permittee *is automatically terminated* on the effective date of the individual permit." 40 C.F.R. § 122.28(b)(3)(iv) (emphasis added); *see also* WAC 173-226-080(4) (same), -200(7) (same). The federal regulations further specify that "[a] source excluded from a general permit solely because it already has an individual permit may request that the individual permit be revoked, and that it be covered by the general permit." 40 C.F.R. § 122.28(b)(3)(v). These regulations specifically prevent a discharger from obtaining coverage under both a general and individual permit for the same discharge at the same time. Instead, the regulation requires that coverage under a general permit automatically terminates when a general permit is issued. Likewise, general permit coverage may only be obtained when an individual permit is fully revoked.

Ecology's own regulations recognize this distinction by defining "General Permit" as "a permit that covers multiple dischargers of a point source category within a designated geographical area, *in lieu of individual permits being issued to each discharger*." WAC 173-226-030(13) (emphasis added). Yet, the PSNGP is not in lieu of individual permits, but is in addition to individual permits contrary to both EPA's and Ecology's regulations.

Because discharges from the four County WWTPs that are required to obtain coverage under the PSNGP are already fully authorized by their individual NPDES permits, Ecology cannot require coverage for and regulate the same discharges under the PSNGP. The PSNGP is therefore unlawful and invalid as it applies to the County's WWTPs and all other WWTPs whose discharges are fully authorized by individual NPDES permits.

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3. *The PSNGP Impermissibly Modifies the County's Individual NPDES Permits*

The individual NPDES permits for the four County WWTPs that are subject to the PSNGP authorize discharges to Puget Sound of treated wastewater, which includes nutrients, subject only to the conditions of those permits. The PSNGP imposes substantial additional requirements on these authorized discharges. This impermissibly modifies the requirements of the individual permits without adhering to the NPDES permit modification procedures mandated by the applicable federal and state NPDES permitting regulations.

As the Board explained in *Citizens Against SeaTac Expansion v. Ecology*, "an entity that already has an effective permit does not need to apply for an NPDES permit" when the entity, Ecology, or an interested person seeks a modification of the permit. PCHB No. 01-090 (Order Denying Stay, Aug. 29, 2001) (internal quotation marks omitted) (citing 40 C.F.R. § 122.21(a)(1)). Rather, if an entity, Ecology, or an interested person wishes to modify an existing permit, they must comply with 40 C.F.R. § 124.5, applicable to modification, revocation, reissuance, and termination of an existing NPDES permit. *Citizens Against SeaTac Expansion v. Ecology*, PCHB No. 01-090 (Order Granting Summary Judgment, Jan. 4, 2002). Permits may only be modified for the reasons specified in 40 C.F.R. § 122.62, unless they are minor modifications. *Id.*

The PSNGP purports to authorize permittees who obtain coverage under the PSNGP to "discharge nutrients." But the County's WWTPs are already fully authorized to discharge wastewater, which necessarily contains nutrients, as the PSNGP recognizes. *See* Fact Sheet at 12. Functionally, the PSNGP does not authorize the discharge of anything. The only legal effect of the PSNGP is to modify the effluent limits, monitoring requirements, reporting requirements, and other conditions of the individual NPDES permits that the County already holds.

Individual permits can only be modified for one of the 18 enumerated causes specified in 40 C.F.R. § 122.62. *Puget Soundkeeper All. v. Ecology*, PCHB No. 15-050 (Order Granting Respondents' Motion for Summary Judgment, Jan. 6, 2016); *see also* WAC 173-220-

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150(1)(d), -190(1). Ecology has not identified any of the causes listed in 40 C.F.R. § 122.62 as a facility-specific reason for modifying the individual NPDES permits for the County's four WWTPs. Moreover, the individual NPDES permits for two of the WWTPs, South and West Point, have expired and therefore cannot be modified, only renewed. *See* 40 C.F.R. § 122.46(b); 49 Fed. Reg. 37,998, 38,045 (Sept. 26, 1984) ("Permits which have 'expired' cannot be modified. While expired permits may be continued in effect beyond the permit terms [pending final action on a permit renewal application], ... these permits may only be changed by reissuance.").

Even if Ecology had cause to modify the individual NPDES permits and the ability to do so, the regulations required Ecology to prepare draft permits addressing the individual permit modifications and to provide public notice and an opportunity for comment on each of the individual proposed permit modifications for the County's four WWTPs. *See* 40 C.F.R. §§ 124.5(c)(1), 124.6(d), 124.10(a)(1)(ii), (b)(1), (d)(1); WAC 173-220-190(3). Ecology did not do so.

The PSNGP modifies the requirements of the individual NPDES permits for the 58 facilities subject to the PSNGP, including the County's four WWTPs, by imposing additional NPDES permit requirements on the discharges from those facilities. Ecology has not identified a facility-specific cause for modifying the individual permits, and does not have the legal authority to modify the permits for two of the County's WWTPs. Even if Ecology did have cause and authority to modify the individual NPDES permits, it failed to comply with the permit modification procedures established by EPA's and Ecology's NPDES permit regulations. Therefore, the PSNGP is invalid as to the County's WWTPs and the other WWTPs subject to the Permit. Ecology cannot evade permit modification requirements and procedures by imposing a general permit on individually authorized discharges.

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4. *PSNGP Condition S3 Is Unreasonable and Unlawful Because It Has No Legal Basis and Is Inconsistent with Other PSNGP Provisions*

Condition S3.A prohibits discharges that cause or contribute to violations of water quality standards. The animating factor that led Ecology to issue the PSNGP and require the 58 dischargers subject to the Permit to obtain coverage under it is Ecology's determination that each of those individual WWTPs is causing or contributing to violations of the dissolved oxygen water quality standards by discharging TIN *at its current levels*. More specifically, the Fact Sheet states that

> nutrients, particularly inorganic nitrogen, discharged from domestic wastewater treatment plants contribute to low dissolved oxygen concentrations in Puget Sound that do not meet state water quality criteria.... The [modeled] circulation patterns showed how discharges in one basin can affect the water quality in other basins. Thus, all wastewater discharges to the greater Puget Sound area containing nitrogen currently contribute to existing DO [dissolved oxygen] impairments meeting the threshold for reasonable potential under 40 C.F.R. 122.44(d)(1)(iii).

Fact Sheet at 32-33.

Notwithstanding this assertion, the PSNGP authorizes each discharger subject to the PSNGP to continue discharging at what the PSNGP purports to be its current levels of TIN, subject to future evaluations that may result in unspecified reductions in TIN discharges. For example, Condition S4.B sets forth TIN action levels for each of the WWTPs classified by Ecology as "dominant dischargers" based on Ecology's calculation of the WWTP's *current* TIN discharges.[2] Similarly, although small WWTPs are not subject to action levels, Condition S6 allows them to continue discharging at their current TIN levels.

Furthermore, Condition S3.B includes a presumption that compliance with the monitoring, evaluation, optimization, corrective action, and other PSNGP requirements will result in compliance with water quality standards:

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[2] Ecology has concluded that a facility subject to these action levels has a one percent chance of exceeding the action level, based on its current operations, in any given year.

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> Ecology presumes that a Permittee complies with water quality standards unless discharge monitoring data or other site-specific information demonstrates that a discharge causes or contributes to a violation of water quality standards, when the Permittee complies with the following conditions. The Permittee must fully comply with all permit conditions, including planning, optimization, corrective actions (as necessary), sampling, monitoring, reporting, waste management, and recordkeeping conditions.

Id. This means that, so long as an individual WWTP does not exceed its TIN action level (or if it does exceed that level, it undertakes the measures required in Condition S4.D), that individual WWTP is presumed by Ecology to be in compliance with the PSNGP. This is so even though Ecology has determined that each WWTP's current discharge is causing or contributing to a water quality standards violation, and even though Condition S3.A explicitly prohibits discharges that cause water quality standards violations.

Thus, the PSNGP is unreasonable and internally inconsistent. It purports to allow discharges in Conditions S4.B, S5.B, and S6 that Ecology believes contribute to water quality standard violations and that are expressly disallowed in Condition S3.A. In other words, the PSNGP presumes compliance with water quality standards only if the permittee complies with water quality standards.

In addition to being unreasonable and internally inconsistent, Condition S3 is unlawful because it has no legal basis. Having determined that discharges of nutrients from the WWTPs have a reasonable potential to cause or contribute to a water quality standards violation, Ecology is required to establish permit effluent limits for nutrients. *See* 40 C.F.R. § 122.44(d)(1)(i); *Nat. Res. Def. Council v. U.S. Env't Prot. Agency* ("*NRDC*"), 808 F.3d 556, 577 (2d Cir. 2015). If numeric effluent limits for nutrients are "infeasible," "[b]est management practices" may be used instead. 40 C.F.R. § 122.44(k)(3); *see NRDC*, 808 F.3d at 577. But Condition S3.A is neither a numeric effluent limit nor a best management practice.

The condition is not a numeric effluent limit because it does not tell the permittee, Ecology, or the public what discharge quality the WWTP must achieve. The court in *NRDC*

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rejected a general NPDES permit condition nearly identical to Condition S3.A for precisely that reason.

> This narrative standard is insufficient to give ... [the permittee] guidance as to what is expected or to allow any permitting authority to determine whether ... [the permittee] is violating water quality standards. By requiring ... [permittees] to control discharges "as necessary to meet applicable water quality standards" without giving specific guidance on the discharge limits, EPA fails to fulfill its duty to "regulat[e] in fact, not only in principle." ... [This condition], although found by EPA to be required ... in fact add[s] nothing.

808 F.3d at 578 (fourth brackets in original; citation omitted).

Condition S3.A is also not a "best management practice" that may be used in lieu of a numeric effluent limit. "Best management practices" are "schedules of *activities*, prohibitions of *practices*, maintenance *procedures*, and other *management practices* to prevent or reduce the pollution of 'waters of the United States.'" 40 C.F.R. § 122.2 (emphasis added). Condition S3.A, however, does not require or prohibit any activities, practices, or procedures. Therefore, it cannot serve as a narrative substitute for numeric effluent limits, even if numeric limits are "infeasible." *See NRDC*, 808 F.3d at 579 (holding that a general NPDES permit nearly identical to Condition S3 did not qualify as a best management practice); *see also Wash. State Dairy Fed'n v. State*, 18 Wn. App. 2d 259, 297, 490 P.3d 290 (2021) (holding that a general permit prohibition on violating water quality standards is "not an adequate effluent limitation").

Condition S3.A cannot be justified as a numeric or narrative effluent limit, nor does it have any other legal basis. Rather, the condition simply exposes each of the permittees to liability, including penalties of up to $56,460 per day per violation, *see* 33 U.S.C. § 1319(d); 40 C.F.R. § 19.4, if an after-the-fact determination is made that the permittee's discharges caused or contributed to a violation of water quality standards. Determinations of the discharge levels needed to meet water quality standards, however, must be made before the permit is issued and used to establish effluent limits so that the permittee can take the steps needed to comply with standards. *See NRDC*, 808 F.3d at 579-80 (rejecting argument that a permit condition requiring

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compliance with water quality standards is a sufficient water quality-based effluent limit because it allows standards to be met through enforcement or other corrective actions).

Because Condition S3 is unreasonable, inconsistent with other PSNGP conditions, and without any legal basis, it is unlawful and invalid.

C. The County Will Be Irreparably Harmed in the Absence of a Stay

In addition to the County's likelihood of success on the merits, a stay is warranted because the County and its ratepayers will be irreparably harmed by the PSNGP. Compliance with the PSNGP will require the County to immediately begin spending millions of dollars on monitoring, evaluation, and treatment system optimization. These efforts will divert funds and personnel from ongoing capital projects and other measures to ensure compliance with existing NPDES permits, improve reliability, and increase system capacity. In addition, the treatment system optimization measures required by the PSNGP could result in violations of the County's individual NPDES permit, and those potential violations and PSNGP Condition S3.A's immediate prohibition on contributing to violations of water quality standards could expose the County to substantial liability from an agency enforcement action or CWA citizen suit. And, ultimately, the measures required by the PSNGP may be for naught because they will not enable the County to achieve the 3 mg/L or less TIN discharge limit that Ecology expects to impose in future iterations of the PSNGP.[3]

The County must immediately begin to implement Condition S4.C.3, which requires the County to investigate ways to reduce TIN loads in its influent. The County has limited control

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[3] As detailed in the True Declaration, the County will be required to spend at least $350,000 annually to comply with the enhanced influent and effluent monitoring requirements, $700,000 in the first two years to develop a Nitrogen Optimization Plan and Report for each of its WWTPs and $1.2 million to begin optimization implementation, $500,000 for outside consultants to assist with the optimization planning efforts in the first two years, and $950,000 annually in increased operation and maintenance costs. True Decl. ¶ 7. The County will have to divert at least seven staff members, and then eventually backfill their positions. *Id.* The County is also required to *immediately* implement the selected optimization strategy identified under Condition S4.C.1 and then document the implementation of the selected optimization strategy for each plant by March 2023, which will cost $5 million a year per plant. *Id.* ¶ 10.

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over the TIN load in its influent stream and will need to conduct extensive stakeholder engagement to even determine what options are feasible. True Decl. ¶ 16. The County estimates this will cost a minimum of $600,000 annually, simply to satisfy the staffing required for this effort. *Id.*

The County recognizes that expenditure of funds alone does not constitute irreparable harm under the stay regulations. *Martig Eng'g & Seashore Villa Mobile Home Park v. Ecology*, PCHB No. 03-013 (Order Denying Stay, Mar. 28, 2003). While these are significant costs that will directly impact King County ratepayers and citizens, the irreparable harm also arises from the enormous diversion of resources that will be required to immediately begin complying with the PSNGP. The immediate optimization requirements imposed by the PSNGP will have a cascading negative effect across the County's capital program, resulting in the reassignment of project managers, engineers, operations staff, and construction managers. True Decl. ¶ 10. It will result in the delay of capital projects that are needed to increase system reliability, maintain system capacity, reduce overflows, and maintain permit compliance. *Id.* As an example of a critically impacted program, the County's West Point Capital Improvement Program ("Program") has over $600 million of active and planned projects to improve the reliability of the West Point Treatment Plant. Staff currently assigned to the Program will now need to be reassigned to comply with the PSNGP. *Id.* This will result in the deferral of projects that are badly needed at West Point to improve reliability. *Id.* This increases the risk of equipment failures and may result in an increase in plant bypasses, secondary treatment bypasses, increased risks to worker safety, and, ultimately, harm to the environment.

Additionally, immediate implementation of nitrogen optimization strategies at each WWTP has the real potential to cause violations of individual NPDES permits. True Decl. ¶ 11. For example, the South Plant operates under NPDES Waste Discharge Permit No. WA0029581, which includes a pH limit and a prohibition on the bypass of sewage around the secondary treatment process. *Id.* Operating South Plant to biologically remove nitrogen will likely result in a violation of both these requirements due to reduced flow capacity and the existing configuration of the treatment plant. Condition S1.A of the NPDES Waste Discharge Permit No. WA0029581.

Further, if the County determines that a plant's annual TIN load exceeds its assigned action load (or, if applicable, the County's cumulative or "bubbled" load for all three dominant discharging plants), then the County must proceed to take the corrective actions identified in Condition S4.D. Based on the County's data, the current discharge of TIN in effluent from any of the three dominant County dischargers demonstrates that the action levels, or bubbled action level, are expected to be exceeded within the first permit cycle. True Decl. ¶ 12. When the County exceeds the action level, Condition S4.D requires the County to prepare a strategy, in the form of an engineering report, that identifies treatment options and design alternatives to reduce the annual effluent load by at least 10% below the action level. An engineering report sufficient to comply with the permit is estimated to cost $5 million for each plant. True Decl. ¶ 13. This will add to the cascading effect, further delaying critical capital improvements already in the planning phase.

Yet this enormous outlay of resources will likely be for naught. Although Ecology is requiring the County to spend tens of millions of dollars to immediately evaluate, optimize, and modify its existing treatment systems, it is simultaneously requiring permittees to determine how each of their WWTPs will comply with a 3 mg/l TIN discharge limit as part of the required "Nutrient Reduction Evaluation" required under Condition S4.E.3. Accordingly, Ecology is signaling that compliance with a 3 mg/L, or stricter, limit is what the agency is going to require in the future once it actually establishes AKART for domestic WWTPs that discharge nutrients to the Salish Sea, and once it determines what numeric water quality-based effluent limits are necessary for the County's four WWTPs to meet applicable dissolved oxygen water quality standards.

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To meet TIN discharge limits as low as 3 mg/L at the County's four WWTPs, the County will have to employ tertiary treatment processes. To achieve tertiary treatment, the County will have to build new WWTPs because its existing plants were not built to remove TIN and cannot be retrofitted to accommodate tertiary treatment. True Decl. ¶ 18.

This means that if the PSNGP is not stayed, the County will be forced to (1) immediately plan for and begin to optimize its four treatment plants; (ii) take the onerous corrective action dictated under the PSNGP (which may cause it to violate its individual permits); (iii) forgo or delay necessary improvements that it was otherwise planning at its four WWTPs; and (iv) spend tens of millions of ratepayer dollars in the process, only to have that expenditure wasted when the County is forced to employ tertiary treatment to meet aggressive treatment goals that will require the County to build new WWTPs altogether. True Decl. ¶ 19.

The Board has repeatedly held that, when an activity authorized or required under a permit is certain to have an irreparable impact, the appellant can demonstrate irreparable injury, even when the exact contours of the impact are not certain. *See Raymond A. Clough, Jr., v. Ecology*, PCHB No. 12-064 (Order Granting Partial Stay, Aug. 31, 2014) (finding irreparable harm to wetland from construction activities even though boundaries of wetland had not been delineated and actual harm was uncertain); *Carl & Dana Strode v. Ecology*, PCHB Nos. 11-085, 11-086, 11-089 (Order on Stay, Aug. 4, 2011) (finding irreparable harm from aquatic herbicide application even though exact location of herbicide application was not known).

Here, the County has demonstrated certain irreparable harm from the massive diversion of resources required to comply with the PSNGP when those compliance measures are likely to prove to have been wasted. This massive waste of resources will irreparably harm the County and its ratepayers.

The County will also be irreparably harmed because the internally inconsistent provisions of the PSNGP—on the one hand finding that the County's current TIN discharges are violating water quality standards, while on the other hand explicitly permitting the County to discharge

TIN at current levels—will place the County at an immediate risk of an Ecology enforcement action or citizen suit under section 505 of the CWA and liability for violating the Act.

More specifically, the Permit presumes that permittees are in compliance with applicable water quality standards so long as the permittee strictly complies with the Permit. The PSNGP establishes "TIN action levels" (Condition S4.B) for each dominant WWTP discharger that Ecology asserts were established at current discharge levels. The PSNGP requires the dominant dischargers to discharge at or below those TIN action levels, and, if those action levels are exceeded, to take appropriate corrective action. *See generally* Condition S4.

Yet, at the same time, Ecology decided to issue the PSNGP and to make it immediately applicable to the County's four WWTPs, because Ecology has concluded that the current TIN discharges from the 58 covered WWTPs are causing or contributing to violations of the DO water quality standards. *See* Fact Sheet at 32-33 (explaining that modeling demonstrates that TIN collectively discharged from domestic wastewater treatment plants contributes to low dissolved oxygen concentrations in Puget Sound that do not meet water quality criteria).

In short, under Condition S3, Ecology has both authorized and prohibited the same discharge, rendering the County, and for that matter all dischargers covered under the Permit, susceptible to liability for discharging nutrients in amounts that Ecology has concluded violate the DO water quality standards. The inconsistent provisions of the Permit irreparably harm the County by subjecting it to legal liability as soon as the PSNGP takes effect.

Accordingly, the Board must stay the permit to preserve the status quo and prevent the irreparable loss of rights and waste of resources that will occur if the PSNGP is allowed to take effect before the Board is able to determine if the PSNGP is valid. *Raymond A. Clough, Jr. v. Ecology*, PCHB No. 12-064 (Order Granting Partial Stay, Aug. 31, 2012).

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DATED: December 28, 2021

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Attorneys for Appellant
King County

CERTIFICATE OF SERVICE

I, Lynn A. Stevens, certify and declare:

I am over the age of 18 years, make this Declaration based upon personal knowledge, and am competent to testify regarding the facts contained herein.

On December 28, 2021, I served true and correct copies of the document to which this certificate is attached on the following persons in the manner listed below:

The Department of Ecology
Appeals Coordinator/Processing Desk
300 Desmond Drive SE
Lacey, WA 98503
[ ] Via Facsimile
[■] Via U.S. Mail
[■] Via Legal Messenger
[ ] Via Federal Express

Bob Ferguson
Washington State Attorney General
Office of the Attorney General
Ecology Division
1125 Washington Street, SE
Olympia, WA 98501
[ ] Via Facsimile
[■] Via U.S. Mail
[■] Via Legal Messenger
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The Pollution Control Hearings Board
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Tumwater, WA 98501
eluho@eluho.wa.gov
[ ] Via Facsimile
[■] Via U.S. Mail
[■] Via Email
[ ] Via Federal Express

I certify under penalty of perjury pursuant to the laws of the State of Washington that the foregoing is true and correct.

SIGNED on December 28, 2021, at Seattle, Washington.

Lynn A. Stevens

EXHIBIT A

Issuance Date: February 26, 2018
Effective Date: March 01, 2018
Expiration Date: February 28, 2023

National Pollutant Discharge Elimination System
Waste Discharge Permit No. WA0032247

State of Washington
DEPARTMENT OF ECOLOGY
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

In compliance with the provisions of
The State of Washington Water Pollution Control Law
Chapter 90.48 Revised Code of Washington
and
The Federal Water Pollution Control Act
(The Clean Water Act)
Title 33 United States Code, Section 1342 et seq.

King County Department of Natural Resources and Parks,
Wastewater Treatment Division
King Street Center, KSC-NR-700
201 South Jackson Street
Seattle, Washington 98104-3855

is authorized to discharge in accordance with the Special and General Conditions that follow.

Plant Name: Brightwater Wastewater Treatment Plant (WWTP)	Receiving Water: Puget Sound
Plant Location: 22505 SR 9 SE, Woodinville, WA 98072	Discharge Locations: Outfall 001 *Diffuser 1* Latitude: 47.777138360 Longitude: -122.416948716 *Diffuser 2* Latitude: 47.776987265 Longitude: -122.417957020
Plant Type: Activated Sludge with Hollow Fiber Membranes; Chemically Enhanced Primary Treatment for Peak Wet Weather Flows	

Rachel McCrea
Water Quality Section Manager
Northwest Regional Office
Washington State Department of Ecology

Exhibit A

Table of Contents

Summary of Permit Report Submittals

This list is intended as a summary of submittal requirements in the permit and may not include all submittals required by the permit. The Permittee must refer to the Special and General Conditions of this permit for additional submittal requirements and submit reports according to their instructions.

Permit Section	Submittal	Frequency	First Submittal Date
S3.A	Discharge Monitoring Report (DMR)	Monthly	04/15/2018
S3.A	Discharge Monitoring Report (DMR)	Quarterly	07/15/2018
S3.A	Discharge Monitoring Report (DMR)	Semiannual	01/15/2019
S3.A	Discharge Monitoring Report (DMR)	Annual	03/15/2019
S4.E	Wasteload Assessment	1/permit cycle	12/31/2022
S5.G.a.1	Operations and Maintenance Manual	1/permit cycle	07/31/2018
S5.G.a.3	Operations and Maintenance Manual Updates	1/permit cycle	09/01/2022
S6.A.4	Pretreatment Report	1/year	04/30/2018
S9.B	Wet Weather Bypass Annual Report	1/year	07/01/2018
S9.C	Utility Analysis Report	1/permit cycle	09/01/2022
S9.E	MBR Pilot Testing Report	1/permit cycle	07/31/2018
S10	Outfall Evaluation	1/permit cycle	12/01/2021
S11.A	Acute Toxicity Effluent Test Results for Permit Renewal	2/permit cycle	See condition for specific due dates
S12.A	Chronic Toxicity Effluent Test Results for Permit Renewal	2/permit cycle	See condition for specific due dates
S13	Application for Permit Renewal	1/permit cycle	09/01/2022

Special Conditions

S1. Discharge limits

S1.A. Effluent limits

All discharges and activities authorized by this permit must comply with the terms and conditions of this permit. The discharge of any of the following pollutants more frequently than, or at a level in excess of, that identified and authorized by this permit violates the terms and conditions of this permit.

Beginning on the effective date of this permit, the Permittee may discharge treated domestic wastewater to Puget Sound at the permitted location subject to compliance with the following limits:

Effluent Limits: Outfall 001 See discharge coordinates on cover sheet		
Parameter	**Average Monthly [a]**	**Average Weekly [b]**
Biochemical Oxygen Demand (5-day) (BOD_5)	30 milligrams/liter (mg/L) 10,233 pounds/day (lbs/day) 85% removal of influent BOD_5	45 mg/L 15,350 lbs/day
Total Suspended Solids (TSS)	30 mg/L 10,233 lbs/day 85% removal of influent TSS	45 mg/L 15,350 lbs/day
Total Residual Chlorine	0.5 mg/L	0.75mg/L
Parameter	**Minimum**	**Maximum**
pH	6.0 standard units	9.0 standard units
Parameter	**Monthly Geometric Mean**	**Weekly Geometric Mean**
Fecal Coliform Bacteria [c]	200/100 milliliter (mL)	400/100 mL

a	Average monthly effluent limit means the highest allowable average of daily discharges over a calendar month. To calculate the discharge value to compare to the limit, you add the value of each daily discharge measured during a calendar month and divide this sum by the total number of daily discharges measured. See footnote c for fecal coliform calculations.
b	Average weekly discharge limit means the highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges' measured during that week. See footnote c for fecal coliform calculations.
c	Ecology provides directions to calculate the monthly and the weekly geometric mean in publication No. 04-10-020, Information Manual for Treatment Plant Operators.

S1.B. Mixing zone authorization

Mixing zone for Outfall 001

The following paragraphs define the maximum boundaries of the mixing zones:

Chronic mixing zone

The mixing zone is a series of overlapping circles with radius of 794 feet measured from the center of each discharge port. The aggregate region of the mixing zone encompasses an oblong circular area measuring 2,088 feet long and 1,588 feet wide, centered around the 500-foot long diffuser. The mixing zone extends from the bottom to the top of the water column. The concentration of pollutants at the edge of the chronic zone must meet chronic aquatic life criteria and human health criteria.

Acute mixing zone

The acute mixing zone is a series of overlapping circles with radius of 79.4 feet measured from the center of each discharge port. The aggregate region of the mixing zone encompasses an oblong circular area measuring 658 feet long and 158.8 feet wide, centered around the 500-foot long diffuser. The mixing zone extends from the bottom to the top of the water column. The concentration of pollutants at the edge of the acute zone must meet acute aquatic life criteria.

Available Dilution (dilution factor)	
Acute Aquatic Life Criteria	115
Chronic Aquatic Life Criteria	238
Human Health Criteria - Carcinogen	511
Human Health Criteria - Non-carcinogen	415

S2. Monitoring requirements

S2.A. Monitoring schedule

The Permittee must monitor in accordance with the following schedule and the requirements specified in Appendix A.

Parameter	Units & Speciation	Minimum Sampling Frequency	Sample Type
(1) Wastewater influent, monitored at Headworks			
Wastewater Influent means the raw sewage flow from the collection system into the treatment facility. Sample the wastewater entering the headworks of the treatment plant excluding any side-stream returns from inside the plant.			
Flow	MGD	Continuous [a]	Metered/Recorded
BOD_5	mg/L	5/week	24-hr Composite [b]
BOD_5	lbs/day	5/week	Calculation [c]
TSS	mg/L	5/week	24-hr Composite
TSS	lbs/day	5/week	Calculation

Parameter	Units & Speciation	Minimum Sampling Frequency	Sample Type
(2) Final wastewater effluent, monitored at the Influent Pump Station (IPS)			
Final Wastewater Effluent means wastewater exiting the last treatment process or operation. Typically, this is after or at the exit from the chlorine contact chamber or other disinfection process. The Permittee may take effluent samples for the BOD_5 analysis before or after the disinfection process. If taken after, the Permittee must dechlorinate and reseed the sample.			
Flow	MGD	Continuous	Metered/recorded
BOD_5	mg/L	5/week	24-hr Composite
BOD_5	lbs/day	5/week	Calculation
BOD_5	% removal	1/month	Calculation [d]
TSS	mg/L	5/week	24-hr Composite
TSS	lbs/day	5/week	Calculation
TSS	% removal	1/month	Calculation [d]
Total Residual Chlorine	mg/L	Continuous	Metered/recorded [e]
pH [f]	Standard Units	Continuous	Metered/recorded
Fecal Coliform [g]	# /100 ml	5/week	Grab
Total Phosphorus	mg/L as P	1/Month	24-hr Composite
Soluble Reactive Phosphorus	mg/L as P	1/Month	24-hr Composite
Total Ammonia	mg/L as N	1/Month	24-hr Composite
Nitrate plus Nitrite Nitrogen	mg/L as N	1/Month	24-hr Composite
Total Kjeldahl Nitrogen (TKN)	mg/L as N	1/Month	24-hr Composite
(3) Wet weather bypass, monitored at the Chemically-Enhanced Primary Clarifier Effluent Channel			
The Permittee must monitor and report the following parameters for each split stream flow event in which the Permittee diverts a portion of the plant's influent to chemically enhanced primary treatment and bypasses the MBR treatment system. All parameters are monitored at the effluent channel of the active chemically enhanced primary clarifier(s), unless otherwise noted. See Special Condition S9 for additional requirements for wet weather bypasses.			
Calculated Membrane Flow Capacity	MGD	1/day [h]	Calculation [i]
Maximum Membrane TMP [j]	Pounds per square inch (psi)	1/day [h]	Measurement
Headworks Flow Rate [k]	MGD	1/day [h]	Measurement
Total Volume	Million Gallons (MG)	1/day [h]	Calculation
Total Duration of Bypass	Hours	1/day [h]	Measurement
Total Storm Duration [L]	Hours	1/day [h]	Measurement
Total Precipitation [m]	Inches	1/day [h]	Measurement or Calculation
BOD_5	mg/L	1/day [h]	Composite [n]
BOD_5	% removal	1/day [h]	Calculation [d]
TSS	mg/L	1/day [h]	Composite [n]
TSS	% removal	1/day [h]	Calculation [d]
pH	Standard Units	1/day [h]	Measurement
Priority Pollutants (PP) – Total Metals	µg/L; nanograms(ng/L) for mercury	2/year [o]	Composite [n] Grab for mercury [p]

Parameter	Units & Speciation	Minimum Sampling Frequency	Sample Type
(4) Priority pollutant testing, monitored in influent at Headworks, effluent at IPS, and in biosolids			
The Permittee must monitor the following parameters in the influent at the headworks, and biosolids in accordance with the Pretreatment requirements in Special Condition S6.B. The Permittee must also monitor effluent at the IPS in accordance with the Pretreatment requirements in Special Conditions S6.B and as required by the NPDES permit application. The schedule for pH below applies only to influent and biosolids since the effluent monitoring schedule above requires more frequent effluent monitoring for that parameter. Oil and grease monitoring applies only to influent and effluent.			
pH (influent and biosolids)	Standard units	1/quarter	Grab
Oil and Grease (influent and effluent)	mg/L	1/quarter	Grab
Cyanide	micrograms/liter (µg/L)	1/quarter	Grab
Total Phenolic Compounds	µg/L	1/quarter	Grab
PP – Total Metals	µg/L; nanograms (ng/L) for mercury	1/quarter	24-Hour composite Grab for mercury [p]
PP – Volatile Organic Compounds	µg/L	1/year	Manual Composite [q]
PP – Acid-extractable Compounds	µg/L	1/year	24-Hour composite
PP – Base-neutral Compounds	µg/L	1/year	24-Hour composite
PP – Pesticides/PCB Compounds	µg/L	1/year	24-Hour composite
(5) Permit renewal application requirements – final effluent monitored at IPS			
This section includes parameters required by the application that are not otherwise required by routine monitoring. The Permittee must report results with quarterly monitoring listed above			
Temperature	Degrees Celsius	1/quarter	Grab
Dissolved Oxygen	mg/L	1/quarter	Grab
Total Dissolved Solids	mg/L	1/quarter	Grab
Total Hardness	mg/L	1/quarter	Grab
(6) Whole effluent toxicity testing – final wastewater effluent			
Acute Toxicity Testing	See condition S11 for testing requirements	2/permit cycle during months specified in condition S11	24-hr composite
Chronic Toxicity Testing	See condition S12 for testing requirements	2/permit cycle during months specified in condition S12	24-hr composite

Monitoring schedule notes	
a	Continuous means uninterrupted except for brief lengths of time for calibration, power failure, or unanticipated equipment repair or maintenance. The Permittee must sample every 6 hours when continuous monitoring is not possible.
b	24-hour composite means a series of individual samples collected over a 24-hour period into a single container, and analyzed as one sample.
c	Calculate mass concurrently with the respective concentration of a sample, using the following formula: Concentration (in mg/L) X Flow (in MGD) X Conversion Factor (8.34) = lbs/day

d	Calculate the monthly average percent removal using the following formula: $$\% \text{ removal} = \frac{\text{Influent concentration (mg/L)} - \text{Effluent concentration (mg/L)}}{\text{Influent concentration (mg/L)}} \times 100$$ where influent and effluent concentrations are the monthly average concentrations of BOD_5 and TSS.
e	The Permittee must continuously record effluent total residual chlorine concentration using inline analyzers. Report the highest concentration from instantaneous data averaged over a maximum interval of 10 minutes as the daily maximum concentration.
f	The Permittee must continuously record effluent pH using inline analyzers. Report the daily maximum and minimum pH values from instantaneous data averaged over a maximum interval of 5 minutes. Do not report daily average pH values.
g	Report a numerical value for fecal coliforms following the procedures in Ecology's *Information Manual for Wastewater Treatment Plant Operators*, Publication Number 04-10-020. Do not report a result as too numerous to count (TNTC).
h	The Permittee must monitor and report all parameters in section 3 of this monitoring schedule, except metals, each day in which wet weather bypassing occurs. Report individual sample results on the monthly DMR in which bypassing occurred and summarize the results in the annual bypass report (S9.B). Report "No Discharge" for the CEPC monitoring point on the monthly DMR when no bypassing occurs during the month.
i	Membrane Flow Capacity to be calculated based on daily peak flow tests conducted on the day of a wet weather bypass event.
j	The maximum membrane TMP is the highest measured transmembrane pressure recorded at the initiation of a wet weather bypass event.
k	The Permittee must record and report the influent flow rate to the WWTP at the time of initiating a wet weather bypass. The Permittee must also calculate and report the average flow rate to the WWTP over the duration of the wet weather bypass event.
L	Storm duration is the amount of total time when precipitation that contributed to a wet weather bypass event occurred.
m	The Permittee must report precipitation for each storm event that led to a wet weather bypass. It may report precipitation using a single rain gauge that most represents precipitation over the drainage area tributary to the treatment plant or it may report precipitation based on an aggregate of multiple rain gauges in the drainage basin.
n	The Permittee must limit composite sampling of CEPC effluent to the duration of each wet weather bypass event. It may use automated composite sampling equipment or manually composite a series of grab samples over the duration of the bypass.
o	The Permittee must monitor metals in the CEPC effluent during a wet weather bypass event. Report individual results on the semiannual DMR corresponding to the months in which metals testing occurred. The semiannual monitoring periods are January through June and July through December.
p	Mercury monitoring requires clean sampling using EPA Method 1669 and low-level analysis using EPA Method 1631E. The Permittee will report mercury results with all other priority pollutant metals testing.
q	Manual composite refers to the collection of multiple discrete grab samples that are mixed and analyzed as a single sample. See Special Condition S6.B.1 for further details.

S2.B. Sampling and analytical procedures

Samples and measurements taken to meet the requirements of this permit must represent the volume and nature of the monitored parameters. The Permittee must conduct representative sampling of any unusual discharge or discharge condition, including bypasses, upsets, and maintenance-related conditions that may affect effluent quality.

Sampling and analytical methods used to meet the monitoring requirements specified in this permit must conform to the latest revision of the *Guidelines Establishing Test Procedures for the Analysis of Pollutants* contained in 40 CFR Part 136 (or as applicable in 40 CFR subchapters N [Parts 400–471] or O [Parts 501-503]) unless otherwise specified in this permit . Ecology may only specify alternative methods for parameters without permit limits and for those parameters without an EPA approved test method in 40 CFR Part 136.

S2.C. Flow measurement and continuous monitoring devices

The Permittee must:

1. Select and use appropriate flow measurement and continuous monitoring devices and methods consistent with accepted scientific practices.
2. Install, calibrate, and maintain these devices to ensure the accuracy of the measurements is consistent with the accepted industry standard, the manufacturer’s recommendation, and approved O&M manual procedures for the device and the wastestream.
3. Calibrate continuous monitoring instruments weekly unless it can demonstrate a longer period is sufficient based on monitoring records.
   The Permittee:
   a. May calibrate apparatus for continuous monitoring of dissolved oxygen by air calibration.
   b. Must calibrate continuous pH measurement instruments using a grab sample analyzed in the lab with a pH meter calibrated with standard buffers and analyzed within 15 minutes of sampling.
   c. Must calibrate continuous chlorine measurement instruments using a grab sample analyzed in the laboratory within 15 minutes of sampling.
4. Calibrate flow-monitoring devices at a minimum frequency of at least one calibration per year.
5. Maintain calibration records for at least three years.

S2.D. Laboratory accreditation

The Permittee must ensure that all monitoring data required by Ecology for permit specified parameters is prepared by a laboratory registered or accredited under the provisions of chapter 173-50 WAC, *Accreditation of Environmental Laboratories*. Flow, temperature, settleable solids, conductivity, pH, and internal process control parameters are exempt from this requirement. The Permittee must obtain accreditation for conductivity and pH if it must receive accreditation or registration for other parameters.

S3. Reporting and recording requirements

The Permittee must monitor and report in accordance with the following conditions. Falsification of information submitted to Ecology is a violation of the terms and conditions of this permit.

S3.A. Discharge monitoring reports

The first monitoring period begins on the effective date of the permit (unless otherwise specified). The Permittee must:

1. Summarize, report, and submit monitoring data obtained during each monitoring period on the electronic discharge monitoring report (DMR) form provided by Ecology within the Water Quality Permitting Portal. Include data for each of the parameters tabulated in Special Condition S2 and as required by the form. Report a value for each day sampling occurred (unless specifically exempted in the permit) and for the summary values (when applicable) included on the electronic form.
2. Ensure that DMRs are electronically submitted no later than the dates specified below, unless otherwise specified in this permit.
3. The Permittee must also submit an electronic copy of the laboratory report as an attachment using WQWebDMR. The contract laboratory reports must also include information on the chain of custody, QA/QC results, and documentation of accreditation for the parameter.
4. Submit DMRs for parameters with the monitoring frequencies specified in S2 (monthly, quarterly, annual, etc.) at the reporting schedule identified below. The Permittee must:
    a. Submit **monthly** DMRs by the 15th day of the following month.
    b. Submit **quarterly DMRs**, unless otherwise specified in the permit, by the 15th day of the month following the monitoring period. Quarterly sampling periods are January through March, April through June, July through September, and October through December. The Permittee must submit the first quarterly DMR on July 15, 2018 for the quarter beginning on April 1, 2018.
    c. Submit **semiannual DMRs** to report metals testing of the CEPC effluent by July 15 and January 15 of each year. Semiannual sampling periods are January through June, and July through December. The first sampling period begins July 1, 2018 and the first DMR is due January 15, 2019. If there are no qualifying wet weather bypass events during a semiannual monitoring period, the Permittee must report "No Discharge" on the DMR for that period.

d. Submit **annual DMRs** by March 15th of each year for monitoring completed the previous year. The first monitoring period begins on the effective date of the permit and lasts 12 calendar months. The first annual DMR is due March 15, 2019.

e. Submit permit renewal application monitoring data in WQWebDMR on quarterly DMRs as required by S3.A.4.b.

5. Enter the "No Discharge" reporting code for an entire DMR, for a specific monitoring point, or for a specific parameter as appropriate, if the Permittee did not discharge wastewater or a specific pollutant during a given monitoring period.

6. Report single analytical values below detection as "less than the detection level (DL)" by entering < followed by the numeric value of the detection level (e.g. < 2.0) on the DMR. If the method used did not meet the minimum DL and quantitation level (QL) identified in the permit, report the actual QL and DL in the comments or in the location provided.

7. Report single analytical values between the detection level (DL) and the quantitation level (QL) by entering the estimated value, the code for estimated value/below quantitation limit (j) and any additional information in the comments. Submit a copy of the laboratory report as an attachment using WQWebDMR.

8. **Not** report zero for bacteria monitoring. Report as required by the laboratory method.

9. Calculate and report an arithmetic average value for each day for bacteria if multiple samples were taken in one day.

10. Calculate the geometric mean values for bacteria (unless otherwise specified in the permit) using:

    a. The reported numeric value for all bacteria samples measured above the detection value except when it took multiple samples in one day. If the Permittee takes multiple samples in one day it must use the arithmetic average for the day in the geometric mean calculation.

    b. The detection value for those samples measured below detection.

11. Report the test method used for analysis in the comments if the laboratory used an alternative method not specified in the permit and as allowed in Appendix A.

12. Calculate average values and calculated total values (unless otherwise specified in the permit) using:

    a. The reported numeric value for all parameters measured between the detection value and the quantitation value for the sample analysis.

    b. One-half the detection value (for values reported below detection) if the lab detected the parameter in another sample from the same monitoring point for the reporting period.

c. Zero (for values reported below detection) if the lab did not detect the parameter in another sample for the reporting period.

13. Report single-sample grouped parameters (for example: priority pollutants, PAHs, pulp and paper chlorophenolics, TTOs) on the WQWebDMR form and include: sample date, concentration detected, detection limit (DL) (as necessary), and laboratory quantitation level (QL) (as necessary).

S3.B. Permit submittals and schedules

The Permittee must use the Water Quality Permitting Portal – Permit Submittals application (unless otherwise specified in the permit) to submit all other written permit-required reports by the date specified in the permit.

When another permit condition requires submittal of a paper (hard-copy) report, the Permittee must ensure that it is postmarked or received by Ecology no later than the dates specified by this permit. Send these paper reports to Ecology at:

Water Quality Permit Coordinator
Department of Ecology
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

S3.C. Records retention

The Permittee must retain records of all monitoring information for a minimum of three (3) years. Such information must include all calibration and maintenance records and all original recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for this permit. The Permittee must extend this period of retention during the course of any unresolved litigation regarding the discharge of pollutants by the Permittee or when requested by Ecology.

S3.D. Recording of results

For each measurement or sample taken, the Permittee must record the following information:

1. The date, exact place, method, and time of sampling or measurement.
2. The individual who performed the sampling or measurement.
3. The dates the analyses were performed.
4. The individual who performed the analyses.
5. The analytical techniques or methods used.
6. The results of all analyses.

S3.E. Additional monitoring by the Permittee

If the Permittee monitors any pollutant more frequently than required by Special Condition S2 of this permit, then the Permittee must include the results of such monitoring in the calculation and reporting of the data submitted in the Permittee's DMR unless otherwise specified by Special Condition S2.

S3.F. Reporting permit violations

The Permittee must take the following actions when it violates or is unable to comply with any permit condition:

1. Immediately take action to stop, contain, and cleanup unauthorized discharges or otherwise stop the noncompliance and correct the problem.
2. If applicable, immediately repeat sampling and analysis. Submit the results of any repeat sampling to Ecology within thirty (30) days of sampling.

a. Immediate reporting

The Permittee must immediately report to Ecology and the Snohomish County Health District or Public Health of Seattle-King County (depending on location impacted by the incident) at the numbers listed below all:

- Failures of the disinfection system.
- Collection system overflows.
- Plant bypasses discharging to marine surface waters.
- Any other failures of the sewage system (pipe breaks, etc.)

Northwest Regional Office	425-649-7000
Snohomish County Health District	425-339-5200
Public Health of Seattle-King County	(206) 477-8050

If the reportable incident impacts marine waters, the Permittee must also contact the Department of Health, Shellfish Program:

Department of Health,	360-236-3330 (business hours)
Shellfish Program	360-789-8962 (after business hours)

Additionally, for any sanitary sewer overflow (SSO) that discharges to a municipal separate storm sewer system (MS4), the Permittee must notify the appropriate MS4 owner or operator.

b. Twenty-four-hour reporting

The Permittee must report the following occurrences of noncompliance by telephone, to Ecology at the telephone numbers listed above, within 24 hours from the time the Permittee becomes aware of any of the following circumstances:

1. Any noncompliance that may endanger health or the environment, unless previously reported under immediate reporting requirements.

2. Any unanticipated bypass that causes an exceedance of an effluent limit in the permit (See Part S5.F, "Bypass Procedures").
3. Any upset that causes an exceedance of an effluent limit in the permit (See G.15, "Upset").
4. Any violation of a maximum daily or instantaneous maximum discharge limit for any of the pollutants in Section S1.A of this permit.
5. Any overflow prior to the treatment works, whether or not such overflow endangers health or the environment or exceeds any effluent limit in the permit.

c. Report within five days

The Permittee must also submit a written report within five business days of the time that the Permittee becomes aware of any reportable event under S3.F.2.a or S3.F.2.b, above. Submit the written report electronically using the *Water Quality Permitting Portal – Permit Submittals* application under the "As Needed, 5-day Written Follow-up" submittal schedule. Include the ERTS number in the name of the file uploaded for this submittal. If the letter covers multiple ERTS reports, include the incident date in the file name (example file names: "ERTS XXXXXX follow-up" or "follow-up-MMDDYYYY incidents"). The report must contain:

1. A description of the noncompliance and its cause.
2. The period of noncompliance, including exact dates and times.
3. The estimated time the Permittee expects the noncompliance to continue if not yet corrected.
4. Steps taken or planned to reduce, eliminate, and prevent recurrence of the noncompliance.
5. If the noncompliance involves an overflow prior to the treatment works, an estimate of the quantity (in gallons) of untreated overflow.

d. Waiver of written reports

Ecology may waive the written report required in subpart c, above, on a case-by-case basis upon request if the Permittee has submitted a timely oral report.

e. All other permit violation reporting

The Permittee must report all permit violations, which do not require immediate or within 24 hours reporting, when it submits monitoring reports for S3.A ("Reporting"). The reports must contain the information listed in subpart c, above. Compliance with these requirements does not relieve the Permittee from responsibility to maintain continuous compliance with the terms and conditions of this permit or the resulting liability for failure to comply.

S3.G. Other reporting

a. Spills of oil or hazardous materials

The Permittee must report a spill of oil or hazardous materials in accordance with the requirements of RCW 90.56.280 and chapter 173-303-145. You can obtain further instructions at the following website: https://ecology.wa.gov/About-us/Get-involved/Report-an-environmental-issue/Report-a-spill.

b. Failure to submit relevant or correct facts

Where the Permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application, or in any report to Ecology, it must submit such facts or information promptly.

S3.H. Maintaining a copy of this permit

The Permittee must keep a copy of this permit at the facility and make it available upon request to Ecology inspectors.

S4. Facility loading

S4.A. Design criteria

The flows or waste loads for the permitted facility must not exceed the following design criteria:

Maximum Month Design Flow (MMDF)	40.9 MGD
BOD_5 Influent Loading for Maximum Month	66,063 lbs/day
TSS Influent Loading for Maximum Month	61,400 lbs/day

S4.B. Plans for maintaining adequate capacity

a. Conditions triggering plan submittal

The Permittee must submit a plan and a schedule for continuing to maintain capacity to Ecology when:

1. The actual flow or waste load reaches 85 percent of any one of the design criteria in S4.A for three consecutive months.
2. The projected plant flow or loading would reach design capacity within five years.

b. Plan and schedule content

The plan and schedule must identify the actions necessary to maintain adequate capacity for the expected population growth and to meet the limits and requirements of the permit. The Permittee must consider the following topics and actions in its plan.

1. Analysis of the present design and proposed process modifications.

2. Reduction or elimination of excessive infiltration and inflow of uncontaminated ground and surface water into the sewer system.
3. Limits on future sewer extensions or connections or additional waste loads.
4. Modification or expansion of facilities.
5. Reduction of industrial or commercial flows or waste loads.

Engineering documents associated with the plan must meet the requirements of WAC 173-240-060, "Engineering Report," and be approved by Ecology prior to any construction.

S4.C. Duty to mitigate

The Permittee must take all reasonable steps to minimize or prevent any discharge or sludge use or disposal in violation of this permit that has a reasonable likelihood of adversely affecting human health or the environment.

S4.D. Notification of new or altered sources

1. The Permittee must submit written notice to Ecology whenever any new discharge or a substantial change in volume or character of an existing discharge into the wastewater treatment plant is proposed which:
    a. Would interfere with the operation of, or exceed the design capacity of, any portion of the wastewater treatment plant.
    b. Is not part of an approved general sewer plan or approved plans and specifications.
    c. Is subject to pretreatment standards under 40 CFR Part 403 and Section 307(b) of the Clean Water Act.
2. This notice must include an evaluation of the wastewater treatment plant's ability to adequately transport and treat the added flow and/or waste load, the quality and volume of effluent to be discharged to the treatment plant, and the anticipated impact on the Permittee's effluent [40 CFR 122.42(b)].

S4.E. Wasteload assessment

The Permittee must conduct an assessment of its influent flow and waste load and submit a report to Ecology by December 31, 2022. The report must contain:

1. A description of compliance or noncompliance with the permit effluent limits.
2. A comparison between the existing and design:
    a. Monthly average dry weather and wet weather flows.
    b. Maximum month flows.
    c. Peak flows.
    d. BOD_5 loadings.
    e. Total suspended solids loadings.
3. The percent change in the above parameters since the previous report.

4. The present and design population or population equivalent.
5. The projected population growth rate.
6. The estimated date upon which the Permittee expects the wastewater treatment plant to reach design capacity, according to the most restrictive of the parameters above.
7. An Infiltration and Inflow (I/I) update that describes:
   a. For the collection system owned and operated by the County:
      i. The results of recent I/I monitoring
      ii. A summary of recent I/I improvement projects.
      iii. Projects planned to improve I/I.
   b. For the collection systems owned and operated by component agencies:
      i. Measures taken to encourage component agencies to control I/I.
      ii. Any known I/I concerns.
      iii. Steps planned to further encourage I/I reduction projects.

S5. Operation and maintenance

The Permittee must at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances), which are installed to achieve compliance with the terms and conditions of this permit. Proper operation and maintenance also includes keeping a daily operation logbook (paper or electronic), adequate laboratory controls, and appropriate quality assurance procedures. This provision of the permit requires the Permittee to operate backup or auxiliary facilities or similar systems only when the operation is necessary to achieve compliance with the conditions of this permit.

S5.A. Certified operator

This permitted facility must be operated by an operator certified by the state of Washington for at least a Class IV plant. This operator must be in responsible charge of the day-to-day operation of the wastewater treatment plant. An operator certified for at least a Class III plant must be in charge during all regularly scheduled shifts.

S5.B. Operation and maintenance program

The Permittee must:

1. Institute an adequate operation and maintenance program for the entire sewage system.
2. Keep maintenance records on all major electrical and mechanical components of the treatment plant, as well as the sewage system and pumping stations. Such records must clearly specify the frequency and type of maintenance recommended by the manufacturer and must show the frequency and type of maintenance performed.
3. Make maintenance records available for inspection at all times.

S5.C. Short-term reduction

The Permittee must schedule any facility maintenance, which might require interruption of wastewater treatment and degrade effluent quality, during non-critical water quality periods and carry this maintenance out according to the approved O&M manual or as otherwise approved by Ecology.

If a Permittee contemplates a reduction in the level of treatment that would cause a violation of permit discharge limits on a short-term basis for any reason, and such reduction cannot be avoided, the Permittee must:

1. Give written notification to Ecology, if possible, thirty (30) days prior to such activities.
2. Detail the reasons for, length of time of, and the potential effects of the reduced level of treatment.

This notification does not relieve the Permittee of its obligations under this permit.

S5.D. Electrical power failure

The Permittee must ensure that adequate safeguards prevent the discharge of untreated wastes or wastes not treated in accordance with the requirements of this permit during electrical power failure at the treatment plant and/or sewage lift stations. Adequate safeguards include, but are not limited to, alternate power sources, standby generator(s), or retention of inadequately treated wastes.

The Permittee must maintain Reliability Class II (EPA 430-99-74-001) at the wastewater treatment plant. Reliability Class II requires a backup power source sufficient to operate all vital components and critical lighting and ventilation during peak wastewater flow conditions. Vital components used to support the secondary processes (i.e., mechanical aerators or aeration basin air compressors) need not be operable to full levels of treatment, but must be sufficient to maintain the biota.

S5.E. Prevent connection of inflow

The Permittee must strictly enforce its sewer ordinances and not allow the connection of inflow (roof drains, foundation drains, etc.) to the sanitary sewer system.

S5.F. Bypass procedures

A bypass is the intentional diversion of waste streams from any portion of a treatment facility. This permit prohibits all bypasses except when the bypass is for essential maintenance, as authorized in special condition S5.F.1, or is approved by Ecology as an anticipated bypass following the procedures in S5.F.2. Special Condition S9 authorizes anticipated wet weather bypasses of the MBR treatment system under specific conditions and limits.

1. Bypass for essential maintenance without the potential to cause violation of permit limits or conditions.

   This permit allows bypasses for essential maintenance of the treatment system when necessary to ensure efficient operation of the system. The Permittee may bypass the treatment system for essential maintenance only if doing so does not cause violations of effluent limits. The Permittee is not required to notify Ecology when bypassing for essential maintenance. However the Permittee must comply with the monitoring requirements specified in special condition S2.B.

2. Anticipated bypasses for non-essential maintenance

   Ecology may approve an anticipated bypass under the conditions listed below. This permit prohibits any anticipated bypass that is not approved through the following process.

   a. If a bypass is for non-essential maintenance, the Permittee must notify Ecology, if possible, at least ten (10) days before the planned date of bypass. The notice must contain:

      - A description of the bypass and the reason the bypass is necessary.
      - An analysis of all known alternatives which would eliminate, reduce, or mitigate the potential impacts from the proposed bypass.
      - A cost-effectiveness analysis of alternatives.
      - The minimum and maximum duration of bypass under each alternative.
      - A recommendation as to the preferred alternative for conducting the bypass.
      - The projected date of bypass initiation.
      - A statement of compliance with SEPA.
      - A request for modification of water quality standards as provided for in WAC 173-201A-410, if an exceedance of any water quality standard is anticipated.
      - Details of the steps taken or planned to reduce, eliminate, and prevent recurrence of the bypass.

   b. For probable construction bypasses, the Permittee must notify Ecology of the need to bypass as early in the planning process as possible. The Permittee must consider the analysis required above during the project planning and design process. The project-specific engineering report as well as the plans and specifications must include details of probable construction bypasses to the extent practical. In cases where the Permittee determines the probable need to bypass early, the Permittee must continue to analyze conditions up to and including the construction period in an effort to minimize or eliminate the bypass.

c. Ecology will determine if the Permittee has met the conditions of special condition S5.F.2 a and b and consider the following prior to issuing a determination letter, an administrative order, or a permit modification as appropriate for an anticipated bypass:

- If the Permittee planned and scheduled the bypass to minimize adverse effects on the public and the environment.
- If the bypass is unavoidable to prevent loss of life, personal injury, or severe property damage. "Severe property damage" means substantial physical damage to property, damage to the treatment facilities which would cause them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass.
- If feasible alternatives to the bypass exist, such as:
  - The use of auxiliary treatment facilities.
  - Retention of untreated wastes.
  - Stopping production.
  - Maintenance during normal periods of equipment downtime, but not if the Permittee should have installed adequate backup equipment in the exercise of reasonable engineering judgment to prevent a bypass which occurred during normal periods of equipment downtime or preventative maintenance.
  - Transport of untreated wastes to another treatment facility.

S5.G. Operations and maintenance (O&M) manual

a. O&M manual submittal and requirements

The Permittee must:

1. Submit an electronic copy of the current Operations and Maintenance (O&M) Manual for the permitted facility that meets the requirements of 173-240-080 WAC by July 31, 2018. Due to the large size and complexity of the manual, the Permittee must submit the electronic files on a portable digital storage device, (flash drive, DVD or CD); do not submit files through the Water Quality Permitting Portal – Permit Submittals application.
2. Review the O&M Manual at least annually.
3. Submit to Ecology for review all substantial changes or updates to the O&M Manual whenever it incorporates them into the manual. Submit electronic copies of all updated sections by September 1, 2022.
4. Keep the approved O&M Manual at the permitted facility.
5. Follow the instructions and procedures of this manual.

b. O&M manual components

In addition to the requirements of WAC 173-240-080(1) through (5), the O&M Manual must be consistent with the guidance in Table G1-3 in the *Criteria for Sewage Works Design* (Orange Book), 2008. The O&M Manual must include:

1. Emergency procedures for cleanup in the event of wastewater system upset or failure.
2. A review of system components which if failed could pollute surface water or could impact human health. Provide a procedure for a routine schedule of checking the function of these components.
3. Wastewater system maintenance procedures that contribute to the generation of process wastewater.
4. Reporting protocols for submitting reports to Ecology to comply with the reporting requirements in the discharge permit.
5. Any directions to maintenance staff when cleaning or maintaining other equipment or performing other tasks which are necessary to protect the operation of the wastewater system (for example, defining maximum allowable discharge rate for draining a tank, blocking all floor drains before beginning the overhaul of a stationary engine).
6. The treatment plant process control monitoring schedule.
7. Minimum staffing adequate to operate and maintain the treatment processes and carry out compliance monitoring required by the permit.

S6. Pretreatment

S6.A. General requirements

1. The Permittee must implement the Industrial Pretreatment Program in accordance with King County Code 28.84.060 as amended by King County Ordinance No. 11963 on January 1, 1996, legal authorities, policies, procedures, and financial provisions described in the Permittee's approved pretreatment program submittal entitled "Industrial Pretreatment Program" and dated April 27, 1981; any approved revisions thereto; and the General Pretreatment Regulations (40 CFR Part 403). At a minimum, the Permittee must undertake the following pretreatment implementation activities:

   a. Enforce categorical pretreatment standards under Section 307(b) and (c) of the Federal Clean Water Act (hereinafter, the Act), prohibited discharge standards as set forth in 40 CFR 403.5, local limits, or state standards, which ever are most stringent or apply at the time of issuance or modification of a local industrial waste discharge permit. Locally derived limits are defined as pretreatment standards under Section 307(d) of the Act and are not limited to categorical industrial facilities.

b. Issue industrial waste discharge permits to all significant industrial users [SIUs, as defined in 40 CFR 403.3(v)(i)(ii)] contributing to the treatment system, including those from other jurisdictions. Industrial waste discharge permits must contain as a minimum, all the requirements of 40 CFR 403.8 (f)(l)(iii). The Permittee must coordinate the permitting process with Ecology regarding any industrial facility which may possess a state waste discharge permit issued by Ecology.

c. Maintain and update, as necessary, records identifying the nature, character, and volume of pollutants contributed by industrial users to the treatment works. The Permittee must maintain records for at least a three-year period.

d. Perform inspections, surveillance, and monitoring activities on industrial users to determine or confirm compliance with pretreatment standards and requirements. The Permittee must conduct a thorough inspection of SIUs annually, except Middle-Tier Categorical Industrial Users, as defined by 40 CFR 403.8(f)(2)(v)(B)&(C), need only be inspected once every two years. The Permittee must conduct regular local monitoring of SIU wastewaters commensurate with the character and volume of the wastewater but not less than once per year except for Middle-Tier Categorical Industrial Users which may be sampled once every two years. The Permittee must collect and analyze samples in accordance with 40 CFR Part 403.12(b)(5)(ii)-(v) and 40 CFR Part 136.

e. Enforce and obtain remedies for non-compliance by any industrial users with applicable pretreatment standards and requirements. Once violations have been identified, the Permittee must take timely and appropriate enforcement action to address the non-compliance. The Permittee's action must follow its enforcement response procedures and any amendments, thereof.

f. Publish, at least annually in a newspaper of general circulation within the Permittee's service area, a list of all non-domestic users which, at any time in the previous 12 months, were in significant non-compliance as defined in 40 CFR 403.8(f)(2)(vii).

g. If the Permittee elects to conduct sampling of an SIU's discharge in lieu of requiring user self-monitoring, it must satisfy all requirements of 40 CFR Part 403.12. This includes monitoring and record keeping requirements of sections 403.12(g) and (o). For SIU's subject to categorical standards (i.e., CIUs), the Permittee may either complete baseline and initial compliance reports for the CIU (when required by 403.12(b) and (d)) or require these of the CIU. The Permittee must ensure SIUs are provided the results of sampling in a timely manner, inform SIUs of their right to sample, their obligations to report any sampling they do, to respond to non-compliance, and to submit other notifications. These include a slug load report (403.12(f)), notice of changed discharge (403.12(j)), and hazardous waste notifications (403.12(p)). If sampling for the SIU, the Permittee must not sample less than once in every six month period unless the Permittee's approved program includes procedures for reduction of monitoring for Middle-Tier or Non-Significant Categorical Users per 403.12(e)(2) and (3) and those procedures have been followed.

h. Develop and maintain a data management system designed to track the status of the Permittee's industrial user inventory, industrial user discharge characteristics, and compliance status.

i. Maintain adequate staff, funds, and equipment to implement its pretreatment program.

j. Establish, where necessary, contracts or legally binding agreements with contributing jurisdictions to ensure compliance with applicable pretreatment requirements by commercial or industrial users within these jurisdictions. These contracts or agreements must identify the agency responsible for the various implementation and enforcement activities to be performed in the contributing jurisdiction.

2. Per 40 CFR 403.8(f)(2)(vii), the Permittee must evaluate each Significant Industrial User to determine if a Slug Control Plan is needed to prevent slug discharges which may cause interference, pass-through, or in any other way result in violations of the Permittee's regulations, local limits or permit conditions. The Slug Control Plan evaluation shall occur within one year of a user's designation as a SIU. In accordance with 40 CFR 403.8(f)(1)(iii)(B)(6) the Permittee shall include slug discharge control requirements in an SIU's permit if the Permittee determines that they are necessary.

3. Whenever Ecology determines that any waste source contributes pollutants to the Permittee's treatment works in violation of Subsection (b), (c), or (d) of Section 307 of the Act, and the Permittee has not taken adequate corrective action, Ecology will notify the Permittee of this determination. If the Permittee fails to take appropriate enforcement action within 30 days of this notification, Ecology may take appropriate enforcement action against the source or the Permittee.

4. Pretreatment Report

   The Permittee must submit the annual report according to the instructions in Special Condition S3.B, Permit Submittals and Schedules. Submit one electronic copy of the annual report using the Water Quality Permitting Portal – Permit Submittals application by April 30th of each year.

   The report must include the following information:

   a. An updated listing of non-domestic industrial dischargers.

   b. Summarized Results of wastewater sampling at the treatment plant as specified in Subsection S6.B below. The Permittee must submit complete results of each sampling event on the appropriate quarterly or annual DMR through Ecology's WQWebDMR system, as described in Special Condition S3.A. The Permittee must calculate removal rates for each pollutant and evaluate the adequacy of the existing local limits in prevention of treatment plant interference, pass through of pollutants that could affect receiving water quality and biosolids contamination.

c. Status of program implementation, including:

- Any substantial modifications to the pretreatment program as originally approved by Ecology, including staffing and funding levels.
- Any interferences, upsets, or permit violations experienced at the WWTP that are directly attributable to wastes from industrial users.
- Listing of industrial users inspected and/or monitored, and a summary of the results.
- Listing of industrial users scheduled for inspection and/or monitoring for the next year, and expected frequencies.
- Listing of industrial users notified of promulgated pretreatment standards and/or local standards as required in 40 CFR 403.8(f)(2)(iii). The list must indicate which industrial users are on compliance schedules and the final date of compliance for each.
- Listing of industrial users issued industrial waste discharge permits.
- Planned changes in the pretreatment program implementation plan.

d. Status of compliance activities, including:

- Listing of industrial users that failed to submit baseline monitoring reports or any other reports required under 40 CFR 403.12 and in the Permittee's pretreatment program, dated April 27, 1981.
- Listing of industrial users that were at any time during the reporting period not complying with federal, state, or local pretreatment standards or with applicable compliance schedules for achieving those standards, and the duration of such non-compliance.
- Summary of enforcement activities and other corrective actions taken or planned against non-complying industrial users. The Permittee must supply to Ecology a copy of the public notice of facilities that were in significant non-compliance.

5. The Permittee must request and obtain approval from Ecology before making any significant changes to the approved local pretreatment program. The Permittee must follow the procedure in 40 CFR 403.18 (b) and (c).

S6.B. Monitoring requirements

The Permittee must monitor its influent, effluent, and biosolids at the Brightwater WWTP for the priority pollutants identified in Tables II and III of Appendix D of 40 CFR Part 122 as amended, any compounds identified as a result of Condition S6.B.4, and any other pollutants expected from nondomestic sources using U.S. EPA-approved procedures for collection, preservation, storage, and analysis. The Permittee must test influent, effluent, and biosolids samples for the priority pollutant metals (Table III, 40 CFR 122, Appendix D) on a quarterly basis throughout the term of this permit. The Permittee must test influent, effluent, and biosolids samples for the organic priority pollutants (Table II, 40 CFR 122, Appendix D) on an annual basis.

1. The Permittee must sample Brightwater WWTP influent and effluent on a day when industrial discharges are occurring at normal to maximum levels. The Permittee must obtain 24-hour composite samples for the analysis of acid and base/neutral extractable compounds and metals. The Permittee must collect samples for the analysis of volatile organic compounds and samples must be collected using grab sampling techniques at equal intervals for a total of four grab samples per day.

   The laboratory may run a single analysis for volatile pollutants (using GC/MS procedures approved by 40 CFR 136) for each monitoring day by compositing equal volumes of each grab sample directly in the GC purge and trap apparatus in the laboratory, with no less than 1 ml of each grab included in the composite.

   Unless otherwise indicated, all reported test data for metals must represent the total amount of the constituent present in all phases, whether solid, suspended, or dissolved, elemental or combined including all oxidation states.

   The Permittee must handle, prepare, and analyze all wastewater samples taken for GC/MS analysis using procedures approved by 40 CFR 136.

2. The Permittee must collect a biosolids sample concurrently with a wastewater sample as a single grab sample of residual biosolids. Sampling and analysis must be performed using procedures approved by 40 CFR 136 unless the Permittee requests an alternate method and Ecology has approved.

3. The Permittee must take cyanide, phenols, and oils as grab samples. Oils must be hexane soluble or equivalent, and should be measured in the influent and effluent only.

4. In addition to quantifying pH, oil and grease, and all priority pollutants, the Permittee must make a reasonable attempt to identify all other substances and quantify all pollutants shown to be present by gas chromatograph/mass spectrometer (GC/MS) analysis using procedures approved by 40 CFR 136. The Permittee should attempt to make determinations of pollutants for each fraction, which produces identifiable spectra on total ion plots (reconstructed gas chromatograms). The Permittee should attempt to make determinations from all peaks with responses 5% or greater than the nearest internal standard. The 5% value is based on internal standard concentrations of 30 μg/l, and must be adjusted downward if higher internal standard concentrations are used or adjusted upward if lower internal standard concentrations are used. The Permittee may express results for non-substituted aliphatic compounds as total hydrocarbon content. The Permittee must use a laboratory whose computer data processing programs are capable of comparing sample mass spectra to a computerized library of mass spectra, with visual confirmation by an

experienced analyst. For all detected substances which are determined to be pollutants, the Permittee must conduct additional sampling and appropriate testing to determine concentration and variability, and to evaluate trends.

S6.C. Reporting of monitoring results

The Permittee must submit data from each sampling event electronically on quarterly and annual DMRs through the WQWebDMR system, as outlined in Special Condition S3.A. The Permittee must also include a summary of monitoring results in the Annual Pretreatment Report.

S6.D. Local limit development

As sufficient data become available, the Permittee must, in consultation with Ecology, reevaluate their local limits in order to prevent pass through or interference. If Ecology determines that any pollutant present causes pass through or interference, or exceeds established biosolids standards, the Permittee must establish new local limits or revise existing local limits as required by 40 CFR 403.5. Ecology may also require the Permittee to revise or establish local limits for any pollutant discharged from the treatment works that has a reasonable potential to exceed the water quality standards, sediment standards, or established effluent limits, or causes whole effluent toxicity. Ecology makes this determination in the form of an Administrative Order.

Ecology may modify this permit to incorporate additional requirements relating to the establishment and enforcement of local limits for pollutants of concern. Any permit modification is subject to formal due process procedures under state and federal law and regulation.

S7. Solid wastes

S7.A. Solid waste handling

The Permittee must handle and dispose of all solid waste material in such a manner as to prevent its entry into state ground or surface water.

S7.B. Leachate

The Permittee must not allow leachate from its solid waste material to enter state waters without providing all known, available, and reasonable methods of treatment, nor allow such leachate to cause violations of the State Surface Water Quality Standards, Chapter 173-201A WAC, or the State Ground Water Quality Standards, Chapter 173-200 WAC. The Permittee must apply for a permit or permit modification as may be required for such discharges to state ground or surface waters.

S8. Spill control plan

S8.A Spill control plan submittals and requirements

The Permittee must:

1. Review the existing spill control plan for the permitted facility at least annually and update the plan as needed.

2. Send changes to the plan to Ecology.
3. Follow the plan and any supplements throughout the term of the permit.

S.B. Spill control plan components

The spill control plan must include the following:

1. A list of all oil and petroleum products and other materials used and/or stored on-site, which when spilled, or otherwise released into the environment, designate as dangerous waste (DW) or extremely hazardous waste (EHW) by the procedures set forth in WAC 173-303-070. Include other materials used and/or stored on-site which may become pollutants or cause pollution upon reaching state's waters.
2. A description of preventive measures and facilities (including an overall facility plot showing drainage patterns) which prevent, contain, or treat spills of these materials.
3. A description of the reporting system the Permittee will use to alert responsible managers and legal authorities in the event of a spill.
4. A description of operator training to implement the plan.

The Permittee may submit plans and manuals required by 40 CFR Part 112, contingency plans required by Chapter 173-303 WAC, or other plans required by other agencies, which meet the intent of this section.

S9. Wet weather operations

S9.A. Flow blending approval

The Permittee may initiate a bypass of the membrane bioreactor (MBR) treatment components at the permitted facility when the flows entering the facility are within 10% of exceeding the calculated available daily Membrane Flow Capacity. The following conditions apply to each wet weather bypass event.

1. The membrane control system must be operating in “TMP Control Mode”.
2. The Permittee must determine available Membrane Flow Capacity using an automated peak flow test performed simultaneously on two MBR trains for a one-hour period each day. The available Membrane Flow Capacity for the facility is the average individual train flow rate measured during the two-train peak flow test multiplied by the maximum number of installed MBR trains.
3. The Permittee must minimize the release of pollutants to the environment by taking the following actions:
    - Maximize flow through the MBR treatment system,
    - Maximize the use of storage capacity in the influent system, and
    - Divert flow to the West Point and/or South WWTPs, if conveyance and treatment capacity for those facilities is available.

4. When bypassing the MBR treatment components, the Permittee must ensure all bypass flows receive treatment through screening, grit removal, chemically enhanced primary clarification, and disinfection. The final discharge must meet the effluent limits listed in special condition S1.
5. The bypass event must result from increased flows caused by wet weather. The Permittee must document the duration and amount of rainfall for each storm event that causes a wet weather bypass.

Bypasses that do meet the above conditions are subject to the bypass provisions of special condition S5.F.

S9.B. Records and reporting

The Permittee must maintain records of all bypasses at the treatment plant. These records must document the date, duration, and volume of each bypass event, and the magnitude of the associated precipitation event. The records must also indicate the influent flow rate at the time when bypassing is initiated and the average influent flow rate during the split flow event.

The Permittee must report on the facility's monthly DMR all data from bypass monitoring listed in table S2A(3) of this permit. In addition, the Permittee must submit an annual bypass report by July 1st each year that summarizes all bypass occurrences for the previous year.

The annual report must document that each bypass complied with the authorizing conditions in part A above. It must also include a net environmental benefit (NEB) analysis. The NEB section must calculate the actual mass of BOD_5 and TSS discharged through the marine outfall on a monthly and annual basis and compare the results to a theoretical mass loading for a conventional, non-blending plant with the following assumed effluent quality:

Annual Average BOD_5 and TSS Concentrations:	15 mg/L
Maximum Monthly BOD_5 and TSS Concentrations:	25 mg/L

S9.C. Utility analysis report

The Permittee must submit an updated Utility Analysis Report by September 1, 2022.

S9.D. Net environmental benefit (NEB) performance standard

A performance standard applies to the Net Environmental Benefit achieved by the Brightwater WWTP. Achievement of the NEB is required in accordance with the standards in the table below which were approved by Ecology as part of the facility plan approval. If the Brightwater WWTP does not meet the required NEB, the Permittee must submit an explanation in the annual report(s) explaining the cause of non-compliance of the NEB and measures that will be taken to ensure achievement of the NEB.

Net Environmental Benefit Required[1]

Parameter	Net Environmental Benefit (percent reduction in BOD/TSS) [a, b]
Phase 1 – Revised (2012-2030) [c]	
BOD_5	
Maximum year [d]	51 percent
Maximum month [d]	16 percent
TSS	
Maximum year [d]	66 percent
Maximum month [d]	47 percent
a	Net environmental benefit is the reduction in a pollutant from the actual discharge compared to the theoretical discharge from a Conventional Activated Sludge (CAS) process.
b	Assumes CAS = 15 mg/L BOD_5/TSS for yearly conditions and 25 mg/L BOD_5/TSS for maximum-month condition.
c	Based on flow projections for 2030 and utilization of 0.8 million gallons of inline storage upstream of Hollywood Pump Station
d	20-year maximum flow based on 60 years of simulation.

S9.E. MBR pilot testing report

The Permittee must submit by July 31, 2018, a report that presents the findings of MBR pilot testing conducted at the Brightwater WWTP beginning in December 2014. The report must identify the variables testing revealed as potential causes of seasonal decreases in membrane performance. The report must also describe operational changes the Permittee may make to improve seasonal performance.

S10. Outfall evaluation

The Permittee must inspect the submerged portion of the outfall line and diffuser to document its integrity and continued function. If conditions allow for a photographic verification, the Permittee must include such verification in the report. By December 1, 2021, the Permittee must submit the inspection report to Ecology through the Water Quality Permitting Portal – Permit Submittals application. The Permittee must submit hard-copies of any video files to Ecology as required by Permit Condition S3.B. The Portal does not support submittal of video files.

[1] King County Wastewater Treatment Division, Brightwater Regional Wastewater Treatment System, Facilities Plan, May 2005, p 4-35 and King County Wastewater Treatment Division, Brightwater Regional Wastewater Treatment System, Facilities Plan Amendment No. 3, October 2016, p 15-17.

The inspector must at a minimum:

- Assess the physical condition of the outfall pipe, diffuser, and associated couplings and pipe anchors.
- Evaluate whether alignment issues reported in the 2012 Brightwater Marine Outfall Inspection and Commissioning report have worsened. Issues included the suspension of pipeline sections over depressions in the seabed and a slight rotation of one pipe as it sank into place during construction.
- Determine the extent of sediment accumulation in the vicinity of the diffuser.
- Ensure diffuser ports are free of obstructions and are allowing uniform flow.
- Confirm physical location (latitude/longitude) and depth (at MLLW) of the diffuser section of the outfall.

S11. Acute toxicity

S11.A. Testing when there is no permit limit for acute toxicity

The Permittee must:

1. Conduct acute toxicity testing on final effluent during the year prior to applying for permit renewal. Testing must occur once during the third quarter of 2021, no later than September 30, 2021, and once during the first quarter of 2022, no later than March 31, 2022.
2. Conduct acute toxicity testing on a series of at least five concentrations of effluent, including 100% effluent and a control.
3. Use each of the following species and protocols for each acute toxicity test:

Acute Toxicity Tests	Species	Method
Fathead minnow 96-hour static-renewal test	*Pimephales promelas*	EPA-821-R-02-012
Daphnid 48-hour static test	*Ceriodaphnia dubia, Daphnia pulex,* or *Daphnia magna*	EPA-821-R-02-012

4. Submit the results to Ecology electronically through the Water Quality Permitting Portal – Permit Submittals application by November 15, 2021 (for third quarter 2021 testing) and May 15, 2022 (for first quarter 2022 testing). The Permittee must also summarize the results in the next application for permit renewal.

S11.B. Sampling and reporting requirements

1. The Permittee must submit all reports for toxicity testing in accordance with the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. Reports must contain toxicity data, bench sheets, and reference toxicant results for test methods. In addition, the Permittee must submit toxicity test data in electronic format (CETIS export file preferred) for entry into Ecology's database.

2. The Permittee must collect 24-hour composite samples of effluent at the IPS for toxicity testing. The Permittee must cool the samples to 0 - 6 degrees Celsius during collection and send them to the lab immediately upon completion. The lab must begin the toxicity testing as soon as possible but no later than 36 hours after sampling was completed.
3. The laboratory must conduct water quality measurements on all samples and test solutions for toxicity testing, as specified in the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*.
4. All toxicity tests must meet quality assurance criteria and test conditions specified in the most recent versions of the EPA methods listed in Subsection C and the Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. If Ecology determines any test results to be invalid or anomalous, the Permittee must repeat the testing with freshly collected effluent.
5. The laboratory must use control water and dilution water meeting the requirements of the EPA methods listed in Section A or pristine natural water of sufficient quality for good control performance.
6. The Permittee must conduct whole effluent toxicity tests on an unmodified sample of final effluent.
7. The Permittee may choose to conduct a full dilution series test during compliance testing in order to determine dose response. In this case, the series must have a minimum of five effluent concentrations and a control. The series of concentrations must include the acute critical effluent concentration (ACEC). The ACEC equals 0.87% effluent.
8. All whole effluent toxicity tests, effluent screening tests, and rapid screening tests that involve hypothesis testing must comply with the acute statistical power standard of 29% as defined in WAC 173-205-020. If the test does not meet the power standard, the Permittee must repeat the test on a fresh sample with an increased number of replicates to increase the power.

S12. Chronic toxicity

S12.A. Testing when there is no permit limit for chronic toxicity

The Permittee must:

1. Conduct chronic toxicity testing on final effluent during the year prior to applying for permit renewal. Testing must occur once during the fourth quarter of 2021, no later than December 31, 2021, and once during the second quarter of 2022, no later than June 30, 2022.
2. Conduct chronic toxicity testing on a series of at least five concentrations of effluent and a control. This series of dilutions must include the acute critical effluent concentration (ACEC). The ACEC equals 0.87% effluent. The series of dilutions should also contain the CCEC of 0.42% effluent.

3. Compare the ACEC to the control using hypothesis testing at the 0.05 level of significance as described in Appendix H, EPA/600/4-89/001.
4. Submit the results to Ecology electronically through the Water Quality Permitting Portal – Permit Submittals application by February 15, 2022 (for fourth quarter 2021 testing) and August 15, 2022 (for second quarter 2022 testing). The Permittee must also summarize the results in the next application for permit renewal.
5. Perform chronic toxicity tests with all of the following species and the most recent version of the following protocols:

Saltwater Chronic Test	Species	Method
Topsmelt survival and growth	*Atherinops affinis*	EPA/600/R-95/136
Mysid shrimp survival and growth	*Americamysis bahia* (formerly *Mysidopsis bahia*)	EPA-821-R-02-014

S12.B. Sampling and reporting requirements

1. The Permittee must submit all reports for toxicity testing in accordance with the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. Reports must contain toxicity data, bench sheets, and reference toxicant results for test methods. In addition, the Permittee must submit toxicity test data in electronic format (CETIS export file preferred) for entry into Ecology's database.
2. The Permittee must collect 24-hour composite samples of effluent at the IPS for toxicity testing. The Permittee must cool the samples to 0 - 6 degrees Celsius during collection and send them to the lab immediately upon completion. The lab must begin the toxicity testing as soon as possible but no later than 36 hours after sampling was completed.
3. The laboratory must conduct water quality measurements on all samples and test solutions for toxicity testing, as specified in the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*.
4. All toxicity tests must meet quality assurance criteria and test conditions specified in the most recent versions of the EPA methods listed in Section C and the Ecology Publication no. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. If Ecology determines any test results to be invalid or anomalous, the Permittee must repeat the testing with freshly collected effluent.
5. The laboratory must use control water and dilution water meeting the requirements of the EPA methods listed in Subsection C or pristine natural water of sufficient quality for good control performance.
6. The Permittee must conduct whole effluent toxicity tests on an unmodified sample of final effluent.

7. The Permittee may choose to conduct a full dilution series test during compliance testing in order to determine dose response. In this case, the series must have a minimum of five effluent concentrations and a control. The series of concentrations must include the CCEC and the ACEC. The CCEC and the ACEC may either substitute for the effluent concentrations that are closest to them in the dilution series or be extra effluent concentrations. The CCEC equals 0.42% effluent. The ACEC equals 0.87% effluent.
8. All whole effluent toxicity tests that involve hypothesis testing must comply with the chronic statistical power standard of 39% as defined in WAC 173-205-020. If the test does not meet the power standard, the Permittee must repeat the test on a fresh sample with an increased number of replicates to increase the power.

S13. Application for permit renewal or modification for facility changes

The Permittee must submit an application for renewal of this permit by September 1, 2022.

The Permittee must also submit a new application or addendum at least one hundred eighty (180) days prior to commencement of discharges, resulting from the activities listed below, which may result in permit violations. These activities include any facility expansions, production increases, or other planned changes, such as process modifications, in the permitted facility.

General Conditions

G1. Signatory requirements

1. All applications submitted to Ecology must be signed and certified.
   a. In the case of corporations, by a responsible corporate officer. For the purpose of this section, a responsible corporate officer means:
      - A president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision making functions for the corporation, or
      - The manager of one or more manufacturing, production, or operating facilities, provided, the manager is authorized to make management decisions which govern the operation of the regulated facility including having the explicit or implicit duty of making major capital investment recommendations, and initiating and directing other comprehensive measures to assure long-term environmental compliance with environmental laws and regulations; the manager can ensure that the necessary systems are established or actions taken to gather complete and accurate information for permit application requirements; and where authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

   b. In the case of a partnership, by a general partner.
   c. In the case of sole proprietorship, by the proprietor.
   d. In the case of a municipal, state, or other public facility, by either a principal executive officer or ranking elected official.

   Applications for permits for domestic wastewater facilities that are either owned or operated by, or under contract to, a public entity shall be submitted by the public entity.

2. All reports required by this permit and other information requested by Ecology must be signed by a person described above or by a duly authorized representative of that person. A person is a duly authorized representative only if:
   a. The authorization is made in writing by a person described above and submitted to Ecology.
   b. The authorization specifies either an individual or a position having responsibility for the overall operation of the regulated facility, such as the position of plant manager, superintendent, position of equivalent responsibility, or an individual or position having overall responsibility for environmental matters. (A duly authorized representative may thus be either a named individual or any individual occupying a named position.)

3. Changes to authorization. If an authorization under paragraph G1.2, above, is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, a new authorization satisfying the requirements of paragraph G1.2, above, must be submitted to Ecology prior to or together with any reports, information, or applications to be signed by an authorized representative.

4. Certification. Any person signing a document under this section must make the following certification:

   "I certify under penalty of law, that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

G2. Right of inspection and entry

The Permittee must allow an authorized representative of Ecology, upon the presentation of credentials and such other documents as may be required by law:

1. To enter upon the premises where a discharge is located or where any records must be kept under the terms and conditions of this permit.
2. To have access to and copy, at reasonable times and at reasonable cost, any records required to be kept under the terms and conditions of this permit.
3. To inspect, at reasonable times, any facilities, equipment (including monitoring and control equipment), practices, methods, or operations regulated or required under this permit.
4. To sample or monitor, at reasonable times, any substances or parameters at any location for purposes of assuring permit compliance or as otherwise authorized by the Clean Water Act.

G3. Permit actions

This permit may be modified, revoked and reissued, or terminated either at the request of any interested person (including the Permittee) or upon Ecology's initiative. However, the permit may only be modified, revoked and reissued, or terminated for the reasons specified in 40 CFR 122.62, 40 CFR 122.64 or WAC 173-220-150 according to the procedures of 40 CFR 124.5.

1. The following are causes for terminating this permit during its term, or for denying a permit renewal application:
   a. Violation of any permit term or condition.
   b. Obtaining a permit by misrepresentation or failure to disclose all relevant facts.
   c. A material change in quantity or type of waste disposal.
   d. A determination that the permitted activity endangers human health or the environment, or contributes to water quality standards violations and can only be regulated to acceptable levels by permit modification or termination.

e. A change in any condition that requires either a temporary or permanent reduction, or elimination of any discharge or sludge use or disposal practice controlled by the permit.

f. Nonpayment of fees assessed pursuant to RCW 90.48.465.

g. Failure or refusal of the Permittee to allow entry as required in RCW 90.48.090.

2. The following are causes for modification but not revocation and reissuance except when the Permittee requests or agrees:

   a. A material change in the condition of the waters of the state.

   b. New information not available at the time of permit issuance that would have justified the application of different permit conditions.

   c. Material and substantial alterations or additions to the permitted facility or activities which occurred after this permit issuance.

   d. Promulgation of new or amended standards or regulations having a direct bearing upon permit conditions, or requiring permit revision.

   e. The Permittee has requested a modification based on other rationale meeting the criteria of 40 CFR Part 122.62.

   f. Ecology has determined that good cause exists for modification of a compliance schedule, and the modification will not violate statutory deadlines.

   g. Incorporation of an approved local pretreatment program into a municipality's permit.

3. The following are causes for modification or alternatively revocation and reissuance:

   a. When cause exists for termination for reasons listed in 1.a through 1.g of this section, and Ecology determines that modification or revocation and reissuance is appropriate.

   b. When Ecology has received notification of a proposed transfer of the permit. A permit may also be modified to reflect a transfer after the effective date of an automatic transfer (General Condition G7) but will not be revoked and reissued after the effective date of the transfer except upon the request of the new Permittee.

G4. Reporting planned changes

The Permittee must, as soon as possible, but no later than one hundred eighty (180) days prior to the proposed changes, give notice to Ecology of planned physical alterations or additions to the permitted facility, production increases, or process modification which will result in:

1. The permitted facility being determined to be a new source pursuant to 40 CFR 122.29(b).
2. A significant change in the nature or an increase in quantity of pollutants discharged.

3. A significant change in the Permittee's sludge use or disposal practices. Following such notice, and the submittal of a new application or supplement to the existing application, along with required engineering plans and reports, this permit may be modified, or revoked and reissued pursuant to 40 CFR 122.62(a) to specify and limit any pollutants not previously limited. Until such modification is effective, any new or increased discharge in excess of permit limits or not specifically authorized by this permit constitutes a violation.

G5. Plan review required

Prior to constructing or modifying any wastewater control facilities, an engineering report and detailed plans and specifications must be submitted to Ecology for approval in accordance with chapter 173-240 WAC. Engineering reports, plans, and specifications must be submitted at least one hundred eighty (180) days prior to the planned start of construction unless a shorter time is approved by Ecology. Facilities must be constructed and operated in accordance with the approved plans.

G6. Compliance with other laws and statutes

Nothing in this permit excuses the Permittee from compliance with any applicable federal, state, or local statutes, ordinances, or regulations.

G7. Transfer of this permit

In the event of any change in control or ownership of facilities from which the authorized discharge emanate, the Permittee must notify the succeeding owner or controller of the existence of this permit by letter, a copy of which must be forwarded to Ecology.

1. Transfers by Modification

   Except as provided in paragraph (2) below, this permit may be transferred by the Permittee to a new owner or operator only if this permit has been modified or revoked and reissued under 40 CFR 122.62(b)(2), or a minor modification made under 40 CFR 122.63(d), to identify the new Permittee and incorporate such other requirements as may be necessary under the Clean Water Act.

2. Automatic Transfers

   This permit may be automatically transferred to a new Permittee if:

   a. The Permittee notifies Ecology at least thirty (30) days in advance of the proposed transfer date.

   b. The notice includes a written agreement between the existing and new Permittees containing a specific date transfer of permit responsibility, coverage, and liability between them.

   c. Ecology does not notify the existing Permittee and the proposed new Permittee of its intent to modify or revoke and reissue this permit. A modification under this subparagraph may also be minor modification under 40 CFR 122.63. If this notice is not received, the transfer is effective on the date specified in the written agreement.

G8. Reduced production for compliance

The Permittee, in order to maintain compliance with its permit, must control production and/or all discharges upon reduction, loss, failure, or bypass of the treatment facility until the facility is restored or an alternative method of treatment is provided. This requirement applies in the situation where, among other things, the primary source of power of the treatment facility is reduced, lost, or fails.

G9. Removed substances

Collected screenings, grit, solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters must not be resuspended or reintroduced to the final effluent stream for discharge to state waters.

G10. Duty to provide information

The Permittee must submit to Ecology, within a reasonable time, all information which Ecology may request to determine whether cause exists for modifying, revoking and reissuing, or terminating this permit or to determine compliance with this permit. The Permittee must also submit to Ecology upon request, copies of records required to be kept by this permit.

G11. Other requirements of 40 CFR

All other requirements of 40 CFR 122.41 and 122.42 are incorporated in this permit by reference.

G12. Additional monitoring

Ecology may establish specific monitoring requirements in addition to those contained in this permit by administrative order or permit modification.

G13. Payment of fees

The Permittee must submit payment of fees associated with this permit as assessed by Ecology.

G14. Penalties for violating permit conditions

Any person who is found guilty of willfully violating the terms and conditions of this permit is deemed guilty of a crime, and upon conviction thereof shall be punished by a fine of up to ten thousand dollars ($10,000) and costs of prosecution, or by imprisonment in the discretion of the court. Each day upon which a willful violation occurs may be deemed a separate and additional violation.

Any person who violates the terms and conditions of a waste discharge permit may incur, in addition to any other penalty as provided by law, a civil penalty in the amount of up to ten thousand dollars ($10,000) for every such violation. Each and every such violation is a separate and distinct offense, and in case of a continuing violation, every day's continuance is deemed to be a separate and distinct violation.

G15. Upset

Definition – "Upset" means an exceptional incident in which there is unintentional and temporary noncompliance with technology-based permit effluent limits because of factors beyond the reasonable control of the Permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

An upset constitutes an affirmative defense to an action brought for noncompliance with such technology-based permit effluent limits if the requirements of the following paragraph are met.

A Permittee who wishes to establish the affirmative defense of upset must demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:

1. An upset occurred and that the Permittee can identify the cause(s) of the upset.
2. The permitted facility was being properly operated at the time of the upset.
3. The Permittee submitted notice of the upset as required in Special Condition S3.F.
4. The Permittee complied with any remedial measures required under S3.F of this permit.

In any enforcement action the Permittee seeking to establish the occurrence of an upset has the burden of proof.

G16. Property rights

This permit does not convey any property rights of any sort, or any exclusive privilege.

G17. Duty to comply

The Permittee must comply with all conditions of this permit. Any permit noncompliance constitutes a violation of the Clean Water Act and is grounds for enforcement action; for permit termination, revocation and reissuance, or modification; or denial of a permit renewal application.

G18. Toxic pollutants

The Permittee must comply with effluent standards or prohibitions established under Section 307(a) of the Clean Water Act for toxic pollutants within the time provided in the regulations that establish those standards or prohibitions, even if this permit has not yet been modified to incorporate the requirement.

G19. Penalties for tampering

The Clean Water Act provides that any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than two (2) years per violation, or by both. If a conviction of a person is for a violation committed after a first conviction of such person under this condition, punishment shall be a fine of not more than $20,000 per day of violation, or by imprisonment of not more than four (4) years, or by both.

G20. Compliance schedules

Reports of compliance or noncompliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of this permit must be submitted no later than fourteen (14) days following each schedule date.

G21. Service agreement review

The Permittee must submit to Ecology any proposed service agreements and proposed revisions or updates to existing agreements for the operation of any wastewater treatment facility covered by this permit. The review is to ensure consistency with chapters 90.46 and 90.48 RCW as required by RCW 70.150.040(9). In the event that Ecology does not comment within a thirty-day (30) period, the Permittee may assume consistency and proceed with the service agreement or the revised/updated service agreement.

Appendix A

LIST OF POLLUTANTS WITH ANALYTICAL METHODS, DETECTION LIMITS AND QUANTITATION LEVELS

The Permittee must use the specified analytical methods, detection limits (DLs) and quantitation levels (QLs) in the following table for permit and application required monitoring unless:

- Another permit condition specifies other methods, detection levels, or quantitation levels.
- The method used produces measurable results in the sample and EPA has listed it as an EPA-approved method in 40 CFR Part 136.

If the Permittee uses an alternative method, not specified in the permit and as allowed above, it must report the test method, DL, and QL on the discharge monitoring report or in the required report.

If the Permittee is unable to obtain the required DL and QL in its effluent due to matrix effects, the Permittee must submit a matrix-specific detection limit (MDL) and a quantitation limit (QL) to Ecology with appropriate laboratory documentation.

When the permit requires the Permittee to measure the base neutral compounds in the list of priority pollutants, it must measure all of the base neutral pollutants listed in the table below. The list includes EPA required base neutral priority pollutants and several additional polynuclear aromatic hydrocarbons (PAHs). The Water Quality Program added several PAHs to the list of base neutrals below from Ecology's Persistent Bioaccumulative Toxics (PBT) List. It only added those PBT parameters of interest to Appendix A that did not increase the overall cost of analysis unreasonably.

Ecology added this appendix to the permit in order to reduce the number of analytical "non-detects" in permit-required monitoring and to measure effluent concentrations near or below criteria values where possible at a reasonable cost.

The lists below include conventional pollutants (as defined in CWA section 502(6) and 40 CFR Part 122.), toxic or priority pollutants as defined in CWA section 307(a)(1) and listed in 40 CFR Part 122 Appendix D, 40 CFR Part 401.15 and 40 CFR Part 423 Appendix A), and nonconventionals. 40 CFR Part 122 Appendix D (Table V) also identifies toxic pollutants and hazardous substances which are required to be reported by dischargers if expected to be present. This permit Appendix A list does not include those parameters.

CONVENTIONAL POLLUTANTS

Pollutant	CAS Number (if available)	Recommended Analytical Protocol	Detection (DL)[1] *µg/L unless specified*	Quantitation Level (QL)[2] *µg/L unless specified*
Biochemical Oxygen Demand		SM5210-B		2 mg/L
Biochemical Oxygen Demand, Soluble		SM5210-B [3]		2 mg/L
Fecal Coliform		SM 9221E,9222	N/A	Specified in method - sample aliquot dependent
Oil and Grease (HEM) (Hexane Extractable Material)		1664 A or B	1,400	5,000
pH		SM4500-H^+ B	N/A	N/A
Total Suspended Solids		SM2540-D		5 mg/L

NONCONVENTIONAL POLLUTANTS

Pollutant & CAS No. (if available)	CAS Number (if available)	Recommended Analytical Protocol	Detection (DL)[1] µg/L unless specified	Quantitation Level (QL)[2] µg/L unless specified
Alkalinity, Total		SM2320-B		5 mg/L as CaCO3
Aluminum, Total	7429-90-5	200.8	2.0	10
Ammonia, Total (as N)		SM4500-NH3-B and C/D/E/G/H		20
Barium Total	7440-39-3	200.8	0.5	2.0
BTEX (benzene +toluene + ethylbenzene + m,o,p xylenes)		EPA SW 846 8021/8260	1	2
Boron, Total	7440-42-8	200.8	2.0	10.0
Chemical Oxygen Demand		SM5220-D		10 mg/L
Chloride		SM4500-Cl B/C/D/E and SM4110 B		Sample and limit dependent
Chlorine, Total Residual		SM4500 Cl G		50.0
Cobalt, Total	7440-48-4	200.8	0.05	0.25
Color		SM2120 B/C/E		10 color units
Dissolved oxygen		SM4500-OC/OG		0.2 mg/L
Flow		Calibrated device		
Fluoride	16984-48-8	SM4500-F E	25	100
Hardness, Total		SM2340B		200 as CaCO3
Iron, Total	7439-89-6	200.7	12.5	50
Magnesium, Total	7439-95-4	200.7	10	50
Manganese, Total	7439-96-5	200.8	0.1	0.5
Molybdenum, Total	7439-98-7	200.8	0.1	0.5
Nitrate + Nitrite Nitrogen (as N)		SM4500-NO3- E/F/H		100
Nitrogen, Total Kjeldahl (as N)		SM4500-N_{org}B/C and SM4500NH_3-B/C/D/EF/G/H		300
NWTPH Dx [4]		Ecology NWTPH Dx	250	250
NWTPH Gx [5]		Ecology NWTPH Gx	250	250
Phosphorus, Total (as P)		SM 4500 PB followed by SM4500-PE/PF	3	10
Salinity		SM2520-B		3 practical salinity units or scale (PSU or PSS)

NONCONVENTIONAL POLLUTANTS

Pollutant & CAS No. (if available)	CAS Number (if available)	Recommended Analytical Protocol	Detection (DL)[1] µg/L unless specified	Quantitation Level (QL)[2] µg/L unless specified
Settleable Solids		SM2540 -F		Sample and limit dependent
Soluble Reactive Phosphorus (as P)		SM4500-P E/F/G	3	10
Sulfate (as mg/L SO_4)		SM4110-B		0.2 mg/L
Sulfide (as mg/L S)		SM4500-S^2F/D/E/G		0.2 mg/L
Sulfite (as mg/L SO_3)		SM4500-SO3B		2 mg/L
Temperature (max. 7-day avg.)		Analog recorder or use micro-recording devices known as thermistors		0.2º C
Tin, Total	7440-31-5	200.8	0.3	1.5
Titanium, Total	7440-32-6	200.8	0.5	2.5
Total Coliform		SM 9221B, 9222B, 9223B	N/A	Specified in method - sample aliquot dependent
Total Organic Carbon		SM5310-B/C/D		1 mg/L
Total dissolved solids		SM2540 C		20 mg/L

PRIORITY POLLUTANTS	PP #	CAS Number (if available)	Recommended Analytical Protocol	Detection (DL)[1] *µg/L unless specified*	Quantitation Level (QL) [2] *µg/L unless specified*
METALS, CYANIDE & TOTAL PHENOLS					
Antimony, Total	114	7440-36-0	200.8	0.3	1.0
Arsenic, Total	115	7440-38-2	200.8	0.1	0.5
Beryllium, Total	117	7440-41-7	200.8	0.1	0.5
Cadmium, Total	118	7440-43-9	200.8	0.05	0.25
Chromium (hex) dissolved	119	18540-29-9	SM3500-Cr C	0.3	1.2
Chromium, Total	119	7440-47-3	200.8	0.2	1.0
Copper, Total	120	7440-50-8	200.8	0.4	2.0
Lead, Total	122	7439-92-1	200.8	0.1	0.5
Mercury, Total	123	7439-97-6	1631E	0.0002	0.0005
Nickel, Total	124	7440-02-0	200.8	0.1	0.5
Selenium, Total	125	7782-49-2	200.8	1.0	1.0
Silver, Total	126	7440-22-4	200.8	0.04	0.2
Thallium, Total	127	7440-28-0	200.8	0.09	0.36
Zinc, Total	128	7440-66-6	200.8	0.5	2.5
Cyanide, Total	121	57-12-5	335.4	5	10
Cyanide, Weak Acid Dissociable	121		SM4500-CN I	5	10
Cyanide, Free Amenable to Chlorination (Available Cyanide)	121		SM4500-CN G	5	10
Phenols, Total	65		EPA 420.1		50

PRIORITY POLLUTANTS	**PP #**	**CAS Number (if available)**	**Recommended Analytical Protocol**	**Detection (DL)[1] *µg/L unless specified***	**Quantitation Level (QL) [2] *µg/L unless specified***
ACID COMPOUNDS					
2-Chlorophenol	24	95-57-8	625.1	3.3	9.9
2,4-Dichlorophenol	31	120-83-2	625.1	2.7	8.1
2,4-Dimethylphenol	34	105-67-9	625.1	2.7	8.1
4,6-dinitro-o-cresol (2-methyl-4,6,-dinitrophenol)	60	534-52-1	625.1/1625B	24	72
2,4 dinitrophenol	59	51-28-5	625.1	42	126
2-Nitrophenol	57	88-75-5	625.1	3.6	10.8
4-Nitrophenol	58	100-02-7	625.1	2.4	7.2
Parachlorometa cresol (4-chloro-3-methylphenol)	22	59-50-7	625.1	3.0	9.0
Pentachlorophenol	64	87-86-5	625.1	3.6	10.8
Phenol	65	108-95-2	625.1	1.5	4.5
2,4,6-Trichlorophenol	21	88-06-2	625.1	2.7	8.1

PRIORITY POLLUTANTS	**PP #**	**CAS Number (if available)**	**Recommended Analytical Protocol**	**Detection (DL)[1] *µg/L unless specified***	**Quantitation Level (QL) [2] *µg/L unless specified***
VOLATILE COMPOUNDS					
Acrolein	2	107-02-8	624.1	5	10
Acrylonitrile	3	107-13-1	624.1	1.0	2.0
Benzene	4	71-43-2	624.1	4.4	13.2
Bromoform	47	75-25-2	624.1	4.7	14.1
Carbon tetrachloride	6	56-23-5	624.1/601 or SM6230B	2.8	8.4
Chlorobenzene	7	108-90-7	624.1	6.0	18.0
Chloroethane	16	75-00-3	624.1 or 601	1.0	2.0
2-Chloroethylvinyl Ether	19	110-75-8	624.1	1.0	2.0
Chloroform	23	67-66-3	624.1 or SM6210B	1.6	4.8
Dibromochloromethane (chlordibromomethane)	51	124-48-1	624.1	3.1	9.3
1,2-Dichlorobenzene	25	95-50-1	624.1	1.9	7.6
1,3-Dichlorobenzene	26	541-73-1	624.1	1.9	7.6
1,4-Dichlorobenzene	27	106-46-7	624.1	4.4	17.6
Dichlorobromomethane	48	75-27-4	624.1	2.2	6.6
1,1-Dichloroethane	13	75-34-3	624.1	4.7	14.1
1,2-Dichloroethane	10	107-06-2	624.1	2.8	8.4
1,1-Dichloroethylene	29	75-35-4	624.1	2.8	8.4
1,2-Dichloropropane	32	78-87-5	624.1	6.0	18.0
1,3-dichloropropene (mixed isomers) (1,2-dichloropropylene) [6]	33	542-75-6	624.1	5.0	15.0
Ethylbenzene	38	100-41-4	624.1	7.2	21.6
Methyl bromide (Bromomethane)	46	74-83-9	624.1 or 601	5.0	10.0
Methyl chloride (Chloromethane)	45	74-87-3	624.1	1.0	2.0
Methylene chloride	44	75-09-2	624.1	2.8	8.4
1,1,2,2-Tetrachloroethane	15	79-34-5	624.1	6.9	20.7
Tetrachloroethylene	85	127-18-4	624.1	4.1	12.3
Toluene	86	108-88-3	624.1	6.0	18.0
1,2-Trans-Dichloroethylene (Ethylene dichloride)	30	156-60-5	624.1	1.6	4.8
1,1,1-Trichloroethane	11	71-55-6	624.1	3.8	11.4

PRIORITY POLLUTANTS	**PP #**	**CAS Number (if available)**	**Recommended Analytical Protocol**	**Detection (DL)[1] *µg/L unless specified***	**Quantitation Level (QL) [2] *µg/L unless specified***
VOLATILE COMPOUNDS					
1,1,2-Trichloroethane	14	79-00-5	624.1	5.0	15.0
Trichloroethylene	87	79-01-6	624.1	1.9	5.7
Vinyl chloride	88	75-01-4	624.1 or SM6200B	1.0	2.0

PRIORITY POLLUTANTS	**PP #**	**CAS Number (if available)**	**Recommended Analytical Protocol**	**Detection (DL)[1] *µg/L unless specified***	**Quantitation Level (QL) [2] *µg/L unless specified***
BASE/NEUTRAL COMPOUNDS (compounds in bold are Ecology PBTs)					
Acenaphthene	1	83-32-9	625.1	1.9	5.7
Acenaphthylene	77	208-96-8	625.1	3.5	10.5
Anthracene	78	120-12-7	625.1	1.9	5.7
Benzidine	5	92-87-5	625.1	44	132
Benzyl butyl phthalate	67	85-68-7	625.1	2.5	7.5
Benzo(*a*)anthracene	72	56-55-3	625.1	7.8	23.4
Benzo(b)fluoranthene (3,4-benzofluoranthene) [7]	74	205-99-2	610/625.1	4.8	14.4
Benzo(j)fluoranthene [7]		**205-82-3**	625.1	0.5	1.0
Benzo(k)fluoranthene (11,12-benzofluoranthene) [7]	75	207-08-9	610/625.1	2.5	7.5
Benzo(b,j,k)fluoranthene (combined according to footnote 7) [7]			625.1	7.8	22.9
Benzo(r,s,t)pentaphene		**189-55-9**	625.1	1.3	5.0
Benzo(*a*)pyrene	73	50-32-8	610/625.1	2.5	7.5
Benzo(*ghi*)Perylene	79	191-24-2	610/625.1	4.1	12.3
Bis(*2-chloroethoxy)*methane	43	111-91-1	625.1	5.3	15.9
Bis(*2-chloroethyl*)ether	18	111-44-4	611/625.1	5.7	17.1
Bis(*2-chloroisopropyl*)ether	42	39638-32-9	625.1	0.5	1.0
Bis(*2-ethylhexyl*)phthalate	66	117-81-7	625.1	2.5	7.5
4-Bromophenyl phenyl ether	41	101-55-3	625.1	1.9	5.7
2-Chloronaphthalene	20	91-58-7	625.1	1.9	5.7
4-Chlorophenyl phenyl ether	40	7005-72-3	625.1	4.2	12.6
Chrysene	76	218-01-9	610/625.1	2.5	7.5
Dibenzo (a,h)acridine		**226-36-8**	610M/625M	2.5	10.0
Dibenzo (a,j)acridine		**224-42-0**	610M/625M	2.5	10.0
Dibenzo(a-*h*)anthracene (1,2,5,6-dibenzanthracene)	82	53-70-3	625.1	2.5	7.5
Dibenzo(a,e)pyrene		192-65-4	610M/625M	2.5	10.0
Dibenzo(a,h)pyrene		189-64-0	625M	2.5	10.0
3,3-Dichlorobenzidine	28	91-94-1	605/625.1	16.5	49.5
Diethyl phthalate	70	84-66-2	625.1	1.9	5.7
Dimethyl phthalate	71	131-11-3	625.1	1.6	4.8
Di-n-butyl phthalate	68	84-74-2	625.1	2.5	7.5
2,4-dinitrotoluene	35	121-14-2	609/625.1	5.7	17.1
2,6-dinitrotoluene	36	606-20-2	609/625.1	1.9	5.7
Di-n-octyl phthalate	69	117-84-0	625.1	2.5	7.5
1,2-Diphenylhydrazine (*as Azobenzene*)	37	122-66-7	1625B	5.0	20
Fluoranthene	39	206-44-0	625.1	2.2	6.6
Fluorene	80	86-73-7	625.1	1.9	5.7
Hexachlorobenzene	9	118-74-1	612/625.1	1.9	5.7
Hexachlorobutadiene	52	87-68-3	625.1	0.9	2.7

PRIORITY POLLUTANTS	**PP #**	**CAS Number (if available)**	**Recommended Analytical Protocol**	**Detection (DL)[1] *µg/L unless specified***	**Quantitation Level (QL) [2] *µg/L unless specified***
BASE/NEUTRAL COMPOUNDS (compounds in bold are Ecology PBTs)					
Hexachlorocyclopentadiene	53	77-47-4	1625B/625	2.0	4.0
Hexachloroethane	12	67-72-1	625.1	1.6	4.8
Indeno(*1,2,3-cd*)Pyrene	83	193-39-5	610/625.1	3.7	11.1
Isophorone	54	78-59-1	625.1	2.2	6.6
3-Methyl cholanthrene		**56-49-5**	625.1	2.0	8.0
Naphthalene	55	91-20-3	625.1	1.6	4.8
Nitrobenzene	56	98-95-3	625.1	1.9	5.7
N-Nitrosodimethylamine	61	62-75-9	607/625.1	2.0	4.0
N-Nitrosodi-n-propylamine	63	621-64-7	607/625.1	0.5	1.0
N-Nitrosodiphenylamine	62	86-30-6	625.1	1.0	2.0
Perylene		**198-55-0**	625.1	1.9	7.6
Phenanthrene	81	85-01-8	625.1	5.4	16.2
Pyrene	84	129-00-0	625.1	1.9	5.7
1,2,4-Trichlorobenzene	8	120-82-1	625.1	1.9	5.7

PRIORITY POLLUTANT	**PP #**	**CAS Number (if available)**	**Recommended Analytical Protocol**	**Detection (DL)[1] *µg/L unless specified***	**Quantitation Level (QL) [2] *µg/L unless specified***
DIOXIN					
2,3,7,8-Tetra-Chlorodibenzo-P-Dioxin (2,3,7,8 TCDD)	129	1746-01-6	1613B	1.3 pg/L	5 pg/L

PRIORITY POLLUTANTS	**PP #**	**CAS Number (if available)**	**Recommended Analytical Protocol**	**Detection (DL)[1] *µg/L unless specified***	**Quantitation Level (QL) [2] *µg/L unless specified***
PESTICIDES/PCBs					
Aldrin	89	309-00-2	608.3	4.0 ng/L	12 ng/L
alpha-BHC	102	319-84-6	608.3	3.0 ng/L	9.0 ng/L
beta-BHC	103	319-85-7	608.3	6.0 ng/L	18 ng/L
gamma-BHC (Lindane)	104	58-89-9	608.3	4.0 ng/L	12 ng/L
delta-BHC	105	319-86-8	608.3	9.0 ng/L	27 ng/L
Chlordane [8]	91	57-74-9	608.3	14 ng/L	42 ng/L
4,4'-DDT	92	50-29-3	608.3	12 ng/L	36 ng/L
4,4'-DDE	93	72-55-9	608.3	4.0 ng/L	12 ng/L
4,4' DDD	94	72-54-8	608.3	11ng/L	33 ng/L
Dieldrin	90	60-57-1	608.3	2.0 ng/L	6.0 ng/L
alpha-Endosulfan	95	959-98-8	608.3	14 ng/L	42 ng/L
beta-Endosulfan	96	33213-65-9	608.3	4.0 ng/L	12 ng/L
Endosulfan Sulfate	97	1031-07-8	608.3	66 ng/L	198 ng/L
Endrin	98	72-20-8	608.3	6.0 ng/L	18 ng/L
Endrin Aldehyde	99	7421-93-4	608.3	23 ng/L	70 ng/L
Heptachlor	100	76-44-8	608.3	3.0 ng/L	9.0 ng/L
Heptachlor Epoxide	101	1024-57-3	608.3	83 ng/L	249 ng/L
PCB-1242 [9]	106	53469-21-9	608.3	0.065	0.095
PCB-1254	107	11097-69-1	608.3	0.065	0.095
PCB-1221	108	11104-28-2	608.3	0.065	0.095
PCB-1232	109	11141-16-5	608.3	0.065	0.095
PCB-1248	110	12672-29-6	608.3	0.065	0.095
PCB-1260	111	11096-82-5	608.3	0.065	0.095
PCB-1016 [9]	112	12674-11-2	608.3	0.065	0.095
Toxaphene	113	8001-35-2	608.3	240 ng/L	720 ng/L

1. Detection level (DL) or detection limit means the minimum concentration of an analyte (substance) that can be measured and reported with a 99% confidence that the analyte concentration is greater than zero as determined by the procedure given in 40 CFR part 136, Appendix B.

2. Quantitation Level (QL) also known as Minimum Level of Quantitation (ML) – The lowest level at which the entire analytical system must give a recognizable signal and acceptable calibration point for the analyte. It is equivalent to the concentration of the lowest calibration standard or a multiple of the method detection limit. The Permittee must ensure that the analytical lab derives QLs for each analyte according to the procedures documented in the specific analytical method used by the lab.
ALSO GIVEN AS:
The smallest detectable concentration of analyte greater than the Detection Limit (DL) where the accuracy (precision & bias) achieves the objectives of the intended purpose. (Report of the Federal Advisory Committee on Detection and Quantitation Approaches and Uses in Clean Water Act Programs Submitted to the US Environmental Protection Agency, December 2007).

3. Soluble Biochemical Oxygen Demand method note: First, filter the sample through a Millipore Nylon filter (or equivalent) - pore size of 0.45-0.50 um (prep all filters by filtering 250 ml of laboratory grade deionized water through the filter and discard). Then, analyze sample as per method 5210-B.

4. NWTPH Dx - Northwest Total Petroleum Hydrocarbons Diesel Extended Range – see http://www.ecy.wa.gov/biblio/97602.html

5. NWTPH Gx - Northwest Total Petroleum Hydrocarbons Gasoline Extended Range – see http://www.ecy.wa.gov/biblio/97602.html

6. 1, 3-dichloroproylene (mixed isomers) - You may report this parameter as two separate parameters: cis-1, 3-dichlorpropropene (10061-01-5) and trans-1, 3-dichloropropene (10061-02-6).

7. Total Benzofluoranthenes - Because Benzo(b)fluoranthene, Benzo(j)fluoranthene and Benzo(k)fluoranthene co-elute you may report these three isomers as total benzofluoranthenes.

8. Chlordane – You may report alpha-chlordane (5103-71-9) and gamma-chlordane (5103-74-2) in place of chlordane (57-74-9). If you report alpha and gamma-chlordane, the DL/PQLs that apply are 14/42 ng/L.

9. PCB 1016 & PCB 1242 – You may report these two PCB compounds as one parameter called PCB 1016/1242.

EXHIBIT B

Issuance Date:	July 1, 2015
Effective Date:	August 1,2015
Expiration Date:	July 31, 2020

National Pollutant Discharge Elimination System
Waste Discharge Permit No. WA0029581

State of Washington
DEPARTMENT OF ECOLOGY
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

In compliance with the provisions of
The State of Washington Water Pollution Control Law
Chapter 90.48 Revised Code of Washington
and
The Federal Water Pollution Control Act
(The Clean Water Act)
Title 33 United States Code, Section 1342 et seq.

King County Wastewater Treatment Division
King Street Center, KSC-NR-0512
Seattle, Washington 98104-3855

is authorized to discharge in accordance with the Special and General Conditions that follow.

Plant Location:	Receiving Water:
King County South Wastewater Treatment Plant 1200 Monster Road SW Renton, WA 98057	Puget Sound – Central
Treatment Type: Activated Sludge with chlorine disinfection	

Kevin C. Fitzpatrick
Water Quality Section Manager
Northwest Regional Office
Washington State Department of Ecology

Exhibit B

Table of Contents

Summary of Permit Report Submittals

Refer to the Special and General Conditions of this permit for additional submittal requirements.

Permit Section	Submittal	Frequency	First Submittal Date
S3.A	Discharge Monitoring Report (DMR)	Monthly	September 15, 2015
S3.A	Permit application and priority pollutant data in WQWebDMR	Annually	July 31, 2016
S3.F	Reporting Permit Violations	As necessary	
S4.B	Plans for Maintaining Adequate Capacity	As necessary	
S4.D	Notification of New or Altered Sources	As necessary	
S4.E	Wasteload Assessment	1/permit cycle	October 31, 2018
S5.F	Bypass Notification	As necessary	
S5.G	Operations and Maintenance Manual Update	As necessary	
S6.A.4	Pretreatment Report	1/year	April 30, 2016
S8	Spill Control Plan Update	As necessary	
S9.A	Sediment Sampling and Analysis Plan	1/permit cycle	December 1, 2016
S9.B	Sediment Data Report	1/permit cycle	December 1, 2018
S10.A	Acute Toxicity Effluent Test Results - Submit with Permit Renewal Application	2 tests/permit cycle, 1 submittal/permit cycle	Tests: 2018, 1st and 3rd quarters. Submittal: July 31, 2019
S11.A	Chronic Toxicity Effluent Test Results with Permit Renewal Application	2 tests/permit cycle, 1 submittal/permit cycle	Tests: 2018, 2nd and 4th quarters. Submittal: July 31, 2019
S13	Application for Permit Renewal	1/permit cycle	July 31, 2019
G4	Reporting Planned Changes	As necessary	
G5	Engineering Report for Construction or Modification Activities	As necessary	

Special Conditions

S1. Discharge limits

S1.A. Effluent limits

Puget Sound (Marine) Outfall No. 001

All discharges and activities authorized by this permit must comply with the terms and conditions of this permit. The discharge of any of the following pollutants more frequently than, or at a level in excess of, that identified and authorized by this permit violates the terms and conditions of this permit.

Beginning on the effective date of this permit, the Permittee may discharge treated municipal wastewater to the Puget Sound at the permitted locations subject to compliance with the following limits:

Effluent Limits: Outfall 001 (Puget Sound) *North Diffuser Lat/Long:* 47.602778˚, -122.429000˚ *South Diffuser Lat/Long:* 47.599722˚, -122.429028˚		
Parameter	**Average Monthly** [a]	**Average Weekly** [b]
Carbonaceous Biochemical Oxygen Demand (5-day) ($CBOD_5$)	25 milligrams/liter (mg/L) 30,000 pounds/day (lbs/day) 85% removal of influent $CBOD_5$	40 mg/L 48,000 lbs/day
Total Suspended Solids (TSS)	30 mg/L 36,000 lbs/day 85% removal of influent TSS	45 mg/L 54,000 lbs/day
	Average Monthly	**Maximum Daily** [c]
Total Residual Chlorine	500 µg/L	750 µg/L
	Instantaneous Minimum	**Instantaneous Maximum**
pH [d]	6.0 standard units	9.0 standard units
	Monthly Geometric Mean	**Weekly Geometric Mean**
Fecal Coliform Bacteria [e]	200/100 milliliter (mL)	400/100 mL

[a] Average monthly effluent limit is the highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month.

[b] Average weekly discharge limit is the highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges measured during that week.

[c] Maximum daily effluent limit is the highest allowable daily discharge. The daily discharge is the average discharge of a pollutant measured during a calendar day. This does not apply to pH.

[d] Report the instantaneous maximum and minimum pH monthly. Do not average pH values.

[e] Ecology provides directions to calculate the monthly and the weekly geometric mean in publication No. 04-10-020, *Information Manual for Treatment Plant Operators* available at: http://www.ecy.wa.gov/pubs/0410020.pdf

Green River (Freshwater) - Outfall No. 002

Beginning on the effective date of this permit and lasting through the expiration date, the Permittee is authorized to discharge treated municipal wastewater at the Green River outfall for maintenance purposes only under the following conditions:

1. The Permittee must obtain approval from Ecology at least five (5) working days in advance of the discharging to the Green River for maintenance purposes.
2. The duration of the discharge must not exceed four (4) hours.
3. The discharge must comply with the limits specified below.

Effluent Limits: Outfall 002A (Green River) *Lat/Long:* 47.467500˚, -122.244167˚	
Parameter	**Maximum Daily** [1]
Effluent Flow, MGD [2]	Must be less than or equal to: 0.25 * Green River Flow (MGD) / 5
$CBOD_5$	20 mg/L
Total Suspended Solids	20 mg/L
Total Residual Chlorine	95 µg/L
pH	Shall not be outside the range 6.0 to 9.0
	Maximum Geometric Mean
Fecal Coliform	200/100 mL

[1] Maximum daily effluent limit is the highest allowable daily discharge. In this case, the daily discharge is the average measurement over the discharge duration.

[2] Effluent flow limit is based on a dilution factor of 5, which is required to assure compliance with water quality criteria.

4. The Permittee may only discharge when the Green River flow is greater than 500 cfs.
5. The Permittee must treat any maintenance discharges to the Green River using secondary treatment, disinfection, and dechlorination.
6. The Permittee must monitor the discharge as required in S2.A to ensure that effluent limits are met.
7. The Permittee must sample receiving water turbidity as detailed in S2.A.
8. Any discharge from the treatment plant that results in water quality violations or contributes significantly to a fish kill is a violation of this permit.
9. The Permittee may only discharge, as a result of maintenance activities, during the out-going tide (after a high tide and before the subsequent low tide).
10. The Permittee should consider fish migration patterns when scheduling maintenance discharges.

S1.B. Mixing zone authorization

Outfall 001 – Puget Sound (marine)

The following paragraphs define the maximum boundaries of the mixing zones:

Chronic mixing zone

The chronic mixing zone consists of circles surrounding each discharge port with radii of 825 feet measured from the center of each port. The mixing zone extends from the bottom to the top of the water column. The concentration of pollutants at the edge of the chronic zone must meet chronic aquatic life criteria and human health criteria.

Acute mixing zone

The extended acute mixing zone consists of circles surrounding each discharge port with radii of 82 feet measured from the center of each port. The mixing zone extends from the bottom to the top of the water column. The concentration of pollutants at the edge of the acute zone must meet acute aquatic life criteria.

Outfall 001 - Available Dilution (dilution factor)	
Acute Aquatic Life Criteria	186
Chronic Aquatic Life Criteria	225
Human Health Criteria - Carcinogen	428
Human Health Criteria - Non-carcinogen	428

Outfall 002 – Green River (freshwater)

The Green River outfall is used as an emergency/backup outfall and is permitted for maintenance purposes only; emergency discharges from this outfall are permitted under S5.F. No chronic mixing zone is granted because maintenance discharges are permitted for durations of 4 hours or less.

Acute mixing zone

The acute mixing zone encompasses 25% of the river flow in accordance with WAC 173-201A-400(12). The resulting dilution factor is 5.0. The mixing zone extends 100 feet upstream, 300 feet downstream, and from the bottom to the top of the water column. The concentration of pollutants at the edge of the acute zone must meet acute aquatic life criteria.

Outfall 002 - Available Dilution (dilution factor)	
Chronic Dilution Ratio*	Not Applicable
Acute Dilution Ratio	5.0:1

* Maintenance discharges are permitted for durations of 4 hours or less and therefore a chronic dilution factor is not applicable.

S2. Monitoring requirements

S2.A. Monitoring schedules

The Permittee must monitor in accordance with the following schedules and must use the laboratory method, detection level (DL), and quantitation level (QL) specified in Appendix A or corresponding Sampling Analysis Plan/Quality Assurance Project Plan (SAP/QAPP) documents. Alternative methods from 40 CFR Part 136 are acceptable for those parameters without limits, and if the DL and QL are equivalent to those specified in Appendix A, corresponding SAP/QAPP documents, or sufficient to produce a measurable quantity.

Monitoring Requirements for Outfall 001 – Puget Sound

Parameter	Units	Minimum Sampling Frequency	Sample Type
(1) Wastewater influent (raw sewage from the collection system into the treatment facility)			
BOD_5	mg/L	1/week	24-hour composite [a]
	lbs/day [b]	1/week	Calculation
$CBOD_5$	mg/L	4/week	24-hour composite
	lbs/day [b]	4/week	Calculation
TSS	mg/L	4/week	24-hour composite
	lbs/day [b]	4/week	Calculation
(2) Final wastewater effluent (wastewater exiting the last treatment process or operation)			
Flow	MGD	Continuous [c]	Metered/recorded
$CBOD_5$ [d]	mg/L	4/week	24-hour composite
	lbs/day [b]	4/week	Calculation
	% removal [e]	Monthly	Calculation
TSS	mg/L	4/week	24-hour composite
	lbs/day [b]	4/week	Calculation
	% removal [e]	Monthly	Calculation
Chlorine (Total Residual)	µg/L	Continuous	Metered/recorded
Fecal Coliform [f]	# /100 ml	5/week	Grab [g]
pH [h]	Standard Units	Continuous	Metered/recorded
Total Ammonia	mg/L as N	Monthly	24-hour composite
	lbs/day [b]	Monthly	Calculation
Nitrate plus Nitrite Nitrogen	mg/L as N	Monthly	24-hour composite
Total Kjeldahl Nitrogen (TKN)	mg/L as N	Monthly	24-hour composite
Total Phosphorus	mg/L as P	Monthly	24-hour composite
Soluble Reactive Phosphorus	mg/L as P	Monthly	24-hour composite
Cyanide	micrograms/liter (µg/L)	2/year: Aug & Jan	Grab

Parameter	Units	Minimum Sampling Frequency	Sample Type
Total Phenolic Compounds	µg/L	2/year: Aug & Jan	Grab
Priority Pollutants (PP) – Total Metals [i]	µg/L ng/L for mercury	2/year: Aug & Jan	24-hour composite Grab for mercury
PP – Volatile Organic Compounds [i]	µg/L	2/year: Aug & Jan	Grab
PP – Acid-extractable Compounds [i]	µg/L	2/year: Aug & Jan	24-hour composite
PP – Base-neutral Compounds [i]	µg/L	2/year: Aug & Jan	24-hour composite
PP – PCBs [i]	µg/L	2/year: Aug & Jan	24-hour composite
(3) Whole effluent toxicity testing – As specified in Permit Conditions S10 & S11			
Acute Toxicity Testing		2/permit cycle	24-hour composite
Chronic Toxicity Testing		2/permit cycle	24-hour composite
(4) Pretreatment - As specified in Permit Condition S6			
(5) Permit Application Requirements – Final Wastewater Effluent			
Dissolved Oxygen	mg/L	1/year in Aug	Grab
Oil and Grease (HEM)	mg/L	1/year in Aug	Grab
Total Dissolved Solids	mg/L	1/year in Aug	24-hour composite
Total Hardness	mg/L	1/year in Aug	24-hour composite
Alkalinity	mg/L as CaCO3	1/year in Aug	Grab
Temperature	˚C	1/year in Aug	Grab
(6) Sediment - As specified in Permit Condition S9			

[a] 24-hour composite means a series of individual samples collected over a 24-hour period into a single container, and analyzed as one sample.

[b] lbs/day = Concentration (in mg/L) x Flow (in MGD) x Conversion Factor (8.34). Calculate using the average flow measured during the sample collection period.

[c] "Continuous" means uninterrupted except for brief lengths of time for calibration, power failure, or unanticipated equipment repair or maintenance. The time interval for the associated data logger must be no greater than 30 minutes. The Permittee must sample every six hours when continuous monitoring is not possible.

[d] Effluent samples for $CBOD_5$ analysis may be taken before or after the disinfection process. If taken after, dechlorinate and reseed the sample.

[e] % removal = $\frac{\text{Influent monthly average conc. (mg/L)} - \text{Effluent monthly average conc. (mg/L)}}{\text{Influent monthly average concentration (mg/L)}} \times 100$

[f] Report a numerical value for fecal coliforms following the procedures in Ecology's *Information Manual for Wastewater Treatment Plant Operators*, Publication Number 04-10-020 available at: http://www.ecy.wa.gov/programs/wq/permits/guidance.html. Do not report a result as too numerous to count (TNTC).

[g] Grab means an individual sample collected over a fifteen (15) minute, or less, period.

[h] Report the instantaneous maximum and minimum pH daily. Do not average pH values.

[i] Record and report the effluent flow discharged on the day of the priority pollutant samples.
See Appendix A or corresponding SAP/QAPP for the required detection (DL) or quantitation (QL) levels.
Report single analytical values below detection as "less than (detection level)" where (detection level) is the numeric value specified in Appendix A.
Report single analytical values between the detection and quantitation levels with qualifier code of 'j' following the value. If unable to obtain the required DL and QL due to matrix effects, the Permittee must submit a matrix specific MDL and a QL with appropriate laboratory documentation.

Monitoring Requirements for Outfall 002A – Green River

Parameter	Units	Minimum Sampling Frequency	Sample Type
(1) Wastewater Final Effluent (wastewater exiting the last treatment process or operation)			
Effluent Flow - maximum	MGD	Continuous	Metered/recorded
Duration	Hours	Once per event	Measurement
$CBOD_5$	mg/L	Once per event	Composite of equal volume grab samples during event
TSS	mg/L	Once per event	Composite of equal volume grab samples during event
pH	s.u.	Continuous	Metered/recorded
Fecal Coliform	# /100 ml	Once per event	Grab
Total Residual Chlorine	µg/L	Continuous	Metered/recorded
Dilution Factor *	None	Once per event	Calculated
(2) Downstream of Discharge - 300 feet			
River Flow	cfs	Once per event	Measurement
Turbidity	NTU	Once per event	Grab
(3) Upstream of Discharge			
Turbidity	NTU	Once per event	Grab

* Dilution Factor = [0.25 * River Flow, MGD] / [Effluent Flow, MGD], report as comment on DMR

S2.B. Sampling and analytical procedures

Samples and measurements taken to meet the requirements of this permit must represent the volume and nature of the monitored parameters. The Permittee must conduct representative sampling of any unusual discharge or discharge condition, including bypasses, upsets, and maintenance-related conditions that may affect effluent quality.

Sampling and analytical methods used to meet the monitoring requirements specified in this permit must conform to the latest revision of the *Guidelines Establishing Test Procedures for the Analysis of Pollutants* contained in 40 CFR Part 136 (or as applicable in 40 CFR subchapters N [Parts 400–471] or O [Parts 501-503]) unless otherwise specified in this permit . Ecology may only specify alternative methods for parameters without permit limits and for those parameters without an EPA approved test method in 40 CFR Part 136.

S2.C. Flow measurement and continuous monitoring devices

The Permittee must:

1. Select and use appropriate flow measurement and continuous monitoring devices and methods consistent with accepted scientific practices.

2. Install, calibrate, and maintain these devices to ensure the accuracy of the measurements is consistent with the accepted industry standard, the manufacturer's recommendation, and approved O&M manual procedures for the device and the wastestream.
3. Calibrate continuous monitoring instruments consistent with the manufacturer's recommendation.
4. Maintain calibration records for at least three years.

S2.D. Laboratory accreditation

The Permittee must ensure that all monitoring data required by Ecology for permit specified parameters is prepared by a laboratory registered or accredited under the provisions of chapter 173-50 WAC, *Accreditation of Environmental Laboratories*. Flow and internal process control parameters are exempt from this requirement.

S3. Reporting and recording requirements

The Permittee must monitor and report in accordance with the following conditions. Falsification of information submitted to Ecology is a violation of the terms and conditions of this permit.

S3.A. Discharge monitoring reports

The first monitoring period begins on the effective date of the permit. Permittee must:

1. Summarize, report, and submit monitoring data obtained during each monitoring period on the electronic discharge monitoring report (DMR) form provided by Ecology within the Water Quality Permitting Portal. Include data for each of the parameters tabulated in Special Condition S2 and as required by the form. Report a value for each day sampling occurred and for the summary values (when applicable) included on the electronic form.

   To find out more information and to sign up for the Water Quality Permitting Portal go to: http://www.ecy.wa.gov/programs/wq/permits/paris/webdmr.html

2. Enter the "No Discharge" reporting code for an entire DMR, for a specific monitoring point, or for a specific parameter as appropriate, if the Permittee did not discharge wastewater or a specific pollutant during a given monitoring period.
3. Report single analytical values below detection as "less than the detection level (DL)" by entering < followed by the numeric value of the detection level (e.g. < 2.0) on the DMR. If the method used did not meet the minimum DL and quantitation level (QL) identified in the permit, report the actual QL and DL in the comments or in the location provided.
4. **Not** report zero for bacteria monitoring. Report as required by the laboratory method.
5. Calculate the geometric mean values for bacteria using:

   a. The reported numeric value for all bacteria samples measured above the detection value except when it took multiple samples in one day. If the Permittee takes multiple samples in one day it must use the arithmetic average for that day in the geometric mean calculation.

   b. The detection value for those samples measured below detection.

6. Report the test method used for analysis in the comments if the laboratory used an alternative method not specified in the permit and as allowed in Appendix A.

7. Calculate average values and total values (unless otherwise specified in the permit) using:

   a. The reported numeric value for all parameters measured between the agency-required detection value and the agency-required quantitation value.

   b. One-half the detection value (for values reported below detection) if the lab detected the parameter in another sample from the same monitoring point for the reporting period.

   c. Zero (for values reported below detection) if the lab did not detect the parameter in another sample for the reporting period.

8. Report single-sample grouped parameters (for example: priority pollutants) on the WQWebDMR form and include sample date, concentration detected, detection limit (DL) (as necessary), laboratory quantitation level (QL) (as necessary), and CAS number. The Permittee must also submit an electronic copy of the laboratory report as an attachment using WQWebDMR. The contract laboratory reports must also include information on the chain of custody, QA/QC results, and documentation of accreditation for the parameter.

9. Ensure that DMRs are electronically submitted no later than the dates specified below, unless otherwise specified in this permit.

10. Submit DMRs in WQWebDMR for parameters with the monitoring frequencies specified in S2 (monthly, annually, etc.) at the reporting schedule identified below. The Permittee must:

    a. Submit **monthly** DMRs by the 15th day of the following month.

    b. Submit **annual** DMRs by July 31th for the previous calendar year. These submittals must include the permit renewal application monitoring data, priority pollutant, cyanide, and phenolic compound data as required in Special Condition S2.A. The annual sampling period is the calendar year.

S3.B. Permit submittals and schedules

The Permittee must use the *Water Quality Permitting Portal – Permit Submittals* application to submit all other written permit-required reports by the date specified in the permit.

When another permit condition requires submittal of a paper (hard-copy) report, the Permittee must ensure that it is postmarked or received by Ecology no later than the dates specified by this permit. Send these paper reports to Ecology at:

Water Quality Permit Coordinator
Department of Ecology
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

S3.C. Records retention

The Permittee must retain records of all monitoring information for a minimum of three (3) years. Such information must include all calibration and maintenance records and all original recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for this permit. The Permittee must extend this period of retention during the course of any unresolved litigation regarding the discharge of pollutants by the Permittee or when requested by Ecology.

S3.D. Recording of results

For each measurement or sample taken, the Permittee must record the following information:

1. The date, exact place, method, and time of sampling or measurement.
2. The individual who performed the sampling or measurement.
3. The dates the analyses were performed.
4. The individual who performed the analyses.
5. The analytical techniques or methods used.
6. The results of all analyses.

S3.E. Additional monitoring by the Permittee

If the Permittee monitors any pollutant more frequently than required by Special Condition S2 of this permit, then the Permittee must include the results of such monitoring in the calculation and reporting of the data submitted in the Permittee's DMR unless otherwise specified by Special Condition S2.

S3.F. Reporting permit violations

The Permittee must take the following actions when it violates or is unable to comply with any permit condition:

1. Immediately take action to stop, contain, and cleanup unauthorized discharges or otherwise stop the noncompliance and correct the problem.
2. If applicable, immediately repeat sampling and analysis. Submit the results of any repeat sampling to Ecology within thirty (30) days of sampling.

a. *Immediate reporting*

The Permittee must **immediately** report to Ecology and the Department of Health, Shellfish Program, and Public Health of Seattle-King County (phone numbers listed below), all:

- Failures of the disinfection system
- Collection system overflows
- Plant bypasses discharging to marine surface waters
- Any other failures of the sewage system (pipe breaks, etc.)

The Permittee must also *immediately* report any collection system overflows discharging to a waterbody used as a source of drinking water to Ecology, the Department of Health Drinking Water Program, and Public Health of Seattle-King County.

Ecology - Northwest Regional Office	425-649-7000
Department of Health - Shellfish Program	360-236-3330 (business hours) 360-789-8962 (after business hours)
Public Health of Seattle-King County	206-477-8177
Department of Health, Drinking Water Program	800-521-0323 (business hours) 877-481-4901 (after business hours)

Additionally, for any sanitary sewer overflow (SSO) that discharges to a municipal separate storm sewer system (MS4), the Permittee must notify the appropriate MS4 owner or operator.

b. *Twenty-four-hour reporting*

The Permittee must report the following occurrences of noncompliance by telephone, to Ecology at the telephone number listed above, within 24 hours from the time the Permittee becomes aware of any of the following circumstances:

i. Any noncompliance that may endanger health or the environment, unless previously reported under immediate reporting requirements.

ii. Any unanticipated bypass that causes an exceedance of an effluent limit in the permit (See Part S5.F, "Bypass Procedures").

iii. Any upset that causes an exceedance of an effluent limit in the permit (see G15, "Upset").

iv. Any violation of a maximum daily or instantaneous maximum discharge limit for any of the pollutants in Section S1.A of this permit.

v. Any overflow prior to the treatment works, whether or not such overflow endangers health or the environment or exceeds any effluent limit in the permit.

c. *Report within five days*

The Permittee must also submit a written report within five business days of the time that the Permittee becomes aware of any reportable event under subparts a or b, above. The report must contain:

i. A description of the noncompliance and its cause.

ii. The period of noncompliance, including exact dates and times.

iii. The estimated time the Permittee expects the noncompliance to continue if not yet corrected.

iv. Steps taken or planned to reduce, eliminate, and prevent recurrence of the noncompliance.

v. If the noncompliance involves an overflow prior to the treatment works, an estimate of the quantity (in gallons) of untreated overflow.

d. *Waiver of written reports*

Ecology may waive the written report required in subpart c, above, on a case-by-case basis upon request if the Permittee has submitted a timely oral report.

e. *All other permit violation reporting*

The Permittee must report all permit violations, which do not require immediate or within 24 hours reporting, when it submits monitoring reports for S3.A ("Reporting"). The reports must contain the information listed in subpart c, above. Compliance with these requirements does not relieve the Permittee from responsibility to maintain continuous compliance with the terms and conditions of this permit or the resulting liability for failure to comply.

S3.G. Other reporting

1. Spills of oil or hazardous materials

   The Permittee must report a spill of oil or hazardous materials in accordance with the requirements of RCW 90.56.280 and chapter 173-303-145. You can obtain further instructions at the following website: http://www.ecy.wa.gov/programs/spills/other/reportaspill.htm .

2. Failure to submit relevant or correct facts

   Where the Permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application, or in any report to Ecology, it must submit such facts or information promptly.

S3.H. Maintaining a copy of this permit

The Permittee must keep a copy of this permit at the facility and make it available upon request to Ecology inspectors.

S4. Facility loading

S4.A. Design criteria

The flows or waste loads for the permitted facility must not exceed the following design criteria:

Maximum Month Design Flow (MMDF)	144 MGD
BOD_5 Influent Loading for Maximum Month	251,000 lbs/day
TSS Influent Loading for Maximum Month	235,000 lbs/day

S4.B. Plans for maintaining adequate capacity

1. Conditions triggering plan submittal

   The Permittee must submit a plan and a schedule for continuing to maintain capacity to Ecology when:

   a. The actual flow or waste load reaches 85 percent of any one of the design criteria in S4.A for three consecutive months.

   b. The projected plant flow or loading would reach design capacity within five years.

2. Plan and schedule content

   The plan and schedule must identify the actions necessary to maintain adequate capacity for the expected population growth and to meet the limits and requirements of the permit. The Permittee must consider the following topics and actions in its plan.

   a. Analysis of the present design and proposed process modifications.

   b. Reduction or elimination of excessive infiltration and inflow of uncontaminated ground and surface water into the sewer system.

   c. Limits on future sewer extensions or connections or additional waste loads.

   d. Modification or expansion of facilities.

   e. Reduction of industrial or commercial flows or waste loads

   Engineering documents associated with the plan must meet the requirements of WAC 173-240-060, "Engineering Report," and be approved by Ecology prior to any construction.

S4.C. Duty to mitigate

The Permittee must take all reasonable steps to minimize or prevent any discharge or biosolids use or disposal in violation of this permit that has a reasonable likelihood of adversely affecting human health or the environment.

S4.D. Notification of new or altered sources

1. The Permittee must submit written notice to Ecology whenever any new discharge or a substantial change in volume or character of an existing discharge into the wastewater treatment plant is proposed which:
   a. Would interfere with the operation of, or exceed the design capacity of, any portion of the wastewater treatment plant.
   b. Is not part of an approved general sewer plan or approved plans and specifications.
   c. Is subject to pretreatment standards under 40 CFR Part 403 and Section 307(b) of the Clean Water Act.
2. This notice must include an evaluation of the wastewater treatment plant's ability to adequately transport and treat the added flow and/or waste load, the quality and volume of effluent to be discharged to the treatment plant, and the anticipated impact on the Permittee's effluent [40 CFR 122.42(b)].

S4.E. Wasteload assessment

The Permittee must conduct an assessment of its influent flow and waste load and submit a report to Ecology by October 31, 2018. The report must contain:

1. A description of compliance or noncompliance with the permit effluent limits.
2. A comparison between the existing and design:
   a. Monthly average dry weather and wet weather flows.
   b. Maximum month flows.
   c. Peak flows.
   d. BOD_5 loadings.
   e. Total suspended solids loadings.
3. The percent change in the above parameters since the previous report.
4. The present and design population or population equivalent.
5. The projected population growth rate.
6. The estimated date upon which the Permittee expects the wastewater treatment plant to reach design capacity, according to the most restrictive of the parameters above.
7. An Infiltration and Inflow (I/I) update that describes:
   a. For the collection system owned and operated by the County:
      i. The results of recent I/I monitoring
      ii. A summary of recent I/I improvement projects.
      iii. Projects planned to improve I/I.

b. For the collection systems owned and operated by component agencies:
   i. Measures taken to encourage component agencies to control I/I.
   ii. Any known I/I concerns.
   iii. Steps planned to further encourage I/I reduction projects.

S5. Operation and maintenance

The Permittee must at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances), which are installed to achieve compliance with the terms and conditions of this permit. Proper operation and maintenance also includes keeping a daily operation logbook (paper or electronic), adequate laboratory controls, and appropriate quality assurance procedures. This provision of the permit requires the Permittee to operate backup or auxiliary facilities or similar systems only when the operation is necessary to achieve compliance with the conditions of this permit.

S5.A. Certified operator

This permitted facility must be operated by an operator certified by the state of Washington for at least a Class IV plant. This operator must be in responsible charge of the day-to-day operation of the wastewater treatment plant. An operator certified for at least a Class III plant must be in charge during all regularly scheduled shifts.

S5.B. Operation and maintenance program

The Permittee must:

1. Institute an adequate operation and maintenance program for the entire sewage system.
2. Keep maintenance records on all major electrical and mechanical components of the treatment plant, as well as the sewage system and pumping stations. Such records must clearly specify the frequency and type of maintenance recommended by the manufacturer and must show the frequency and type of maintenance performed.
3. Make maintenance records available for inspection at all times.

S5.C. Short-term reduction

The Permittee must schedule any facility maintenance, which might require interruption of wastewater treatment and degrade effluent quality, during non-critical water quality periods and carry this maintenance out according to the approved O&M manual or as otherwise approved by Ecology.

If a Permittee contemplates a reduction in the level of treatment that would cause a violation of permit discharge limits on a short-term basis for any reason, and such reduction cannot be avoided, the Permittee must:

1. Give written notification to Ecology, if possible, thirty (30) days prior to such activities.
2. Detail the reasons for, length of time of, and the potential effects of the reduced level of treatment.

This notification does not relieve the Permittee of its obligations under this permit.

S5.D. Electrical power failure

The Permittee must ensure that adequate safeguards prevent the discharge of untreated wastes or wastes not treated in accordance with the requirements of this permit during electrical power failure at the treatment plant and/or sewage lift stations. Adequate safeguards include, but are not limited to, alternate power sources, standby generator(s), or retention of inadequately treated wastes.

The Permittee must maintain Reliability Class II (EPA 430-99-74-001) at the wastewater treatment plant. Reliability Class II requires a backup power source sufficient to operate all vital components and critical lighting and ventilation during peak wastewater flow conditions. Vital components used to support the secondary processes (i.e., mechanical aerators or aeration basin air compressors) need not be operable to full levels of treatment, but must be sufficient to maintain the biota.

S5.E. Prevent connection of inflow

The Permittee must strictly enforce its sewer ordinances and not allow the connection of inflow (roof drains, foundation drains, etc.) to the sanitary sewer system within King County control.

S5.F. Bypass procedures

This permit prohibits a bypass, which is the intentional diversion of waste streams from any portion of a treatment facility. Ecology may take enforcement action against a Permittee for a bypass unless one of the following circumstances (1, 2, or 3) applies.

1. Bypass for essential maintenance without the potential to cause violation of permit limits or conditions.

   This permit authorizes a bypass if it allows for essential maintenance and does not have the potential to cause violations of limits or other conditions of this permit, or adversely impact public health as determined by Ecology prior to the bypass. The Permittee must submit prior notice, if possible, at least ten (10) days before the date of the bypass.

2. Bypass which is unavoidable, unanticipated, and results in noncompliance of this permit.

   This permit authorizes such a bypass only if:

a. Bypass is unavoidable to prevent loss of life, personal injury, or severe property damage. “Severe property damage” means substantial physical damage to property, damage to the treatment facilities which would cause them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass.

b. No feasible alternatives to the bypass exist, such as:

- The use of auxiliary treatment facilities.
- Retention of untreated wastes.
- Maintenance during normal periods of equipment downtime, but not if the Permittee should have installed adequate backup equipment in the exercise of reasonable engineering judgment to prevent a bypass.
- Transport of untreated wastes to another treatment facility.

c. Ecology is properly notified of the bypass as required in Special Condition S3.F of this permit.

3. If bypass is anticipated and has the potential to result in noncompliance of this permit.

a. The Permittee must notify Ecology at least thirty (30) days before the planned date of bypass. The notice must contain:

- A description of the bypass and its cause.
- An analysis of all known alternatives which would eliminate, reduce, or mitigate the need for bypassing.
- A cost-effectiveness analysis of alternatives including comparative resource damage assessment.
- The minimum and maximum duration of bypass under each alternative.
- A recommendation as to the preferred alternative for conducting the bypass.
- The projected date of bypass initiation.
- A statement of compliance with SEPA.
- A request for modification of water quality standards as provided for in WAC 173-201A-410, if an exceedance of any water quality standard is anticipated.
- Details of the steps taken or planned to reduce, eliminate, and prevent reoccurrence of the bypass.

b. For probable construction bypasses, the Permittee must notify Ecology of the need to bypass as early in the planning process as possible. The Permittee must consider the analysis required above during the project planning and design process. The project-specific engineering report or facilities plan as well as the plans and specifications must include details of probable construction bypasses to the extent practical. In cases where the Permittee determines the probable need to bypass early, the Permittee must continue to analyze conditions up to and including the construction period in an effort to minimize or eliminate the bypass.

c. Ecology will consider the following prior to issuing an administrative order for this type of bypass:

- If the bypass is necessary to perform construction or maintenance-related activities essential to meet the requirements of this permit.
- If feasible alternatives to bypass exist, such as the use of auxiliary treatment facilities, retention of untreated wastes, stopping production, maintenance during normal periods of equipment down time, or transport of untreated wastes to another treatment facility.
- If the Permittee planned and scheduled the bypass to minimize adverse effects on the public and the environment.

After consideration of the above and the adverse effects of the proposed bypass and any other relevant factors, Ecology will approve or deny the request. Ecology will give the public an opportunity to comment on bypass incidents of significant duration, to the extent feasible. Ecology will approve a request to bypass by issuing an administrative order under RCW 90.48.120.

S5.G. Operations and maintenance (O&M) manuals

1. O&M manual submittal and requirements

   The Permittee must:

   a. Review the O&M Manuals at least annually.

   b. Submit to Ecology for review and approval substantial changes or updates to the O&M Manuals.

   c. Keep the approved O&M Manuals at the permitted facility.

   d. Follow the instructions and procedures of the manuals.

2. O&M manual components

   In addition to the requirements of WAC 173-240-080 (1) through (5), the O&M manuals must include:

   a. Emergency procedures for cleanup in the event of wastewater system upset or failure.

   b. A review of system components which if failed could pollute surface water or could impact human health. Provide a procedure for a routine schedule of checking the function of these components.

   c. Wastewater system maintenance procedures that contribute to the generation of process wastewater.

d. Reporting protocols for submitting reports to Ecology to comply with the reporting requirements in the discharge permit.

e. Any directions to maintenance staff when cleaning or maintaining other equipment or performing other tasks which are necessary to protect the operation of the wastewater system (for example, defining maximum allowable discharge rate for draining a tank, blocking all floor drains before beginning the overhaul of a stationary engine).

f. The treatment plant process control monitoring schedule.

S6. Pretreatment

S6.A. General requirements

1. The Permittee must implement the Industrial Pretreatment Program in accordance with King County Code 28.84.060 as amended by King County Ordinance No. 11963 on January 1, 1996, legal authorities, policies, procedures, and financial provisions described in the Permittee's approved pretreatment program submittal entitled "Industrial Pretreatment Program" and dated April 27, 1981; any approved revisions thereto; and the General Pretreatment Regulations (40 CFR Part 403). At a minimum, the Permittee must undertake the following pretreatment implementation activities:

    a. Enforce categorical pretreatment standards under Section 307(b) and (c) of the Federal Clean Water Act (hereinafter, the Act), prohibited discharge standards as set forth in 40 CFR 403.5, local limits, or state standards, which ever are most stringent or apply at the time of issuance or modification of a local industrial waste discharge permit. Locally derived limits are defined as pretreatment standards under Section 307(d) of the Act and are not limited to categorical industrial facilities.

    b. Issue industrial waste discharge permits to all significant industrial users [SIUs, as defined in 40 CFR 403.3(v)(i)(ii)] contributing to the treatment system, including those from other jurisdictions. Industrial waste discharge permits must contain as a minimum, all the requirements of 40 CFR 403.8 (f)(l)(iii). The Permittee must coordinate the permitting process with Ecology regarding any industrial facility which may possess a state waste discharge permit issued by Ecology.

    c. Maintain and update, as necessary, records identifying the nature, character, and volume of pollutants contributed by industrial users to the treatment works. The Permittee must maintain records for at least a three-year period.

    d. Perform inspections, surveillance, and monitoring activities on industrial users to determine or confirm compliance with pretreatment standards and requirements. The Permittee must conduct a thorough inspection of SIUs annually, except Middle-Tier Categorical Industrial Users, as defined by 40 CFR 403.8(f)(2)(v)(B)&(C), need only be inspected once every two years. The Permittee must conduct regular local monitoring of SIU wastewaters commensurate with the character and volume of the wastewater but not less than once per year except for Middle-Tier Categorical Industrial Users which may be sampled once every two years. The Permittee must collect and analyze samples in accordance with 40 CFR Part 403.12(b)(5)(ii)-(v) and 40 CFR Part 136.

e. Enforce and obtain remedies for non-compliance by any industrial users with applicable pretreatment standards and requirements. Once violations have been identified, the Permittee must take timely and appropriate enforcement action to address the non-compliance. The Permittee's action must follow its enforcement response procedures and any amendments, thereof.

f. Publish, at least annually in a newspaper of general circulation within the Permittee's service area, a list of all non-domestic users which, at any time in the previous 12 months, were in significant non-compliance as defined in 40 CFR 403.8(f)(2)(vii).

g. If the Permittee elects to conduct sampling of an SIU's discharge in lieu of requiring user self-monitoring, it must satisfy all requirements of 40 CFR Part 403.12. This includes monitoring and record keeping requirements of sections 403.12(g) and (o). For SIU's subject to categorical standards (i.e., CIUs), the Permittee may either complete baseline and initial compliance reports for the CIU (when required by 403.12(b) and (d)) or require these of the CIU. The Permittee must ensure SIUs are provided the results of sampling in a timely manner, inform SIUs of their right to sample, their obligations to report any sampling they do, to respond to non-compliance, and to submit other notifications. These include a slug load report (403.12(f)), notice of changed discharge (403.12(j)), and hazardous waste notifications (403.12(p)). If sampling for the SIU, the Permittee must not sample less than once in every six month period unless the Permittee's approved program includes procedures for reduction of monitoring for Middle-Tier or Non-Significant Categorical Users per 403.12(e)(2) and (3) and those procedures have been followed.

h. Develop and maintain a data management system designed to track the status of the Permittee's industrial user inventory, industrial user discharge characteristics, and compliance status.

i. Maintain adequate staff, funds, and equipment to implement its pretreatment program.

j. Establish, where necessary, contracts or legally binding agreements with contributing jurisdictions to ensure compliance with applicable pretreatment requirements by commercial or industrial users within these jurisdictions. These contracts or agreements must identify the agency responsible for the various implementation and enforcement activities to be performed in the contributing jurisdiction.

2. Per 40 CFR 403.8(f)(2)(vii), the Permittee must evaluate each Significant Industrial User to determine if a Slug Control Plan is needed to prevent slug discharges which may cause interference, pass-through, or in any other way result in violations of the Permittee's regulations, local limits or permit conditions. The Slug Control Plan evaluation shall occur within one year of a user's designation as a SIU. In accordance with 40 CFR 403.8(f)(1)(iii)(B)(6) the Permittee shall include slug discharge control requirements in an SIU's permit if the Permittee determines that they are necessary.

3. Whenever Ecology determines that any waste source contributes pollutants to the Permittee's treatment works in violation of Subsection (b), (c), or (d) of Section 307 of the Act, and the Permittee has not taken adequate corrective action, Ecology will notify the Permittee of this determination. If the Permittee fails to take appropriate enforcement action within 30 days of this notification, Ecology may take appropriate enforcement action against the source or the Permittee.

4. Pretreatment Report

   The Permittee must provide to Ecology an annual report that briefly describes its program activities during the previous calendar year. By April 30th, the Permittee must send the annual report to Ecology at:

   Water Quality Permit Coordinator
   Department of Ecology
   Northwest Regional Office
   3190 160th Avenue SE
   Bellevue, WA 98008-5452

   The report must include the following information:

   a. An updated listing of non-domestic industrial dischargers.

   b. Results of wastewater sampling at the treatment plant as specified in Subsection S6.B below. The Permittee must calculate removal rates for each pollutant and evaluate the adequacy of the existing local limits in prevention of treatment plant interference, pass through of pollutants that could affect receiving water quality and biosolids contamination.

   c. Status of program implementation, including:

      i. Any substantial modifications to the pretreatment program as originally approved by Ecology, including staffing and funding levels.

      ii. Any interferences, upsets, or permit violations experienced at the WWTP that are directly attributable to wastes from industrial users.

      iii. Listing of industrial users inspected and/or monitored, and a summary of the results.

      iv. Listing of industrial users scheduled for inspection and/or monitoring for the next year, and expected frequencies.

v. Listing of industrial users notified of promulgated pretreatment standards and/or local standards as required in 40 CFR 403.8(f)(2)(iii). The list must indicate which industrial users are on compliance schedules and the final date of compliance for each.

vi. Listing of industrial users issued industrial waste discharge permits.

vii. Planned changes in the pretreatment program implementation plan.

d. Status of compliance activities, including:

i. Listing of industrial users that failed to submit baseline monitoring reports or any other reports required under 40 CFR 403.12 and in the Permittee's pretreatment program, dated April 27, 1981.

ii. Listing of industrial users that were at any time during the reporting period not complying with federal, state, or local pretreatment standards or with applicable compliance schedules for achieving those standards, and the duration of such non-compliance.

iii. Summary of enforcement activities and other corrective actions taken or planned against non-complying industrial users. The Permittee must supply to Ecology a copy of the public notice of facilities that were in significant non-compliance.

5. The Permittee must request and obtain approval from Ecology before making any significant changes to the approved local pretreatment program. The Permittee must follow the procedure in 40 CFR 403.18 (b) and (c).

S6.B. Monitoring requirements

The Permittee must monitor its influent, effluent, and biosolids at the South Plant WWTP for the priority pollutants identified in Tables II and III of Appendix D of 40 CFR Part 122 as amended, any compounds identified as a result of Condition S6.B.4, and any other pollutants expected from nondomestic sources using U.S. EPA-approved procedures for collection, preservation, storage, and analysis. The Permittee must test influent, effluent, and biosolids samples for the priority pollutant metals (Table III, 40 CFR 122, Appendix D) on a quarterly basis throughout the term of this permit. The Permittee must test influent, effluent, and biosolids samples for the organic priority pollutants (Table II, 40 CFR 122, Appendix D) on an annual basis.

1. The Permittee must sample South Plant WWTP influent and effluent on a day when industrial discharges are occurring at normal to maximum levels. The Permittee must obtain 24-hour composite samples for the analysis of acid and base/neutral extractable compounds and metals. The Permittee must collect samples for the analysis of volatile organic compounds and samples must be collected using grab sampling techniques at equal intervals for a total of four grab samples per day.

   The laboratory may run a single analysis for volatile pollutants (using GC/MS procedures approved by 40 CFR 136) for each monitoring day by compositing equal volumes of each grab sample directly in the GC purge and trap apparatus in the laboratory, with no less than 1 ml of each grab included in the composite.

Unless otherwise indicated, all reported test data for metals must represent the total amount of the constituent present in all phases, whether solid, suspended, or dissolved, elemental or combined including all oxidation states.

The Permittee must handle, prepare, and analyze all wastewater samples taken for GC/MS analysis using procedures approved by 40 CFR 136.

2. The Permittee must collect a biosolids sample concurrently with a wastewater sample as a single grab sample of residual biosolids. Sampling and analysis must be performed using procedures approved by 40 CFR 136 unless the Permittee requests an alternate method and Ecology has approved.
3. The Permittee must take cyanide, phenols, and oils as grab samples. Oils must be hexane soluble or equivalent, and should be measured in the influent and effluent only.
4. In addition to quantifying pH, oil and grease, and all priority pollutants, the Permittee must make a reasonable attempt to identify all other substances and quantify all pollutants shown to be present by gas chromatograph/mass spectrometer (GC/MS) analysis using procedures approved by 40 CFR 136. The Permittee should attempt to make determinations of pollutants for each fraction, which produces identifiable spectra on total ion plots (reconstructed gas chromatograms). The Permittee should attempt to make determinations from all peaks with responses 5% or greater than the nearest internal standard. The 5% value is based on internal standard concentrations of 30 μg/l, and must be adjusted downward if higher internal standard concentrations are used or adjusted upward if lower internal standard concentrations are used. The Permittee may express results for non-substituted aliphatic compounds as total hydrocarbon content. The Permittee must use a laboratory whose computer data processing programs are capable of comparing sample mass spectra to a computerized library of mass spectra, with visual confirmation by an experienced analyst. For all detected substances which are determined to be pollutants, the Permittee must conduct additional sampling and appropriate testing to determine concentration and variability, and to evaluate trends.

S6.C. Reporting of monitoring results

The Permittee must include a summary of monitoring results in the Annual Pretreatment Report.

S6.D. Local limit development

As sufficient data become available, the Permittee must, in consultation with Ecology, reevaluate their local limits in order to prevent pass through or interference. If Ecology determines that any pollutant present causes pass through or interference, or exceeds established biosolids standards, the Permittee must establish new local limits or revise existing local limits as required by 40 CFR 403.5. Ecology may also require the Permittee to revise or establish local limits for any pollutant discharged from the treatment works that has a reasonable potential to exceed the water quality standards, sediment standards, or established effluent limits, or causes whole effluent toxicity. Ecology makes this determination in the form of an Administrative Order.

Ecology may modify this permit to incorporate additional requirements relating to the establishment and enforcement of local limits for pollutants of concern. Any permit modification is subject to formal due process procedures under state and federal law and regulation.

S7. Solid wastes

S7.A. Solid waste handling

The Permittee must handle and dispose of all solid waste material in such a manner as to prevent its entry into state ground or surface water.

S7.B. Leachate

The Permittee must not allow leachate from its solid waste material to enter state waters without providing all known, available, and reasonable methods of treatment, nor allow such leachate to cause violations of the State Surface Water Quality Standards, Chapter 173-201A WAC, or the State Ground Water Quality Standards, Chapter 173-200 WAC. The Permittee must apply for a permit or permit modification as may be required for such discharges to state ground or surface waters.

S8. Spill control plan

S8.A Spill control plan submittals and requirements

The Permittee must:

1. Review the existing spill plan at least annually and update the spill plan as needed.
2. Send significant changes to the plan to Ecology.
3. Follow the plan and any supplements throughout the term of the permit.

S8.B. Spill control plan components

The spill control plan must include the following:

1. A list of all oil and petroleum products and other materials used and/or stored on-site, which when spilled, or otherwise released into the environment, designate as dangerous waste (DW) or extremely hazardous waste (EHW) by the procedures set forth in WAC 173-303-070. Include other materials used and/or stored on-site which may become pollutants or cause pollution upon reaching state's waters.

2. A description of preventive measures and facilities (including an overall facility plot showing drainage patterns) which prevent, contain, or treat spills of these materials.
3. A description of the reporting system the Permittee will use to alert responsible managers and legal authorities in the event of a spill.
4. A description of operator training to implement the plan.

The Permittee may submit plans and manuals required by 40 CFR Part 112, contingency plans required by Chapter 173-303 WAC, or other plans required by other agencies, which meet the intent of this section.

S9. Sediment monitoring

S9.A. Sediment sampling and analysis plan

The Permittee must submit to Ecology for review and approval a sediment sampling and analysis plan for sediment monitoring by December 1, 2016. The purpose of the plan is to recharacterize sediment (the nature and extent of chemical contamination and biological toxicity) quality in the vicinity of the Permittee's discharge locations. The Permittee must sample the top 10 cm of sediment at the same eight stations sampled during the previous permit term, and the sediments must be analyzed for the 47 chemicals with SMS numeric criteria as well as conventional analytes. The Permittee must follow the guidance provided in the current version of the *Sediment Source Control Standards User Manual, Appendix B: sediment sampling and analysis plan.*

S9.B. Sediment data report

Following Ecology approval of the sediment sampling and analysis plan, the Permittee must collect sediments between August 15th and September 30th of 2017. The Permittee must submit to Ecology a sediment data report containing the results of the sediment sampling and analysis no later than December 1, 2018. The sediment data report must conform to the approved sediment sampling and analysis plan. The report must document when the data was successfully loaded into EIM as required below.

In addition to a sediment data report, submit the sediment chemical and any biological data to Ecology's EIM database (http://www.ecy.wa.gov/eim/). Data must be submitted to EIM according to the instructions on the EIM website. The data submittal portion of the EIM website (http://www.ecy.wa.gov/eim/submitdata.htm) provides information and help on formats and requirements for submitting tabular data.

S10. Acute toxicity

S10.A. Testing when there is no permit limit for acute toxicity

The Permittee must:

1. Conduct acute toxicity testing on final effluent once in the first quarter of 2018 and once in the third quarter of 2018.
2. Conduct acute toxicity testing on a series of at least five concentrations of effluent, including 100% effluent and a control.
3. Use each of the following species and protocols for each acute toxicity test:

Acute Toxicity Tests	Species	Method
Fathead minnow 96-hour static-renewal test	*Pimephales promelas*	EPA-821-R-02-012
Daphnid 48-hour static test	*Ceriodaphnia dubia, Daphnia pulex,* or *Daphnia magna*	EPA-821-R-02-012

4. Submit the results to Ecology with the permit renewal application.

S10.B. Sampling and reporting requirements

1. The Permittee must submit all reports for toxicity testing in accordance with the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. Reports must contain toxicity data, bench sheets, and reference toxicant results for test methods. In addition, the Permittee must submit toxicity test data in electronic format (CETIS export file preferred) for entry into Ecology's database.
2. The Permittee must collect 24-hour composite effluent samples for toxicity testing. The Permittee must cool the samples to 0 - 6 degrees Celsius during collection and send them to the lab immediately upon completion. The lab must begin the toxicity testing as soon as possible but no later than 36 hours after sampling was completed.
3. The laboratory must conduct water quality measurements on all samples and test solutions for toxicity testing, as specified in the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*.
4. All toxicity tests must meet quality assurance criteria and test conditions specified in the most recent versions of the EPA methods listed in Subsection C and the Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. If Ecology determines any test results to be invalid or anomalous, the Permittee must repeat the testing with freshly collected effluent.
5. The laboratory must use control water and dilution water meeting the requirements of the EPA methods listed in Section A or pristine natural water of sufficient quality for good control performance.

6. The Permittee must collect effluent samples for whole effluent toxicity testing just prior to the chlorination step in the treatment process.
7. The Permittee may choose to conduct a full dilution series test during compliance testing in order to determine dose response. In this case, the series must have a minimum of five effluent concentrations and a control. The series of concentrations must include the acute critical effluent concentration (ACEC). The ACEC equals 0.54% effluent.
8. All whole effluent toxicity tests, effluent screening tests, and rapid screening tests that involve hypothesis testing must comply with the acute statistical power standard of 29% as defined in WAC 173-205-020. If the test does not meet the power standard, the Permittee must repeat the test on a fresh sample with an increased number of replicates to increase the power.

S11. Chronic toxicity

S11.A. Testing when there is no permit limit for chronic toxicity

The Permittee must:

1. Conduct chronic toxicity testing on final effluent once in the second quarter of 2018 and once in the fourth quarter of 2018.
2. Conduct chronic toxicity testing on a series of at least five concentrations of effluent and a control. This series of dilutions must include the acute critical effluent concentration (ACEC). The ACEC equals 0.54% effluent. The series of dilutions should also contain the CCEC of 0.44% effluent.
3. Compare the ACEC to the control using hypothesis testing at the 0.05 level of significance as described in Appendix H, EPA/600/4-89/001.
4. Submit the results to Ecology with the next permit renewal application.
5. Perform chronic toxicity tests with all of the following species and the most recent version of the following protocols:

Saltwater Chronic Test	Species	Method
Topsmelt survival and growth	*Atherinops affinis*	EPA/600/R-95/136
Mysid shrimp survival and growth	*Americamysis bahia* (formerly *Mysidopsis bahia*)	EPA-821-R-02-014

S11.B. Sampling and reporting requirements

1. The Permittee must submit all reports for toxicity testing in accordance with the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. Reports must contain toxicity data, bench sheets, and reference toxicant results for test methods. In addition, the Permittee must submit toxicity test data in electronic format (CETIS export file preferred) for entry into Ecology's database.

2. The Permittee must collect 24-hour composite effluent samples for toxicity testing. The Permittee must cool the samples to 0 - 6 degrees Celsius during collection and send them to the lab immediately upon completion. The lab must begin the toxicity testing as soon as possible but no later than 36 hours after sampling was completed.
3. The laboratory must conduct water quality measurements on all samples and test solutions for toxicity testing, as specified in the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*.
4. All toxicity tests must meet quality assurance criteria and test conditions specified in the most recent versions of the EPA methods listed in Section C and the Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. If Ecology determines any test results to be invalid or anomalous, the Permittee must repeat the testing with freshly collected effluent.
5. The laboratory must use control water and dilution water meeting the requirements of the EPA methods listed in Subsection C or pristine natural water of sufficient quality for good control performance.
6. The Permittee must collect effluent samples for whole effluent toxicity testing just prior to the chlorination step in the treatment process.
7. The Permittee may choose to conduct a full dilution series test during compliance testing in order to determine dose response. In this case, the series must have a minimum of five effluent concentrations and a control. The series of concentrations must include the CCEC and the ACEC. The CCEC and the ACEC may either substitute for the effluent concentrations that are closest to them in the dilution series or be extra effluent concentrations. The CCEC equals 0.44% effluent. The ACEC equals 0.54% effluent.
8. All whole effluent toxicity tests that involve hypothesis testing must comply with the chronic statistical power standard of 39% as defined in WAC 173-205-020. If the test does not meet the power standard, the Permittee must repeat the test on a fresh sample with an increased number of replicates to increase the power.

S12. Use of effluent from effluent transfer system

The Permittee may distribute effluent from the effluent transfer system (ETS) for use and return to the ETS for discharge via Outfall #001 of this permit – without modification of this permit – under the following conditions:

1. The distributed ETS effluent must meet all treatment and disinfection requirements of Condition S1 of this permit.
2. The effluent is used at the Boeing facility in the approved, closed loop, noncontact chiller project.

3. The Permittee may distribute ETS effluent to a similar closed-loop, noncontact system only after it requests and receives specific written approval from both the Departments of Ecology and Health.
4. The effluent returned to the ETS system for discharge via Outfall #001 must meet all permit requirements for that discharge.
5. The Permittee obtains, files, and enforces a signed user contract assuring compliance with all requirements of the approved project. All new contracts must be approved by the Departments of Ecology and Health and signed by all parties prior to any distribution of the effluent.
6. The Permittee immediately notifies all users during instances of noncompliance.

No other uses of ETS effluent are authorized under this permit.

S13. Application for permit renewal or modification for facility changes

The Permittee must submit an application for renewal of this permit by July 31, 2019.

The Permittee must also submit a new application or supplement at least one hundred eighty (180) days prior to commencement of discharges, resulting from the activities listed below, which may result in permit violations. These activities include any facility expansions, production increases, or other planned changes, such as process modifications, in the permitted facility.

General Conditions

G1. Signatory requirements

1. All applications, reports, or information submitted to Ecology must be signed and certified.
   a. In the case of corporations, by a responsible corporate officer. For the purpose of this section, a responsible corporate officer means:
      - A president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision making functions for the corporation, or
      - The manager of one or more manufacturing, production, or operating facilities, provided, the manager is authorized to make management decisions which govern the operation of the regulated facility including having the explicit or implicit duty of making major capital investment recommendations, and initiating and directing other comprehensive measures to assure long-term environmental compliance with environmental laws and regulations; the manager can ensure that the necessary systems are established or actions taken to gather complete and accurate information for permit application requirements; and where authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

   b. In the case of a partnership, by a general partner.
   c. In the case of sole proprietorship, by the proprietor.
   d. In the case of a municipal, state, or other public facility, by either a principal executive officer or ranking elected official.

   Applications for permits for domestic wastewater facilities that are either owned or operated by, or under contract to, a public entity shall be submitted by the public entity.

2. All reports required by this permit and other information requested by Ecology must be signed by a person described above or by a duly authorized representative of that person. A person is a duly authorized representative only if:
   a. The authorization is made in writing by a person described above and submitted to Ecology.
   b. The authorization specifies either an individual or a position having responsibility for the overall operation of the regulated facility, such as the position of plant manager, superintendent, position of equivalent responsibility, or an individual or position having overall responsibility for environmental matters. (A duly authorized representative may thus be either a named individual or any individual occupying a named position.)

3. Changes to authorization. If an authorization under paragraph G1.2, above, is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, a new authorization satisfying the requirements of paragraph G1.2, above, must be submitted to Ecology prior to or together with any reports, information, or applications to be signed by an authorized representative.

4. Certification. Any person signing a document under this section must make the following certification:

   "I certify under penalty of law, that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

G2. Right of inspection and entry

The Permittee must allow an authorized representative of Ecology, upon the presentation of credentials and such other documents as may be required by law:

1. To enter upon the premises where a discharge is located or where any records must be kept under the terms and conditions of this permit.
2. To have access to and copy, at reasonable times and at reasonable cost, any records required to be kept under the terms and conditions of this permit.
3. To inspect, at reasonable times, any facilities, equipment (including monitoring and control equipment), practices, methods, or operations regulated or required under this permit.
4. To sample or monitor, at reasonable times, any substances or parameters at any location for purposes of assuring permit compliance or as otherwise authorized by the Clean Water Act.

G3. Permit actions

This permit may be modified, revoked and reissued, or terminated either at the request of any interested person (including the Permittee) or upon Ecology's initiative. However, the permit may only be modified, revoked and reissued, or terminated for the reasons specified in 40 CFR 122.62, 40 CFR 122.64 or WAC 173-220-150 according to the procedures of 40 CFR 124.5.

1. The following are causes for terminating this permit during its term, or for denying a permit renewal application:
   a. Violation of any permit term or condition.
   b. Obtaining a permit by misrepresentation or failure to disclose all relevant facts.
   c. A material change in quantity or type of waste disposal.
   d. A determination that the permitted activity endangers human health or the environment, or contributes to water quality standards violations and can only be regulated to acceptable levels by permit modification or termination.

e. A change in any condition that requires either a temporary or permanent reduction, or elimination of any discharge or biosolids use or disposal practice controlled by the permit.

f. Nonpayment of fees assessed pursuant to RCW 90.48.465.

g. Failure or refusal of the Permittee to allow entry as required in RCW 90.48.090.

2. The following are causes for modification but not revocation and reissuance except when the Permittee requests or agrees:

a. A material change in the condition of the waters of the state.

b. New information not available at the time of permit issuance that would have justified the application of different permit conditions.

c. Material and substantial alterations or additions to the permitted facility or activities which occurred after this permit issuance.

d. Promulgation of new or amended standards or regulations having a direct bearing upon permit conditions, or requiring permit revision.

e. The Permittee has requested a modification based on other rationale meeting the criteria of 40 CFR Part 122.62.

f. Ecology has determined that good cause exists for modification of a compliance schedule, and the modification will not violate statutory deadlines.

g. Incorporation of an approved local pretreatment program into a municipality's permit.

3. The following are causes for modification or alternatively revocation and reissuance:

a. When cause exists for termination for reasons listed in 1.a through 1.g of this section, and Ecology determines that modification or revocation and reissuance is appropriate.

b. When Ecology has received notification of a proposed transfer of the permit. A permit may also be modified to reflect a transfer after the effective date of an automatic transfer (General Condition G7) but will not be revoked and reissued after the effective date of the transfer except upon the request of the new Permittee.

G4. Reporting planned changes

The Permittee must, as soon as possible, but no later than one hundred eighty (180) days prior to the proposed changes, give notice to Ecology of planned physical alterations or additions to the permitted facility, production increases, or process modification which will result in:

1. The permitted facility being determined to be a new source pursuant to 40 CFR 122.29(b).
2. A significant change in the nature or an increase in quantity of pollutants discharged.

3. A significant change in the Permittee's biosolids use or disposal practices. Following such notice, and the submittal of a new application or supplement to the existing application, along with required engineering plans and reports, this permit may be modified, or revoked and reissued pursuant to 40 CFR 122.62(a) to specify and limit any pollutants not previously limited. Until such modification is effective, any new or increased discharge in excess of permit limits or not specifically authorized by this permit constitutes a violation.

G5. Plan review required

Prior to constructing or modifying any wastewater control facilities, an engineering report and detailed plans and specifications must be submitted to Ecology for approval in accordance with chapter 173-240 WAC. Engineering reports, plans, and specifications must be submitted at least one hundred eighty (180) days prior to the planned start of construction unless a shorter time is approved by Ecology. Facilities must be constructed and operated in accordance with the approved plans.

G6. Compliance with other laws and statutes

Nothing in this permit excuses the Permittee from compliance with any applicable federal, state, or local statutes, ordinances, or regulations.

G7. Transfer of this permit

In the event of any change in control or ownership of facilities from which the authorized discharge emanate, the Permittee must notify the succeeding owner or controller of the existence of this permit by letter, a copy of which must be forwarded to Ecology.

1. Transfers by Modification

   Except as provided in paragraph (2) below, this permit may be transferred by the Permittee to a new owner or operator only if this permit has been modified or revoked and reissued under 40 CFR 122.62(b)(2), or a minor modification made under 40 CFR 122.63(d), to identify the new Permittee and incorporate such other requirements as may be necessary under the Clean Water Act.

2. Automatic Transfers

   This permit may be automatically transferred to a new Permittee if:

   a. The Permittee notifies Ecology at least thirty (30) days in advance of the proposed transfer date.

   b. The notice includes a written agreement between the existing and new Permittees containing a specific date transfer of permit responsibility, coverage, and liability between them.

   c. Ecology does not notify the existing Permittee and the proposed new Permittee of its intent to modify or revoke and reissue this permit. A modification under this subparagraph may also be minor modification under 40 CFR 122.63. If this notice is not received, the transfer is effective on the date specified in the written agreement.

G8. Reduced production for compliance

The Permittee, in order to maintain compliance with its permit, must control production and/or all discharges upon reduction, loss, failure, or bypass of the treatment facility until the facility is restored or an alternative method of treatment is provided. This requirement applies in the situation where, among other things, the primary source of power of the treatment facility is reduced, lost, or fails.

G9. Removed substances

Collected screenings, grit, solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters must not be resuspended or reintroduced to the final effluent stream for discharge to state waters.

G10. Duty to provide information

The Permittee must submit to Ecology, within a reasonable time, all information which Ecology may request to determine whether cause exists for modifying, revoking and reissuing, or terminating this permit or to determine compliance with this permit. The Permittee must also submit to Ecology upon request, copies of records required to be kept by this permit.

G11. Other requirements of 40 CFR

All other requirements of 40 CFR 122.41 and 122.42 are incorporated in this permit by reference.

G12. Additional monitoring

Ecology may establish specific monitoring requirements in addition to those contained in this permit by administrative order or permit modification.

G13. Payment of fees

The Permittee must submit payment of fees associated with this permit as assessed by Ecology.

G14. Penalties for violating permit conditions

Any person who is found guilty of willfully violating the terms and conditions of this permit is deemed guilty of a crime, and upon conviction thereof shall be punished by a fine of up to ten thousand dollars ($10,000) and costs of prosecution, or by imprisonment in the discretion of the court. Each day upon which a willful violation occurs may be deemed a separate and additional violation.

Any person who violates the terms and conditions of a waste discharge permit may incur, in addition to any other penalty as provided by law, a civil penalty in the amount of up to ten thousand dollars ($10,000) for every such violation. Each and every such violation is a separate and distinct offense, and in case of a continuing violation, every day's continuance is deemed to be a separate and distinct violation.

G15. Upset

Definition – "Upset" means an exceptional incident in which there is unintentional and temporary noncompliance with technology-based permit effluent limits because of factors beyond the reasonable control of the Permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

An upset constitutes an affirmative defense to an action brought for noncompliance with such technology-based permit effluent limits if the requirements of the following paragraph are met.

A Permittee who wishes to establish the affirmative defense of upset must demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:

1. An upset occurred and that the Permittee can identify the cause(s) of the upset.
2. The permitted facility was being properly operated at the time of the upset.
3. The Permittee submitted notice of the upset as required in Special Condition S3.E.
4. The Permittee complied with any remedial measures required under S3.E of this permit.

In any enforcement action the Permittee seeking to establish the occurrence of an upset has the burden of proof.

G16. Property rights

This permit does not convey any property rights of any sort, or any exclusive privilege.

G17. Duty to comply

The Permittee must comply with all conditions of this permit. Any permit noncompliance constitutes a violation of the Clean Water Act and is grounds for enforcement action; for permit termination, revocation and reissuance, or modification; or denial of a permit renewal application.

G18. Toxic pollutants

The Permittee must comply with effluent standards or prohibitions established under Section 307(a) of the Clean Water Act for toxic pollutants within the time provided in the regulations that establish those standards or prohibitions, even if this permit has not yet been modified to incorporate the requirement.

G19. Penalties for tampering

The Clean Water Act provides that any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than two (2) years per violation, or by both. If a conviction of a person is for a violation committed after a first conviction of such person under this condition, punishment shall be a fine of not more than $20,000 per day of violation, or by imprisonment of not more than four (4) years, or by both.

G20. Compliance schedules

Reports of compliance or noncompliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of this permit must be submitted no later than fourteen (14) days following each schedule date.

G21. Service agreement review

The Permittee must submit to Ecology any proposed service agreements and proposed revisions or updates to existing agreements for the operation of any wastewater treatment facility covered by this permit. The review is to ensure consistency with chapters 90.46 and 90.48 RCW as required by RCW 70.150.040(9). In the event that Ecology does not comment within a thirty-day (30) period, the Permittee may assume consistency and proceed with the service agreement or the revised/updated service agreement.

Appendix A

LIST OF POLLUTANTS WITH ANALYTICAL METHODS, DETECTION LIMITS AND QUANTITATION LEVELS

The Permittee must use the specified analytical methods, detection limits (DLs) and quantitation levels (QLs) in the following table for permit and application required monitoring unless:

- Another permit condition specifies other methods, detection levels, or quantitation levels.
- The method used produces measurable results in the sample and EPA has listed it as an EPA-approved method in 40 CFR Part 136, or EPA has granted the laboratory written permission to use the method.
- The Permittee knows that an alternate, less sensitive method (higher DL and QL) from those listed below is sufficient to produce measurable results in their effluent.
- If the Permittee is unable to obtain the required DL and QL due to matrix effects (such as for treatment plant influent or CSO effluent), the Permittee must strive to achieve to lowest possible DL and QL and report the DL and QL in the required report.

If the Permittee uses an alternative method, not specified in the permit and as allowed above, it must report the test method, DL, and QL on the discharge monitoring report or in the required report.

All pollutants that have numeric limits in Section S1 of this permit must be analyzed with the methods specified below. When the permit requires the Permittee to measure the base neutral compounds in the list of priority pollutants, it must measure all of the base neutral pollutants listed in the table below. The list includes EPA required base neutral priority pollutants and several additional polynuclear aromatic hydrocarbons (PAHs). The Water Quality Program added several PAHs to the list of base neutrals below from Ecology's Persistent Bioaccumulative Toxics (PBT) List. It only added those PBT parameters of interest to Appendix A that did not increase the overall cost of analysis unreasonably.

Ecology added this appendix to the permit in order to reduce the number of analytical "non-detects" in permit-required monitoring and to measure effluent concentrations near or below criteria values where possible at a reasonable cost.

CONVENTIONAL PARAMETERS

Pollutant & CAS No. ***(if available)***	**Recommended Analytical Protocol**	**Detection (DL)[1], µg/L unless specified**	**Quantitation Level (QL)[2], µg/L unless specified**
Biochemical Oxygen Demand	SM5210-B		2 mg/L
Total Suspended Solids	SM2540-D		5 mg/L
Total Ammonia (as N)	SM4500-NH3-B and C/D/E/G/H Kerouel & Aminot 1997		0.3 mg/L
Dissolved oxygen	SM4500-OC/OG		0.2 mg/L
Temperature (max. 7-day avg.)	Analog recorder or use micro-recording devices known as thermistors		0.2º C
pH	SM4500-H^+ B	N/A	N/A

NONCONVENTIONAL PARAMETERS

Pollutant & CAS No. (if available)	**Recommended Analytical Protocol**	**Detection (DL)[1], µg/L unless specified**	**Quantitation Level (QL)[2], µg/L unless specified**
Total Alkalinity	SM2320-B		5.0 mg/L as CaCO3
Chlorine, Total Residual	SM4500 Cl G 4500 Cl D/E, Hach 8370		50.0
Fecal Coliform	SM 9221E,9222 B, D	N/A	Specified in method - sample aliquot dependent
Total Coliform	SM 9221B, 9222B,9223B	N/A	Specified in method - sample aliquot dependent
Nitrate + Nitrite Nitrogen (as N)	SM4500-NO3- E/F/H		200
Nitrogen, Total Kjeldahl (as N)	SM4500-N_{org}B/C and SM4500NH_3-B/C/D/EF/G/H EPA 351.2		500
Nitrogen, Total (as N)	SM4500-N-C	50	100
Soluble Reactive Phosphorus (as P)	SM4500- PE/PF	100	100
Phosphorus, Total (as P)	SM 4500 PB followed by SM4500-PE/PF	100	300

Exhibit B

Pollutant & CAS No. (if available)	Recommended Analytical Protocol	Detection (DL)[1], µg/L unless specified	Quantitation Level (QL)[2], µg/L unless specified
Oil and Grease (HEM)	1664 A or B	1,400	5,000
Salinity	SM2520-B		3 practical salinity units or scale (PSU or PSS)
Settleable Solids	SM2540 -F		Sample and limit dependent
Sulfate (as mg/L SO_4)	SM4110-B, 4500-SO4 E		7.1 mg/L
Sulfide (as mg/L S)	SM4500-S^2F/D/E/G		200
Sulfite (as mg/L SO_3)	SM4500-SO3B		2000
Total dissolved solids	SM2540 C		98 mg/L
Total Hardness	SM2340B C, 200.7, 200.8		200 as $CaCO_3$
Aluminum, Total (7429-90-5)	200.8	2.0	10
Barium Total (7440-39-3)	200.8	0.5	2.0
BTEX (benzene +toluene + ethylbenzene + m,o,p xylenes)	EPA SW 846 8021/8260	1	2
Boron Total (7440-42-8)	200.8	2.0	10.0
Cobalt, Total (7440-48-4)	200.8	0.05	0.25
Iron, Total (7439-89-6)	200.7, 200.8	12.5	50
Magnesium, Total (7439-95-4)	200.7, 200.8	10	50
Molybdenum, Total (7439-98-7)	200.8	0.1	0.5
Manganese, Total (7439-96-5)	200.8	0.1	0.5
NWTPH Dx [4]	Ecology NWTPH Dx	250	250
NWTPH Gx [5]	Ecology NWTPH Gx	250	250
Tin, Total (7440-31-5)	200.8	0.3	1.5
Titanium, Total (7440-32-6)	200.8	0.5	2.5

Pollutant & CAS No. (if available)	Recommended Analytical Protocol	Detection (DL)[1], µg/L unless specified	Quantitation Level (QL)[2], µg/L unless specified
METALS, CYANIDE & TOTAL PHENOLS			
Antimony, Total (7440-36-0)	200.8	0.3	1.0
Arsenic, Total (7440-38-2)	200.8	0.1	0.5
Beryllium, Total (7440-41-7)	200.8	0.1	0.5
Cadmium, Total (7440-43-9)	200.8	0.05	0.25
Chromium (hex) dissolved (18540-29-9)	SM3500-Cr B	5	10
Chromium, Total (7440-47-3)	200.8	0.2	1.0
Copper, Total (7440-50-8)	200.8	0.4	2.0
Lead, Total (7439-92-1)	200.8	0.1	0.5
Mercury, Total (7439-97-6)	1631E	0.0002	0.0005
Nickel, Total (7440-02-0)	200.8	0.1	0.5
Selenium, Total (7782-49-2)	200.8	1.0	1.0
Silver, Total (7440-22-4)	200.8	0.04	0.2
Thallium, Total (7440-28-0)	200.8	0.09	0.36
Zinc, Total (7440-66-6)	200.8	0.5	2.5
Cyanide, Total (57-12-5)	335.4, SM4500-CN-C,E	5	10
Cyanide, Weak Acid Dissociable	SM4500-CN I	5	10
Cyanide, Free Amenable to Chlorination (Available Cyanide)	SM4500-CN G	5	10
Phenols, Total	EPA 420.1		50
ACID COMPOUNDS			
2-Chlorophenol (95-57-8)	625	1.0	2.0
2,4-Dichlorophenol (120-83-2)	625	0.5	1.0
2,4-Dimethylphenol (105-67-9)	625	0.5	1.0
4,6-dinitro-o-cresol (534-52-1) (2-methyl-4,6,-dinitrophenol)	625/1625B	2.0	4.0
2,4 dinitrophenol (51-28-5)	625	1.5	3.0
2-Nitrophenol (88-75-5)	625	0.5	1.0
4-nitrophenol (100-02-7)	625	1.0	2.0
Parachlorometa cresol (59-50-7) (4-chloro-3-methylphenol)	625	1.0	2.0
Pentachlorophenol (87-86-5)	625	0.5	1.0

Pollutant & CAS No. (if available)	Recommended Analytical Protocol	Detection (DL)[1], µg/L unless specified	Quantitation Level (QL)[2], µg/L unless specified
Phenol (108-95-2)	625	2.0	4.0
2,4,6-Trichlorophenol (88-06-2)	625	2.0	4.0
VOLATILE COMPOUNDS			
Acrolein (107-02-8)	624	5	10
Acrylonitrile (107-13-1)	624	1.0	2.0
Benzene (71-43-2)	624	1.0	2.0
Bromoform (75-25-2)	624	1.0	2.0
Carbon tetrachloride (56-23-5)	624/601 or SM6230B	1.0	2.0
Chlorobenzene (108-90-7)	624	1.0	2.0
Chloroethane (75-00-3)	624/601	1.0	2.0
2-Chloroethylvinyl Ether (110-75-8)	624	1.0	2.0
Chloroform (67-66-3)	624 or SM6210B	1.0	2.0
Dibromochloromethane (124-48-1)	624	1.0	2.0
1,2-Dichlorobenzene (95-50-1)	624	1.9	7.6
1,3-Dichlorobenzene (541-73-1)	624	1.9	7.6
1,4-Dichlorobenzene (106-46-7)	624	4.4	17.6
Dichlorobromomethane (75-27-4)	624	1.0	2.0
1,1-Dichloroethane (75-34-3)	624	1.0	2.0
1,2-Dichloroethane (107-06-2)	624	1.0	2.0
1,1-Dichloroethylene (75-35-4)	624	1.0	2.0
1,2-Dichloropropane (78-87-5)	624	1.0	2.0
1,3-dichloropropene (mixed isomers) (1,2-dichloropropylene) (542-75-6) [6]	624	1.0	2.0
Ethylbenzene (100-41-4)	624	1.0	2.0
Methyl bromide (74-83-9) (Bromomethane)	624/601	5.0	10.0
Methyl chloride (74-87-3) (Chloromethane)	624	1.0	2.0
Methylene chloride (75-09-2)	624	5.0	10.0
1,1,2,2-Tetrachloroethane (79-34-5)	624	1.9	2.0
Tetrachloroethylene (127-18-4)	624	1.0	2.0
Toluene (108-88-3)	624	1.0	2.0
1,2-Trans-Dichloroethylene (156-60-5) (Ethylene dichloride)	624	1.0	2.0
1,1,1-Trichloroethane (71-55-6)	624	1.0	2.0
1,1,2-Trichloroethane (79-00-5)	624	1.0	2.0
Trichloroethylene (79-01-6)	624	1.0	2.0
Vinyl chloride (75-01-4)	624/SM6200B	1.0	2.0
BASE/NEUTRAL COMPOUNDS (compounds in bold are Ecology PBTs)			
Acenaphthene (83-32-9)	625	0.2	0.4
Acenaphthylene (208-96-8)	625	0.3	0.6
Anthracene (120-12-7)	625	0.3	0.6
Benzidine (92-87-5)	625	20	40
Benzyl butyl phthalate (85-68-7)	625	0.3	0.6
Benzo(*a*)anthracene (56-55-3)	625	0.3	0.6
Benzo(b)fluoranthene (3,4-benzofluoranthene) (205-99-2) [7]	610/625	0.8	1.6
Benzo(j)fluoranthene (205-82-3) [7]	625	0.5	1.0
Benzo(k)fluoranthene (11,12-benzofluoranthene) (207-08-9) [7]	610/625	0.8	1.6
Benzo(r,s,t)pentaphene (189-55-9)	625	1.3	5.0
Benzo(*a*)pyrene (50-32-8)	610/625	0.5	1.0
Benzo(*ghi*)Perylene (191-24-2)	610/625	0.5	1.0
Bis(*2-chloroethoxy)*methane (111-91-1)	625	5.3	21.2
Bis(*2-chloroethyl*)ether (111-44-4)	611/625	0.3	1.0
Bis(*2-chloroisopropyl*)ether (39638-32-9)	625	0.5	1.0
Bis(*2-ethylhexyl*)phthalate (117-81-7)	625	0.3	1.0
4-Bromophenyl phenyl ether (101-55-3)	625	0.3	0.5
2-Chloronaphthalene (91-58-7)	625	0.3	0.6
4-Chlorophenyl phenyl ether (7005-72-3)	625	0.3	0.5

Pollutant & CAS No. (if available)	Recommended Analytical Protocol	Detection (DL)[1], µg/L unless specified	Quantitation Level (QL)[2], µg/L unless specified
Chrysene (218-01-9)	610/625	0.3	0.6
Dibenzo (a,h)acridine (226-36-8)	610M/625M	2.5	10.0
Dibenzo (a,j)acridine (224-42-0)	610M/625M	2.5	10.0
Dibenzo(a-*h*)anthracene (53-70-3)(1,2,5,6-dibenzanthracene)	625	0.8	1.6
Dibenzo(a,e)pyrene (192-65-4)	610M/625M	2.5	10.0
Dibenzo(a,h)pyrene (189-64-0)	625M	2.5	10.0
3,3-Dichlorobenzidine (91-94-1)	605/625	2.0	4.0
Diethyl phthalate (84-66-2)	625	1.9	7.6
Dimethyl phthalate (131-11-3)	625	1.6	6.4
Di-n-butyl phthalate (84-74-2)	625	0.5	1.0
2,4-dinitrotoluene (121-14-2)	609/625	1.0	2.0
2,6-dinitrotoluene (606-20-2)	609/625	1.0	2.0
Di-n-octyl phthalate (117-84-0)	625	0.3	0.6
1,2-Diphenylhydrazine (*as Azobenzene*) (122-66-7)	1625B, 625	5.0	20
Fluoranthene (206-44-0)	625	0.3	0.6
Fluorene (86-73-7)	625	0.3	0.6
Hexachlorobenzene (118-74-1)	612/625	0.3	0.6
Hexachlorobutadiene (87-68-3)	625	0.5	1.0
Hexachlorocyclopentadiene (77-47-4)	1625B/625	2.0	4.0
Hexachloroethane (67-72-1)	625	0.5	1.0
Indeno(*1,2,3-cd*)Pyrene (193-39-5)	610/625	0.5	1.0
Isophorone (78-59-1)	625	0.5	1.0
3-Methyl cholanthrene (56-49-5)	625	2.0	8.0
Naphthalene (91-20-3)	625	0.4	0.75
Nitrobenzene (98-95-3)	625	0.5	1.0
N-Nitrosodimethylamine (62-75-9)	607/625	2.0	4.0
N-Nitrosodi-n-propylamine (621-64-7)	607/625	0.5	1.0
N-Nitrosodiphenylamine (86-30-6)	625	1.0	2.0
Perylene (198-55-0)	625	1.9	7.6
Phenanthrene (85-01-8)	625	0.3	0.6
Pyrene (129-00-0)	625	0.3	0.6
1,2,4-Trichlorobenzene (120-82-1)	625	0.3	0.6
PCBs			
PCB-1242 [8]	608	0.25	0.5
PCB-1254	608	0.25	0.5
PCB-1221	608	0.25	0.5
PCB-1232	608	0.25	0.5
PCB-1248	608	0.25	0.5
PCB-1260	608	0.13	0.5
PCB-1016 [8]	608	0.13	0.5

1. Detection level (DL) or detection limit means the minimum concentration of an analyte (substance) that can be measured and reported with a 99% confidence that the analyte concentration is greater than zero as determined by the procedure given in 40 CFR part 136, Appendix B.
2. Quantitation Level (QL) also known as Minimum Level of Quantitation (ML) – TThe smallest detectable concentration of analyte greater than the Detection Limit (DL) where the accuracy (precision & bias) achieves the objectives of the intended purpose. (Report of the Federal Advisory Committee on Detection and Quantitation Approaches and Uses in Clean Water Act Programs Submitted to the US Environmental Protection Agency December 2007).
3. Soluble Biochemical Oxygen Demand method note: First, filter the sample through a Millipore Nylon filter (or equivalent) - pore size of 0.45-0.50 um (prep all filters by filtering 250 ml of laboratory grade deionized water through the filter and discard). Then, analyze sample as per method 5210-B.
4. NWTPH Dx - Northwest Total Petroleum Hydrocarbons Diesel Extended Range – see http://www.ecy.wa.gov/biblio/97602.html
5. NWTPH Gx - Northwest Total Petroleum Hydrocarbons Gasoline Extended Range – see http://www.ecy.wa.gov/biblio/97602.html
6. 1, 3-dichloroproylene (mixed isomers) You may report this parameter as two separate parameters: cis-1, 3-dichlorpropropene (10061-01-5) and trans-1, 3-dichloropropene (10061-02-6).
7. Total Benzofluoranthenes – Because Benzo(b)fluoranthene, Benzo(j)fluoranthene and Benzo(k)fluoranthene co-elute you may report these three isomers as total benzofluoranthenes.
8. PCB 1016 & PCB 1242 – You may report these two PCB compounds as one parameter called PCB 1016/1242.

EXHIBIT C

Issuance Date: December 19, 2014
Effective Date: February 1, 2015
Expiration Date: January 31, 2020

National Pollutant Discharge Elimination System
Waste Discharge Permit No. WA0029181

State of Washington
DEPARTMENT OF ECOLOGY
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

In compliance with the provisions of
The State of Washington Water Pollution Control Law
Chapter 90.48 Revised Code of Washington
and
The Federal Water Pollution Control Act
(The Clean Water Act)
Title 33 United States Code, Section 1342 et seq.

KING COUNTY WASTEWATER TREATMENT DIVISION – WEST POINT WASTEWATER TREATMENT PLANT & COMBINED SEWER OVERFLOW SYSTEM

King Street Center, KSC-NR-0512
201 South Jackson Street
Seattle, WA 98104-3855

is authorized to discharge in accordance with the Special and General Conditions that follow.

Facility Name	West Point Wastewater Treatment Plant (serves combined sewer area)	Alki Storage and CSO Treatment Plant	Carkeek Storage and CSO Treatment Plant	Denny/Elliott West Storage and CSO Treatment Plant	Henderson/MLK Storage and CSO Treatment Plant
Plant Address	1400 Discovery Park Blvd Seattle, WA 98199	3380 Beach Drive SW Seattle, WA 98116-2616	1201 NW Carkeek Park Rd, Seattle, WA 98177-4640	545 Elliott Ave W Seattle, WA 98119	Outlet Regulator 9829 42nd Ave S Seattle, WA 98118
Receiving Water	Puget Sound	Puget Sound	Puget Sound	Elliott Bay	Duwamish Waterway
Plant Type	Secondary, Activated Sludge, Chlorine Disinfection	Satellite CSO Storage and Treatment Plant	Satellite CSO Storage and Treatment Plant	Satellite CSO Storage and Treatment Plant	Satellite CSO Storage and Treatment Plant
Discharge Location:	Lat: 47.661111˚ Long: -122.446389˚	Lat: 47.57025˚ Long: -122.4225˚	Lat: 47.71264˚ Long: -122.38789˚	Lat: 47.61755˚ Long: -122.36186˚	Lat: 47.51194˚ Long: -122.29736˚

Kevin C. Fitzpatrick
Water Quality Section Manager
Northwest Regional Office
Washington State Department of Ecology

Exhibit C

Table of Contents

Summary of Permit Report Submittals

Section	Submittal	Frequency	First Submittal Date
S3.A	Discharge Monitoring Report	Monthly Annually	March 15, 2015 July 31, 2015
S3.F	Reporting Permit Violations	As necessary	
S4.B	Plans for Maintaining Adequate Capacity	As necessary	
S4.D	Notification of New or Altered Sources	As necessary	
S4.E	Wasteload Assessment	1/permit cycle	With permit application
S5.F	Bypass Notification	As necessary	
S5.G	Operations and Maintenance Update	As necessary	
S6.A	Pretreatment Report	1/year	March 31, 2015
S8	Acute Toxicity Effluent Tests (testing in 1st and 3rd quarters of 2017)	2 tests/permit cycle, 1 submittal/permit cycle	With permit application
S9	Chronic Toxicity Effluent Tests (testing in 2nd and 4th quarters of 2017)	2 tests/permit cycle, 1 submittal/permit cycle	With permit application
S10	Wet Weather Operation Reports	As necessary with monthly DMR submittal	
S11.C	CSO Monthly Report	Monthly with monthly DMR submittal	
S11.C	CSO Annual Report	Annually	July 31, 2015
S11.D	CSO Reduction Plan Amendment	1/permit cycle	With permit application
S11.F.d	CSO Post Construction Monitoring Data Report	1/permit cycle	December 1, 2019
S12	Spill Control Plan Update	As necessary	
S13.A	Sediment Sampling & Analysis Plan- West Pt Sediment Data Report - West Pt	1/permit cycle	December 1, 2016 December 1, 2018
S13.B	Sediment Sampling & Analysis Plan- CSO Outfalls Sediment Data Report - CSO Outfalls	1/permit cycle	December 1, 2016 December 1, 2018
S13.C	Sediment Quality at CSO Outfalls Summary Report	1/permit cycle	December 1, 2018
S14	Outfall Evaluation Reports – West Point and CSO TPs	1/permit cycle	With permit application
S15	Elliott West Copper Reduction Assessment	1/permit cycle	November 1, 2018
S16	Elliott West Settleable Solids Removal Assessment	1/permit cycle	November 1, 2018
S17	Application for Permit Renewal	1/permit cycle	January 31, 2019
G1	Notice of Change in Authorization	As necessary	
G4	Reporting Planned Changes	As necessary	
G5	Engineering Report for Construction or Modification Activities	As necessary	
G13	Payment of Fees	As assessed	

Special Conditions

S1. Discharge limits

All discharges and activities authorized by this permit must comply with the terms and conditions of this permit. The discharge of any of the following pollutants more frequently than, or at a level in excess of, that identified and authorized by this permit violates the terms and conditions of this permit.

S1.A. Effluent limits for Outfall 001 - West Point wastewater treatment plant

Beginning on the effective date of this permit and lasting through the expiration date, the Permittee may discharge treated municipal wastewater at the permitted locations subject to compliance with the following limits:

Effluent Limits: Outfall #001 - West Point WWTP Latitude: 47.661111˚ Longitude: -122.446389˚		
Parameter	**Average Monthly [a]**	**Average Weekly [b]**
Carbonaceous Biochemical Oxygen Demand (5-day)	25 milligrams/liter (mg/L) 44,800 pounds/day (lbs/day) May–Oct: 85% removal of influent $CBOD_5$ Nov–April: 80% removal of influent $CBOD_5$	40 mg/L 71,700 lbs/day
Total Suspended Solids	30 mg/L, 53,800 lbs/day May–Oct: 85% removal of influent TSS Nov–April: 80% removal of influent TSS	45 mg/L 80,700 lbs/day
	Monthly Geometric Mean	**Weekly Geometric Mean**
Fecal Coliform Bacteria [c]	200/100 mL	400/100 mL
	Instantaneous Minimum	**Instantaneous Maximum**
pH [d]	6.0	9.0
	Average Monthly [a]	**Maximum Daily [e]**
Total Residual Chlorine	139 µg/L	364 µg/L

[a] Average monthly effluent limit means the highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month.

[b] Average weekly discharge limit means the highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges measured during that week.

[c] Ecology provides directions to calculate this value in publication No. 04-10-020, *Information Manual for Treatment Plant Operators,* available at: http://www.ecy.wa.gov/pubs/0410020.pdf.

[d] Report the instantaneous maximum and minimum pH monthly. Do not average pH values.

[e] Maximum daily effluent limit means the highest allowable daily discharge. The daily discharge is the average measurement of the pollutant over the day.

S1.B. Effluent limits for the CSO treatment plants

Beginning on the effective date of this permit and lasting through the expiration date, the Permittee may discharge treated combined sewer overflows at the following permitted locations subject to compliance with the following limits. Discharges from these outfalls are prohibited except as a result of precipitation events.

Effluent Limits: Outfall #051 - Alki CSO TP Latitude: 47.57025˚ Longitude: -122.4225˚		
Parameter	**Average Monthly**	**Annual Average [a]**
Total Suspended Solids Removal Efficiency [b]	Report	Equal to or greater than 50% removal of influent TSS
	Monthly Geometric Mean	
Fecal Coliform Bacteria	400/100 mL [c]	
		Annual Average [a]
Settleable Solids		0.3 mL/L/hr
	Instantaneous Minimum	**Instantaneous Maximum**
pH [d]	6.0	9.0
	Maximum Daily [e]	
Total Residual Chlorine	234 µg/L	
	Long-Term Average [f]	
Number of Discharge Events	29 events/year	
Discharge Volume	108 million gallons/year	

[a] Calculate annual averages as the average of all ‘event’ averages. Do not omit one event per year from calculation. Data must be collected and reported on a calendar year basis via WQWebDMR and in the Annual CSO Report.

[b] Calculate the TSS total removal efficiency on a mass balance basis as the percent of solids captured at the CSO treatment facility and then permanently removed at the West Point WWTP. The reported daily average TSS % removal efficiency at the West Point WWTP, corresponding to the event, must be used for calculating the total removal efficiency for the CSO facility. Note: While % TSS removal is reported on a monthly basis, compliance is based on the annual average as reported via WQWebDMR and in the annual CSO report as required in S11.

[c] For the monthly geometric mean, calculate the geometric mean of all samples collected during the month; use a value of 1 for the geomean calc when fecal coliform results are 0. Do not include non-discharge days in the calculation. Ecology provides directions to calculate this value in publication No. 04-10-020, *Information Manual for Treatment Plant Operators,* available at: http://www.ecy.wa.gov/pubs/0410020.pdf.

[d] Report the instantaneous maximum and minimum pH monthly. Do not average pH values.

[e] Maximum daily effluent limit means the highest allowable daily discharge. The daily discharge is the average measurement of the pollutant measured over a calendar day while discharging.

[f] Long-term average will be assessed using data collected over the full permit cycle. Data must be collected and reported for the period of the permit cycle prior to permit renewal, as required in S4.E.

Effluent Limits: Outfall #046 - Carkeek CSO TP Latitude: 47.71264˚ Longitude: -122.38789˚		
Parameter	**Average Monthly**	**Annual Average [a]**
Total Suspended Solids Removal Efficiency [b]	Report	Equal to or greater than 50% removal of influent TSS
	Monthly Geometric Mean	
Fecal Coliform Bacteria [c]	400/100 mL	
		Annual Average [a]
Settleable Solids		0.3 mL/L/hr
	Instantaneous Minimum	**Instantaneous Maximum**
pH [d]	6.0	9.0
	Maximum Daily [e]	
Total Residual Chlorine	490 µg/L	
	Long-Term Average [f]	
Number of Discharge Events	10 events/year	
Discharge Volume	46 million gallons/year	

[a] Calculate annual averages as the average of all 'event' averages. Do not omit one event per year from calculation. Data must be collected and reported on a calendar year basis via WQWebDMR and in the Annual CSO Report.

[b] Calculate the TSS total removal efficiency on a mass balance basis as the percent of solids captured at the CSO treatment facility and then permanently removed at the West Point WWTP. The reported daily average TSS % removal efficiency at the West Point WWTP, corresponding to the event, must be used for calculating the total removal efficiency for the CSO facility. Note: While % TSS removal is reported on a monthly basis, compliance is based on the annual average as reported via WQWebDMR and in the annual CSO report as required in S11.

[c] For the monthly geometric mean, calculate the geometric mean of all samples collected during the month; use a value of 1 for the geomean calc when fecal coliform results are 0. Do not include non-discharge days in the calculation. Ecology provides directions to calculate this value in publication No. 04-10-020, *Information Manual for Treatment Plant Operators,* available at: http://www.ecy.wa.gov/pubs/0410020.pdf.

[d] Report the instantaneous maximum and minimum pH monthly. Do not average pH values.

[e] Maximum daily effluent limit means the highest allowable daily discharge. The daily discharge is the average measurement of the pollutant measured over a calendar day while discharging.

[f] Long-term average will be assessed using data collected over the full permit cycle. Data must be collected and reported for the period of the permit cycle prior to permit renewal, as required in S4.E.

Effluent Limits: Outfall #027B - Elliott West CSO TP Latitude: 47.61755˚ Longitude: -122.361856˚		
Parameter	**Average Monthly**	**Annual Average [a]**
Total Suspended Solids Removal Efficiency [b]	Report	Equal to or greater than 50% removal of influent TSS
	Monthly Geometric Mean	
Fecal Coliform Bacteria [c]	400/100 mL	
		Annual Average [a]
Settleable Solids		0.3 mL/L/hr
	Instantaneous Minimum	**Instantaneous Maximum**
pH [d]	6.0	9.0
	Maximum Daily [e]	
Total Residual Chlorine	109 µg/L	

[a] Calculate annual averages as the average of all ‘event’ averages. Do not omit one event per year from calculation. Data must be collected and reported on a calendar year basis via WQWebDMR and in the Annual CSO Report.

[b] Calculate the TSS total removal efficiency on a mass balance basis as the percent of solids captured at the CSO treatment facility and then permanently removed at the West Point WWTP. The reported daily average TSS % removal efficiency at the West Point WWTP, corresponding to the event, must be used for calculating the total removal efficiency for the CSO facility. Note: While % TSS removal is reported on a monthly basis, compliance is based on the annual average as reported via WQWebDMR and in the annual CSO report as required in S11.

[c] For the monthly geometric mean, calculate the geometric mean of all samples collected during the month; use a value of 1 for the geomean calc when fecal coliform results are 0. Do not include non-discharge days in the calculation. Ecology provides directions to calculate this value in publication No. 04-10-020, *Information Manual for Treatment Plant Operators,* available at: http://www.ecy.wa.gov/pubs/0410020.pdf.

[d] Report the instantaneous maximum and minimum pH monthly. Do not average pH values.

[e] Maximum daily effluent limit means the highest allowable daily discharge. The daily discharge is the average measurement of the pollutant measured over a calendar day while discharging.

Effluent Limits: Outfall #044 - Henderson/MLK CSO TP Latitude: 47.51194˚ Longitude: -122.29736˚		
Parameter	**Average Monthly**	**Annual Average [a]**
Total Suspended Solids Removal Efficiency [b]	Report	Equal to or greater than 50% removal of influent TSS
	Monthly Geometric Mean	
Fecal Coliform Bacteria [c]	400/100 mL	
		Annual Average [a]
Settleable Solids		0.3 mL/L/hr
	Instantaneous Minimum	**Instantaneous Maximum**
pH [d]	6.0	9.0
	Maximum Daily [e]	
Total Residual Chlorine	39 µg/L	

[a] Calculate annual averages as the average of all 'event' averages. Do not omit one event per year from calculation. Data must be collected and reported on a calendar year basis via WQWebDMR and in the Annual CSO Report.

[b] Calculate the TSS total removal efficiency on a mass balance basis as the percent of solids captured at the CSO treatment facility and then permanently removed at the West Point WWTP. The reported daily average TSS % removal efficiency at the West Point WWTP, corresponding to the event, must be used for calculating the total removal efficiency for the CSO facility. Note: While % TSS removal is reported on a monthly basis, compliance is based on the annual average as reported via WQWebDMR and in the annual CSO report as required in S11.

[c] For the monthly geometric mean, calculate the geometric mean of all samples collected during the month; use a value of 1 for the geomean calc when fecal coliform results are 0. Do not include non-discharge days in the calculation. Ecology provides directions to calculate this value in publication No. 04-10-020, *Information Manual for Treatment Plant Operators,* available at: http://www.ecy.wa.gov/pubs/0410020.pdf.

[d] Report the instantaneous maximum and minimum pH monthly. Do not average pH values.

[e] Maximum daily effluent limit means the highest allowable daily discharge. The daily discharge is the average measurement of the pollutant measured over a calendar day while discharging.

S1.C. Mixing zone authorizations

Table 1 summarizes the mixing boundaries and dilution factors for the West Point WWTP and CSO treatment plant outfalls.

Table 1. Dilution zone sizes and dilution factors for permitted outfalls

Outfall	Mixing Zone Radius (feet) [a]		Dilution Factors			
	Chronic	**Acute**	**Aquatic Life Chronic**	**Aquatic Life Acute**	**Human Health: Carcinogen**	**Human Health: Non-Carcinogen**
West Point WWTP	430	43	188	28	324	324
Alki CSO [b]	343	34	99	20		
Carkeek CSO [b]	395	39.5	104	75		
Elliott West CSO [b]	260	26	9.7	8.4		
Henderson/MLK CSO [b]	312 [c]	31.2 [c]	10.3	1.9		

[a] As measured from each port.

[b] Mixing zone dilution modeling is more accurate for continuous discharges. The resultant dilution factor that is achieved in the mixing zone of an intermittent discharge such as this is an approximation that is based on reasonable assumptions about the flow characteristics of the discharge and conditions of the receiving water.

[c] Since this is a river discharge, these dimensions represent distance downstream of outfall instead of radius.

S2. Monitoring requirements

S2.A. Monitoring schedules

The Permittee must monitor in accordance with the schedules in the following tables and the requirements specified in Appendix A or any corresponding *Sampling Analysis Plan/Quality Assurance Project Plan (SAP/QAPP)* documents. Alternative methods from 40 CFR Part 136 are acceptable only for those parameters without limits and if the DL and QL are equivalent to those specified in Appendix A, any corresponding SAP/QAPP documents, or sufficient to produce a measurable quantity.

Table 2. Monitoring Schedule – West Point WWTP (001)

Parameter	Units	Minimum Frequency	Sample Type
(1) Wastewater Influent [a]			
BOD_5	mg/L	1/week	24-hr Composite [b]
	lbs/day [c]	1/week	Calculation
$CBOD_5$	mg/L	1/day	24-hr Composite
	lbs/day [c]	1/day	Calculation
TSS	mg/L	1/day	24-hr Composite
	lbs/day	1/day	Calculation
(2) Final Wastewater Effluent [d]			
Flow	MGD	Continuous [e]	Meter
$CBOD_5$ [f]	mg/L	1/day	24-hr Composite
	lbs/day [c]	1/day	Calculation
	% removal [g]	1/month	Calculation
TSS	mg/L	1/day	24-hr Composite
	lbs/day [c]	1/day	Calculation
	% removal [g]	1/month	Calculation
Chlorine (after dechlorination)	µg/L	Continuous [e]	Meter
Fecal Coliform	# /100 ml	1/day	Grab [h]
pH	Standard Units	Continuous [e]	Meter
(3) Effluent Characterization – Final Wastewater Effluent			
Total Ammonia	mg/L N	1/month	24-hr Composite
	lbs/day	1/month	Calculation
Nitrate + Nitrite Nitrogen	mg/L N	1/month	24-hr Composite
Total Kjeldahl Nitrogen	mg/L N	1/month	24-hr Composite
Total Phosphorus	mg/L P	1/month	24-hr Composite
Soluble Reactive Phosphorus	mg/L P	1/month	24-hr Composite
(4) Whole Effluent Toxicity Testing – Final Wastewater Effluent - As specified in Permit Conditions S8 & S9.			
Acute Toxicity Testing		2/permit cycle	24-hr Composite
Chronic Toxicity Testing		2/permit cycle	24-hr Composite
(5) Pretreatment - As specified in Permit Condition S6.			
(6) CSO Monitoring - As specified in Permit Condition S11.			
(7) Permit Application Requirements – Final Wastewater Effluent [j]			
Dissolved Oxygen	mg/L	1/year in Aug	Grab
Oil and Grease (HEM)	mg/L	1/year in Aug	Grab
Total Dissolved Solids	mg/L	1/year in Aug	24-hr Composite
Total Hardness	mg/L	1/year in Aug	24-hr Composite
Alkalinity	mg/L as $CaCO_3$	1/year in Aug	Grab

Table 2. Monitoring Schedule – West Point WWTP (001)

Parameter	Units	Minimum Frequency	Sample Type
Temperature	˚C	1/year in Aug	Grab
Cyanide	µg/L	2/year [i, j]	Grab
Total Phenolic Compounds	µg/L	2/year [i, j]	Grab
Priority Pollutants (PP) – Total Metals	µg/L (ng for mercury)	2/year [i, j]	24-hr Composite; Grab for mercury
PP – Volatile Organic Compounds	µg/L	2/year [i, j]	Grab
PP – Acid-extractable Compounds	µg/L	2/year [i, j]	24-hr Composite
PP – Base-neutral Compounds	µg/L	2/year [i, j]	24-hr Composite
(8) Sediment Study - As specified in Permit Condition S13.A.			

[a] Wastewater Influent means the raw sewage flow from the collection system into the treatment facility. Sample the wastewater entering the headworks of the plant excluding any side-stream returns from inside the plant.

[b] 24-hour composite means a series of individual samples collected over a 24-hour period in a single container and analyzed as one sample.

[c] lbs/day = Concentration (in mg/L) x Flow (in MGD) x Conversion Factor (8.34) = lbs/day. Calculate using the average flow measured during the sample collection period.

[d] Final Wastewater Effluent means wastewater which is exiting, or has exited, the last treatment process or operation.

[e] "Continuous" means uninterrupted except for brief lengths of time for calibration, power failure, or unanticipated equipment repair or maintenance. The Permittee must sample every six hours when continuous monitoring is not possible.

[f] Effluent samples for $CBOD_5$ analysis may be taken before or after the disinfection process. If taken after, dechlorinate and reseed the sample.

[g] % removal = $\frac{\text{Influent monthly average concentration (mg/L)} - \text{Effluent monthly average concentration (mg/L)}}{\text{Influent monthly average concentration (mg/L)}} \times 100$

[h] "Grab" means an individual sample collected over a 15-minute, or less, period.

[i] One of the two annual sampling events must occur when flows are being diverted around the secondary process (i.e. instantaneous effluent flow rate is greater than 300 MGD) or when the average daily precipitation is equal to or greater than 0.25 inches.

[j] The Permittee must record and report the wastewater treatment plant flow discharged on the day it collects the sample for Appendix A pollutant testing with the discharge monitoring report.

See Appendix A or corresponding SAP/QAPP for the required detection (DL) or quantitation (QL) levels.

Report single analytical values below detection as "less than (detection level)" where (detection level) is the numeric value specified in Appendix A.

Report single analytical values between the detection and quantitation levels with qualifier code of 'j' following the value. If unable to obtain the required DL and QL due to matrix effects, the Permittee must submit a matrix specific MDL and a QL with appropriate laboratory documentation.

Table 3. Monitoring Schedule for all CSO TPs: Alki-051, Carkeek-046, Elliott West-027, Henderson/MLK-044

Parameter	Units	Minimum Frequency	Sample Type
(1) Influent [a]			
Volume	MG	Per Event [b]	Meter/Calculation [c]
BOD_5	mg/L	Per Event	Flow Proportional Composite [d]
TSS	mg/L	Per Event	Flow Proportional Composite
(2) Final Effluent [e]			
Volume	MG	Per Event	Meter/Calculation
BOD_5	mg/L	Per Event	Flow Proportional Composite
TSS	mg/L	Per Event	Flow Proportional Composite
	% removal [f]	1/month	Calculation
Settleable Solids	mL/L/hr	Per Event	Flow Proportional Composite
Total Residual Chlorine	ug/L	Continuous during events [g]	Meter
Fecal Coliform	# /100 ml	Per Event	Grab [h, i]
pH	Std Units	Continuous during events	Meter
Copper, total recoverable [j]	µg/L	Elliott West and Henderson/MLK: Per Event All others: 1/year	Flow Proportional Composite
Cyanide	µg/L	Elliott West: 4/yr	Grab
Dissolved Oxygen	mg/L	Elliott West: Per Event starting in Nov 2016 All others: 1/year	Meter or Grab
Discharge Duration	Hours	Per Event	Meter/Calculation
Storm Duration [k]	Hours	Per Event	Meter/Calculation
Precipitation	Inches	Per Event	Meter/Calculation
(3) Effluent Characterization – Final Effluent			
Total Ammonia	mg/L N	Henderson/MLK: 1st 4 discharge events, then 1/year All others: 1/year	Flow Proportional Composite
Nitrate-Nitrite Nitrogen	mg/L N		Flow Proportional Composite
Total Kjeldahl Nitrogen	mg/L N		Flow Proportional Composite
Total Phosphorus	mg/L P		Flow Proportional Composite
Soluble Reactive Phosphorus	mg/L P		Flow Proportional Composite
Total Alkalinity	mg $CaCO_3$/L		Flow Proportional Composite or Grab
Temperature	°C		Grab
Priority Pollutants (PP)–Total Metals	µg/L		Flow Proportional Composite; Grab for mercury
PP – Volatile Organic Compounds	µg/L		Grab
PP – Acid-extractable Compounds	µg/L		Flow Proportional Composite
PP – Base-neutral Compounds	µg/L		Flow Proportional Composite
Cyanide	µg/L		Grab
Total Phenols	µg/L		Grab
PP – Total PCBs [l]	µg/L	Henderson/MLK only: 1/year	Flow Proportional Composite
(4) Permit Application Requirements – Final Effluent [m]			
Oil and Grease	mg/L	1/year	Grab
Total Dissolved Solids	mg/L	1/year	Flow Proportional Composite

Table 3. Monitoring Schedule for all CSO TPs: Alki-051, Carkeek-046, Elliott West-027, Henderson/MLK-044

Parameter	Units	Minimum Frequency	Sample Type
Total Hardness	mg/L	1/year	Flow Proportional Composite

[a] Influent means the combined raw sewage and stormwater flows from the collection system into the treatment facility. Sample the wastewater entering the treatment plant.

[b] "Per Event" means a unique flow event as defined in the *Permit Writer's Manual*, p. V-30. Ecology defines the minimum inter-event period as 24 hours. A CSO event is considered to have ended only after at least 24 hours has elapsed since the last measured occurrence of an overflow.

[c] "Meter/Calculation" means the total volume of the discharge or amount of precipitation event as estimated by direct measurement or indirectly by calculation (i.e. flow weirs, pressure transducers, tipping bucket). Precipitation must be measured by the nearest precipitation-measuring device as owned and operated by King County and actively monitored during the period of interest.

[d] "Flow proportional composite" means a series of individual samples collected over a flow period in a single container, and analyzed as one sample. The composite sample should represent the entire discharge event.

[e] "Final Effluent" means treated CSO effluent which is discharged to the receiving water, sampled after the dechlorination process. The Permittee may take effluent samples for the BOD_5 analysis before or after the disinfection process. If taken after, dechlorinate and reseed the sample.

[f] The total removal efficiency for TSS is to be calculated on a mass balance basis as the percent of solids captured at the CSO Treatment Plant and then permanently removed at the West Point Treatment Plant based on the estimated removal efficiency at West Point.

[g] "Continuous" means uninterrupted except for brief lengths of time for calibration, power failure, or unanticipated equipment repair or maintenance. The Permittee must sample every hour when continuous monitoring is not possible.

[h] "Grab" means an individual sample collected over a 15-minute, or less, period.

[i] Fecal grab samples must be taken at specific time intervals after the discharge begins to the receiving water as follows:

1. 1 sample within first 3 hours.
2. 1 sample between 3-8 hours.
3. 1 sample between 20-24 hours.
4. If discharge extends beyond 24 hours, at a minimum take 1 sample each day until the discharge ends.

If more than 1 sample is collected within the time intervals listed above, report the average of the fecal values for that time interval. Report one fecal value for each interval (as appropriate for the discharge duration) and calculate the monthly geomean using all of the reported fecal values for the month.
Chlorine and pH analyzer readings must be logged when fecal coliform samples are taken. Each individual fecal coliform sample should be dechlorinated.

[j] Copper sampling must be performed with laboratory-verified sampling procedures.

[k] Storm duration is the total amount of time precipitation occurred that contributed to a discharge event; it is determined on a case-by-case basis.

[l] PCB monitoring only required for the Henderson/MLK CSO treatment plant. Total PCBs must be analyzed using method 1668 with a detection limit of 0.0001 µg/L or lower.

[m] The Permittee must record and report the wastewater treatment plant flow discharged on the day it collects the sample for Appendix A pollutant testing with the discharge monitoring report.

See Appendix A or corresponding SAP/QAPP for the required detection (DL) or quantitation (QL) levels.

Report single analytical values below detection as "less than [detection level]" where [detection level] is the numeric value specified in Appendix A.

Report single analytical values between the detection and quantitation levels with qualifier code of 'j' following the value.

Untreated CSO Outfalls

The Permittee must monitor all discharges from the CSO outfalls listed in Special Condition S11, not including any CSO treatment plants, using the following monitoring schedule. The Permittee must use automatic flow monitoring equipment to collect the information required below, and must calibrate flow monitoring equipment according to requirements in Condition S2.C. A CSO discharge is defined as any untreated CSO which will exit or has exited the CSO outfall.

Table 4. Monitoring Schedule – Untreated CSO Outfalls

Parameter	Units	Minimum Sampling Frequency	Sample Type
Volume Discharged	MG	Per Event [a]	Meter/Calculation [b]
Discharge Duration	Hours	Per Event	Meter/Calculation
Storm Duration [c]	Hours	Per Event	Meter/Calculation
Precipitation	Inches	Per Event	Meter/Calculation
Sediments – As specified in Permit Condition S13.C.			

[a] "Per Event" means a unique flow event as defined in the *Permit Writer's Manual*, p. V-30. Ecology defines the minimum inter-event period as 24 hours. A CSO event is considered to have ended only after at least 24 hours has elapsed since the last measured occurrence of an overflow.

[b] "Meter/Calculation" means the total volume of the discharge or amount of precipitation event as estimated by direct measurement or indirectly by calculation (i.e. flow weirs, pressure transducers, tipping bucket). Precipitation must be measured by the nearest possible precipitation-measuring device and actively monitored during the period of interest.

[c] Storm duration is the total amount of time precipitation occurred that contributed to a discharge event; it is determined on a case-by-case basis.

S2.B. Sampling and analytical procedures

Samples and measurements taken to meet the requirements of this permit must represent the volume and nature of the monitored parameters. The Permittee must conduct representative sampling of any unusual discharge or discharge condition, including bypasses, upsets, and maintenance-related conditions that may affect effluent quality.

Sampling and analytical methods used to meet the monitoring requirements specified in this permit must conform to the latest revision of the *Guidelines Establishing Test Procedures for the Analysis of Pollutants* contained in 40 CFR Part 136 (or as applicable in 40 CFR subchapters N [Parts 400–471] or O [Parts 501-503]) unless otherwise specified in this permit. Ecology may only specify alternative methods for parameters without permit limits and for those parameters without an EPA approved test method in 40 CFR Part 136.

S2.C. Flow measurement, field measurement, and continuous monitoring devices

The Permittee must:

1. Select and use appropriate flow measurement, field measurement, and continuous monitoring devices and methods consistent with accepted scientific practices.

2. Install and maintain these devices to ensure the accuracy of the measurements is consistent with the accepted industry standard and the manufacturer's recommendation for that type of device.
3. Calibrate continuous monitoring instruments consistent with the manufacturer's recommendation.
4. Maintain calibration records for at least three years.

S2.D. Laboratory accreditation

The Permittee must ensure that all monitoring data required by Ecology for permit specified parameters is prepared by a laboratory registered or accredited under the provisions of chapter 173-50 WAC, *Accreditation of Environmental Laboratories*. Flow, temperature, settleable solids, and internal process control parameters are exempt from this requirement. .

S3. Reporting and recording requirements

The Permittee must monitor and report in accordance with the following conditions. Falsification of information submitted to Ecology is a violation of the terms and conditions of this permit.

S3.A. Reporting

The first monitoring period begins on the effective date of the permit. The Permittee must:

1. Summarize, report, and submit monitoring data obtained during each monitoring period on the electronic Discharge Monitoring Report (DMR) form provided by Ecology within the Water Quality Permitting Portal. Include data for each of the parameters tabulated in Special Condition S2 and as required by the form. Report a value for each day sampling occurred (unless specifically exempted in the permit) and for the summary values (when applicable) included on the electronic form.

   To find out more information and to sign up for the Water Quality Permitting Portal go to: http://www.ecy.wa.gov/programs/wq/permits/paris/webdmr.html.
2. Enter the "no discharge" reporting code for an entire DMR, for a specific monitoring point, or for a specific parameter as appropriate, if the Permittee did not discharge wastewater or a specific pollutant during a given monitoring period.
3. Report single analytical values below detection as "less than the detection level (DL)" by entering < followed by the numeric value of the detection level (e.g. < 2.0) on the DMR. If the method used did not meet the minimum DL and quantitation level (QL) identified in the permit, report the actual QL and DL in the comments or in the location provided.
4. Report the test method used for analysis in the comments if the laboratory used an alternative method not specified in the permit and as allowed in Appendix A.

5. Calculate average values and calculated total values (unless otherwise specified in the permit) using:
   a. The reported numeric value for all parameters measured between the agency-required detection value and the agency-required quantitation value.
   b. One-half the detection value (for values reported below detection) if the lab detected the parameter in another sample for the reporting period.
   c. Zero (for values reported below detection) if the lab did not detect the parameter in another sample for the reporting period.
6. Report priority pollutant data on the WQWebDMR form and include sample date, concentration detected, detection limit (DL) (as necessary), laboratory quantitation level (QL) (as necessary), and CAS number. The Permittee must also submit an electronic PDF copy of the laboratory report as an attachment using WQWebDMR. The laboratory report must provide the following information: date sampled, sample location, date of analysis, parameter name, CAS number, analytical method/number, detection limit (DL), laboratory quantitation level (QL), reporting units, and concentration detected. The laboratory report must also include information on the chain of custody, QA/QC results, and documentation of accreditation for the parameter.
7. Submit DMRs for parameters with the monitoring frequencies specified in S2 (monthly, quarterly, annual, etc.) at the reporting schedule identified below. The Permittee must:
   a. Submit **monthly** DMRs by the 15th day of the following month.
   b. Submit **annual** DMRs by July 31st for the previous calendar year. The annual sampling period is the calendar year.

S3.B. Permit submittals and schedules

The Permittee must use the *Water Quality Permitting Portal – Permit Submittals* application to submit all other written permit-required reports by the date specified in the permit.

When another permit condition requires submittal of a report/file that cannot be accepted by the Water Quality Permitting Portal (i.e. video file for outfall inspection), the Permittee must ensure that the report/file is postmarked or received by Ecology no later than the dates specified by this permit. Send these reports/files to Ecology at:

Water Quality Permit Coordinator
Department of Ecology
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

S3.C. Records retention

The Permittee must retain records of all monitoring information for a minimum of three (3) years. Such information must include all calibration and maintenance records and all original recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for this permit. The Permittee must extend this period of retention during the course of any unresolved litigation regarding the discharge of pollutants by the Permittee or when requested by Ecology.

S3.D. Recording of results

For each measurement or sample taken, the Permittee must record the following information:

1. The date, exact place, method, and time of sampling or measurement.
2. The individual who performed the sampling or measurement.
3. The dates the analyses were performed.
4. The individual who performed the analyses.
5. The analytical techniques or methods used and the relevant detection limits.
6. The results of all analyses.

S3.E. Additional monitoring by the Permittee

If the Permittee monitors any pollutant more frequently than required by Special Condition S2 of this permit, then the Permittee must include the results of such monitoring in the calculation and reporting of the data submitted in the Permittee's DMR or annual CSO report, as appropriate. If the Permittee monitors sediment or untreated CSO discharges more frequently than required by this permit, then the Permittee must enter the results of such monitoring into Ecology's EIM database or include the results in the annual CSO report, as appropriate.

S3.F. Reporting permit violations

The Permittee must take the following actions when it violates or is unable to comply with any permit condition:

1. Immediately take action to stop, contain, and cleanup unauthorized discharges or otherwise stop the non-compliance and correct the problem.
2. If applicable, immediately repeat sampling and analysis. Submit the results of any repeat sampling to Ecology within thirty (30) days of sampling.

a. Immediate reporting

The Permittee must *immediately* report to Ecology and the Department of Health, Shellfish Program, and King County Public Health (at the numbers listed below), all:

- Failures of the disinfection systems.
- Collection system overflows other than permitted CSO discharges.

- Plant bypasses discharging to marine surface waters, other than as described in Section S10.
- Any other failures of the sewage system (pipe breaks, etc.)

Additionally, for any sanitary sewer overflow (SSO) that discharges to a municipal separate storm sewer system (MS4), the Permittee must notify the appropriate MS4 owner or operator.

Northwest Regional Office	425-649-7000
Department of Health, Shellfish Program	360-236-3330 (business hours) 360-789-8962 (after business hours)
Public Health of Seattle-King County	206-296-4932

b. *Twenty-four-hour reporting*

The Permittee must report the following occurrences of non-compliance by telephone, to Ecology at the telephone numbers listed above, within 24 hours from the time the Permittee becomes aware of any of the following circumstances:

1. Any non-compliance that may endanger health or the environment, unless previously reported under immediate reporting requirements.
2. Any unanticipated bypass that causes an exceedance of an effluent limit in the permit (See Section S5.F, "Bypass Procedures").
3. Any upset that causes an exceedance of an effluent limit in the permit (See G15, "Upset").
4. Any violation of a maximum daily or instantaneous maximum discharge limit for any of the pollutants in Section S1 of this permit for the West Point outfall 001.
5. Any overflow prior to the treatment works, whether or not such overflow endangers health or the environment or exceeds any effluent limit in the permit.

c. *Report within five days*

The Permittee must also submit a written report within five business days of the time that the Permittee becomes aware of any reportable event under subparts a or b, above. The report must contain:

1. A description of the non-compliance and its cause.
2. The period of non-compliance, including exact dates and times.
3. The estimated time the Permittee expects the non-compliance to continue if not yet corrected.
4. Steps taken or planned to reduce, eliminate, and prevent recurrence of the non-compliance.

5. If the non-compliance involves an overflow prior to the treatment works, an estimate of the quantity (in gallons) of untreated overflow.

d. *Waiver of written reports*

Ecology may waive the written report required in subpart c, above, on a case-by-case basis upon request if the Permittee has submitted a timely oral report.

e. *All other permit violation reporting*

The Permittee must report all permit violations, which do not require immediate or within 24 hours reporting, when it submits monitoring reports for S3.A ("Reporting"). The reports must contain the information listed in subpart c, above. Compliance with these requirements does not relieve the Permittee from responsibility to maintain continuous compliance with the terms and conditions of this permit or the resulting liability for failure to comply.

f. *Report submittal*

The Permittee must submit reports to the address listed in S3.B.

S3.G. Other reporting

a. *Spills of oil or hazardous materials*

The Permittee must report a spill of oil or hazardous materials in accordance with the requirements of RCW 90.56.280 and chapter 173-303-145. You can obtain further instructions at the following website: http://www.ecy.wa.gov/programs/spills/other/reportaspill.htm .

b. *Failure to submit relevant or correct facts*

Where the Permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application, or in any report to Ecology, it must submit such facts or information promptly.

S3.H. Maintaining a copy of this permit

The Permittee must keep a copy of this permit at all treatment facilities and make it available upon request to Ecology inspectors.

S4. Facility loading (West Point WWTP)

S4.A. Design criteria

The flows or waste loads for the permitted West Point WWTP must not exceed the following design criteria:

Maximum Month Design Flow (MMDF)	215 MGD
BOD_5 Influent Loading for Maximum Month	201,000 lbs/day
TSS Influent Loading for Maximum Month	218,000 lbs/day

S4.B. Plans for maintaining adequate capacity

a. Conditions triggering plan submittal

The Permittee must submit a plan and a schedule for continuing to maintain capacity to Ecology when:

1. The actual flow or waste load reaches 85 percent of any one of the design criteria in S4.A for three consecutive months, or
2. The projected plant flow or loading would reach design capacity within five years.

b. Plan and schedule content

The plan and schedule must identify the actions necessary to maintain adequate capacity for the expected population growth and to meet the limits and requirements of the permit. The Permittee must consider the following topics and actions in its plan.

1. Analysis of the present design and proposed process modifications.
2. Reduction or elimination of excessive infiltration and inflow of uncontaminated ground and surface water into the sewer system.
3. Limits on future sewer extensions or connections or additional waste loads.
4. Modification or expansion of facilities.
5. Reduction of industrial or commercial flows or waste loads.

Engineering documents associated with the plan must meet the requirements of WAC 173-240-060, "Engineering Report," and be approved by Ecology prior to any construction.

S4.C. Duty to mitigate

The Permittee must take all reasonable steps to minimize or prevent any discharge, use, or disposal of sludge or biosolids in violation of this permit that has a reasonable likelihood of adversely affecting human health or the environment.

S4.D. Notification of new or altered sources

1. The Permittee must submit written notice to Ecology whenever any new discharge or a substantial change in volume or character of an existing discharge into the wastewater treatment plant is proposed which:
   a. Would interfere with the operation of, or exceed the design capacity of, any portion of the wastewater treatment plant.
   b. Is not part of an approved general sewer plan or approved plans and specifications.
   c. Is subject to pretreatment standards under 40 CFR Part 403 and Section 307(b) of the Clean Water Act.

2. This notice must include an evaluation of the wastewater treatment plant's ability to adequately transport and treat the added flow and/or waste load, the quality and volume of effluent to be discharged to the treatment plant, and the anticipated impact on the Permittee's effluent [40 CFR 122.42(b)].

S4.E. Wasteload assessment

The Permittee must conduct wasteload assessments of the West Point WWTP and each CSO treatment plant and submit a report to Ecology with the next permit application. The Permittee must also submit the report electronically. The report must contain:

1. A description of compliance or non-compliance with the permit effluent limits.
2. A comparison between the existing and design:
    a. Monthly average dry weather and wet weather flows.
    b. Peak flows.
    c. $CBOD_5$ and TSS loadings (West Point only).
    d. 5-year average of annual discharge events and annual discharge volume for the Alki and Carkeek CSO treatment plants.
3. The percent change in the above parameters since the previous report.
4. The present and design population or population equivalent.
5. The projected population growth rate.
6. The estimated date upon which the Permittee expects the wastewater treatment plant to reach design capacity, according to the most restrictive of the parameters above.

S5. Operation and maintenance

The Permittee must at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances), which are installed to achieve compliance with the terms and conditions of this permit. Proper operation and maintenance also includes keeping a daily operation logbook (paper or electronic), adequate laboratory controls, and appropriate quality assurance procedures. This provision of the permit requires the Permittee to operate backup or auxiliary facilities or similar systems only when the operation is necessary to achieve compliance with the conditions of this permit.

S5.A. Certified operator

These permitted facilities must be operated by an operator certified by the state of Washington for at least a Class IV plant. This operator must be in responsible charge of the day-to-day operation of the wastewater treatment facilities. An operator certified for at least a Class III plant must be in charge during all regularly scheduled shifts.

S5.B. *Operation and maintenance program*

The Permittee must:

1. Maintain the operation and maintenance program for the entire sewage system under the ownership and control of KC.
2. Keep maintenance records on all major electrical and mechanical components of the treatment plant, as well as the sewage system and pumping stations. Such records must clearly specify the frequency and type of maintenance recommended by the manufacturer and must show the frequency and type of maintenance performed.
3. Make maintenance records available for inspection at all times.

S5.C. *Short-term reduction*

The Permittee must schedule any facility maintenance, which might require interruption of wastewater treatment and degrade effluent quality, during non-critical water quality periods and carry this maintenance out in a manner approved by Ecology.

If a Permittee contemplates a reduction in the level of treatment that would cause a violation of permit discharge limits on a short-term basis for any reason, and such reduction cannot be avoided, the Permittee must:

1. Give written notification to Ecology, if possible, thirty (30) days prior to such activities.
2. Detail the reasons for, length of time of, and the potential effects of the reduced level of treatment.

This notification does not relieve the Permittee of its obligations under this permit.

S5.D. *Electrical power failure*

The Permittee must ensure that adequate safeguards prevent the discharge of untreated wastes or wastes not treated in accordance with the requirements of this permit during electrical power failure at the treatment plant and/or sewage lift stations. Adequate safeguards include, but are not limited to, alternate power sources, standby generator(s), or retention of inadequately treated wastes.

The Permittee must maintain Reliability Class II (EPA 430-99-74-001) at the wastewater treatment plant. Reliability Class II requires a backup power source sufficient to operate all vital components and critical lighting and ventilation during peak wastewater flow conditions. Vital components used to support the secondary processes (i.e., mechanical aerators or aeration basin air compressors) need not be operable to full levels of treatment, but must be sufficient to maintain the biota.

S5.E. *Prevent connection of inflow*

The Permittee must strictly enforce its sewer ordinances and not allow the connection of inflow (roof drains, foundation drains, etc.) to the sanitary sewer system where under ownership and control of King County.

S5.F. *Bypass procedures*

This permit prohibits a bypass, which is the intentional diversion of waste streams from any portion of a treatment facility. Ecology may take enforcement action against a Permittee for a bypass unless one of the following circumstances (1, 2, or 3) applies.

1. Bypass for essential maintenance without the potential to cause violation of permit limits or conditions.

   This permit authorizes a bypass if it allows for essential maintenance and does not have the potential to cause violations of limits or other conditions of this permit, or adversely impact public health as determined by Ecology prior to the bypass. The Permittee must submit prior notice, if possible, at least ten (10) days before the date of the bypass.

2. Bypass which is unavoidable, unanticipated, and results in non-compliance of this permit.

   This permit authorizes such a bypass only if:

   a. Bypass is unavoidable to prevent loss of life, personal injury, or severe property damage. "Severe property damage" means substantial physical damage to property, damage to the treatment facilities which would cause them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass.

   b. No feasible alternatives to the bypass exist, such as:

      - The use of auxiliary treatment facilities.
      - Retention of untreated wastes.
      - Maintenance during normal periods of equipment downtime, but not if the Permittee should have installed adequate backup equipment in the exercise of reasonable engineering judgment to prevent a bypass.
      - Transport of untreated wastes to another treatment facility or preventative maintenance.

   c. Ecology is properly notified of the bypass as required in Special Condition S3.E of this permit.

3. If bypass is anticipated and has the potential to result in non-compliance of this permit.

   a. The Permittee must notify Ecology at least thirty (30) days before the planned date of bypass. The notice must contain:

      - A description of the bypass and its cause.
      - An analysis of all known alternatives which would eliminate, reduce, or mitigate the need for bypassing.
      - A cost-effectiveness analysis of alternatives including comparative resource damage assessment.

- The minimum and maximum duration of bypass under each alternative.
- A recommendation as to the preferred alternative for conducting the bypass.
- The projected date of bypass initiation.
- A statement of compliance with SEPA.
- A request for modification of water quality standards as provided for in WAC 173-201A-410, if an exceedance of any water quality standard is anticipated.
- Details of the steps taken or planned to reduce, eliminate, and prevent reoccurrence of the bypass.

b. For probable construction bypasses, the Permittee must notify Ecology of the need to bypass as early in the planning process as possible. The Permittee must consider the analysis required above during preparation of the engineering report or facilities plan and plans and specifications and must include these to the extent practical. In cases where the Permittee determines the probable need to bypass early, the Permittee must continue to analyze conditions up to and including the construction period in an effort to minimize or eliminate the bypass.

c. Ecology will consider the following prior to issuing an administrative order for this type of bypass:

- If the bypass is necessary to perform construction or maintenance-related activities essential to meet the requirements of this permit.
- If feasible alternatives to bypass exist, such as the use of auxiliary treatment facilities, retention of untreated wastes, stopping production, maintenance during normal periods of equipment down time, or transport of untreated wastes to another treatment facility.
- If the Permittee planned and scheduled the bypass to minimize adverse effects on the public and the environment.

After consideration of the above and the adverse effects of the proposed bypass and any other relevant factors, Ecology will approve or deny the request. Ecology will give the public an opportunity to comment on bypass incidents of significant duration, to the extent feasible. Ecology will approve a request to bypass by issuing an administrative order under RCW 90.48.120.

S5.G. Operations and maintenance (O&M) manual

a. O&M manual submittal and requirements

The Permittee must:

1. Review the O&M manuals at least annually.

2. Submit to Ecology for review and approval substantial changes or updates to the O&M manuals whenever it incorporates them into the manual. The Permittee must submit an electronic copy (preferably as a PDF).
3. Keep the approved O&M manuals at the permitted facility.
4. Follow the instructions and procedures of these manuals.

b. *O&M manual components*

In addition to the requirements of WAC 173-240-080 (1) through (5), the O&M manuals must include:

- Emergency procedures for cleanup in the event of wastewater system upset or failure.
- A review of system components which if failed could pollute surface water or could impact human health. Provide a procedure for a routine schedule of checking the function of these components.
- Wastewater system maintenance procedures that contribute to the generation of process wastewater.
- Reporting protocols for submitting reports to Ecology to comply with the reporting requirements in the discharge permit.
- Any directions to maintenance staff when cleaning or maintaining other equipment or performing other tasks which are necessary to protect the operation of the wastewater system (for example, defining maximum allowable discharge rate for draining a tank, blocking all floor drains before beginning the overhaul of a stationary engine).
- Treatment plant process control monitoring schedules.

S6. Pretreatment

S6.A. General requirements

1. The Permittee must implement the Industrial Pretreatment Program in accordance with King County Code 28.84.060 as amended by King County Ordinance No. 11963 on January 1, 1996, legal authorities, policies, procedures, and financial provisions described in the Permittee's approved pretreatment program submittal entitled "Industrial Pretreatment Program" and dated April 27, 1981; any approved revisions thereto; and the General Pretreatment Regulations (40 CFR Part 403). At a minimum, the Permittee must undertake the following pretreatment implementation activities:

   a. Enforce categorical pretreatment standards under Section 307(b) and (c) of the Federal Clean Water Act (hereinafter, the Act), prohibited discharge standards as set forth in 40 CFR 403.5, local limits, or state standards, which ever are most stringent or apply at the time of issuance or modification of a local industrial waste discharge permit. Locally derived limits are defined as pretreatment standards under Section 307(d) of the Act and are not limited to categorical industrial facilities.

b. Issue industrial waste discharge permits to all significant industrial users [SIUs, as defined in 40 CFR 403.3(v)(i)(ii)] contributing to the treatment system, including those from other jurisdictions. Industrial waste discharge permits must contain as a minimum, all the requirements of 40 CFR 403.8 (f)(l)(iii). The Permittee must coordinate the permitting process with Ecology regarding any industrial facility which may possess a state waste discharge permit issued by Ecology.

c. Maintain and update, as necessary, records identifying the nature, character, and volume of pollutants contributed by industrial users to the treatment works. The Permittee must maintain records for at least a three-year period.

d. Perform inspections, surveillance, and monitoring activities on industrial users to determine or confirm compliance with pretreatment standards and requirements. The Permittee must conduct a thorough inspection of SIUs annually, except Middle-Tier Categorical Industrial Users, as defined by 40 CFR 403.8(f)(2)(v)(B)&(C), need only be inspected once every two years, unless they discharge to a CSO outfall (controlled and uncontrolled) located within the Lower Duwamish Waterway cleanup site boundary, in which case they must be inspected annually. The Permittee must conduct regular local monitoring of SIU wastewaters commensurate with the character and volume of the wastewater but not less than once per year except for Middle-Tier Categorical Industrial Users which may be sampled once every two years. The Permittee must collect and analyze samples in accordance with 40 CFR Part 403.12(b)(5)(ii)-(v) and 40 CFR Part 136.

e. Enforce and obtain remedies for non-compliance by any industrial users with applicable pretreatment standards and requirements. Once violations have been identified, the Permittee must take timely and appropriate enforcement action to address the non-compliance. The Permittee's action must follow its enforcement response procedures and any amendments, thereof.

f. Publish, at least annually in a newspaper of general circulation within the Permittee's service area, a list of all non-domestic users which, at any time in the previous 12 months, were in significant non-compliance as defined in 40 CFR 403.8(f)(2)(vii).

g. If the Permittee elects to conduct sampling of an SIU's discharge in lieu of requiring user self-monitoring, it must satisfy all requirements of 40 CFR Part 403.12. This includes monitoring and record keeping requirements of sections 403.12(g) and (o). For SIU's subject to categorical standards (i.e., CIUs), the Permittee may either complete baseline and initial compliance reports for the CIU (when required by 403.12(b) and (d)) or require these of the CIU. The Permittee must ensure SIUs are provided the results of sampling in a timely manner, inform SIUs of their right to sample, their obligations to report any sampling they do, to respond to non-compliance, and to submit other notifications.

These include a slug load report (403.12(f)), notice of changed discharge (403.12(j)), and hazardous waste notifications (403.12(p)). If sampling for the SIU, the Permittee must not sample less than once in every six month period unless the Permittee's approved program includes procedures for reduction of monitoring for Middle-Tier or Non-Significant Categorical Users per 403.12(e)(2) and (3) and those procedures have been followed.

h. Develop and maintain a data management system designed to track the status of the Permittee's industrial user inventory, industrial user discharge characteristics, and compliance status.

i. Maintain adequate staff, funds, and equipment to implement its pretreatment program.

j. Establish, where necessary, contracts or legally binding agreements with contributing jurisdictions to ensure compliance with applicable pretreatment requirements by commercial or industrial users within these jurisdictions. These contracts or agreements must identify the agency responsible for the various implementation and enforcement activities to be performed in the contributing jurisdiction.

2. Per 40 CFR 403.8(f)(2)(vii), the Permittee must evaluate each Significant Industrial User to determine if a Slug Control Plan is needed to prevent slug discharges which may cause interference, pass-through, or in any other way result in violations of the Permittee's regulations, local limits or permit conditions. The Slug Control Plan evaluation shall occur within one year of a user's designation as a SIU. In accordance with 40 CFR 403.8(f)(1)(iii)(B)(6) the Permittee shall include slug discharge control requirements in an SIU's permit if the Permittee determines that they are necessary.

3. Whenever Ecology determines that any waste source contributes pollutants to the Permittee's treatment works in violation of Subsection (b), (c), or (d) of Section 307 of the Act, and the Permittee has not taken adequate corrective action, Ecology will notify the Permittee of this determination. If the Permittee fails to take appropriate enforcement action within 30 days of this notification, Ecology may take appropriate enforcement action against the source or the Permittee.

4. *Pretreatment Report*

The Permittee must provide to Ecology an annual report that briefly describes its program activities during the previous calendar year. By March 31st, the Permittee must send the annual report to Ecology at:

Water Quality Permit Coordinator
Department of Ecology
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

The report must include the following information:

a. An updated listing of non-domestic industrial dischargers. Starting with the report submitted in 2016, the list must identify, for each discharger with a King County discharge authorization (minor or major) or discharge permit, the downstream CSO outfall(s) to which the discharger contributes, where applicable.

b. Results of wastewater sampling at the treatment plant as specified in Subsection S6.B below. The Permittee must calculate removal rates for each pollutant and evaluate the adequacy of the existing local limits in prevention of treatment plant interference, pass through of pollutants that could affect receiving water quality and biosolids contamination.

c. Status of program implementation, including:

    i. Any substantial modifications to the pretreatment program as originally approved by Ecology, including staffing and funding levels.

    ii. Any interferences, upsets, or permit violations experienced at the WWTP that are directly attributable to wastes from industrial users.

    iii. Listing of industrial users inspected and/or monitored, and a summary of the results.

    iv. Listing of industrial users scheduled for inspection and/or monitoring for the next year, and expected frequencies.

    v. Listing of industrial users notified of promulgated pretreatment standards and/or local standards as required in 40 CFR 403.8(f)(2)(iii). The list must indicate which industrial users are on compliance schedules and the final date of compliance for each.

    vi. Listing of industrial users issued industrial waste discharge permits.

    vii. Planned changes in the pretreatment program implementation plan.

d. Status of compliance activities, including:

    i. Listing of industrial users that failed to submit baseline monitoring reports or any other reports required under 40 CFR 403.12 and in the Permittee's pretreatment program, dated April 27, 1981.

    ii. Listing of industrial users that were at any time during the reporting period not complying with federal, state, or local pretreatment standards or with applicable compliance schedules for achieving those standards, and the duration of such non-compliance.

    iii. Summary of enforcement activities and other corrective actions taken or planned against non-complying industrial users. The Permittee must supply to Ecology a copy of the public notice of facilities that were in significant non-compliance.

5. The Permittee must request and obtain approval from Ecology before making any significant changes to the approved local pretreatment program. The Permittee must follow the procedure in 40 CFR 403.18 (b) and (c).

S6.B. Monitoring requirements

The Permittee must monitor its influent, effluent, and biosolids at the West Point WWTP for the priority pollutants identified in Tables II and III of Appendix D of 40 CFR Part 122 as amended, any compounds identified as a result of Condition S6.B.4, and any other pollutants expected from nondomestic sources using U.S. EPA-approved procedures for collection, preservation, storage, and analysis. The Permittee must test influent, effluent, and biosolids samples for the priority pollutant metals (Table III, 40 CFR 122, Appendix D) on a quarterly basis throughout the term of this permit. The Permittee must test influent, effluent, and biosolids samples for the organic priority pollutants (Table II, 40 CFR 122, Appendix D) on an annual basis.

1. The Permittee must sample West Point WWTP influent and effluent on a day when industrial discharges are occurring at normal to maximum levels. The Permittee must obtain 24-hour composite samples for the analysis of acid and base/neutral extractable compounds and metals. The Permittee must collect samples for the analysis of volatile organic compounds and samples must be collected using grab sampling techniques at equal intervals for a total of four grab samples per day.

   The laboratory may run a single analysis for volatile pollutants (using GC/MS procedures approved by 40 CFR 136) for each monitoring day by compositing equal volumes of each grab sample directly in the GC purge and trap apparatus in the laboratory, with no less than 1 ml of each grab included in the composite.

   Unless otherwise indicated, all reported test data for metals must represent the total amount of the constituent present in all phases, whether solid, suspended, or dissolved, elemental or combined including all oxidation states.

   The Permittee must handle, prepare, and analyze all wastewater samples taken for GC/MS analysis using procedures approved by 40 CFR 136.

2. The Permittee must collect a biosolids sample concurrently with a wastewater sample as a single grab sample of residual biosolids. Sampling and analysis must be performed using procedures approved by 40 CFR 136 unless the Permittee requests an alternate method and Ecology has approved.

3. The Permittee must take cyanide, phenols, and oils as grab samples. Oils must be hexane soluble or equivalent, and should be measured in the influent and effluent only.

4. In addition to quantifying pH, oil and grease, and all priority pollutants, the Permittee must make a reasonable attempt to identify all other substances and quantify all pollutants shown to be present by gas chromatograph/mass spectrometer (GC/MS) analysis using procedures approved by 40 CFR 136. The Permittee should attempt to make determinations of pollutants for each

fraction, which produces identifiable spectra on total ion plots (reconstructed gas chromatograms). The Permittee should attempt to make determinations from all peaks with responses 5% or greater than the nearest internal standard. The 5% value is based on internal standard concentrations of 30 μg/l, and must be adjusted downward if higher internal standard concentrations are used or adjusted upward if lower internal standard concentrations are used. The Permittee may express results for non-substituted aliphatic compounds as total hydrocarbon content. The Permittee must use a laboratory whose computer data processing programs are capable of comparing sample mass spectra to a computerized library of mass spectra, with visual confirmation by an experienced analyst. For all detected substances which are determined to be pollutants, the Permittee must conduct additional sampling and appropriate testing to determine concentration and variability, and to evaluate trends.

S6.C. Reporting of monitoring results

The Permittee must include a summary of monitoring results in the Annual Pretreatment Report.

S6.D. Local limit development

As sufficient data become available, the Permittee must, in consultation with Ecology, reevaluate their local limits in order to prevent pass through or interference. On a case-by-case basis, as applicable, the Permittee should consider the impacts of CSO discharges on the receiving waterbody when establishing limits for individual permittees. If Ecology determines that any pollutant present causes pass through or interference, or exceeds established biosolids standards, the Permittee must establish new local limits or revise existing local limits as required by 40 CFR 403.5. Ecology may also require the Permittee to revise or establish local limits for any pollutant discharged from the treatment works that has a reasonable potential to exceed the water quality standards, sediment standards, or established effluent limits, or causes whole effluent toxicity. Ecology makes this determination in the form of an Administrative Order.

Ecology may modify this permit to incorporate additional requirements relating to the establishment and enforcement of local limits for pollutants of concern. Any permit modification is subject to formal due process procedures under state and federal law and regulation.

S7. Solid wastes

S7.A. Solid waste handling

The Permittee must handle and dispose of all solid waste material in such a manner as to prevent its entry into state ground or surface water.

S7.B. Leachate

The Permittee must not allow leachate from its solid waste material to enter state waters without providing all known, available, and reasonable methods of treatment, nor allow such leachate to cause violations of the State Surface Water Quality Standards, Chapter 173-201A WAC, or the State Ground Water Quality

Standards, Chapter 173-200 WAC. The Permittee must apply for a permit or permit modification as may be required for such discharges to state ground or surface waters.

S8. Acute toxicity

S8.A. Acute testing

The Permittee must:

1. Conduct acute toxicity testing on final West Point WWTP effluent during the first and third quarters of 2017.
2. Submit the results to Ecology with the permit renewal application.
3. Conduct acute toxicity testing on a series of at least five concentrations of effluent, including 100% effluent and a control.
4. Use each of the following species and protocols for each acute toxicity test:

Acute Toxicity Tests	Species	Method
Fathead minnow 96-hour static-renewal test	*Pimephales promelas*	EPA-821-R-02-012
Daphnid 48-hour static test	*Ceriodaphnia dubia, Daphnia pulex,* or *Daphnia magna*	EPA-821-R-02-012

S8.B. Sampling and reporting requirements

1. The Permittee must submit all reports for toxicity testing in accordance with the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. Reports must contain bench sheets and reference toxicant results for test methods. If the lab provides the toxicity test data in electronic format for entry into Ecology's database, then the Permittee must send the data to Ecology along with the test report, bench sheets, and reference toxicant results.
2. The Permittee must collect 24-hour composite effluent samples for toxicity testing. The Permittee must cool the samples to 0 - 6 degrees Celsius during collection and send them to the lab immediately upon completion. The lab must begin the toxicity testing as soon as possible but no later than 36 hours after sampling was completed.
3. The laboratory must conduct water quality measurements on all samples and test solutions for toxicity testing, as specified in the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*.
4. All toxicity tests must meet quality assurance criteria and test conditions specified in the most recent versions of the EPA methods listed in Subsection C and the Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. If Ecology determines any test results to be invalid or anomalous, the Permittee must repeat the testing with freshly collected effluent.

5. The laboratory must use control water and dilution water meeting the requirements of the EPA methods listed in Section A or pristine natural water of sufficient quality for good control performance.
6. The Permittee must collect effluent samples for whole effluent toxicity testing just prior to the chlorination step in the treatment process.
7. The Permittee may choose to conduct a full dilution series test during compliance testing in order to determine dose response. In this case, the series must have a minimum of five effluent concentrations and a control. The series of concentrations must include the acute critical effluent concentration (ACEC). The ACEC equals 3.6 % effluent.
8. All whole effluent toxicity tests that involve hypothesis testing must comply with the acute statistical power standard of 29% as defined in WAC 173-205-020. If the test does not meet the power standard, the Permittee must repeat the test on a fresh sample with an increased number of replicates to increase the power.

S9. Chronic toxicity

S9.A. Chronic testing

The Permittee must:

1. Conduct chronic toxicity testing on final West Point WWTP effluent during the second and fourth quarters of 2017.
2. Submit the results to Ecology with the permit renewal application.
3. Conduct chronic toxicity testing on a series of at least five concentrations of effluent and a control. This series of dilutions must include the acute critical effluent concentration (ACEC). The ACEC equals 3.6% effluent. The series of dilutions should also contain the CCEC of 0.53 % effluent.
4. Compare the ACEC to the control using hypothesis testing at the 0.05 level of significance as described in Appendix H, EPA/600/4-89/001.
5. Perform chronic toxicity tests with all of the following species and the most recent version of the following protocols:

Saltwater Chronic Test	Species	Method
Topsmelt survival and growth	*Atherinops affinis*	EPA/600/R-95/136
Mysid shrimp survival and growth	*Americamysis bahia* (formerly *Mysidopsis bahia*)	EPA-821-R-02-014

S9.B. Sampling and reporting requirements

1. The Permittee must submit all reports for toxicity testing in accordance with the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. Reports must contain bench sheets and reference toxicant results for test methods. If the lab

provides the toxicity test data in electronic format for entry into Ecology's database, then the Permittee must send the data to Ecology along with the test report, bench sheets, and reference toxicant results.

2. The Permittee must collect 24-hour composite effluent samples for toxicity testing. The Permittee must cool the samples to 0 - 6 degrees Celsius during collection and send them to the lab immediately upon completion. The lab must begin the toxicity testing as soon as possible but no later than 36 hours after sampling was completed.
3. The laboratory must conduct water quality measurements on all samples and test solutions for toxicity testing, as specified in the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*.
4. All toxicity tests must meet quality assurance criteria and test conditions specified in the most recent versions of the EPA methods listed in Section C and the Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. If Ecology determines any test results to be invalid or anomalous, the Permittee must repeat the testing with freshly collected effluent.
5. The laboratory must use control water and dilution water meeting the requirements of the EPA methods listed in Subsection C or pristine natural water of sufficient quality for good control performance.
6. The Permittee must collect effluent samples for whole effluent toxicity testing just prior to the chlorination step in the treatment process.
7. The Permittee may choose to conduct a full dilution series test during compliance testing in order to determine dose response. In this case, the series must have a minimum of five effluent concentrations and a control. The series of concentrations must include the CCEC and the ACEC. The CCEC and the ACEC may either substitute for the effluent concentrations that are closest to them in the dilution series or be extra effluent concentrations. The CCEC equals 0.53% effluent. The ACEC equals 3.6% effluent.
8. All whole effluent toxicity tests that involve hypothesis testing must comply with the chronic statistical power standard of 39% as defined in WAC 173-205-020. If the test does not meet the power standard, the Permittee must repeat the test on a fresh sample with an increased number of replicates to increase the power.

S10. Wet weather operation

CSO-related bypass of the secondary treatment portion of the West Point WWTP is authorized when the instantaneous flow rate to the WWTP exceeds 300 MGD as a result of precipitation events. Bypasses that occur when the instantaneous flow rate is less than 300 MGD are not authorized under this condition and are subject to the bypass provisions as stated in S5.F of the permit. In the event of a CSO-related bypass authorized under this condition, the Permittee must minimize the discharge of pollutants to the environment. At a minimum, CSO-related bypass flows must receive solids and floatables removal, primary clarification, and disinfection. The final discharge must at all times meet the effluent limits of this permit as listed in S1.

The Permittee must maintain records of all CSO-related bypasses at the treatment plant. These records must document the date, duration, and volume of each bypass event, and the magnitude of the precipitation event. The records must also indicate the effluent flow rate at the time when bypassing is initiated. The Permittee must report all occurrences of bypassing on a monthly and annual basis. The monthly report must include the above information and must be included in narrative form with the discharge monitoring report. The annual report must include all of the above information in summary format and should be reported in the annual CSO report per S11.C.

S11. Combined sewer overflows

S11.A. Authorized CSO discharge locations

Beginning on the effective date of this permit, the Permittee may discharge combined wastewater and stormwater from the 38 combined sewer overflow (CSO) outfalls listed in

Table 5. These point source discharges occur intermittently when rain events overload the combined sewer system. The permit prohibits discharges from the CSO outfall sites except as a result of precipitation. This permit does not authorize discharges from CSO outfalls that threaten characteristic uses of the receiving water as identified in the water quality standards, Chapter 173-201A WAC, or that result in an exceedance of the Sediment Management Standards, Chapter 173-204 WAC.

Table 5. Permitted CSO outfalls (38)

Outfall No.	Facility Name	Receiving Water	Latitude	Longitude
003	Ballard Siphon Reg.via Seattle storm drain	Lake Washington Ship Canal	47.663916˚	-122.382333˚
004	11th Ave NW (AKA East Ballard)	Lake Washington Ship Canal	47.659491˚	-122.370774˚
006	Magnolia Overflow	Elliott Bay/Puget Sound	47.630184˚	-122.399021˚
007	Canal Street Overflow	Lake Washington Ship Canal	47.651856˚	-122.358113˚
008	3rd Ave W and Ewing St.	Lake Washington Ship Canal	47.652084˚	-122.360052˚
009	Dexter Ave Regulator	Lake Union	47.632273˚	-122.339235˚
011	E Pine St. PS Emergency Overflow	Lake Washington	47.614926˚	-122.280304˚
012	Belvoir Pump Station Emergency Overflow	Lake Washington	47.656698˚	-122.287589˚
013	MLK Trunkline Overflow - via storm drain	Lake Washington	47.523285˚	-122.262950˚
014	Montlake Overflow	Lake Washington Ship Canal	47.647110˚	-122.304861˚
015	University Regulator	Lake Washington Ship Canal	47.648929˚	-122.311296˚
018	Matthews Park PS Emergency Overflows	Lake Washington	47.697458˚	-122.272650˚
027a	Denny Way Regulator	Elliott Bay	47.618139˚	-122.361888˚
028	King Street Regulator	Elliott Bay	47.599003˚	-122.337425˚
029	Kingdome	Elliott Bay	47.592532˚	-122.342106˚
030	Lander St. Regulator	Elliott Bay	47.581476˚	-122.342997˚

Outfall No.	Facility Name	Receiving Water	Latitude	Longitude
031a, b, c	Hanford #1 Overflow - Via Diagonal Storm Drain	Duwamish River	47.563108˚	-122.345315˚
032	Hanford #2 Regulator	Duwamish - East Waterway	47.577223˚	-122.34278˚
033	Rainier Ave Pump Station	Lake Washington	47.571374˚	-122.27553˚
034	E. Duwamish Pump Station	Duwamish River	47.562985˚	-122.345272˚
035	W. Duwamish Pump Station	Duwamish River	47.563224˚	-122.348256˚
036	Chelan Ave Regulator	Duwamish - West Waterway	47.573667˚	-122.357779˚
037	Harbor Avenue Regulator	Duwamish to Elliott Bay	47.573706˚	-122.361159˚
038	Terminal 115 Overflow	Duwamish River	47.54826˚	-122.340503˚
039	Michigan S. Regulator	Duwamish River	47.54353˚	-122.334967˚
040	8th Ave South Reg. (W. Marginal Way PS)	Duwamish River	47.533648˚	-122.322639˚
041	Brandon Street Regulator	Duwamish River	47.554661˚	-122.340832˚
042	Michigan W. Regulator	Duwamish River	47.541561˚	-122.334994˚
043	East Marginal Pump Station	Duwamish River	47.537048˚	-122.31849˚
044a	Norfolk Outfall	Duwamish River	47.511941˚	-122.297356˚
045	Henderson Pump Station	Lake Washington	47.523285˚	-122.26295˚
048a,b	North Beach Pump Station: a.) wet well, b) inlet structure	Puget Sound	47.704007˚ 47.702142˚	-122.392337˚ -122.392564˚
049	30th Avenue NE Pump Station	Lake Washington	47.656698˚	-122.287589˚
052	53rd Avenue SW Pump Station	Puget Sound	47.584799˚	-122.402552˚
054	63rd Avenue SW Pump Station	Puget Sound	47.570016˚	-122.416301˚
055	SW Alaska Street Overflow	Puget Sound	47.559442˚	-122.406947˚
056	Murray Street Pump Station	Puget Sound	47.540275˚	-122.400003˚
057	Barton Street Pump Station	Puget Sound	47.523886˚	-122.396393˚

S11.B. Nine minimum controls

In accordance with chapter 173-245 WAC and US EPA CSO control policy (59 FR 18688), the Permittee must implement and document the following nine minimum controls (NMC) for CSOs. The Permittee must document compliance with the NMCs in the annual CSO report as required in Special Condition S11.C.

The NMCs are considered technology-based requirements for CSO systems. In order to comply with these requirements, the Permittee must:

1. Implement proper operation and maintenance programs for the sewer system and all CSO outfalls to reduce the magnitude, frequency, and duration of CSOs. The program must consider regular sewer inspections; sewer, catch basin, and regulator cleaning; equipment and sewer collection system repair or replacement, where necessary; and disconnection of illegal connections.
2. Implement procedures that will maximize use of the collection system for wastewater storage that can be accommodated by the storage capacity of the collection system in order to reduce the magnitude, frequency, and duration of CSOs.

3. Review and modify, as appropriate, its existing pretreatment program to minimize CSO impacts from the discharges from non-domestic users. Starting with its annual Pretreatment Report submitted in 2016, the County must include in the report, for each discharger with a King County discharge authorization (major or minor) or discharge permit, the downstream CSO outfall(s) to which the discharger contributes, where applicable.

4. Operate the wastewater treatment plant at maximum treatable flow during all wet weather flow conditions to reduce the magnitude, frequency, and duration of CSOs. The Permittee must deliver all flows to the treatment plant within the constraints of the treatment capacity of the treatment works.

5. Not discharge overflows from CSO outfalls except as a result of precipitation events; dry weather overflows from CSO outfalls are prohibited. The Permittee must report each dry weather overflow to the permitting authority immediately per Special Condition S3.E. When it detects a dry weather overflow, the Permittee must begin corrective action immediately and inspect the dry weather overflow each subsequent day until it has eliminated the overflow.

6. Implement measures to control solid and floatable materials in CSOs.

7. Implement a pollution prevention program focused on reducing the impact of CSOs on receiving waters. Best management practices (BMPs) to control pollutant sources in stormwater in CSO basins must be an element of the pollution prevention program. Ecology's *Stormwater Management Manual for Western Washington* (2012) contains appropriate BMPs for reference.

   Starting with the Annual CSO Report submitted in 2017, the Permittee must include a detailed description of the pollution prevention program, appropriate BMPs, and the legal authority and administrative procedures that will be used to ensure the program is being implemented. If the legal authority and/or administrative procedures are not in place, the Annual CSO Report must include a detailed description of the steps needed to establish such a program and the timeline for getting the program in place.

8. Continue to implement the public notification process that informs citizens of when and where CSOs occur. The process must continue to include (a) a mechanism to alert citizens of CSO occurrences and (b) a system to determine the nature and duration of conditions that are potentially harmful for users of receiving waters due to CSOs.

9. Monitor CSO outfalls to characterize CSO impacts and the efficacy of CSO controls. This must include collection of data to document existing baseline conditions and to evaluate the efficacy of the technology-based controls. This data must include:

   a. Characteristics of the combined sewer system, including the population served by the combined portion of the system and locations of all CSO outfalls.

b. Total number of CSO events, and the frequency and duration of CSOs for all events.

c. Locations and designated uses of receiving water bodies.

d. Water quality data for receiving water bodies.

e. Water quality impacts directly related to CSO (e.g., beach closing, floatables, wash-up episodes, fish kills).

S11.C. Combined sewer overflow reporting

1. *Monthly CSO Report*

   The Permittee must submit a monthly report by the 15th of each month that includes:

   a. Discharge monitoring reports (DMRs) and narrative summaries for each CSO treatment plant (Alki, Carkeek, Elliott West, and Henderson), and

   b. An event-based summary that includes discharge volume, duration, and precipitation for all CSO discharge events that occur during the reporting period.

2. *Annual CSO Report*

   The Permittee must submit a CSO Annual Report to Ecology for review by July 31st of each year. The CSO Annual Report must cover the previous calendar year. The report must comply with the requirements of WAC 173-245-090(1) and must include documentation of compliance with the Nine Minimum Controls for CSOs described in Special Condition S11.B. The Permittee must submit paper and electronic copies of the report, and Excel spreadsheet copies of significant spreadsheets. The CSO Annual Report must include the following information:

   a. A summary of the number and volume of untreated discharge events per outfall for that year.

   b. A summary of the 20-year moving average number of untreated discharge events per outfall, calculated once annually.

   c. An event-based reporting form (provided by Ecology) for all CSO discharges for the reporting period, summarizing all data collected according to the monitoring schedule in Special Condition S11.B.9.

   d. An explanation of the previous year's CSO reduction accomplishments.

   e. A list of CSO reduction projects planned for the next year.

   f. A list of which permitted CSO outfalls can be categorized as meeting the one untreated discharge per year on a 20-year moving average performance standard. This annual assessment may be based on historical long-term discharge data, modeling, or other reasonable methods as approved by Ecology.

S11.D. Combined sewer overflow reduction plan amendment

The Permittee must submit an amendment of its *2012 Long Term Control Plan Amendment* (also referred to as a CSO Reduction Plan) to Ecology for review and approval with the application for permit renewal. The amendment must comply with the requirements of WAC 173-245-090(2).

S11.E. Engineering reports and plans and specifications for CSO reduction projects

The Permittee must submit to Ecology an engineering report for each specific CSO reduction construction project. Engineering documents associated with each CSO reduction project must meet the requirements of WAC 173-240-060, *Engineering Report*, and be approved by Ecology prior to construction. The report must:

1. Specify any contracts, ordinances, methods of financing, or any other arrangements necessary to achieve this objective.
2. Describe how each project will achieve the performance standard of *greatest reasonable control* and explicitly state the expected frequency of overflow events per year per associated outfall after the CSO reduction construction project has been completed.
3. Identify the potential hydraulic impacts of the project on downstream conveyance and treatment facilities.

For each specific CSO reduction construction project, the Permittee must prepare and submit approvable plans and specifications consistent with chapter 173-240-070 WAC to Ecology for review and approval. Ecology must approve plans and specifications prior to construction.

Prior to the start of construction, the Permittee must submit to Ecology a construction quality assurance plan as required by chapter 173-240-075 WAC.

S11.F. Requirements for controlled combined sewer overflows

a. CSOs identified as controlled

Based on monitoring data presented in King County's *2012 Annual CSO Report* and King County's *2012 Long Term Control Plan Amendment*, the 16 CSO outfalls listed in Table 6 meet the requirement of "greatest reasonable reduction" as defined in chapter WAC 173-245-020(22). Frequency of overflow events at these CSO outfalls, as a result of precipitation events, must continue to meet the performance standard.

Table 6. Controlled CSO outfalls (16)

CSO Outfall No	Location/Name	Receiving Water	Latitude	Longitude
007	Canal Street Overflow	Lake Washington Ship Canal	47.651856˚	-122.358113˚
011	E Pine St. PS Emergency Overflow	Lake Washington	47.614926˚	-122.280304˚
012	Belvoir PS Emergency Overflow	Lake Washington	47.656698˚	-122.287589˚
013	MLK Trunkline Overflow - via storm drain	Lake Washington	47.523285˚	-122.26295˚
018	Matthews Park PS Emergency Overflows	Lake Washington	47.697458˚	-122.27265˚
033	Rainier Ave Pump Station	Lake Washington	47.571374˚	-122.27553˚
034	E. Duwamish Pump Station	Duwamish River	47.563224˚	-122.348256˚
035	W. Duwamish Pump Station	Duwamish River	47.562986˚	-122.345272˚
040	8th Ave South Reg. (W Marginal Way PS)	Duwamish River	47.533648˚	-122.322639˚
043	East Marginal Pump Station	Duwamish River	47.537048˚	-122.31849˚
044a	Norfolk Outfall	Duwamish River	47.511941˚	-122.297356˚
045	Henderson Pump Station	Lake Washington	47.523285˚	-122.26295˚
049	30th Avenue NE Pump Station	Lake Washington	47.656698˚	-122.287589˚
052	53rd Avenue SW Pump Station	Puget Sound	47.584799˚	-122.402552˚
054	63rd Avenue SW Pump Station	Puget Sound	47.570016˚	-122.416301˚
055	SW Alaska Street Overflow	Puget Sound	47.559442˚	-122.406947˚

b. *Performance standards for controlled CSO outfalls*

The performance standard for each controlled CSO outfall is not more than one discharge event per outfall per year on average, due to precipitation. Ecology evaluates compliance with the performance standard annually based on a 20 year moving average. The Permittee must report the running 20-year average number of overflow events per year during this permit term from these CSO outfalls in the *CSO Annual Report* required in Section S11.C.

c. *CSO post construction monitoring*

The Permittee must continue to implement a post construction compliance monitoring program to verify the effectiveness of CSO controls and to demonstrate compliance with water quality standards and protection of designated uses. The Permittee must follow the approved *King County 2012 Post Construction Monitoring Plan* and submit to Ecology for review and approval any proposed changes to this plan.

d. *CSO post construction monitoring data report*

The Permittee must submit to Ecology, by December 1, 2019, a post-construction monitoring summary report that demonstrates how each CSO outfall listed as controlled in Table 6, as well as those brought under control during the permit term, achieves performance requirements and complies with state water and sediment quality standards. The report must conform to the approved *CSO Post Construction Monitoring Plan*. For outfalls with SMS exceedances associated with CSO discharges, the report must describe clean-up activities in the vicinity including clean-up actions planned or that have been performed, targeted chemicals, any available pre- and post-cleanup monitoring results, clean-up project schedule, post-project monitoring schedule, and a list of parties involved.

The outfalls scheduled to be controlled during this permit term and to be discussed in the CSO post construction monitoring data report include: Dexter Avenue Regulator (DSN 009), Denny Way Regulator (DSN 027a), Harbor Avenue Regulator (DSN 037), Ballard Siphon Regulator (DSN 003), Barton (DSN 057), Murray (DSN 056), South Magnolia (DSN 006), and North Beach (DSN 048).

S12. Spill control plan

The Permittee must:

1. Review the West Point WWTP Spill Plan at least annually and update as needed.
2. Send updated plans to Ecology when significant changes are made.
3. Follow the plan and any supplements throughout the term of the permit.

The spill control plan must include the following:

1. A list of all oil and petroleum products and other materials used and/or stored on site, which when spilled, or otherwise released into the environment, designate as dangerous waste (DW) or extremely hazardous waste (EHW) by the procedures set forth in WAC 173-303-070. Include other materials used and/or stored on site which may become pollutants or cause pollution upon reaching state's waters.
2. A description of preventive measures and facilities (including an overall facility plot showing drainage patterns) which prevent, contain, or treat spills of these materials.
3. A description of the reporting system the Permittee will use to alert responsible managers and legal authorities in the event of a spill.
4. A description of operator training to implement the plan.

S13. Sediment monitoring

S13.A. Sediment sampling – West Point WWTP

a. *Sediment sampling and analysis plan*

The Permittee must submit to Ecology for review and approval a sediment sampling and analysis plan for sediment monitoring for the West Point WWTP outfall. The Permittee must submit one paper copy and an electronic copy (preferably as a PDF) by December 1, 2016. The purpose of the plan is to re-characterize sediment quality in the vicinity of the discharge location.

The Permittee must:

- Follow the guidance provided in the *Sediment Source Control Standards User Manual, Appendix B: sediment sampling and analysis plan* (Ecology, 2008). Method detection limits must be listed in the plan.
- Collect enough sediment in the top 10 cm at each station to allow for conventional parameter testing (percent solids, total organic carbon, particle size), chemistry testing, and if necessary, bioassay testing. Chemistry tests must be performed before bioassay tests and if there are Sediment Quality Standard (SQS) exceedances, then bioassay tests must be performed.
- Chemistry: Analyze conventional parameters and the full suite of 47 Sediment Management Standards (SMS) marine chemicals at all stations.
- Bioassay: Perform bioassay tests at all stations with SQS exceedances. Run parallel larval echinoderm tests, using standard protocols and screen tube manipulation, in order to see if a physical influence from turbidity in the overlying test water continues to lead to failed bioassays.
- Stations: Collect samples at the same stations as the previous sampling events. Identify the predominant current direction in the vicinity of the outfall on all figures.

b. Sediment data report

Following Ecology approval of the Sediment Sampling and Analysis Plan, the Permittee must collect sediments between August 15th and September 15th. The Permittee must submit to Ecology a Sediment Data Report containing the results of the sediment sampling and analysis no later than December 1, 2018. The Permittee must submit two paper copies and an electronic copy (preferably as a PDF). The sediment data report must conform to the approved sediment sampling and analysis plan.

In addition to a Sediment Data Report, the sediment chemical and biological data must be submitted to Ecology's EIM database (http://www.ecy.wa.gov/eim/), and Ecology's MyEIM tools must be used to confirm the accuracy of the submitted data (http://www.ecy.wa.gov/eim/MyEIM.htm).

S13.B. Sediment sampling – CSO outfalls

The Permittee must model and/or collect sediment samples in the vicinities of controlled CSO outfalls: E. Pine Street Pump Station Emergency Overflow (011), Belvoir (012)/30th Ave NE Pump Station (049), Martin Luther King (013)/Henderson Pump Station (045), Matthews Park Pump Station Emergency Overflow (018), and Rainier Avenue Pump Station Emergency Overflow (033). A sediment sampling and analysis plan (SAP) must be submitted by December 1, 2016 in accordance with (a) below. Following Ecology approval of the sediment SAP, the Permittee must collect sediments according to the SAP. The Permittee must submit to Ecology a sediment data report, in accordance with (b) below, that contains the sediment sampling and analysis results no later than December 1, 2018.

In addition, the Permittee must model and/or sample sediments in accordance with their approved *2012 Post Construction Monitoring Plan* or any subsequent approved plan revisions. Post construction monitoring of sediments is required with the completion of CSO projects once the CSO has been deemed controlled unless sufficient recent data exists that shows there are no SMS exceedances. An exception is made if an area-wide cleanup project is planned with sediment sampling scheduled at cleanup project completion.

For each CSO outfall site that requires sediment monitoring, the Permittee must submit a sediment sampling and analysis plan and data report in accordance with the following.

a. Sediment sampling and analysis plan

The Permittee must submit to Ecology for review and approval a sediment sampling and analysis plan (SSAP) for sediment monitoring at least eight months prior to sediment testing. The Permittee must submit one paper copy and an electronic copy (preferably as a PDF). The purpose of the plan is to characterize sediment (the nature and extent of chemical contamination and biological toxicity) quality in the vicinity of the discharge locations. The SSAP must be consistent with the *CSO Sediment Quality Characterization Sampling and Analysis Plan* in Appendix H of the County's approved *Post-Construction Monitoring Plan.* The Permittee must list method detection limits in the plan.

b. Sediment data report

Following Ecology approval of the Sediment Sampling and Analysis Plan, the Permittee must collect sediments according to the plan. The Permittee must submit to Ecology a Sediment Data Report containing the results of the sediment sampling and analysis no later than ten months after the data was collected. The Permittee must submit two paper copies and an electronic copy (preferably as a PDF). The sediment data report must conform to the approved sediment sampling and analysis plan.

In addition to a Sediment Data Report, the sediment chemical and biological data must be submitted to Ecology's EIM database (http://www.ecy.wa.gov/eim/), and Ecology's MyEIM tools must be used to confirm the accuracy of the submitted data (http://www.ecy.wa.gov/eim/MyEIM.htm).

S13.C. Sediment quality summary at CSO outfalls

The Permittee must submit to Ecology an update to the *2009 Comprehensive Sediment Quality Summary Report* no later than December 1, 2018. The 2009 report summarizes sediment data collected at all CSO outfalls including CSO treatment plants. The purpose of this update is to keep CSO sediment monitoring history information consolidated to help King County and Ecology assess the potential for sediment impacts from CSO discharges.

This update report must provide any new site-specific information including quantity and quality of the discharges, receiving water characteristics, and new knowledge about sediment quality near the CSO outfalls. The report must also include a status of sediment cleanup sites and monitoring plans.

Data not previously submitted and not yet formatted and future data must be formatted in the EIM format.

S14. Outfall evaluation

The Permittee must inspect, once during the permit term, the submerged portions of the West Point WWTP and CSO treatment plant outfall lines and diffusers to document their integrity and continued function. If conditions allow for a photographic verification, the Permittee must include such verification in the reports. The Permittee must submit the inspection reports to Ecology with the NPDES Permit renewal application. The inspector must at minimum:

- Assess the physical condition of the outfall pipes, diffusers, and associated couplings.
- Determine the extent of sediment accumulation in the vicinity of the diffusers.
- Ensure diffuser ports are free of obstructions and are allowing uniform flow.
- Confirm physical location (latitude/longitude) and depth (at MLLW) of the diffuser sections of the outfalls.
- Assess physical condition of anchors used to secure the submarine lines.
- For the West Point WWTP, follow-up on the findings from the 2011 inspection by inspecting gaps and checking for leaks at station 30.

S15. Elliott West CSO treatment plant – copper reduction assessment

The Permittee must assess copper discharges from the Elliott West CSO treatment plant and submit a *Copper Reduction Assessment Report* to Ecology by November 1, 2018. As part of the assessment, the Permittee must:

1. Evaluate sample reliability/accuracy of copper measurements, including potential sample interferences, from the Elliott West facility.
2. Assess copper discharge patterns such as first flush or seasonal (wet season vs. dry season) impacts, land use patterns, etc.
3. Conduct a copper source inventory and provide a list of significant copper sources.
4. Provide a description of copper source control options.
5. Examine opportunities for outfall mixing enhancements.
6. Recommend a preferred strategy with corresponding schedule to address copper discharges from the Elliott West CSO treatment plant.

S16. Elliott West CSO treatment plant – settleable solids removal assessment

The Permittee must assess settleable solids discharges from the Elliott West CSO treatment plant and submit a *Settleable Solids Reduction Assessment Report* to Ecology by November 1, 2018. As part of the assessment, the Permittee must:

1. Assess settleable solids discharge patterns such as seasonal or first flush impacts, stormwater vs. domestic wastewater concentrations, etc.

2. Recommend a preferred strategy with corresponding schedule to address settleable solids discharges from the Elliott West CSO treatment plant in order to meet the annual average settleable solids limit.

S17. Application for permit renewal or facility modifications

The Permittee must submit an application for renewal of this permit one year prior to its expiration date, or by January 31, 2019. The Permittee must submit a paper copy and an electronic copy (preferably as a PDF).

The Permittee must also submit a new application or application supplement at least one hundred eighty (180) days prior to commencement of discharges, resulting from the activities listed below, which may result in permit violations. These activities include any facility expansions, production increases, or other planned changes, such as process modifications, in the permitted facility.

General Conditions

G1. Signatory requirements

1. All applications, reports, or information submitted to Ecology must be signed and certified.

   a. In the case of corporations, by a responsible corporate officer. For the purpose of this section, a responsible corporate officer means:

      - A president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision making functions for the corporation, or
      - The manager of one or more manufacturing, production, or operating facilities, provided, the manager is authorized to make management decisions which govern the operation of the regulated facility including having the explicit or implicit duty of making major capital investment recommendations, and initiating and directing other comprehensive measures to assure long-term environmental compliance with environmental laws and regulations; the manager can ensure that the necessary systems are established or actions taken to gather complete and accurate information for permit application requirements; and where authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

   b. In the case of a partnership, by a general partner.

   c. In the case of sole proprietorship, by the proprietor.

   d. In the case of a municipal, state, or other public facility, by either a principal executive officer or ranking elected official.

   Applications for permits for domestic wastewater facilities that are either owned or operated by, or under contract to, a public entity shall be submitted by the public entity.

2. All reports required by this permit and other information requested by Ecology must be signed by a person described above or by a duly authorized representative of that person. A person is a duly authorized representative only if:

   a. The authorization is made in writing by a person described above and submitted to Ecology.

   b. The authorization specifies either an individual or a position having responsibility for the overall operation of the regulated facility, such as the position of plant manager, superintendent, position of equivalent responsibility, or an individual or position having overall responsibility for environmental matters. (A duly authorized representative may thus be either a named individual or any individual occupying a named position.)

3. Changes to authorization. If an authorization under paragraph G1.2, above, is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, a new authorization satisfying the requirements of

paragraph G1.2, above, must be submitted to Ecology prior to or together with any reports, information, or applications to be signed by an authorized representative.

4. Certification. Any person signing a document under this section must make the following certification:

   I certify under penalty of law, that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

G2. Right of inspection and entry

The Permittee must allow an authorized representative of Ecology, upon the presentation of credentials and such other documents as may be required by law:

1. To enter upon the premises where a discharge is located or where any records must be kept under the terms and conditions of this permit.
2. To have access to and copy, at reasonable times and at reasonable cost, any records required to be kept under the terms and conditions of this permit.
3. To inspect, at reasonable times, any facilities, equipment (including monitoring and control equipment), practices, methods, or operations regulated or required under this permit.
4. To sample or monitor, at reasonable times, any substances or parameters at any location for purposes of assuring permit compliance or as otherwise authorized by the Clean Water Act.

G3. Permit actions

This permit may be modified, revoked and reissued, or terminated either at the request of any interested person (including the Permittee) or upon Ecology's initiative. However, the permit may only be modified, revoked and reissued, or terminated for the reasons specified in 40 CFR 122.62, 40 CFR 122.64 or WAC 173-220-150 according to the procedures of 40 CFR 124.5.

1. The following are causes for terminating this permit during its term, or for denying a permit renewal application:
   a. Violation of any permit term or condition.
   b. Obtaining a permit by misrepresentation or failure to disclose all relevant facts.
   c. A material change in quantity or type of waste disposal.
   d. A determination that the permitted activity endangers human health or the environment, or contributes to water quality standards violations and can only be regulated to acceptable levels by permit modification or termination.

e. A change in any condition that requires either a temporary or permanent reduction, or elimination of any discharge or biosolids use or disposal practice controlled by the permit.

f. Nonpayment of fees assessed pursuant to RCW 90.48.465.

g. Failure or refusal of the Permittee to allow entry as required in RCW 90.48.090.

2. The following are causes for modification but not revocation and reissuance except when the Permittee requests or agrees:

   a. A material change in the condition of the waters of the state.

   b. New information not available at the time of permit issuance that would have justified the application of different permit conditions.

   c. Material and substantial alterations or additions to the permitted facility or activities which occurred after this permit issuance.

   d. Promulgation of new or amended standards or regulations having a direct bearing upon permit conditions, or requiring permit revision.

   e. The Permittee has requested a modification based on other rationale meeting the criteria of 40 CFR Part 122.62.

   f. Ecology has determined that good cause exists for modification of a compliance schedule, and the modification will not violate statutory deadlines.

   g. Incorporation of an approved local pretreatment program into a municipality's permit.

3. The following are causes for modification or alternatively revocation and reissuance:

   a. When cause exists for termination for reasons listed in 1.a through 1.g of this section, and Ecology determines that modification or revocation and reissuance is appropriate.

   b. When Ecology has received notification of a proposed transfer of the permit. A permit may also be modified to reflect a transfer after the effective date of an automatic transfer (General Condition G7) but will not be revoked and reissued after the effective date of the transfer except upon the request of the new Permittee.

G4. Reporting planned changes

The Permittee must, as soon as possible, but no later than one hundred eighty (180) days prior to the proposed changes, give notice to Ecology of planned physical alterations or additions to the permitted facility, production increases, or process modification which will result in:

1. The permitted facility being determined to be a new source pursuant to 40 CFR 122.29(b)

2. A significant change in the nature or an increase in quantity of pollutants discharged.

3. A significant change in the Permittee's biosolids use or disposal practices. Following such notice, and the submittal of a new application or supplement to the existing

application, along with required engineering plans and reports, this permit may be modified, or revoked and reissued pursuant to 40 CFR 122.62(a) to specify and limit any pollutants not previously limited. Until such modification is effective, any new or increased discharge in excess of permit limits or not specifically authorized by this permit constitutes a violation.

G5. Plan review required

Prior to constructing or modifying any wastewater control facilities, an engineering report and detailed plans and specifications must be submitted to Ecology for approval in accordance with chapter 173-240 WAC. Engineering reports, plans, and specifications must be submitted at least one hundred eighty (180) days prior to the planned start of construction unless a shorter time is approved by Ecology. Facilities must be constructed and operated in accordance with the approved plans.

G6. Compliance with other laws and statutes

Nothing in this permit excuses the Permittee from compliance with any applicable federal, state, or local statutes, ordinances, or regulations.

G7. Transfer of this permit

In the event of any change in control or ownership of facilities from which the authorized discharge emanate, the Permittee must notify the succeeding owner or controller of the existence of this permit by letter, a copy of which must be forwarded to Ecology.

1. Transfers by Modification

   Except as provided in paragraph (2) below, this permit may be transferred by the Permittee to a new owner or operator only if this permit has been modified or revoked and reissued under 40 CFR 122.62(b)(2), or a minor modification made under 40 CFR 122.63(d), to identify the new Permittee and incorporate such other requirements as may be necessary under the Clean Water Act.

2. Automatic Transfers

   This permit may be automatically transferred to a new Permittee if:

   a. The Permittee notifies Ecology at least thirty (30) days in advance of the proposed transfer date.

   b. The notice includes a written agreement between the existing and new Permittees containing a specific date transfer of permit responsibility, coverage, and liability between them.

   c. Ecology does not notify the existing Permittee and the proposed new Permittee of its intent to modify or revoke and reissue this permit. A modification under this subparagraph may also be minor modification under 40 CFR 122.63. If this notice is not received, the transfer is effective on the date specified in the written agreement.

G8. Reduced production for compliance

The Permittee, in order to maintain compliance with its permit, must control production and/or all discharges upon reduction, loss, failure, or bypass of the treatment facility until the facility is restored or an alternative method of treatment is provided. This requirement applies in the situation where, among other things, the primary source of power of the treatment facility is reduced, lost, or fails.

G9. Removed substances

Collected screenings, grit, solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters must not be resuspended or reintroduced to the final effluent stream for discharge to state waters.

G10. Duty to provide information

The Permittee must submit to Ecology, within a reasonable time, all information which Ecology may request to determine whether cause exists for modifying, revoking and reissuing, or terminating this permit or to determine compliance with this permit. The Permittee must also submit to Ecology upon request, copies of records required to be kept by this permit.

G11. Other requirements of 40 CFR

All other requirements of 40 CFR 122.41 and 122.42 are incorporated in this permit by reference.

G12. Additional monitoring

Ecology may establish specific monitoring requirements in addition to those contained in this permit by administrative order or permit modification.

G13. Payment of fees

The Permittee must submit payment of fees associated with this permit as assessed by Ecology.

G14. Penalties for violating permit conditions

Any person who is found guilty of willfully violating the terms and conditions of this permit is deemed guilty of a crime, and upon conviction thereof shall be punished by a fine of up to ten thousand dollars ($10,000) and costs of prosecution, or by imprisonment in the discretion of the court. Each day upon which a willful violation occurs may be deemed a separate and additional violation.

Any person who violates the terms and conditions of a waste discharge permit may incur, in addition to any other penalty as provided by law, a civil penalty in the amount of up to ten thousand dollars ($10,000) for every such violation. Each and every such violation is a separate and distinct offense, and in case of a continuing violation, every day's continuance is deemed to be a separate and distinct violation.

G15. Upset

Definition – "Upset" means an exceptional incident in which there is unintentional and temporary non-compliance with technology-based permit effluent limits because of factors beyond the reasonable control of the Permittee. An upset does not include non-compliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

An upset constitutes an affirmative defense to an action brought for non-compliance with such technology-based permit effluent limits if the requirements of the following paragraph are met.

A Permittee who wishes to establish the affirmative defense of upset must demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:

1. An upset occurred and that the Permittee can identify the cause(s) of the upset.
2. The permitted facility was being properly operated at the time of the upset.
3. The Permittee submitted notice of the upset as required in Special Condition S3.F.
4. The Permittee complied with any remedial measures required under S3.F of this permit.

In any enforcement action the Permittee seeking to establish the occurrence of an upset has the burden of proof.

G16. Property rights

This permit does not convey any property rights of any sort, or any exclusive privilege.

G17. Duty to comply

The Permittee must comply with all conditions of this permit. Any permit non-compliance constitutes a violation of the Clean Water Act and is grounds for enforcement action; for permit termination, revocation and reissuance, or modification; or denial of a permit renewal application.

G18. Toxic pollutants

The Permittee must comply with effluent standards or prohibitions established under Section 307(a) of the Clean Water Act for toxic pollutants within the time provided in the regulations that establish those standards or prohibitions, even if this permit has not yet been modified to incorporate the requirement.

G19. Penalties for tampering

The Clean Water Act provides that any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than two (2) years per violation, or by both. If a conviction of a person is for a violation committed after a first conviction of such person under this condition, punishment shall be a fine of not more than $20,000 per day of violation, or by imprisonment of not more than four (4) years, or by both.

G20. Compliance schedules

Reports of compliance or non-compliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of this permit must be submitted no later than fourteen (14) days following each schedule date.

G21. Service agreement review

The Permittee must submit to Ecology any proposed service agreements and proposed revisions or updates to existing agreements for the operation of any wastewater treatment facility covered by this permit. The review is to ensure consistency with chapters 90.46 and 90.48 RCW as required by RCW 70.150.040(9). In the event that Ecology does not comment within a thirty-day (30) period, the Permittee may assume consistency and proceed with the service agreement or the revised/updated service agreement.

Appendix A

LIST OF POLLUTANTS WITH ANALYTICAL METHODS, DETECTION LIMITS AND QUANTITATION LEVELS

The Permittee must use the specified analytical methods, detection limits (DLs) and quantitation levels (QLs) in the following table for permit and application required monitoring unless:

- Another permit condition specifies other methods, detection levels, or quantitation levels.
- The method used produces measurable results in the sample and EPA has listed it as an EPA-approved method in 40 CFR Part 136, or EPA has granted the laboratory written permission to use the method.
- The Permittee knows that an alternate, less sensitive method (higher DL and QL) from those listed below is sufficient to produce measurable results in their effluent.
- If the Permittee is unable to obtain the required DL and QL due to matrix effects (such as for treatment plant influent or CSO effluent), the Permittee must strive to achieve to lowest possible DL and QL and report the DL and QL in the required report.

If the Permittee uses an alternative method, not specified in the permit and as allowed above, it must report the test method, DL, and QL on the discharge monitoring report or in the required report.

All pollutants that have numeric limits in Section S1 of this permit must be analyzed with the methods specified below. When the permit requires the Permittee to measure the base neutral compounds in the list of priority pollutants, it must measure all of the base neutral pollutants listed in the table below. The list includes EPA required base neutral priority pollutants and several additional polynuclear aromatic hydrocarbons (PAHs). The Water Quality Program added several PAHs to the list of base neutrals below from Ecology’s Persistent Bioaccumulative Toxics (PBT) List. It only added those PBT parameters of interest to Appendix A that did not increase the overall cost of analysis unreasonably.

Ecology added this appendix to the permit in order to reduce the number of analytical “non-detects” in permit-required monitoring and to measure effluent concentrations near or below criteria values where possible at a reasonable cost.

CONVENTIONAL PARAMETERS

Pollutant & CAS No. *(if available)*	**Recommended Analytical Protocol**	**Detection (DL)[1] *µg/L unless specified***	**Quantitation Level (QL)[2] *µg/L unless specified***
Biochemical Oxygen Demand	SM5210-B		2 mg/L
Total Suspended Solids	SM2540-D		5 mg/L
Total Ammonia (as N)	SM4500-NH3-B and C/D/E/G/H Kerouel & Aminot 1997		0.3 mg/L
Dissolved oxygen	SM4500-OC/OG		0.2 mg/L
Temperature (max. 7-day avg.)	Analog recorder or use micro-recording devices known as thermistors		0.2º C
pH	SM4500-H^+ B	N/A	N/A

NONCONVENTIONAL PARAMETERS

Pollutant & CAS No. (if available)	**Recommended Analytical Protocol**	**Detection (DL)[1] µg/L unless specified**	**Quantitation Level (QL)[2] µg/L unless specified**
Total Alkalinity	SM2320-B		1.3 mg/L as CaCO3
Chlorine, Total Residual	SM4500 Cl G 4500 Cl D/E, Hach 8370		50.0
Fecal Coliform	SM 9221E,9222	N/A	Specified in method - sample aliquot dependent
Nitrate + Nitrite Nitrogen (as N)	SM4500-NO3- E/F/H		200
Nitrogen, Total Kjeldahl (as N)	SM4500-N_{org}B/C and SM4500NH_3-B/C/D/EF/G/H EPA 351.2		500

Exhibit C

Pollutant & CAS No. (if available)	Recommended Analytical Protocol	Detection (DL)[1] µg/L unless specified	Quantitation Level (QL)[2] µg/L unless specified
Nitrogen, Total (as N)	SM4500-N-C	50	100
Soluble Reactive Phosphorus (as P)	SM4500- PE/PF	100	100
Phosphorus, Total (as P)	SM 4500 PB followed by SM4500-PE/PF	100	300
Oil and Grease (HEM)	1664 A or B	1,400	5,000
Salinity	SM2520-B		3 practical salinity units or scale (PSU or PSS)
Settleable Solids	SM2540 -F		Sample and limit dependent
Sulfate (as mg/L SO_4)	SM4110-B, 4500-SO4 E		7.1 mg/L
Sulfide (as mg/L S)	SM4500-S^2F/D/E/G		200
Sulfite (as mg/L SO_3)	SM4500-SO3B		2000
Total dissolved solids	SM2540 C		20 mg/L
Total Hardness	SM2340B C, 200.7, 200.8		200 as $CaCO_3$
Aluminum, Total (7429-90-5)	200.8	2.0	10
Barium Total (7440-39-3)	200.8	0.5	2.0
BTEX (benzene +toluene + ethylbenzene + m,o,p xylenes)	EPA SW 846 8021/8260	1	2
Boron Total (7440-42-8)	200.8	2.0	10.0
Cobalt, Total (7440-48-4)	200.8	0.05	0.25
Iron, Total (7439-89-6)	200.7, 200.8	12.5	50
Magnesium, Total (7439-95-4)	200.7, 200.8	10	50
Molybdenum, Total (7439-98-7)	200.8	0.1	0.5
Manganese, Total (7439-96-5)	200.8	0.1	0.5
NWTPH Dx [4]	Ecology NWTPH Dx	250	250
NWTPH Gx [5]	Ecology NWTPH Gx	250	250
Tin, Total (7440-31-5)	200.8	0.3	1.5
Titanium, Total (7440-32-6)	200.8	0.5	2.5

METALS, CYANIDE & TOTAL PHENOLS			
Antimony, Total (7440-36-0)	200.8	0.3	1.0
Arsenic, Total (7440-38-2)	200.8	0.1	0.5
Beryllium, Total (7440-41-7)	200.8	0.1	0.5
Cadmium, Total (7440-43-9)	200.8	0.05	0.25
Chromium (hex) dissolved (18540-29-9)	SM3500-Cr B	5	10
Chromium, Total (7440-47-3)	200.8	0.2	1.0
Copper, Total (7440-50-8)	200.8	0.4	2.0
Lead, Total (7439-92-1)	200.8	0.1	0.5
Mercury, Total (7439-97-6)	1631E	0.0002	0.0005
Nickel, Total (7440-02-0)	200.8	0.1	0.5
Selenium, Total (7782-49-2)	200.8	1.0	1.0
Silver, Total (7440-22-4)	200.8	0.04	0.2
Thallium, Total (7440-28-0)	200.8	0.09	0.36
Zinc, Total (7440-66-6)	200.8	0.5	2.5
Cyanide, Total (57-12-5)	335.4, SM4500-CN-C,E	5	10
Cyanide, Weak Acid Dissociable	SM4500-CN I	5	10
Cyanide, Free Amenable to Chlorination (Available Cyanide)	SM4500-CN G	5	10
Phenols, Total	EPA 420.1		50
ACID COMPOUNDS			
2-Chlorophenol (95-57-8)	625	1.0	2.0
2,4-Dichlorophenol (120-83-2)	625	0.5	1.0

2,4-Dimethylphenol (105-67-9)	625	0.5	1.0
4,6-dinitro-o-cresol (534-52-1) (2-methyl-4,6,-dinitrophenol)	625/1625B	2.0	4.0
2,4 dinitrophenol (51-28-5)	625	1.5	3.0
2-Nitrophenol (88-75-5)	625	0.5	1.0
4-nitrophenol (100-02-7)	625	1.0	2.0
Parachlorometa cresol (59-50-7) (4-chloro-3-methylphenol)	625	1.0	2.0
Pentachlorophenol (87-86-5)	625	0.5	1.0
Phenol (108-95-2)	625	2.0	4.0
2,4,6-Trichlorophenol (88-06-2)	625	2.0	4.0
VOLATILE COMPOUNDS			
Acrolein (107-02-8)	624	5	10
Acrylonitrile (107-13-1)	624	1.0	2.0
Benzene (71-43-2)	624	1.0	2.0
Bromoform (75-25-2)	624	1.0	2.0
Carbon tetrachloride (56-23-5)	624/601 or SM6230B	1.0	2.0
Chlorobenzene (108-90-7)	624	1.0	2.0
Chloroethane (75-00-3)	624/601	1.0	2.0
2-Chloroethylvinyl Ether (110-75-8)	624	1.0	2.0
Chloroform (67-66-3)	624 or SM6210B	1.0	2.0
Dibromochloromethane (124-48-1)	624	1.0	2.0
1,2-Dichlorobenzene (95-50-1)	624	1.9	7.6
1,3-Dichlorobenzene (541-73-1)	624	1.9	7.6
1,4-Dichlorobenzene (106-46-7)	624	4.4	17.6
Dichlorobromomethane (75-27-4)	624	1.0	2.0
1,1-Dichloroethane (75-34-3)	624	1.0	2.0
1,2-Dichloroethane (107-06-2)	624	1.0	2.0
1,1-Dichloroethylene (75-35-4)	624	1.0	2.0
1,2-Dichloropropane (78-87-5)	624	1.0	2.0
1,3-dichloropropene (mixed isomers) (1,2-dichloropropylene) (542-75-6) [6]	624	1.0	2.0
Ethylbenzene (100-41-4)	624	1.0	2.0
Methyl bromide (74-83-9) (Bromomethane)	624/601	5.0	10.0
Methyl chloride (74-87-3) (Chloromethane)	624	1.0	2.0
Methylene chloride (75-09-2)	624	5.0	10.0
1,1,2,2-Tetrachloroethane (79-34-5)	624	1.9	2.0
Tetrachloroethylene (127-18-4)	624	1.0	2.0
Toluene (108-88-3)	624	1.0	2.0
1,2-Trans-Dichloroethylene (156-60-5) (Ethylene dichloride)	624	1.0	2.0
1,1,1-Trichloroethane (71-55-6)	624	1.0	2.0
1,1,2-Trichloroethane (79-00-5)	624	1.0	2.0
Trichloroethylene (79-01-6)	624	1.0	2.0
Vinyl chloride (75-01-4)	624/SM6200B	1.0	2.0
BASE/NEUTRAL COMPOUNDS (compounds in bold are Ecology PBTs)			
Acenaphthene (83-32-9)	625	0.2	0.4
Acenaphthylene (208-96-8)	625	0.3	0.6
Anthracene (120-12-7)	625	0.3	0.6
Benzidine (92-87-5)	625	20	40
Benzyl butyl phthalate (85-68-7)	625	0.3	0.6
Benzo(*a*)anthracene (56-55-3)	625	0.3	0.6
Benzo(b)fluoranthene (3,4-benzofluoranthene) (205-99-2) [7]	610/625	0.8	1.6
Benzo(j)fluoranthene (205-82-3) [7]	625	0.5	1.0
Benzo(k)fluoranthene (11,12-benzofluoranthene) (207-08-9) [7]	610/625	0.8	1.6
Benzo(r,s,t)pentaphene (189-55-9)	625	1.3	5.0
Benzo(*a*)pyrene (50-32-8)	610/625	0.5	1.0

Benzo(*ghi*)Perylene (191-24-2)	610/625	0.5	1.0
Bis(*2-chloroethoxy)*methane (111-91-1)	625	5.3	21.2
Bis(*2-chloroethyl*)ether (111-44-4)	611/625	0.3	1.0
Bis(*2-chloroisopropyl*)ether (39638-32-9)	625	0.5	1.0
Bis(*2-ethylhexyl*)phthalate (117-81-7)	625	0.3	1.0
4-Bromophenyl phenyl ether (101-55-3)	625	0.3	0.5
2-Chloronaphthalene (91-58-7)	625	0.3	0.6
4-Chlorophenyl phenyl ether (7005-72-3)	625	0.3	0.5
Chrysene (218-01-9)	610/625	0.3	0.6
Dibenzo (a,h)acridine (226-36-8)	610M/625M	2.5	10.0
Dibenzo (a,j)acridine (224-42-0)	610M/625M	2.5	10.0
Dibenzo(a-*h*)anthracene (53-70-3)(1,2,5,6-dibenzanthracene)	625	0.8	1.6
Dibenzo(a,e)pyrene (192-65-4)	610M/625M	2.5	10.0
Dibenzo(a,h)pyrene (189-64-0)	625M	2.5	10.0
3,3-Dichlorobenzidine (91-94-1)	605/625	2.0	4.0
Diethyl phthalate (84-66-2)	625	1.9	7.6
Dimethyl phthalate (131-11-3)	625	1.6	6.4
Di-n-butyl phthalate (84-74-2)	625	0.5	1.0
2,4-dinitrotoluene (121-14-2)	609/625	1.0	2.0
2,6-dinitrotoluene (606-20-2)	609/625	1.0	2.0
Di-n-octyl phthalate (117-84-0)	625	0.3	0.6
1,2-Diphenylhydrazine (*as Azobenzene*)(122-66-7)	1625B, 625	5.0	20
Fluoranthene (206-44-0)	625	0.3	0.6
Fluorene (86-73-7)	625	0.3	0.6
Hexachlorobenzene (118-74-1)	612/625	0.3	0.6
Hexachlorobutadiene (87-68-3)	625	0.5	1.0
Hexachlorocyclopentadiene (77-47-4)	1625B/625	2.0	4.0
Hexachloroethane (67-72-1)	625	0.5	1.0
Indeno(*1,2,3-cd*)Pyrene (193-39-5)	610/625	0.5	1.0
Isophorone (78-59-1)	625	0.5	1.0
3-Methyl cholanthrene (56-49-5)	625	2.0	8.0
Naphthalene (91-20-3)	625	0.4	0.75
Nitrobenzene (98-95-3)	625	0.5	1.0
N-Nitrosodimethylamine (62-75-9)	607/625	2.0	4.0
N-Nitrosodi-n-propylamine (621-64-7)	607/625	0.5	1.0
N-Nitrosodiphenylamine (86-30-6)	625	1.0	2.0
Perylene (198-55-0)	625	1.9	7.6
Phenanthrene (85-01-8)	625	0.3	0.6
Pyrene (129-00-0)	625	0.3	0.6
1,2,4-Trichlorobenzene (120-82-1)	625	0.3	0.6
DIOXIN			
2,3,7,8-Tetra-Chlorodibenzo-P-Dioxin (176-40-16) (2,3,7,8 TCDD)	1613B	1.3 pg/L	5 pg/L

1. Detection level (DL) or detection limit means the minimum concentration of an analyte (substance) that can be measured and reported with a 99% confidence that the analyte concentration is greater than zero as determined by the procedure given in 40 CFR part 136, Appendix B.
2. Quantitation Level (QL) also known as Minimum Level of Quantitation (ML) – The smallest detectable concentration of analyte greater than the Detection Limit (DL) where the accuracy (precision & bias) achieves the objectives of the intended purpose. (Report of the Federal Advisory Committee on Detection and Quantitation Approaches and Uses in Clean Water Act Programs Submitted to the US Environmental Protection Agency, December 2007).
3. Soluble Biochemical Oxygen Demand method note: First, filter the sample through a Millipore Nylon filter (or equivalent) - pore size of 0.45-0.50 um (prep all filters by filtering 250 ml of laboratory grade deionized water through the filter and discard). Then, analyze sample as per method 5210-B.
4. NWTPH Dx - Northwest Total Petroleum Hydrocarbons Diesel Extended Range – see http://www.ecy.wa.gov/biblio/97602.html
5. NWTPH Gx - Northwest Total Petroleum Hydrocarbons Gasoline Extended Range – see http://www.ecy.wa.gov/biblio/97602.html
6. 1, 3-dichloroproylene (mixed isomers) - You may report this parameter as two separate parameters: cis-1, 3-dichlorpropropene (10061-01-5) and trans-1, 3-dichloropropene (10061-02-6).
7. Total Benzofluoranthenes - Because Benzo(b)fluoranthene, Benzo(j)fluoranthene and Benzo(k)fluoranthene co-elute you may report these three isomers as total benzofluoranthenes.

EXHIBIT D

Issuance Date: January 16, 2017
Effective Date: March 1, 2017
Expiration Date: February 28, 2022

National Pollutant Discharge Elimination System Waste Discharge Permit No. WA0022527

State of Washington
DEPARTMENT OF ECOLOGY
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

In compliance with the provisions of
The State of Washington Water Pollution Control Law
Chapter 90.48 Revised Code of Washington
and
The Federal Water Pollution Control Act
(The Clean Water Act)
Title 33 United States Code, Section 1342 et seq.

Vashon Wastewater Treatment Plant
King County Department of Natural Resources & Parks
Wastewater Treatment Division
201 S. Jackson St.
Seattle, WA 98104-3855

is authorized to discharge in accordance with the Special and General Conditions that follow.

Plant Location: 9621 SW 171 Street Vashon, WA 98070	Receiving Water: Puget Sound
Treatment Type: Oxidation Ditch	

Mark Henley, P.E.
Water Quality Section Manager
Northwest Regional Office
Washington State Department of Ecology

Exhibit D

Table of Contents

Summary of Permit Report Submittals

Refer to the Special and General Conditions of this permit for additional submittal requirements.

Permit Section	Submittal	Frequency	First Submittal Date
S3.A	Discharge Monitoring Report (DMR)	Monthly	April 15, 2017
S3.A	Discharge Monitoring Report (DMR)	Quarterly	July 15, 2017
S3.F	Reporting Permit Violations	As necessary	
S4.B	Plans for Maintaining Adequate Capacity	As necessary	
S4.D	Notification of New or Altered Sources	As necessary	
S5.F	Bypass Notification	As necessary	
S6.A.3	Pretreatment Report	1/year	April 30, 2017
S8	Acute Toxicity Effluent Test Results with Permit Renewal Application	2/permit cycle July 2019 January 2020	July 31, 2021
S9	Chronic Toxicity Effluent Test Results with Permit Renewal Application	2/permit cycle October 2019 March 2020	July 31, 2021
S10	Application for Permit Renewal	1/permit cycle	July 31, 2021
G1	Notice of Change in Authorization	As necessary	
G4	Reporting Planned Changes	As necessary	
G5	Engineering Report for Construction or Modification Activities	As necessary	
G7	Notice of Permit Transfer	As necessary	
G10	Duty to Provide Information	As necessary	
G20	Compliance Schedules	As necessary	
G21	Contract Submittal	As necessary	

Special Conditions

S1. Discharge limits

S1.A. Effluent limits

All discharges and activities authorized by this permit must comply with the terms and conditions of this permit. The discharge of any of the following pollutants more frequently than, or at a level in excess of, that identified and authorized by this permit violates the terms and conditions of this permit.

Beginning on the effective date of this permit, the Permittee may discharge treated domestic wastewater to the Puget Sound at the permitted location subject to compliance with the following limits:

Effluent Limits: Outfall 001 Latitude: 47.452917 Longitude: -122.433333		
Parameter	**Average Monthly [a]**	**Average Weekly [b]**
Biochemical Oxygen Demand (5-day) (BOD_5)	30 milligrams/liter (mg/L) 130 pounds/day (lbs/day) 85% removal of influent BOD_5	45 mg/L 195 lbs/day
Total Suspended Solids (TSS)	30 mg/L 130 lbs/day 85% removal of influent TSS	45 mg/L 195 lbs/day
Parameter	**Minimum**	**Maximum**
pH	6.0 standard units	9.0 standard units
Parameter	**Monthly Geometric Mean**	**Weekly Geometric Mean**
Fecal Coliform Bacteria [c]	200/100 milliliter (mL)	400/100 mL
Parameter	**Maximum Daily [d]**	
Total Residual Chlorine [f]	0.75 mg/L	

a	Average monthly effluent limit means the highest allowable average of daily discharges over a calendar month. To calculate the discharge value to compare to the limit, you add the value of each daily discharge measured during a calendar month and divide this sum by the total number of daily discharges measured. See footnote c for fecal coliform calculations.
b	Average weekly discharge limit means the highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges' measured during that week. See footnote c for fecal coliform calculations.
c	Ecology provides directions to calculate the monthly and the weekly geometric mean in publication No. 04-10-020, Information Manual for Treatment Plant Operators available at: http://www.ecy.wa.gov/pubs/0410020.pdf
d	Maximum daily effluent limit is the highest allowable daily discharge. The daily discharge is the average discharge of a pollutant measured during a calendar day. For pollutants with limits expressed in units of mass, calculate the daily discharge as the total mass of the pollutant discharged over the day. This does not apply to pH or temperature.
f	Chlorine limits apply only during periods when chlorine is used for partial or full disinfection of the effluent. When UV disinfection is the only disinfection method used, chlorine limits do not apply. When not using chlorine for disinfection during the monitoring period, enter qualifier code “M” into the WQWebDMR form.

S1.B. Mixing zone authorization

Mixing zone for Outfall 001

The following paragraphs define the maximum boundaries of the mixing zones:

Chronic mixing zone

The mixing zone is a circular region with radius of 400 feet measured from the center of the discharge port. The mixing zone extends from the bottom to the top of the water column. The concentration of pollutants at the edge of the chronic zone must meet chronic aquatic life criteria and human health criteria.

Acute mixing zone

The acute mixing zone is a circular region with radius of 40 feet measured from the center of the discharge port. The mixing zone extends from the bottom to the top of the water column. The concentration of pollutants at the edge of the acute zone must meet acute aquatic life criteria.

Available Dilution (dilution factor)	
Acute Aquatic Life Criteria	89
Chronic Aquatic Life Criteria	681
Human Health Criteria - Carcinogen	681
Human Health Criteria - Non-carcinogen	681

S2. Monitoring requirements

S2.A. Monitoring schedule

The Permittee must monitor in accordance with the following schedule and the requirements specified in Appendix A.

Parameter	Units & Speciation	Minimum Sampling Frequency	Sample Type
(1) Wastewater influent			
Wastewater Influent means the raw sewage flow from the collection system into the treatment facility. Sample the wastewater entering the headworks of the treatment plant excluding any side-stream returns from inside the plant.			
Flow	gpd	Continuous [a]	Metered/Recorded
BOD_5	mg/L	2/week [c]	24-hr Composite [b]
BOD_5	lbs/day	2/week	Calculation [d]
TSS	mg/L	2/week	24-hr Composite
TSS	lbs/day	2/week	Calculation [d]
(2) Final wastewater effluent			
Final Wastewater Effluent means wastewater exiting the last treatment process or operation. Typically, this is after or at the exit from the chlorine contact chamber or other disinfection process. The Permittee may take effluent samples for the BOD_5 analysis before or after the disinfection process. If taken after, the Permittee must dechlorinate and reseed the sample.			
BOD_5 [g]	mg/L	2/week	24-hr Composite
BOD_5	lbs/day	2/week	Calculation [d]
BOD_5	% removal	1/month	Calculation [e]
TSS	mg/L	2/week	24-hr Composite

Parameter	Units & Speciation	Minimum Sampling Frequency	Sample Type
TSS	lbs/day	2/week	Calculation
TSS	% removal	1/month	Calculation
Chlorine (Total Residual) [h]	mg/L	Daily, when used for disinfection	Grab [f]
Fecal Coliform [i]	CFUs /100 ml	2/week	Grab
pH [j]	Standard Units	Continuous	Metered/Recorded
(3) Effluent characterization – final wastewater effluent			
Acute Toxicity Testing	--	2/permit cycle	24-hr Composite
Chronic Toxicity Testing	--	2/permit cycle	24-hr Composite
Additional requirements specified in Permit Conditions S8 & S9.			
(4) Effluent characterization – final wastewater effluent			
Total Ammonia	mg/L as N	Quarterly [k]	24-hr Composite
Nitrate plus Nitrite Nitrogen	mg/L as N	Quarterly	24-hr Composite
Total Kjeldahl Nitrogen (TKN)	mg/L as N	Quarterly	24-hr Composite
(5) Permit renewal application requirements – final wastewater effluent			
The Permittee must record and report the wastewater treatment plant flow discharged on the day it collects the sample for priority pollutant testing with the discharge monitoring report.			
Temperature [l]	Degrees Celsius	Quarterly during 2020	Measurement
Dissolved Oxygen	mg/L	Quarterly during 2020	Grab
Oil and Grease	mg/L	Quarterly during 2020	Grab
Total Dissolved Solids	mg/L	Quarterly during 2020	24-hr Composite
Total Hardness	mg/L	Quarterly during 2020	24-hr Composite
Cyanide	micrograms/liter (µg/L)	Quarterly during 2020	Grab
Total Phosphorus	mg/L	Quarterly during 2020	24-hr Composite
Priority Pollutants (PP) – Total Metals	µg/L; nanograms(ng/L) for mercury	Quarterly during 2020	24-hr Composite Grab for mercury

a	Continuous means uninterrupted except for brief lengths of time for calibration, power failure, or unanticipated equipment repair or maintenance. The time interval for the associated data logger must be no greater than 30 minutes. The Permittee must sample every 4 hours when continuous monitoring is not possible.
b	24-hour composite means a series of individual samples collected over a 24-hour period into a single container, and analyzed as one sample.
c	2/week means two (2) times during each calendar week.
d	Calculated means figured concurrently with the respective sample, using the following formula: Concentration (in mg/L) X Flow (in MGD) X Conversion Factor (8.34) = lbs/day
e	% removal = $\frac{\text{Influent concentration (mg/L)} - \text{Effluent concentration (mg/L)}}{\text{Influent concentration (mg/L)}} \times 100$ Calculate the percent (%) removal of BOD_5 and TSS using the above equation.
f	Grab means an individual sample collected over a fifteen (15) minute, or less, period.
g	Take effluent samples for the BOD_5 analysis before or after the disinfection process. If taken after, and if sampling occurs during a period when chlorine is being used for disinfection, dechlorinate and reseed the sample.
h	Chlorine limits apply only during emergency periods when UV disinfection is not available and the Permittee uses chlorine to disinfect effluent. During normal operations with UV disinfection, chlorine limits do not apply. When not using chlorine during the monitoring period, enter qualifier code “M” into the WQWebDMR form to indicate that for chlorine was conditional and not required for the monitoring period.

Parameter		Units & Speciation	Minimum Sampling Frequency	Sample Type
i	Report a numerical value for fecal coliforms following the procedures in Ecology's *Information Manual for Wastewater Treatment Plant Operators*, Publication Number 04-10-020 available at: http://www.ecy.wa.gov/programs/wq/permits/guidance.html . Do not report a result as too numerous to count (TNTC).			
j	The Permittee must report the instantaneous maximum and minimum pH daily. Do not average pH values.			
k	Quarterly sampling periods are January through March, April through June, July through September, and October through December. See condition S3.A.10.b for additional details.			
l	Temperature grab sampling must occur when the effluent is at or near its daily maximum temperature, which usually occurs in the late afternoon.			

S2.B. Sampling and analytical procedures

Samples and measurements taken to meet the requirements of this permit must represent the volume and nature of the monitored parameters. The Permittee must conduct representative sampling of any unusual discharge or discharge condition, including bypasses, upsets, and maintenance-related conditions that may affect effluent quality.

Sampling and analytical methods used to meet the monitoring requirements specified in this permit must conform to the latest revision of the *Guidelines Establishing Test Procedures for the Analysis of Pollutants* contained in 40 CFR Part 136 (or as applicable in 40 CFR subchapters N [Parts 400–471] or O [Parts 501-503]) unless otherwise specified in this permit . Ecology may only specify alternative methods for parameters without permit limits and for those parameters without an EPA approved test method in 40 CFR Part 136.

S2.C. Flow measurement and continuous monitoring devices

The Permittee must:

1. Select and use appropriate flow measurement and continuous monitoring devices and methods consistent with accepted scientific practices.
2. Install, calibrate, and maintain these devices to ensure the accuracy of the measurements is consistent with the accepted industry standard, the manufacturer's recommendation, and approved O&M manual procedures for the device and the wastestream.
3. Calibrate continuous monitoring instruments weekly unless it can demonstrate a longer period is sufficient based on monitoring records. The Permittee:
    a. May calibrate apparatus for continuous monitoring of dissolved oxygen by air calibration.
    b. Must calibrate continuous pH measurement instruments using a grab sample analyzed in the lab with a pH meter calibrated with standard buffers and analyzed within 15 minutes of sampling.

4. Calibrate flow-monitoring devices at a minimum frequency of at least one calibration per year or according to manufacturer's recommendation for that type of device.
5. Maintain calibration records for at least three years.

S2.D. Laboratory accreditation

The Permittee must ensure that all monitoring data required by Ecology for permit specified parameters is prepared by a laboratory registered or accredited under the provisions of chapter 173-50 WAC, *Accreditation of Environmental Laboratories*. Flow, temperature, settleable solids, conductivity, pH, and internal process control parameters are exempt from this requirement. The Permittee must obtain accreditation for conductivity and pH if it must receive accreditation or registration for other parameters.

S2.E. Request for reduction in monitoring

The Permittee may request a reduction of the sampling frequency after twelve (12) months of monitoring. Ecology will review each request and at its discretion grant the request when it reissues the permit or by a permit modification.

The Permittee must:

1. Provide a written request.
2. Clearly state the parameters for which it is requesting reduced monitoring.
3. Clearly state the justification for the reduction.

S3. Reporting and recording requirements

The Permittee must monitor and report in accordance with the following conditions. Falsification of information submitted to Ecology is a violation of the terms and conditions of this permit.

S3.A. Discharge monitoring reports

The first monitoring period begins on the effective date of the permit (unless otherwise specified). The Permittee must:

1. Summarize, report, and submit monitoring data obtained during each monitoring period on the electronic discharge monitoring report (DMR) form provided by Ecology within the Water Quality Permitting Portal. Include data for each of the parameters tabulated in Special Condition S2 and as required by the form. Report a value for each day sampling occurred (unless specifically exempted in the permit) and for the summary values (when applicable) included on the electronic form.
2. Enter the "No Discharge" reporting code for an entire DMR, for a specific monitoring point, or for a specific parameter as appropriate, if the Permittee did not discharge wastewater or a specific pollutant during a given monitoring period.

3. Report single analytical values below detection as "less than the detection level (DL)" by entering < followed by the numeric value of the detection level (e.g. < 2.0) on the DMR. If the method used did not meet the minimum DL and quantitation level (QL) identified in the permit, report the actual QL and DL in the comments or in the location provided.
4. **Not** report zero for bacteria monitoring. Report as required by the laboratory method.
5. Calculate and report an arithmetic average value for each day for bacteria if multiple samples were taken in one day.
6. Calculate the geometric mean values for bacteria (unless otherwise specified in the permit) using:
   a. The reported numeric value for all bacteria samples measured above the detection value except when it took multiple samples in one day. If the Permittee takes multiple samples in one day it must use the arithmetic average for the day in the geometric mean calculation.
   b. The detection value for those samples measured below detection.
7. Report the test method used for analysis in the comments if the laboratory used an alternative method not specified in the permit and as allowed in Appendix A.
8. Calculate average values and calculated total values (unless otherwise specified in the permit) using:
   a. The reported numeric value for all parameters measured between the agency-required detection value and the agency-required quantitation value.
   b. One-half the detection value (for values reported below detection) if the lab detected the parameter in another sample from the same monitoring point for the reporting period.
   c. Zero (for values reported below detection) if the lab did not detect the parameter in another sample for the reporting period.
9. Report single-sample grouped parameters (for example: priority pollutants) on the WQWebDMR form and include: sample date, concentration detected, detection limit (DL) (as necessary), and laboratory quantitation level (QL) (as necessary).

   The Permittee must also submit an electronic copy of the laboratory report as an attachment using WQWebDMR. The contract laboratory reports must also include information on the chain of custody, QA/QC results, and documentation of accreditation for the parameter.
10. Ensure that DMRs are electronically submitted no later than the dates specified below, unless otherwise specified in this permit.
11. Submit DMRs for parameters with the monitoring frequencies specified in S2 (monthly, quarterly, annual, etc.) at the reporting schedule identified below.

The Permittee must:

a. Submit **monthly** DMRs by the 15th day of the following month.

b. Submit **quarterly DMRs**, unless otherwise specified in the permit, by the 15th day of the month following the monitoring period. Quarterly sampling periods are January through March, April through June, July through September, and October through December. The Permittee must submit the first quarterly DMR on July 15, 2017 for the quarter beginning on April 1, 2017.

S3.B. Permit submittals and schedules

The Permittee must use the Water Quality Permitting Portal – Permit Submittals application (unless otherwise specified in the permit) to submit all other written permit-required reports by the date specified in the permit.

When another permit condition requires submittal of a paper (hard-copy) report, the Permittee must ensure that it is postmarked or received by Ecology no later than the dates specified by this permit. Send these paper reports to Ecology at:

Water Quality Permit Coordinator
Department of Ecology
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

S3.C. Records retention

The Permittee must retain records of all monitoring information for a minimum of three (3) years. Such information must include all calibration and maintenance records and all original recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for this permit. The Permittee must extend this period of retention during the course of any unresolved litigation regarding the discharge of pollutants by the Permittee or when requested by Ecology.

S3.D. Recording of results

For each measurement or sample taken, the Permittee must record the following information:

1. The date, exact place, method, and time of sampling or measurement.
2. The individual who performed the sampling or measurement.
3. The dates the analyses were performed.
4. The individual who performed the analyses.
5. The analytical techniques or methods used.
6. The results of all analyses.

S3.E. Additional monitoring by the Permittee

If the Permittee monitors any pollutant more frequently than required by Special Condition S2 of this permit, then the Permittee must include the results of such monitoring in the calculation and reporting of the data submitted in the Permittee's DMR unless otherwise specified by Special Condition S2.

S3.F. Reporting permit violations

The Permittee must take the following actions when it violates or is unable to comply with any permit condition:

1. Immediately take action to stop, contain, and cleanup unauthorized discharges or otherwise stop the noncompliance and correct the problem.
2. If applicable, immediately repeat sampling and analysis. Submit the results of any repeat sampling to Ecology within thirty (30) days of sampling.

a. Immediate reporting

The Permittee must **immediately** report to Ecology and the Department of Health, Shellfish Program, and the Local Health Jurisdiction (at the numbers listed below), all:

- Failures of the disinfection system.
- Collection system overflows.
- Plant bypasses discharging to marine surface waters.
- Any other failures of the sewage system (pipe breaks, etc.)

Northwest Regional Office	**425-649-7000**
Department of Health, Shellfish Program	**360-236-3330 (business hours)** **360-789-8962 (after business hours)**
Public Health Seattle-King County	**206-477-8050 (Mon-Fri 8 am to 4 pm)**

Additionally, for any sanitary sewer overflow (SSO) that discharges to a municipal separate storm sewer system (MS4), the Permittee must notify the appropriate MS4 owner or operator.

b. Twenty-four-hour reporting

The Permittee must report the following occurrences of noncompliance by telephone, to Ecology at the telephone numbers listed above, within 24 hours from the time the Permittee becomes aware of any of the following circumstances:

1. Any noncompliance that may endanger health or the environment, unless previously reported under immediate reporting requirements.
2. Any unanticipated bypass that causes an exceedance of an effluent limit in the permit (See Part S5.F, “Bypass Procedures”).
3. Any upset that causes an exceedance of an effluent limit in the permit (See G.15, “Upset”).
4. Any violation of a maximum daily or instantaneous maximum discharge limit for any of the pollutants in Section S1.A of this permit.
5. Any overflow prior to the treatment works, whether or not such overflow endangers health or the environment or exceeds any effluent limit in the permit.

c. Report within five days

The Permittee must also submit a written report within five days of the time that the Permittee becomes aware of any reportable event under subparts a or b, above. The report must contain:

1. A description of the noncompliance and its cause.
2. The period of noncompliance, including exact dates and times.
3. The estimated time the Permittee expects the noncompliance to continue if not yet corrected.
4. Steps taken or planned to reduce, eliminate, and prevent recurrence of the noncompliance.
5. If the noncompliance involves an overflow prior to the treatment works, an estimate of the quantity (in gallons) of untreated overflow.

d. Waiver of written reports

Ecology may waive the written report required in subpart c, above, on a case-by-case basis upon request if the Permittee has submitted a timely oral report.

e. All other permit violation reporting

The Permittee must report all permit violations, which do not require immediate or within 24 hours reporting, when it submits monitoring reports for S3.A ("Reporting"). The reports must contain the information listed in subpart c, above. Compliance with these requirements does not relieve the Permittee from responsibility to maintain continuous compliance with the terms and conditions of this permit or the resulting liability for failure to comply.

S3.G. Other reporting

a. Spills of oil or hazardous materials

The Permittee must report a spill of oil or hazardous materials in accordance with the requirements of RCW 90.56.280 and chapter 173-303-145. You can obtain further instructions at the following website: http://www.ecy.wa.gov/programs/spills/other/reportaspill.htm .

b. Failure to submit relevant or correct facts

Where the Permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application, or in any report to Ecology, it must submit such facts or information promptly.

S3.H. Maintaining a copy of this permit

The Permittee must keep a copy of this permit at the facility and make it available upon request to Ecology inspectors.

S4. Facility loading

S4.A. Design criteria

The flows or waste loads for the permitted facility must not exceed the following design criteria:

Maximum Month Design Flow (MMDF)	**0.52 MGD**
BOD_5 Influent Loading for Maximum Month	**671 lbs/day**
TSS Influent Loading for Maximum Month	**671 lbs/day**

S4.B. Plans for maintaining adequate capacity

a. Conditions triggering plan submittal

The Permittee must submit a plan and a schedule for continuing to maintain capacity to Ecology when:

1. The actual flow or waste load reaches 85 percent of any one of the design criteria in S4.A for three consecutive months.
2. The projected plant flow or loading would reach design capacity within five years.

b. Plan and schedule content

The plan and schedule must identify the actions necessary to maintain adequate capacity for the expected population growth and to meet the limits and requirements of the permit. The Permittee must consider the following topics and actions in its plan.

1. Analysis of the present design and proposed process modifications.
2. Reduction or elimination of excessive infiltration and inflow of uncontaminated ground and surface water into the sewer system.
3. Limits on future sewer extensions or connections or additional waste loads.
4. Modification or expansion of facilities.
5. Reduction of industrial or commercial flows or waste loads.

Engineering documents associated with the plan must meet the requirements of WAC 173-240-060, "Engineering Report," and be approved by Ecology prior to any construction.

S4.C. Duty to mitigate

The Permittee must take all reasonable steps to minimize or prevent any discharge or sludge use or disposal in violation of this permit that has a reasonable likelihood of adversely affecting human health or the environment.

S4.D. Notification of new or altered sources

1. The Permittee must submit written notice to Ecology whenever any new discharge or a substantial change in volume or character of an existing discharge into the wastewater treatment plant is proposed which:

a. Would interfere with the operation of, or exceed the design capacity of, any portion of the wastewater treatment plant.

b. Is not part of an approved general sewer plan or approved plans and specifications.

c. Is subject to pretreatment standards under 40 CFR Part 403 and Section 307(b) of the Clean Water Act.

2. This notice must include an evaluation of the wastewater treatment plant's ability to adequately transport and treat the added flow and/or waste load, the quality and volume of effluent to be discharged to the treatment plant, and the anticipated impact on the Permittee's effluent [40 CFR 122.42(b)].

S5. Operation and maintenance

The Permittee must at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances), which are installed to achieve compliance with the terms and conditions of this permit. Proper operation and maintenance also includes keeping a daily operation logbook (paper or electronic), adequate laboratory controls, and appropriate quality assurance procedures. This provision of the permit requires the Permittee to operate backup or auxiliary facilities or similar systems only when the operation is necessary to achieve compliance with the conditions of this permit.

S5.A. Certified operator

This permitted facility must be operated by an operator certified by the state of Washington for at least a Class II plant. This operator must be in responsible charge of the day-to-day operation of the wastewater treatment plant. An operator certified for at least a Class I plant must be in charge during all regularly scheduled shifts. The Permittee must notify Ecology when the operator in charge at the facility changes. It must provide the new operator's name and certification level and provide the name of the operator leaving the facility.

S5.B. Operation and maintenance program

The Permittee must:

1. Institute an adequate operation and maintenance program for the entire sewage system.

2. Keep maintenance records on all major electrical and mechanical components of the treatment plant, as well as the sewage system and pumping stations. Such records must clearly specify the frequency and type of maintenance recommended by the manufacturer and must show the frequency and type of maintenance performed.

3. Make maintenance records available for inspection at all times.

S5.C. Short-term reduction

The Permittee must schedule any facility maintenance, which might require interruption of wastewater treatment and degrade effluent quality, during non-critical water quality periods and carry this maintenance out according to the approved O&M manual or as otherwise approved by Ecology.

If a Permittee contemplates a reduction in the level of treatment that would cause a violation of permit discharge limits on a short-term basis for any reason, and such reduction cannot be avoided, the Permittee must:

1. Give written notification to Ecology, if possible, thirty (30) days prior to such activities.
2. Detail the reasons for, length of time of, and the potential effects of the reduced level of treatment.

This notification does not relieve the Permittee of its obligations under this permit.

S5.D. Electrical power failure

The Permittee must ensure that adequate safeguards prevent the discharge of untreated wastes or wastes not treated in accordance with the requirements of this permit during electrical power failure at the treatment plant and/or sewage lift stations. Adequate safeguards include, but are not limited to, alternate power sources, standby generator(s), or retention of inadequately treated wastes.

The Permittee must maintain Reliability Class II (EPA 430-99-74-001) at the wastewater treatment plant. Reliability Class II requires a backup power source sufficient to operate all vital components and critical lighting and ventilation during peak wastewater flow conditions. Vital components used to support the secondary processes (i.e., mechanical aerators or aeration basin air compressors) need not be operable to full levels of treatment, but must be sufficient to maintain the biota.

S5.E. Prevent connection of inflow

The Permittee must strictly enforce its sewer ordinances and not allow the connection of inflow (roof drains, foundation drains, etc.) to the sanitary sewer system.

S5.F. Bypass procedures

A bypass is the intentional diversion of waste streams from any portion of a treatment facility. This permit prohibits all bypasses except when the bypass is for essential maintenance, as authorized in special condition S5.F.1, or is approved by Ecology as an anticipated bypass following the procedures in S5.F.2.

1. **Bypass for essential maintenance without the potential to cause violation of permit limits or conditions**

   This permit allows bypasses for essential maintenance of the treatment system when necessary to ensure efficient operation of the system. The Permittee may bypass the treatment system for essential maintenance only if doing so does not cause violations of effluent limits. The Permittee is not required to notify Ecology when bypassing for essential maintenance. However the Permittee must comply with the monitoring requirements specified in special condition S2.B.

2. **Anticipated bypasses for non-essential maintenance**

   Ecology may approve an anticipated bypass under the conditions listed below. This permit prohibits any anticipated bypass that is not approved through the following process.

   a. If a bypass is for non-essential maintenance, the Permittee must notify Ecology, if possible, at least ten (10) days before the planned date of bypass. The notice must contain:

      - A description of the bypass and the reason the bypass is necessary.
      - An analysis of all known alternatives which would eliminate, reduce, or mitigate the potential impacts from the proposed bypass.
      - A cost-effectiveness analysis of alternatives.
      - The minimum and maximum duration of bypass under each alternative.
      - A recommendation as to the preferred alternative for conducting the bypass.
      - The projected date of bypass initiation.
      - A statement of compliance with SEPA.
      - A request for modification of water quality standards as provided for in WAC 173-201A-410, if an exceedance of any water quality standard is anticipated.
      - Details of the steps taken or planned to reduce, eliminate, and prevent recurrence of the bypass.

   b. For probable construction bypasses, the Permittee must notify Ecology of the need to bypass as early in the planning process as possible. The Permittee must consider the analysis required above during the project planning and design process. The project-specific engineering report as well as the plans and specifications must include details of probable construction bypasses to the extent practical. In cases where the Permittee determines the probable need to bypass early, the Permittee must continue to analyze conditions up to and including the construction period in an effort to minimize or eliminate the bypass.

c. Ecology will determine if the Permittee has met the conditions of special condition S5.F.2 a and b and consider the following prior to issuing a determination letter, an administrative order, or a permit modification as appropriate for an anticipated bypass:

- If the Permittee planned and scheduled the bypass to minimize adverse effects on the public and the environment.
- If the bypass is unavoidable to prevent loss of life, personal injury, or severe property damage. "Severe property damage" means substantial physical damage to property, damage to the treatment facilities which would cause them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass.
- If feasible alternatives to the bypass exist, such as:
  - The use of auxiliary treatment facilities.
  - Retention of untreated wastes.
  - Stopping production.
  - Maintenance during normal periods of equipment downtime, but not if the Permittee should have installed adequate backup equipment in the exercise of reasonable engineering judgment to prevent a bypass which occurred during normal periods of equipment downtime or preventative maintenance.
  - Transport of untreated wastes to another treatment facility.

S5.G. Operations and maintenance (O&M) manual

a. O&M manual submittal and requirements

The Permittee must:

1. Review the O&M Manual at least annually.
2. Submit to Ecology for review and approval substantial changes or updates to the O&M Manual whenever it incorporates them into the manual.
3. Keep the approved O&M Manual at the permitted facility.
4. Follow the instructions and procedures of this manual.

b. O&M manual components

In addition to the requirements of WAC 173-240-080(1) through (5), the O&M manual must be consistent with the guidance in Table G1-3 in the *Criteria for Sewage Works Design* (Orange Book), 2008. The O&M manual must include:

1. Emergency procedures for cleanup in the event of wastewater system upset or failure.

2. A review of system components which if failed could pollute surface water or could impact human health. Provide a procedure for a routine schedule of checking the function of these components.
3. Wastewater system maintenance procedures that contribute to the generation of process wastewater.
4. Reporting protocols for submitting reports to Ecology to comply with the reporting requirements in the discharge permit.
5. Any directions to maintenance staff when cleaning or maintaining other equipment or performing other tasks which are necessary to protect the operation of the wastewater system (for example, defining maximum allowable discharge rate for draining a tank, blocking all floor drains before beginning the overhaul of a stationary engine).
6. The treatment plant process control monitoring schedule.
7. Minimum staffing adequate to operate and maintain the treatment processes and carry out compliance monitoring required by the permit.

S6. Pretreatment

S6.A. General requirements

1. The Permittee must implement the Industrial Pretreatment Program in accordance with King County Code 28.84.060 and 28.82 as amended by King County Ordinance No. 11963 on January 1, 1996 and Ordinance No. 16929 on September 30, 2010; legal authorities, policies, procedures, and financial provisions described in the Permittee's approved pretreatment program submittal entitled "Industrial Pretreatment Program" and dated April 27, 1981; any approved revisions thereto; and the General Pretreatment Regulations (40 CFR Part 403), including any revisions to 40 CFR Part 403. At a minimum, the Permittee must undertake the following pretreatment implementation activities:
   a. Enforce categorical pretreatment standards under Section 307(b) and (c) of the Federal Clean Water Act (hereinafter, the Act), prohibited discharge standards as set forth in 40 CFR 403.5, local limits, or state standards, whichever are most stringent or apply at the time of issuance or modification of a local industrial waste discharge permit. Locally derived limits are defined as pretreatment standards under Section 307(d) of the Act and are not limited to categorical industrial facilities.
   b. Issue industrial waste discharge permits to all significant industrial users [SIUs, as defined in 40 CFR 403.3(v)(i)(ii)] contributing to the treatment system, including those from other jurisdictions. Industrial waste discharge permits must contain, as a minimum, all the requirements of 40 CFR 403.8 (f)(l)(iii). The Permittee must coordinate the permitting process with Ecology regarding any industrial facility that may possess a State Waste Discharge Permit issued by Ecology. Once issued, an industrial waste discharge permit takes precedence over a state-issued waste discharge permit.

c. Maintain and update, as necessary, records identifying the nature, character, and volume of pollutants contributed by industrial users to the POTW. The Permittee must maintain records for at least a three-year period.

d. Perform inspections, surveillance, and monitoring activities on industrial users to determine or confirm compliance with pretreatment standards and requirements. The Permittee must conduct a thorough inspection of SIUs annually. The Permittee must conduct regular local monitoring of SIU wastewaters commensurate with the character and volume of the wastewater but not less than once per year per SIU. If an SIU qualifies for reduced monitoring under 40 CFR 403.12(e)(3) (Middle Tier Categorical Industrial Users), inspection and monitoring must be conducted no less frequently than once every 2 years. The Permittee must collect and analyze samples in accordance with 40 CFR Part 403.12(b)(5)(ii)-(v) and 40 CFR Part 136.

e. Enforce and obtain remedies for noncompliance by any industrial users with applicable pretreatment standards and requirements. Once it identifies violations, the Permittee must take timely and appropriate enforcement action to address the noncompliance. The Permittee's action must follow its enforcement response procedures and any amendments, thereof.

f. Publish, at least annually in the largest daily newspaper in the Permittee's service area, a list of all non-domestic users which, at any time in the previous 12 months, were in significant noncompliance as defined in 40 CFR 403.8(f)(2)(vii).

g. If the Permittee elects to conduct sampling of an SIU's discharge in lieu of requiring user self-monitoring, it must satisfy all requirements of 40 CFR Part 403.12. This includes monitoring and record keeping requirements of Sections 403.12(g) and (o). For SIUs subject to categorical standards (CIUs), the Permittee may either complete baseline and initial compliance reports for the CIU (when required by 403.12(b) and (d)) or require these of the CIU. The Permittee must ensure that it provides SIUs the results of sampling in a timely manner, inform SIUs of their right to sample, their obligations to report any sampling they do, to respond to non-compliance, and to submit other notifications. These include a slug load report (403.12(f)), notice of changed discharge (403.12(j)), and hazardous waste notifications (403.12(p)). If sampling for the SIU, the Permittee must not sample less than once in every six-month period unless the Permittee's approved program includes procedures for reduction of monitoring for Middle-Tier or Non-Significant Categorical Users per 403.12(e)(2) and (3) and those procedures have been followed.

h. Develop and maintain a data management system designed to track the status of the Permittee's industrial user inventory, industrial user discharge characteristics, and compliance status.

i. Maintain adequate staff, funds, and equipment to implement its pretreatment program.

j. Establish, where necessary, contracts or legally binding agreements with contributing jurisdictions to ensure compliance with applicable pretreatment requirements by commercial or industrial users within these jurisdictions. These contracts or agreements must identify the agency responsible to perform the various implementation and enforcement activities in the contributing jurisdiction. To the extent that there are contributing jurisdictions in which the Permittee has legal authority which is inadequate with respect to the requirements of 40 CFR 403.8(f)(1), the Permittee must enter into a joint powers agreement that specifies the specific roles, responsibilities, and pretreatment requirements of each jurisdiction and enables the Permittee to enforce its pretreatment regulations within the contributing jurisdiction(s).

k. The Permittee must evaluate whether each new SIU needs a plan to control Slug Discharges within 1 year of designating the entity as a SIU. For purposes of this subsection, a Slug Discharge is any Discharge of a non-routine, episodic nature, including but not limited to an accidental spill or a non-customary batch Discharge, which has a reasonable potential to cause Interference or Pass Through, or in any other way violate the permittee’s regulations, local limits or permit conditions. The Permittee must make this evaluation available to Ecology upon request. The Permittee must required each SIU to immediately notify them of any changes at its facility affecting the potential for a Slug Discharge. If the Permittee decides that a slug control plan is needed, the plan shall contain, at a minimum, the following elements:

   i. Description of discharge practices, including non-routine batch Discharges;
   ii. Description of stored chemicals;
   iii. Procedures for immediately notifying the POTW of Slug Discharges, including any Discharge that would violate a prohibition under 40 CFR 403.5(b) with procedures for follow-up written notification within five days;

2. If necessary, procedures to prevent adverse impact from accidental spills, including inspection and maintenance of storage areas, handling and transfer of materials, loading and unloading operations, control of plant site run-off, worker training, building of containment structures or equipment, measures for containing toxic organic pollutants (including solvents), and/or measures and equipment for emergency response. Whenever Ecology determines that any waste source contributes pollutants to the Permittee's treatment works in violation of Section (b), (c), or (d) of Section 307 of the Act, and the Permittee has not taken adequate corrective action, Ecology will notify the Permittee of this determination. If the Permittee fails to take appropriate enforcement action within 30 days of this notification, Ecology may take appropriate enforcement action against the source or the Permittee.

3. Pretreatment Report

The Permittee must provide to Ecology an annual report that briefly describes its program activities during the previous calendar year.

The Permittee must submit the annual report to Ecology by April 30th of each year. The report must include the following information:

a. An updated non-domestic inventory.

b. Results of wastewater sampling at the treatment plant conducted to support local limit development, if completed during the reporting year. The Permittee must calculate removal rates for each pollutant and evaluate the adequacy of the existing local limits in prevention of treatment plant interference, pass through of pollutants that could affect receiving water quality, and sludge contamination.

c. Status of program implementation, including:

   i. Any substantial modifications to the pretreatment program as originally approved by Ecology, including staffing and funding levels.
   ii. Any interference, upset, or permit violations experienced at the POTW that are directly attributable to wastes from industrial users.
   iii. Listing of industrial users inspected and/or monitored, and a summary of the results.
   iv. Listing of industrial users scheduled for inspection and/or monitoring for the next year, and expected frequencies.
   v. Listing of industrial users notified of promulgated pretreatment standards and/or local standards as required in 40 CFR 403.8(f)(2)(iii). The list must indicate which industrial users are on compliance schedules and the final date of compliance for each.
   vi. Listing of industrial users issued industrial waste discharge permits.
   vii. Planned changes in the approved local pretreatment program. (See Subsection A.7. below)

d. Status of compliance activities, including:

   i. Listing of industrial users that failed to submit baseline monitoring reports or any other reports required under 40 CFR 403.12 and in the Permittee's pretreatment program, dated April 27, 1981.
   ii. Listing of industrial users that were at any time during the reporting period not complying with federal, state, or local pretreatment standards or with applicable compliance schedules for achieving those standards, and the duration of such noncompliance.
   iii. Summary of enforcement activities and other corrective actions taken or planned against non-complying industrial users. The Permittee must supply to Ecology a copy of the public notice of facilities that were in significant noncompliance.

4. The Permittee must request and obtain approval from Ecology before making any significant changes to the approved local pretreatment program. The Permittee must follow the procedure in 40 CFR 403.18 (b) and (c).

S6.B. Local limit development

As sufficient data become available, the Permittee, in consultation with Ecology, must reevaluate its local limits in order to prevent pass through or interference. If Ecology determines that any pollutant present causes pass through or interference, or exceeds established sludge standards, the Permittee must establish new local limits or revise existing local limits as required by 40 CFR 403.5. Ecology may also require the Permittee to revise or establish local limits for any pollutant discharged from the POTW that has a reasonable potential to exceed the Water Quality Standards, Sediment Standards, or established effluent limits, or causes whole effluent toxicity. Ecology makes this determination in the form of an Administrative Order.

Ecology may modify this permit to incorporate additional requirements relating to the establishment and enforcement of local limits for pollutants of concern. Any permit modification is subject to formal due process procedures under state and federal law and regulation.

S7. Solid wastes

S7.A. Solid waste handling

The Permittee must handle and dispose of all solid waste material in such a manner as to prevent its entry into state ground or surface water.

S7.B. Leachate

The Permittee must not allow leachate from its solid waste material to enter state waters without providing all known, available, and reasonable methods of treatment, nor allow such leachate to cause violations of the State Surface Water Quality Standards, Chapter 173-201A WAC, or the State Ground Water Quality Standards, Chapter 173-200 WAC. The Permittee must apply for a permit or permit modification as may be required for such discharges to state ground or surface waters.

S8. Acute toxicity

S8.A. Testing when there is no permit limit for acute toxicity

The Permittee must:

1. Conduct acute toxicity testing on final effluent during the third quarter of 2019 and the first quarter of 2020.
2. Conduct acute toxicity testing on a series of at least five concentrations of effluent, including 100% effluent and a control.
3. Submit the results to Ecology with the permit renewal application.
4. Use each of the following species and protocols for each acute toxicity test:

Acute Toxicity Tests	Species	Method
Fathead minnow 96-hour static-renewal test	*Pimephales promelas*	EPA-821-R-02-012
Daphnid 48-hour static test	*Ceriodaphnia dubia, Daphnia pulex,* or *Daphnia magna*	EPA-821-R-02-012

S8.B. Sampling and reporting requirements

1. The Permittee must submit all reports for toxicity testing in accordance with the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. Reports must contain toxicity data, bench sheets, and reference toxicant results for test methods. In addition, the Permittee must submit toxicity test data in electronic format (CETIS export file preferred) for entry into Ecology's database.
2. The Permittee must collect 24-hour composite effluent samples for toxicity testing. The Permittee must cool the samples to 0 - 6 degrees Celsius during collection and send them to the lab immediately upon completion. The lab must begin the toxicity testing as soon as possible but no later than 36 hours after sampling was completed.
3. The laboratory must conduct water quality measurements on all samples and test solutions for toxicity testing, as specified in the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*.
4. All toxicity tests must meet quality assurance criteria and test conditions specified in the most recent versions of the EPA methods listed in Subsection C and the Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. If Ecology determines any test results to be invalid or anomalous, the Permittee must repeat the testing with freshly collected effluent.
5. The laboratory must use control water and dilution water meeting the requirements of the EPA methods listed in Section A or pristine natural water of sufficient quality for good control performance.
6. The Permittee must conduct whole effluent toxicity tests on an unmodified sample of final effluent.
7. The Permittee may choose to conduct a full dilution series test during compliance testing in order to determine dose response. In this case, the series must have a minimum of five effluent concentrations and a control. The series of concentrations must include the acute critical effluent concentration (ACEC). The ACEC equals 1.12% effluent.
8. All whole effluent toxicity tests, effluent screening tests, and rapid screening tests that involve hypothesis testing must comply with the acute statistical power standard of 29% as defined in WAC 173-205-020. If the test does not meet the power standard, the Permittee must repeat the test on a fresh sample with an increased number of replicates to increase the power.

S9. Chronic toxicity

S9.A. Testing when there is no permit limit for chronic toxicity

The Permittee must:

1. Conduct acute toxicity testing on final effluent during fourth quarter of 2019 and the second quarter of 2020.
2. Conduct chronic toxicity testing on a series of at least five concentrations of effluent and a control. This series of dilutions must include the acute critical effluent concentration (ACEC). The ACEC equals 1.12% effluent. The series of dilutions should also contain the CCEC of 0.15% effluent.
3. Compare the ACEC to the control using hypothesis testing at the 0.05 level of significance as described in Appendix H, EPA/600/4-89/001.
4. Submit the results to Ecology with the permit renewal application.
5. Perform chronic toxicity tests with all of the following species and the most recent version of the following protocols:

Saltwater Chronic Test	Species	Method
Topsmelt survival and growth	*Atherinops affinis*	EPA/600/R-95/136
Mysid shrimp survival and growth	*Americamysis bahia* (formerly *Mysidopsis bahia*)	EPA-821-R-02-014

S9.B. Sampling and reporting requirements

1. The Permittee must submit all reports for toxicity testing in accordance with the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. Reports must contain toxicity data, bench sheets, and reference toxicant results for test methods. In addition, the Permittee must submit toxicity test data in electronic format (CETIS export file preferred) for entry into Ecology's database.
2. The Permittee must collect 24-hour composite effluent samples for toxicity testing. The Permittee must cool the samples to 0 - 6 degrees Celsius during collection and send them to the lab immediately upon completion. The lab must begin the toxicity testing as soon as possible but no later than 36 hours after sampling was completed.
3. The laboratory must conduct water quality measurements on all samples and test solutions for toxicity testing, as specified in the most recent version of Ecology Publication No. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*.
4. All toxicity tests must meet quality assurance criteria and test conditions specified in the most recent versions of the EPA methods listed in Section C and the Ecology Publication no. WQ-R-95-80, *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria*. If Ecology determines any test results to be invalid or anomalous, the Permittee must repeat the testing with freshly collected effluent.

5. The laboratory must use control water and dilution water meeting the requirements of the EPA methods listed in Subsection C or pristine natural water of sufficient quality for good control performance.
6. The Permittee must conduct whole effluent toxicity tests on an unmodified sample of final effluent.
7. The Permittee may choose to conduct a full dilution series test during compliance testing in order to determine dose response. In this case, the series must have a minimum of five effluent concentrations and a control. The series of concentrations must include the CCEC and the ACEC. The CCEC and the ACEC may either substitute for the effluent concentrations that are closest to them in the dilution series or be extra effluent concentrations. The CCEC equals 0.15% effluent. The ACEC equals 1.12% effluent.
8. All whole effluent toxicity tests that involve hypothesis testing must comply with the chronic statistical power standard of 39% as defined in WAC 173-205-020. If the test does not meet the power standard, the Permittee must repeat the test on a fresh sample with an increased number of replicates to increase the power.

S10. Application for permit renewal or modification for facility changes

The Permittee must submit an application for renewal of this permit by July 31, 2021.

The Permittee must also submit a new application or addendum at least one hundred eighty (180) days prior to commencement of discharges, resulting from the activities listed below, which may result in permit violations. These activities include any facility expansions, production increases, or other planned changes, such as process modifications, in the permitted facility.

General Conditions

G1. Signatory requirements

1. All applications, reports, or information submitted to Ecology must be signed and certified.
   a. In the case of corporations, by a responsible corporate officer. For the purpose of this section, a responsible corporate officer means:
      - A president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision making functions for the corporation, or
      - The manager of one or more manufacturing, production, or operating facilities, provided, the manager is authorized to make management decisions which govern the operation of the regulated facility including having the explicit or implicit duty of making major capital investment recommendations, and initiating and directing other comprehensive measures to assure long-term environmental compliance with environmental laws and regulations; the manager can ensure that the necessary systems are established or actions taken to gather complete and accurate information for permit application requirements; and where authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

   b. In the case of a partnership, by a general partner.
   c. In the case of sole proprietorship, by the proprietor.
   d. In the case of a municipal, state, or other public facility, by either a principal executive officer or ranking elected official.

   Applications for permits for domestic wastewater facilities that are either owned or operated by, or under contract to, a public entity shall be submitted by the public entity.
2. All reports required by this permit and other information requested by Ecology must be signed by a person described above or by a duly authorized representative of that person. A person is a duly authorized representative only if:
   a. The authorization is made in writing by a person described above and submitted to Ecology.
   b. The authorization specifies either an individual or a position having responsibility for the overall operation of the regulated facility, such as the position of plant manager, superintendent, position of equivalent responsibility, or an individual or position having overall responsibility for environmental matters. (A duly authorized representative may thus be either a named individual or any individual occupying a named position.)
3. Changes to authorization. If an authorization under paragraph G1.2, above, is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, a new authorization satisfying the requirements of paragraph G1.2, above, must be submitted to Ecology prior to or together with any reports, information, or applications to be signed by an authorized representative.

4. Certification. Any person signing a document under this section must make the following certification:

   "I certify under penalty of law, that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

G2. Right of inspection and entry

The Permittee must allow an authorized representative of Ecology, upon the presentation of credentials and such other documents as may be required by law:

1. To enter upon the premises where a discharge is located or where any records must be kept under the terms and conditions of this permit.
2. To have access to and copy, at reasonable times and at reasonable cost, any records required to be kept under the terms and conditions of this permit.
3. To inspect, at reasonable times, any facilities, equipment (including monitoring and control equipment), practices, methods, or operations regulated or required under this permit.
4. To sample or monitor, at reasonable times, any substances or parameters at any location for purposes of assuring permit compliance or as otherwise authorized by the Clean Water Act.

G3. Permit actions

This permit may be modified, revoked and reissued, or terminated either at the request of any interested person (including the Permittee) or upon Ecology's initiative. However, the permit may only be modified, revoked and reissued, or terminated for the reasons specified in 40 CFR 122.62, 40 CFR 122.64 or WAC 173-220-150 according to the procedures of 40 CFR 124.5.

1. The following are causes for terminating this permit during its term, or for denying a permit renewal application:
   a. Violation of any permit term or condition.
   b. Obtaining a permit by misrepresentation or failure to disclose all relevant facts.
   c. A material change in quantity or type of waste disposal.
   d. A determination that the permitted activity endangers human health or the environment, or contributes to water quality standards violations and can only be regulated to acceptable levels by permit modification or termination.

e. A change in any condition that requires either a temporary or permanent reduction, or elimination of any discharge or sludge use or disposal practice controlled by the permit.

f. Nonpayment of fees assessed pursuant to RCW 90.48.465.

g. Failure or refusal of the Permittee to allow entry as required in RCW 90.48.090.

2. The following are causes for modification but not revocation and reissuance except when the Permittee requests or agrees:

   a. A material change in the condition of the waters of the state.

   b. New information not available at the time of permit issuance that would have justified the application of different permit conditions.

   c. Material and substantial alterations or additions to the permitted facility or activities which occurred after this permit issuance.

   d. Promulgation of new or amended standards or regulations having a direct bearing upon permit conditions, or requiring permit revision.

   e. The Permittee has requested a modification based on other rationale meeting the criteria of 40 CFR Part 122.62.

   f. Ecology has determined that good cause exists for modification of a compliance schedule, and the modification will not violate statutory deadlines.

   g. Incorporation of an approved local pretreatment program into a municipality's permit.

3. The following are causes for modification or alternatively revocation and reissuance:

   a. When cause exists for termination for reasons listed in 1.a through 1.g of this section, and Ecology determines that modification or revocation and reissuance is appropriate.

   b. When Ecology has received notification of a proposed transfer of the permit. A permit may also be modified to reflect a transfer after the effective date of an automatic transfer (General Condition G7) but will not be revoked and reissued after the effective date of the transfer except upon the request of the new Permittee.

G4. Reporting planned changes

The Permittee must, as soon as possible, but no later than one hundred eighty (180) days prior to the proposed changes, give notice to Ecology of planned physical alterations or additions to the permitted facility, production increases, or process modification which will result in:

1. The permitted facility being determined to be a new source pursuant to 40 CFR 122.29(b).
2. A significant change in the nature or an increase in quantity of pollutants discharged.
3. A significant change in the Permittee's sludge use or disposal practices. Following such notice, and the submittal of a new application or supplement to the existing application, along with required engineering plans and reports, this permit may be modified, or revoked and reissued pursuant to 40 CFR 122.62(a) to specify and limit any pollutants not previously limited. Until such modification is effective, any new or increased discharge in excess of permit limits or not specifically authorized by this permit constitutes a violation.

G5. Plan review required

Prior to constructing or modifying any wastewater control facilities, an engineering report and detailed plans and specifications must be submitted to Ecology for approval in accordance with chapter 173-240 WAC. Engineering reports, plans, and specifications must be submitted at least one hundred eighty (180) days prior to the planned start of construction unless a shorter time is approved by Ecology. Facilities must be constructed and operated in accordance with the approved plans.

G6. Compliance with other laws and statutes

Nothing in this permit excuses the Permittee from compliance with any applicable federal, state, or local statutes, ordinances, or regulations.

G7. Transfer of this permit

In the event of any change in control or ownership of facilities from which the authorized discharge emanate, the Permittee must notify the succeeding owner or controller of the existence of this permit by letter, a copy of which must be forwarded to Ecology.

1. Transfers by Modification

   Except as provided in paragraph (2) below, this permit may be transferred by the Permittee to a new owner or operator only if this permit has been modified or revoked and reissued under 40 CFR 122.62(b)(2), or a minor modification made under 40 CFR 122.63(d), to identify the new Permittee and incorporate such other requirements as may be necessary under the Clean Water Act.

2. Automatic Transfers

   This permit may be automatically transferred to a new Permittee if:

   a. The Permittee notifies Ecology at least thirty (30) days in advance of the proposed transfer date.

   b. The notice includes a written agreement between the existing and new Permittees containing a specific date transfer of permit responsibility, coverage, and liability between them.

   c. Ecology does not notify the existing Permittee and the proposed new Permittee of its intent to modify or revoke and reissue this permit. A modification under this subparagraph may also be minor modification under 40 CFR 122.63. If this notice is not received, the transfer is effective on the date specified in the written agreement.

G8. Reduced production for compliance

The Permittee, in order to maintain compliance with its permit, must control production and/or all discharges upon reduction, loss, failure, or bypass of the treatment facility until the facility is restored or an alternative method of treatment is provided. This requirement applies in the situation where, among other things, the primary source of power of the treatment facility is reduced, lost, or fails.

G9. Removed substances

Collected screenings, grit, solids, sludges, filter backwash, or other pollutants removed in the course of treatment or control of wastewaters must not be resuspended or reintroduced to the final effluent stream for discharge to state waters.

G10. Duty to provide information

The Permittee must submit to Ecology, within a reasonable time, all information which Ecology may request to determine whether cause exists for modifying, revoking and reissuing, or terminating this permit or to determine compliance with this permit. The Permittee must also submit to Ecology upon request, copies of records required to be kept by this permit.

G11. Other requirements of 40 CFR

All other requirements of 40 CFR 122.41 and 122.42 are incorporated in this permit by reference.

G12. Additional monitoring

Ecology may establish specific monitoring requirements in addition to those contained in this permit by administrative order or permit modification.

G13. Payment of fees

The Permittee must submit payment of fees associated with this permit as assessed by Ecology.

G14. Penalties for violating permit conditions

Any person who is found guilty of willfully violating the terms and conditions of this permit is deemed guilty of a crime, and upon conviction thereof shall be punished by a fine of up to ten thousand dollars ($10,000) and costs of prosecution, or by imprisonment in the discretion of the court. Each day upon which a willful violation occurs may be deemed a separate and additional violation.

Any person who violates the terms and conditions of a waste discharge permit may incur, in addition to any other penalty as provided by law, a civil penalty in the amount of up to ten thousand dollars ($10,000) for every such violation. Each and every such violation is a separate and distinct offense, and in case of a continuing violation, every day's continuance is deemed to be a separate and distinct violation.

G15. Upset

Definition – “Upset” means an exceptional incident in which there is unintentional and temporary noncompliance with technology-based permit effluent limits because of factors beyond the reasonable control of the Permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

An upset constitutes an affirmative defense to an action brought for noncompliance with such technology-based permit effluent limits if the requirements of the following paragraph are met.

A Permittee who wishes to establish the affirmative defense of upset must demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:

1. An upset occurred and that the Permittee can identify the cause(s) of the upset.
2. The permitted facility was being properly operated at the time of the upset.
3. The Permittee submitted notice of the upset as required in Special Condition S3.F.
4. The Permittee complied with any remedial measures required under S3.F of this permit.

In any enforcement action the Permittee seeking to establish the occurrence of an upset has the burden of proof.

G16. Property rights

This permit does not convey any property rights of any sort, or any exclusive privilege.

G17. Duty to comply

The Permittee must comply with all conditions of this permit. Any permit noncompliance constitutes a violation of the Clean Water Act and is grounds for enforcement action; for permit termination, revocation and reissuance, or modification; or denial of a permit renewal application.

G18. Toxic pollutants

The Permittee must comply with effluent standards or prohibitions established under Section 307(a) of the Clean Water Act for toxic pollutants within the time provided in the regulations that establish those standards or prohibitions, even if this permit has not yet been modified to incorporate the requirement.

G19. Penalties for tampering

The Clean Water Act provides that any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than two (2) years per violation, or by both. If a conviction of a person is for a violation committed after a first conviction of such person under this condition, punishment shall be a fine of not more than $20,000 per day of violation, or by imprisonment of not more than four (4) years, or by both.

G20. Compliance schedules

Reports of compliance or noncompliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of this permit must be submitted no later than fourteen (14) days following each schedule date.

G21. Service agreement review

The Permittee must submit to Ecology any proposed service agreements and proposed revisions or updates to existing agreements for the operation of any wastewater treatment facility covered by this permit. The review is to ensure consistency with chapters 90.46 and 90.48 RCW as required by RCW 70.150.040(9). In the event that Ecology does not comment within a thirty-day (30) period, the Permittee may assume consistency and proceed with the service agreement or the revised/updated service agreement.

Appendix A

LIST OF POLLUTANTS WITH ANALYTICAL METHODS, DETECTION LIMITS AND QUANTITATION LEVELS

The Permittee must use the specified analytical methods, detection limits (DLs) and quantitation levels (QLs) in the following table for permit and application required monitoring unless:

- Another permit condition specifies other methods, detection levels, or quantitation levels.
- The method used produces measurable results in the sample and EPA has listed it as an EPA-approved method in 40 CFR Part 136.

If the Permittee uses an alternative method, not specified in the permit and as allowed above, it must report the test method, DL, and QL on the discharge monitoring report or in the required report.

If the Permittee is unable to obtain the required DL and QL in its effluent due to matrix effects, the Permittee must submit a matrix-specific detection limit (MDL) and a quantitation limit (QL) to Ecology with appropriate laboratory documentation.

Ecology added this appendix to the permit in order to reduce the number of analytical “non-detects” in permit-required monitoring and to measure effluent concentrations near or below criteria values where possible at a reasonable cost.

The lists below include conventional pollutants (as defined in CWA section 502(6) and 40 CFR Part 122.), some toxic or priority pollutants as defined in CWA section 307(a)(1) and listed in 40 CFR Part 122 Appendix D, 40 CFR Part 401.15 and 40 CFR Part 423 Appendix A), and nonconventionals. 40 CFR Part 122 Appendix D (Table V) identifies toxic pollutants and hazardous substances which are required to be reported by dischargers if expected to be present. This permit Appendix A list does not include those parameters.

CONVENTIONAL POLLUTANTS

Pollutant	CAS Number (if available)	Recommended Analytical Protocol	Detection (DL)[1] *µg/L unless specified*	Quantitation Level (QL)[2] *µg/L unless specified*
Biochemical Oxygen Demand		SM5210-B		2 mg/L
Biochemical Oxygen Demand, Soluble		SM5210-B [3]		2 mg/L
Fecal Coliform		SM 9221E,9222	N/A	Specified in method - sample aliquot dependent
Oil and Grease (HEM) (Hexane Extractable Material)		1664 A or B	1,400	5,000
pH		SM4500-H^+ B	N/A	N/A
Total Suspended Solids		SM2540-D		5 mg/L

NONCONVENTIONAL POLLUTANTS

Pollutant & CAS No. (if available)	CAS Number (if available)	Recommended Analytical Protocol	Detection (DL)[1] µg/L unless specified	Quantitation Level (QL)[2] µg/L unless specified
Alkalinity, Total		SM2320-B		5 mg/L as CaCO3
Aluminum, Total	7429-90-5	200.8	2.0	10
Ammonia, Total (as N)		SM4500-NH3-B and C/D/E/G/H		20
Barium Total	7440-39-3	200.8	0.5	2.0
BTEX (benzene +toluene + ethylbenzene + m,o,p xylenes)		EPA SW 846 8021/8260	1	2
Boron, Total	7440-42-8	200.8	2.0	10.0
Chemical Oxygen Demand		SM5220-D		10 mg/L

Exhibit D

NONCONVENTIONAL POLLUTANTS

Pollutant & CAS No. (if available)	CAS Number (if available)	Recommended Analytical Protocol	Detection (DL)[1] µg/L unless specified	Quantitation Level (QL)[2] µg/L unless specified
Chloride		SM4500-Cl B/C/D/E and SM4110 B		Sample and limit dependent
Chlorine, Total Residual		SM4500 Cl G		50.0
Cobalt, Total	7440-48-4	200.8	0.05	0.25
Color		SM2120 B/C/E		10 color units
Dissolved oxygen		SM4500-OC/OG		0.2 mg/L
Flow		Calibrated device		
Fluoride	16984-48-8	SM4500-F E	25	100
Hardness, Total		SM2340B		200 as CaCO3
Iron, Total	7439-89-6	200.7	12.5	50
Magnesium, Total	7439-95-4	200.7	10	50
Manganese, Total	7439-96-5	200.8	0.1	0.5
Molybdenum, Total	7439-98-7	200.8	0.1	0.5
Nitrate + Nitrite Nitrogen (as N)		SM4500-NO3- E/F/H		100
Nitrogen, Total Kjeldahl (as N)		SM4500-N_{org}B/C and SM4500NH_3-B/C/D/EF/G/H		300
NWTPH Dx [4]		Ecology NWTPH Dx	250	250
NWTPH Gx [5]		Ecology NWTPH Gx	250	250
Phosphorus, Total (as P)		SM 4500 PB followed by SM4500-PE/PF	3	10
Salinity		SM2520-B		3 practical salinity units or scale (PSU or PSS)
Settleable Solids		SM2540 -F		Sample and limit dependent
Soluble Reactive Phosphorus (as P)		SM4500-P E/F/G	3	10
Sulfate (as mg/L SO_4)		SM4110-B		0.2 mg/L
Sulfide (as mg/L S)		SM4500-S^2F/D/E/G		0.2 mg/L
Sulfite (as mg/L SO_3)		SM4500-SO3B		2 mg/L
Temperature (max. 7-day avg.)		Analog recorder or use micro-recording devices known as thermistors		0.2º C
Tin, Total	7440-31-5	200.8	0.3	1.5
Titanium, Total	7440-32-6	200.8	0.5	2.5
Total Coliform		SM 9221B, 9222B, 9223B	N/A	Specified in method - sample aliquot dependent
Total Organic Carbon		SM5310-B/C/D		1 mg/L
Total dissolved solids		SM2540 C		20 mg/L

PRIORITY POLLUTANTS	**PP #**	**CAS Number (if available)**	**Recommended Analytical Protocol**	**Detection (DL)[1] *µg/L unless specified***	**Quantitation Level (QL)[2] *µg/L unless specified***
METALS, CYANIDE & TOTAL PHENOLS					
Antimony, Total	114	7440-36-0	200.8	0.3	1.0
Arsenic, Total	115	7440-38-2	200.8	0.1	0.5
Beryllium, Total	117	7440-41-7	200.8	0.1	0.5
Cadmium, Total	118	7440-43-9	200.8	0.05	0.25
Chromium (hex) dissolved	119	18540-29-9	SM3500-Cr C	0.3	1.2
Chromium, Total	119	7440-47-3	200.8	0.2	1.0
Copper, Total	120	7440-50-8	200.8	0.4	2.0
Lead, Total	122	7439-92-1	200.8	0.1	0.5
Mercury, Total	123	7439-97-6	1631E	0.0002	0.0005
Nickel, Total	124	7440-02-0	200.8	0.1	0.5
Selenium, Total	125	7782-49-2	200.8	1.0	1.0
Silver, Total	126	7440-22-4	200.8	0.04	0.2
Thallium, Total	127	7440-28-0	200.8	0.09	0.36
Zinc, Total	128	7440-66-6	200.8	0.5	2.5
Cyanide, Total	121	57-12-5	335.4	5	10
Cyanide, Weak Acid Dissociable	121		SM4500-CN I	5	10
Cyanide, Free Amenable to Chlorination (Available Cyanide)	121		SM4500-CN G	5	10
Phenols, Total	65		EPA 420.1		50

1. Detection level (DL) or detection limit means the minimum concentration of an analyte (substance) that can be measured and reported with a 99% confidence that the analyte concentration is greater than zero as determined by the procedure given in 40 CFR part 136, Appendix B.

2. Quantitation Level (QL) also known as Minimum Level of Quantitation (ML) – The lowest level at which the entire analytical system must give a recognizable signal and acceptable calibration point for the analyte. It is equivalent to the concentration of the lowest calibration standard, assuming that the lab has used all method-specified sample weights, volumes, and cleanup procedures. The QL is calculated by multiplying the MDL by 3.18 and rounding the result to the number nearest to (1, 2, or 5) x 10^n, where n is an integer (64 FR 30417).
   ALSO GIVEN AS:
   The smallest detectable concentration of analyte greater than the Detection Limit (DL) where the accuracy (precision & bias) achieves the objectives of the intended purpose. (Report of the Federal Advisory Committee on Detection and Quantitation Approaches and Uses in Clean Water Act Programs Submitted to the US Environmental Protection Agency December 2007).

3. Soluble Biochemical Oxygen Demand method note: First, filter the sample through a Millipore Nylon filter (or equivalent) - pore size of 0.45-0.50 um (prep all filters by filtering 250 ml of laboratory grade deionized water through the filter and discard). Then, analyze sample as per method 5210-B.

4. NWTPH Dx - Northwest Total Petroleum Hydrocarbons Diesel Extended Range – see http://www.ecy.wa.gov/biblio/97602.html

5. NWTPH Gx - Northwest Total Petroleum Hydrocarbons Gasoline Extended Range – see http://www.ecy.wa.gov/biblio/97602.html

From: Brown, Chad (ECY) <CHBR461@ECY.WA.GOV>
Sent: Wednesday, December 07, 2022 2:21 PM EST
To: Gildersleeve, Melissa (ECY) <MGIL461@ECY.WA.GOV>
CC: Bugica, Kalman (ECY) <kbug461@ECY.WA.GOV>
Subject: Notes on EPA Ecology discussion of NC process / PS D.O.

Melissa,
Here are some key points from the outcome of this meeting---

- We explained our key points referenced below.
- After a lot of questions and discussion EPA agrees accepts our approach and accepts that we aren't going to be doing anything special for D.O. in Puget Sound.
- EPA latched on to one of our draft ideas that we could develop NC procedure documents for each parameter type and waterbody. For example. Performance-base process for each D.O.in marine; D.O. in freshwater; Temperature in freshwater; Temperature in Marine (not sure we need)…. And possibly pH in marine and fresh as well. They felt this gave them more approval options in the case the needed to move forward with just marine D.O. I pointed out that they would need a reason, not convenience for there process, to hold back others and move with just marine D.O.
- We identified two questions that Ecology needs to hear from EPA early in this process
    - Will a rule that considers only the NC of waters make it through ESA without any assessment of the species impacts? This is the basis of NC provisions – need to know this is not changing. (EPA R10 staff still seem to conflate NC with site-specific criteria development process in our standards which are based on biology.)
    - Will EPA support a Performance-based procedure that uses state boundary reference inputs? Example- is NC process now going to require that we model oceanic influence to pre-industrial conditions? Ben Cope has been supporting our take on this – he had use reference for incoming water from Canada on the Columbia R. TMDL.
- EPA R10 counsel attended but no legal staff from EPA HQ – Alex Fidis is tasked with bringing the 'decisions' from this meet to EPA counsel and the DOJ.

From: Brown, Chad (ECY)
Sent: Monday, November 21, 2022 5:26 PM
To: Lavigne, Ronald L (ATG) <ronald.lavigne@atg.wa.gov>
Cc: Bugica, Kalman (ECY) <kbug461@ECY.WA.GOV>; Koberstein, Marla (ECY) <mkob461@ECY.WA.GOV>; Gildersleeve, Melissa (ECY) <MGIL461@ECY.WA.GOV>
Subject: Follow-up information from today

Ron,

Thanks for the pre-meeting today. Here is a write-up regarding what we shared with you in the meeting.

Overview or the issue

EPA is asking that Ecology develop site-specific criteria for the Puget Sound within/ or concurrent to our current rulemaking for natural conditions provision. We believe that EPA's own policies and previous decisions work against a defensible rulemaking for Puget Sound D.O. until our current rulemaking is complete. We cannot add this element to the current rulemaking because it is beyond the scope of the CR-101 (attached to this email) which focuses on updating our NC provisions, not proposing any waterbody-specific criteria.

We also don't believe that these 2 rulemakings could be performed concurrently, because a PS D.O. criteria development that incorporates natural conditions would require us to rely on a process that has not yet been adopted into rule nor approved by EPA.

EPA's Current Policy

EPA's current national policy regarding natural conditions is found within *A Framework for Defining and Documenting Natural Conditions for Development of Site-Specific Natural Background Aquatic Life Criteria for Temperature, Dissolved Oxygen, and pH: Interim Document* (EPA 820-R-15-001; February 2015). Prior to announcing our rulemaking, we asked EPA is this guidance document stands as EPA's current methodology regarding natural condition. EPA confirmed this in a response letter to our inquiry. (response letter attached to this email.)

In this document, EPA states that their policy regarding establishing site-specific natural background criteria is that you establish site-specific numeric aquatic life criteria equal to the value of the natural background, where natural background is defined as due *only* to non-anthropogenic sources.

To do this, EPA says that States and authorized Tribes "should include the following [elements] in their water quality standards":

1. A definition of natural background
2. A provision that site-specific criteria may be set equal to natural background
3. A procedure for determining natural background or reference to another documenting describing the binding procedure that will be used.

These three elements are not novel to this document. In 1997, EPA released a memo entitled *Establishing Site Specific Aquatic Life Criteria Equal to Natural Background* (EPA Office of Water; November 1997). In that document, EPA notes that "in setting criteria equal to natural background the State or Tribe should, at a minimum, include in their water quality standards" the same three elements listed above.

Washington's Current WQS

For Washington's current water quality standards, I'd like to walk through each of these three elements:

1. **A definition of natural background.**

   At WAC 173-201A-020 *Definitions*, we define "natural conditions" or "natural background levels" as the surface water quality present before any human-caused pollution.

   Thus, in my perspective, our WQS contains this element.

2. **A provision that site-specific criteria may be set equal to natural background.**

   At WAC 173-201A-260(1) *Natural and irreversible human conditions*, we state that when a water body does not meet its assigned criteria due to "natural climatic or landscape attributes", the natural conditions are the criteria.

   Thus, our WQS contains this element. **However**, this section of our standards was disapproved by EPA in November 2021. Thus, this element is not applicable for Clean Water Act purposes.

   Additionally, we have this element at WAC 173-201A-310(3) in our Tier I protections. Note that this element was**not** disapproved by EPA in November 2021 but has the same identified "flaw" as -260(1) -- that it does not limit application to only aquatic life criteria.

3. **A procedure for determining natural background.**

   The WQS does not contain detailed language for how to determine natural background, as such.

   At 173-201A-430, we provide the steps that must be taken to develop site-specific criteria. This asserts that development of new criteria must be "scientifically justifiable", among other requirements.

   Thus, I am unsure if our WQS contains language that meets the requirements of this specific element.

Chelan UAA consideration

When we conducted the rulemaking for the Chelan UAA, we referred to the temperature criteria that resulted from the UAA as "site-specific criteria". During our preliminary review of the rule with EPA, they had us modify the technical support document to state that the SSC proposed in the Chelan UAA rule was not based on our SSC provision in part 430 of the standards. EPA asserted that we could not site this provision because part 430 must be based on a the biological needs of organisms in the waterbody and not on natural conditions of the waterbody.

When we reviewed our SSC provision, we agreed because it states that…

"The site-specific analyses for the development of a new water quality criterion must be conducted in a manner that is scientifically justifiable and consistent with the assumptions and rationale in "Guidelines for Deriving National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses," EPA 1985; and conducted in accordance with the procedures established in the "Water Quality Standards Handbook," EPA 1994, as revised." EPA, 1985 are procedures for developing biologically-based numeric criteria and do not consider natural conditions.

Therefore, based on EPA's comments and our review of Part 430, we placed the following note in the Chelan UAA rulemaking based on their comments – "Site-specific criteria [*established in this rule*] are used to describe water body specific criteria associated with the highest attainable use analysis and not the process described in CFR 131.11 or WAC 173-201A-430"

Conclusion

To conclude, from a federal perspective, we do not believe that our WQS contains all three elements necessary to establish site-specific criteria set equal to the natural background. While we clearly have a definition of natural conditions, we fail to have a specific procedure detailed on how we will determine natural background. However, even if one considers our site-specific criteria language to be sufficient, our SSC provision in WAC 173-201A-430 is not sufficient for basing an SSC on natural condition, as made clear in the language of the provision and as echoed in EPA's comments regarding the Chelan UAA rulemaking.

Chad Brown | Water Quality Management Unit Supervisor | Washington Department of Ecology
chad.brown@ecy.wa.gov | 360-522-6441 - mobile


Puget Sound Clean Water Alliance
February 28, 2023

Agenda

Time	Content	Speakers
9:00 – 9:10 AM	Introduction	Cassandra Moore Teresa Peterson
9:10 – 9:25	Context: PSCWA and Puget Sound Institute	Joel Baker
9:25 – 10:10 AM	Puget Sound Wastewater Service Affordability Analysis	Aimee Kinney Susan Burke
10:10 – 10:20 AM	Break	
10:20 – 11:15 AM	Overview of Modeling Results • Whidbey Region • Strait of Georgia & Northern Bays Region	Joel Baker
11:15 – 11:45 AM	Draft Modeling Workplan	Stefano Mazzilli
11:45 – 12:00 PM	Vision and Next Steps for PS CWA	Cassandra Moore Teresa Peterson

University of Washington Puget Sound Institute

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Ongoing Collaboration

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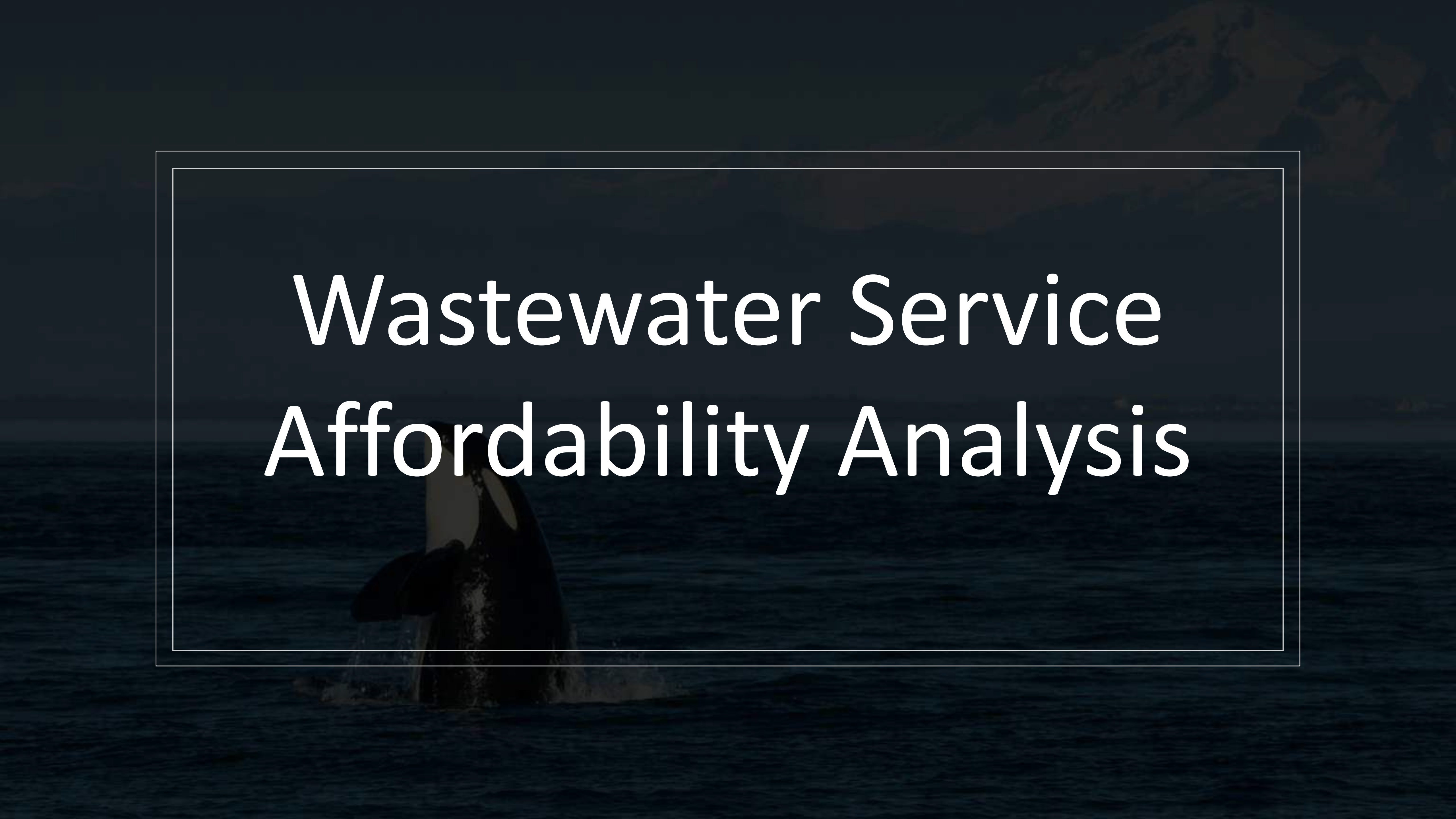
Puget Sound clean water alliance

- Address emerging science needs in the context of utility-scale decision making
- Move beyond nitrogen to consider water quality holistically and proactively
- Collaborate to leverage limited resources
- Provide relevant, timely, and independent scientific analysis
- Connect to cutting-edge research at the University of Washington and globally
- Trusted, scientific journalism
- Coordinate with regulatory and incentive programs



Wastewater Service Affordability Analysis

Wastewater Service Affordability Analysis

Susan Burke, ECO Resource Group & WWU
Aimee Kinney, Puget Sound Institute
Audrey Barber, WWU student
Nate Jo, WWU student
Kevin Bogue, Puget Sound Institute
Sandra Davis, ECO Resource Group

ECO RESOURCE GROUP

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WESTERN WASHINGTON UNIVERSITY
COLLEGE OF BUSINESS AND ECONOMICS


West Point Treatment Plant (Photo: King County)

SUBSCRIBER EDITION

THE BELLINGHAM HERALD

HOMEPAGE

Bellingham sewer rates may quadruple. Here's why

BY ROBERT MITTENDORF

MAY 10, 2022 12:10 PM

Questions

1. How “affordable” are current sewer service costs in the Puget Sound region as measured by %MHI and %LQI?

2. How many sewer service providers would exceed a 2% “affordability” threshold if projected increases attributable to PSNGP-required upgrades are added to current service costs?

3. Is the regional distribution of clean water costs and benefits equitable?

    Are costs borne by ratepayers proportional across providers?
    Will all that benefit from clean water pay a “fair” share?

METHODS

Broad regional survey

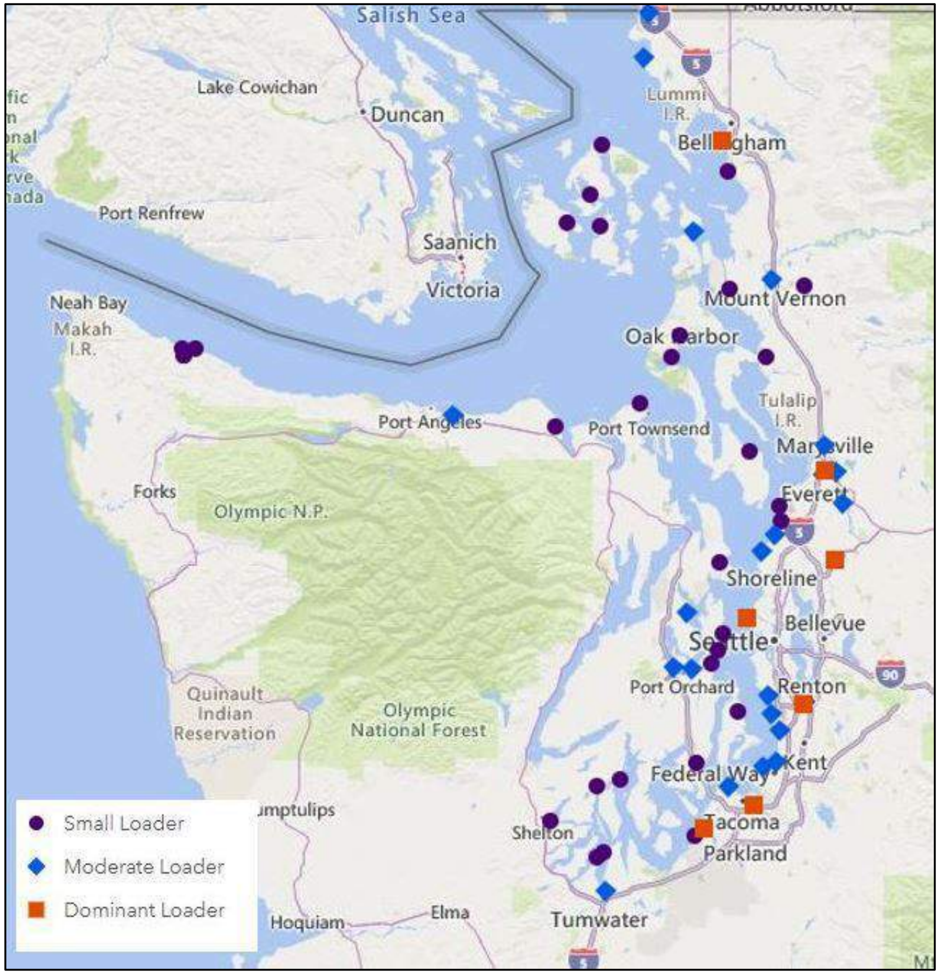
$\neq$

Statistically rigorous for EPA financial capability assessment

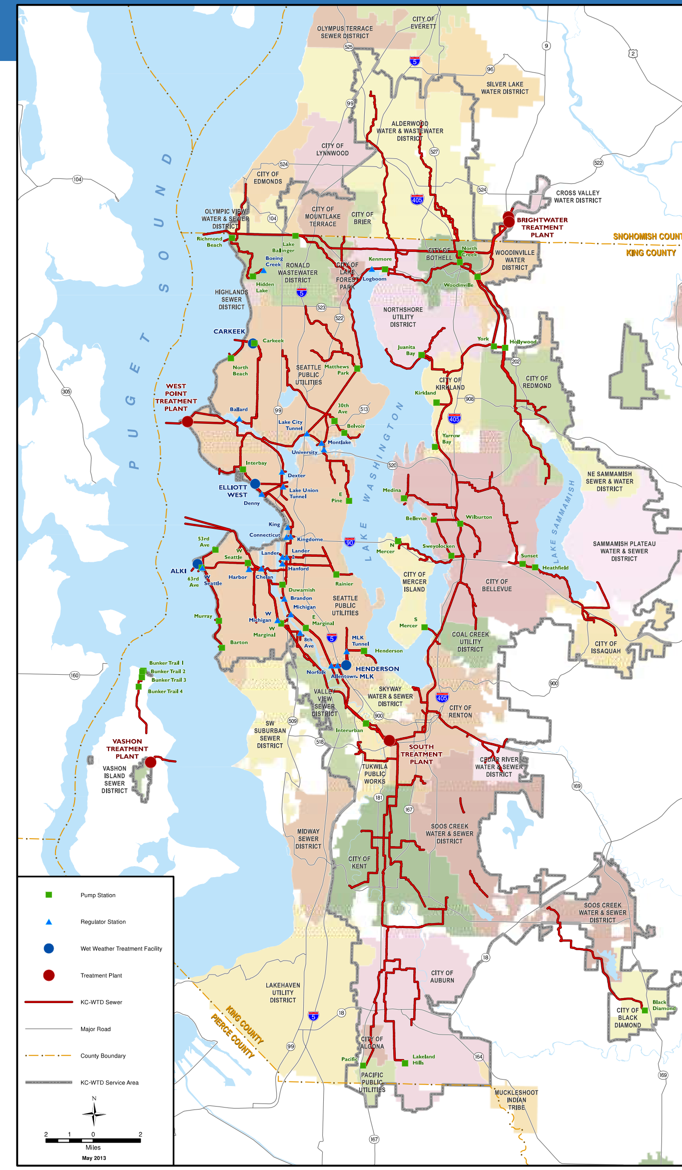
All datasets available open access

https://digital.lib.washington.edu/researchworks/

(1) Identified and obtained service area boundaries for local sewer service providers affected by the PSNGP



WWTPs (n=55)
Permittees (n=40)



Local sewer providers (n=89)

(2) Compiled rate data for local sewer providers and estimated monthly sewer service costs assuming standardized volume (5.5 ccf/household)

	A	B	C	Formula Bar	E	F	G	H	I	J
1	ORGDOHNum	Name/Webpage link	Flat Rate	Number of months in flat rate	Variable Rate	Unit of measure for variable rate (1 = CF, 2 = CCF, 3 = Gallons)	Estimated Monthly Use (based on units of variable rate)	Monthly Flat Rate	Monthly Variable Cost	Total Monthly Sewer Cost
2	01300E	Alderwood Water District	$144.38	2	$0.00	1	5.5	$72.19	$0.00	*$72.19*
3	95904U	Birch Bay Water and Sewer Distr	$22.20	1	$2.90	1	5.5	$22.20	$4.35	*$26.55*
4	418007	Cedar River Water and Sewer Dis	$152.58	2	$0.00	1	5.5	$76.29	$0.00	*$76.29*
5	01450V	City of Algona	$68.02	1	$0.00	1	5.5	$68.02	$0.00	*$68.02*
6	02200C	City of Anacortes	$43.14	1	$0.03	2	550	$43.14	$18.72	*$61.86*
7	03350V	City of Auburn	$75.26	1	$0.00	1	5.5	$75.26	$0.00	*$75.26*
8	97650T	City of Bainbridge Island	$43.54	1	$7.34	1	5.5	$43.54	$40.37	*$83.91*
9	05575B	City of Bellevue	$99.00	2	$5.15	1	5.5	$49.50	$28.33	*$77.83*
10	56003	City of Bellingham	$98.20	2	$0.00	1	5.5	$49.10	$0.00	*$49.10*
11	72207	City of Black Diamond	$72.37	1	$0.00	1	5.5	$72.37	$0.00	*$72.37*
12	07300U	City of Blaine	$115.07	1	$0.00	1	5.5	$115.07	$0.00	*$115.07*
13	07900L	City of Bothell	$139.78	2	$4.63	1	5.5	$69.89	$16.21	*$86.10*
14	08200R	City of Bremerton	$67.23	1	$5.00	1	5.5	$67.23	$27.50	*$94.73*
15	WW_11	City of Brier	$113.78	2	$0.00	1	5.5	$56.89	$0.00	*$56.89*
16	25050N	City of Fife	$90.56	1	$0.00	1	5.5	$90.56	$0.00	*$90.56*

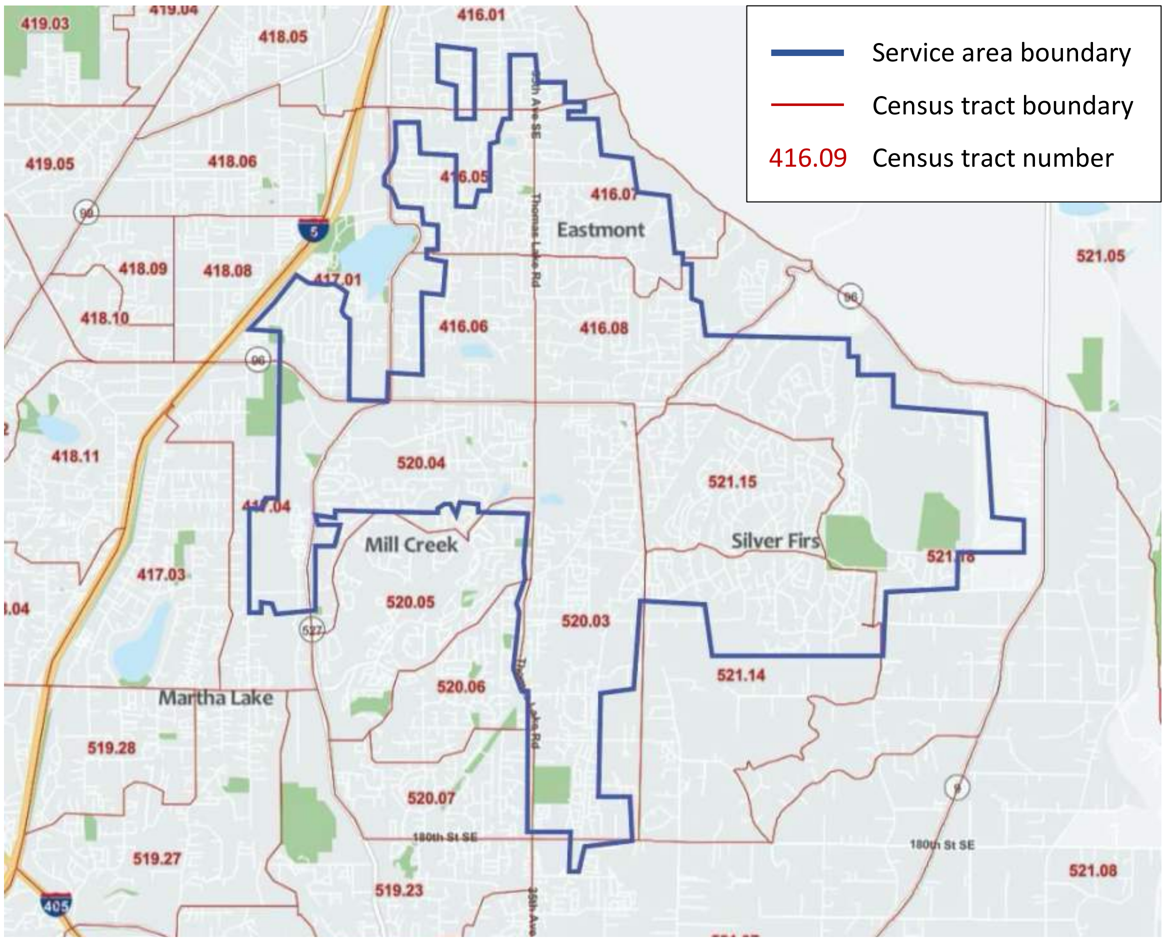
Sources of error:

- Multi-family buildings not included
- State and local utility taxes sometimes incorporated into rates, sometimes not
- Household size and seasonal variation not incorporated into our standardized volume assumption
- Several utilities contacted indicated their actual volumes are higher

(3) Compiled income and population data for 700+ Census tracts

(4) Conducted spatial analysis to correspond service area or city boundaries with Census tracts

(5) Calculated population-weighted MHI & LQI for each service area



Sources: https://www.slwsd.com/servicearea.html and https://data.census.gov/cedsci/table?q=United%20States

Sources of error:

- Service areas and Census tract boundaries differ
- Service area and city boundaries differ
- Households with septic systems within sewer service area not excluded

(6) Calculated annual SFR service cost for 80 local providers as a percentage of MHI and LQI

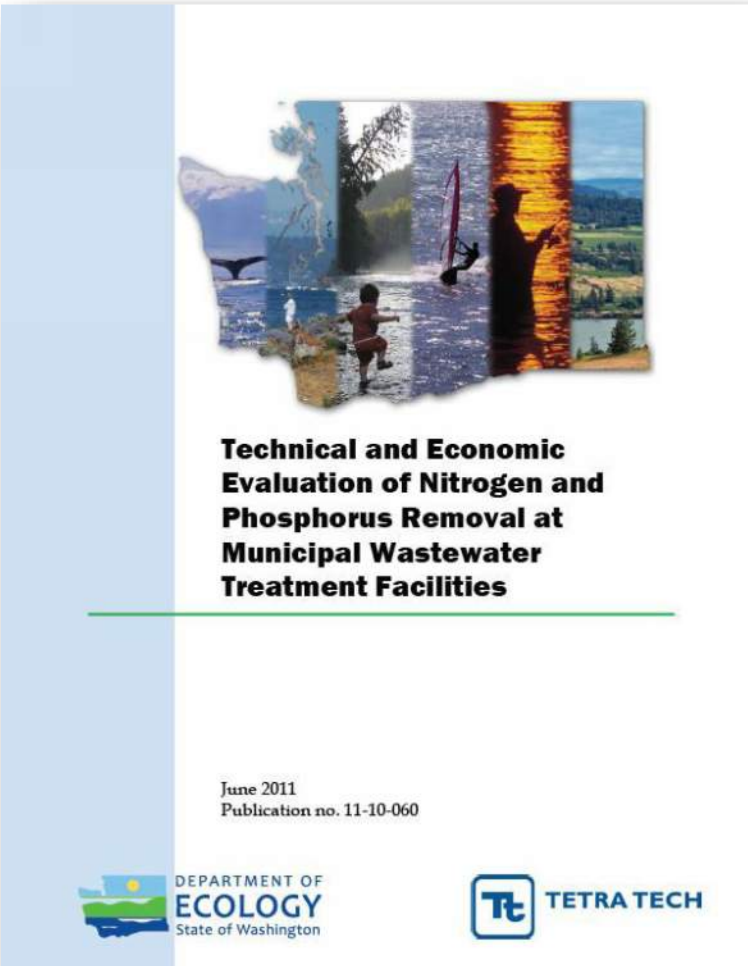
$$\%MHI = \frac{\text{Annual cost of sewer service}}{\text{Median Household Income}}$$

$$\%LQI = \frac{\text{Annual cost of sewer service}}{\text{Lowest Quintile Income}}$$

Sources of error:

- No universally accepted definition of “affordable”
- EPA guidance is in flux, but we elected to present our results relative to the commonly used 2% benchmark

(7) Added predicted monthly cost increase associated with 2 PSNGP upgrade scenarios to service costs estimated in Step 2
(8) Calculated PSNGP-adjusted cost as a percentage of MHI and LQI


Technical and Economic Evaluation of Nitrogen and Phosphorus Removal at Municipal Wastewater Treatment Facilities

June 2011
Publication no. 11-10-060

DEPARTMENT OF ECOLOGY
State of Washington

TETRA TECH

	TIN <3 mg/L year-round	TIN <8 mg/L dry season
$ 2010 [(a)]	$ 19.48	$ 9.43
$ 2022 [(b)]	$ 35.36	$ 17.12

Sources:

(a) Table ES-3 of 2011 report

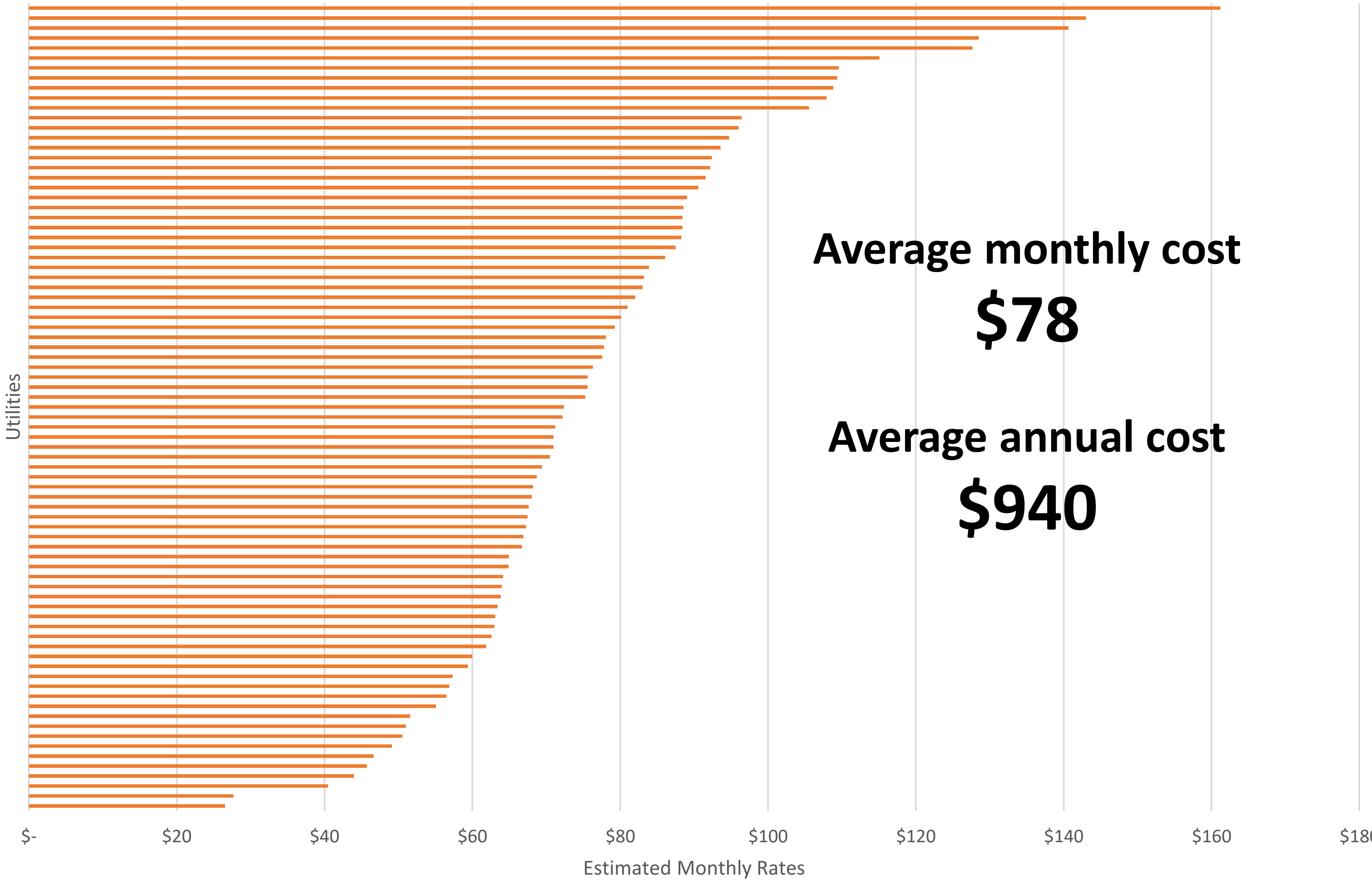
(b) Costs adjusted by inflation factor of 182% (PPI by Commodity: Special Indexes, Construction Materials)

Sources of error:

- Utility Caucus to PSNGP Advisory Committee noted costs will be higher than estimated in the 2011 report
- Projected PSNGP-adjusted cost doesn't include already-scheduled rate increases needed to accommodate other needs

RESULTS

Monthly wastewater service cost



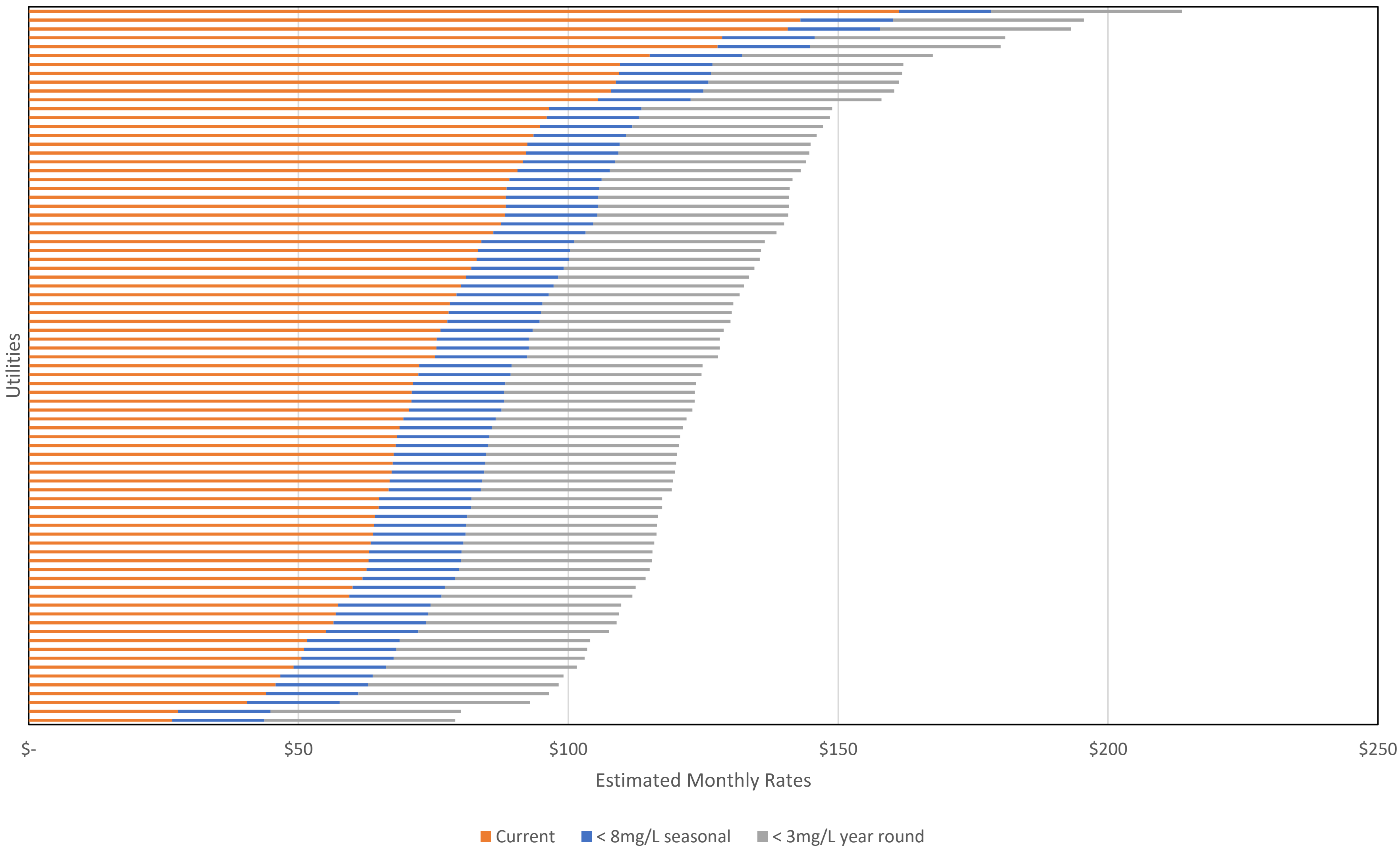
Average monthly cost

$78

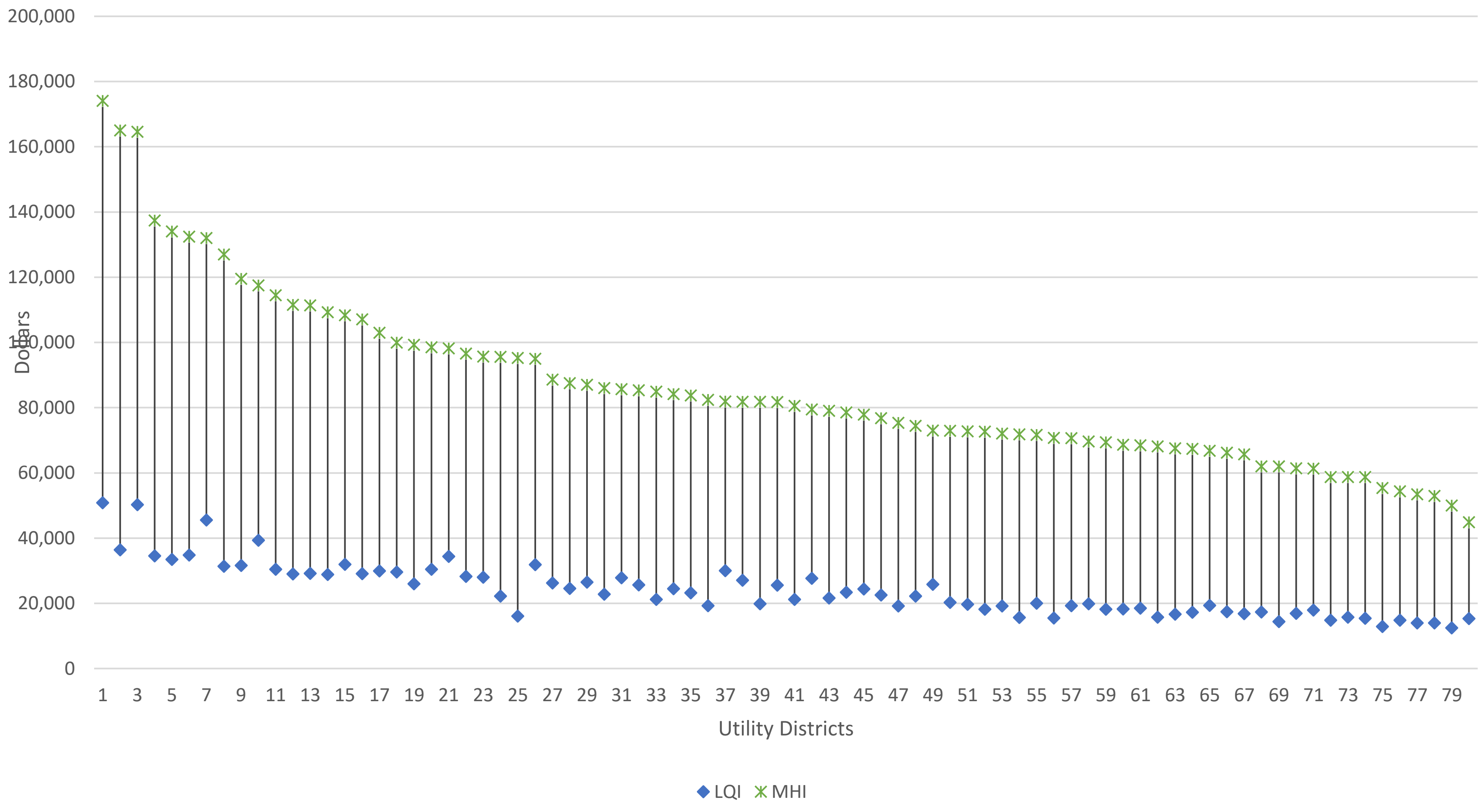
Average annual cost

$940

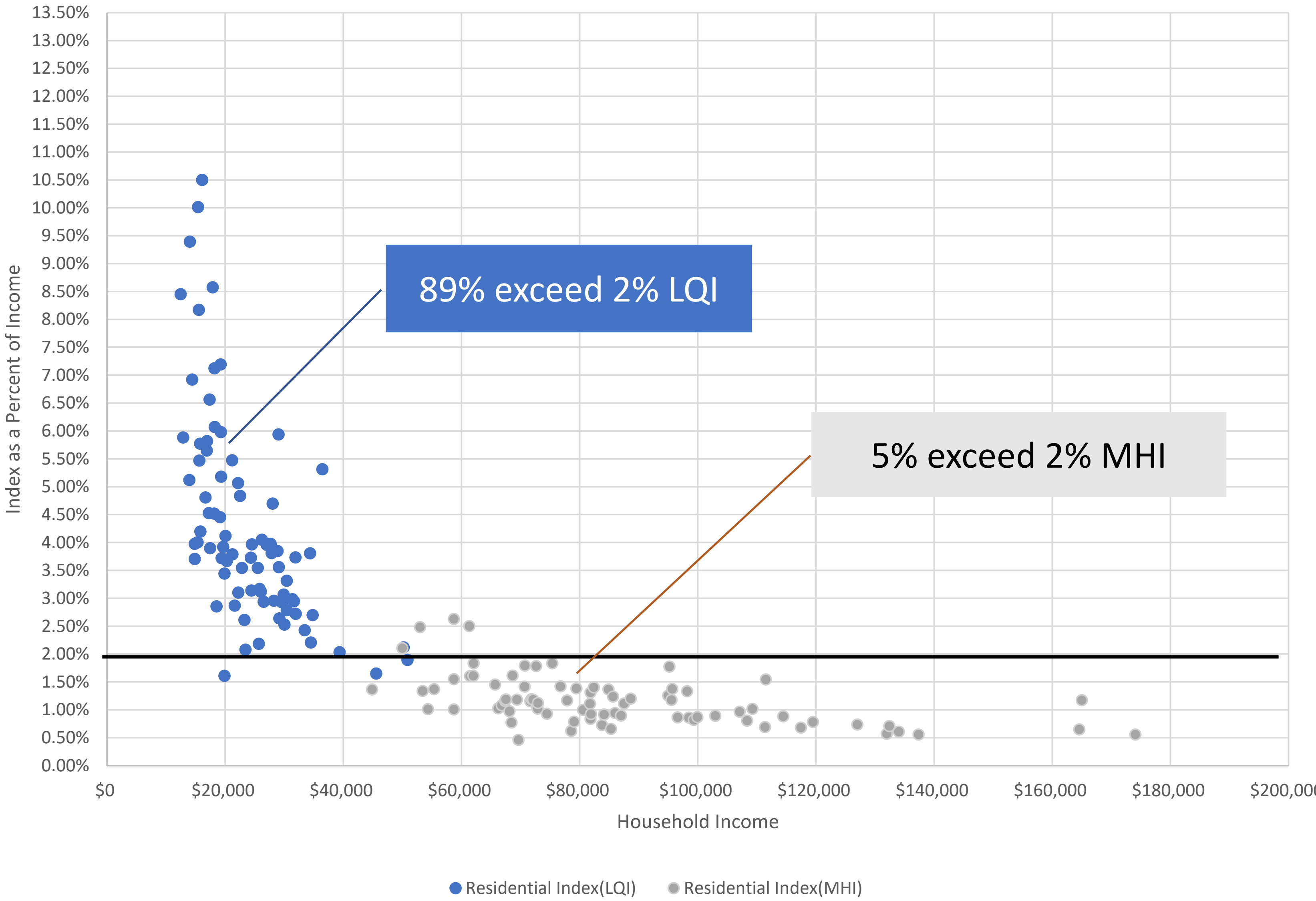
PSNGP-adjusted monthly cost



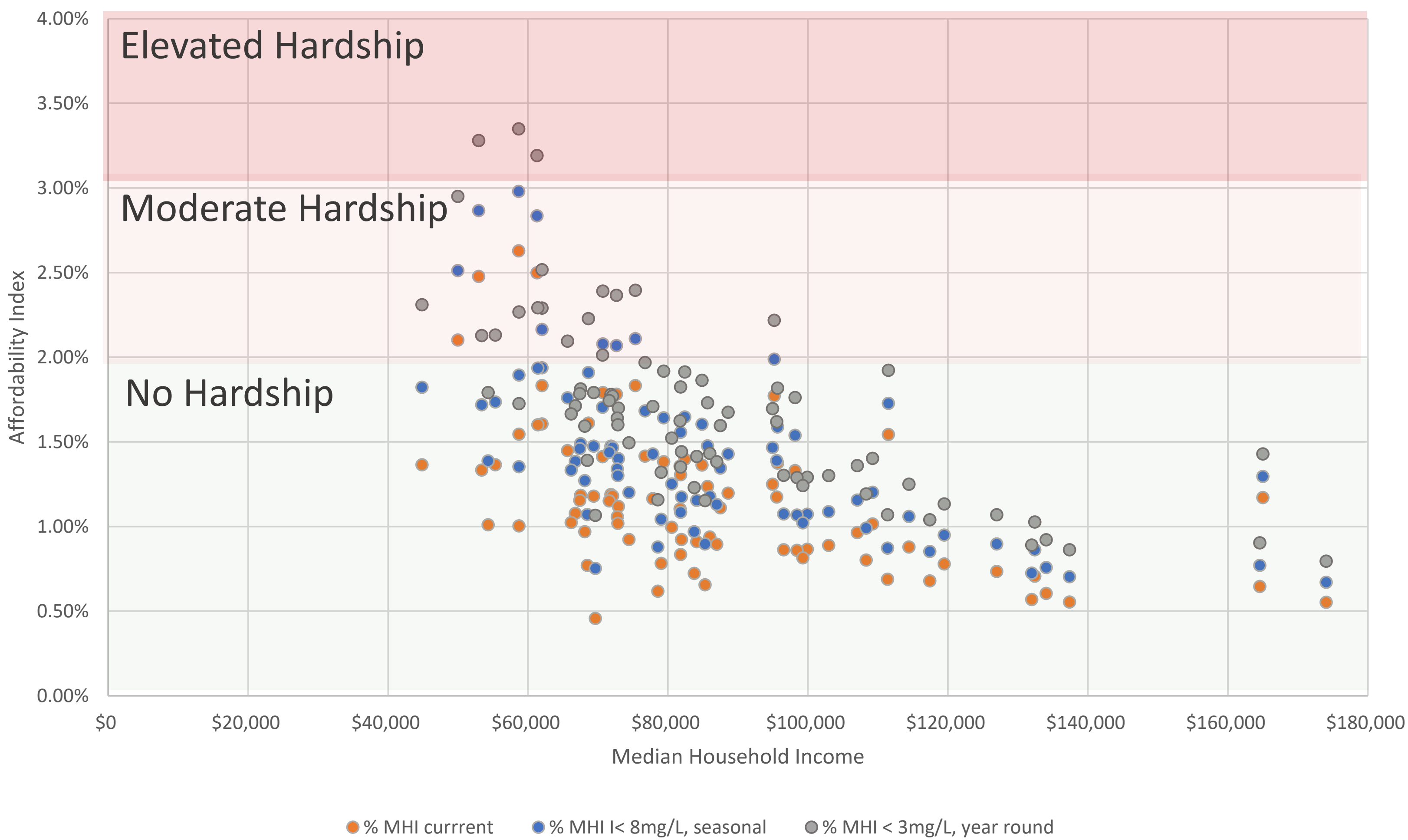
Household Income Ranges



Are current service costs affordable?



PSNGP-adjusted wastewater service costs as %MHI

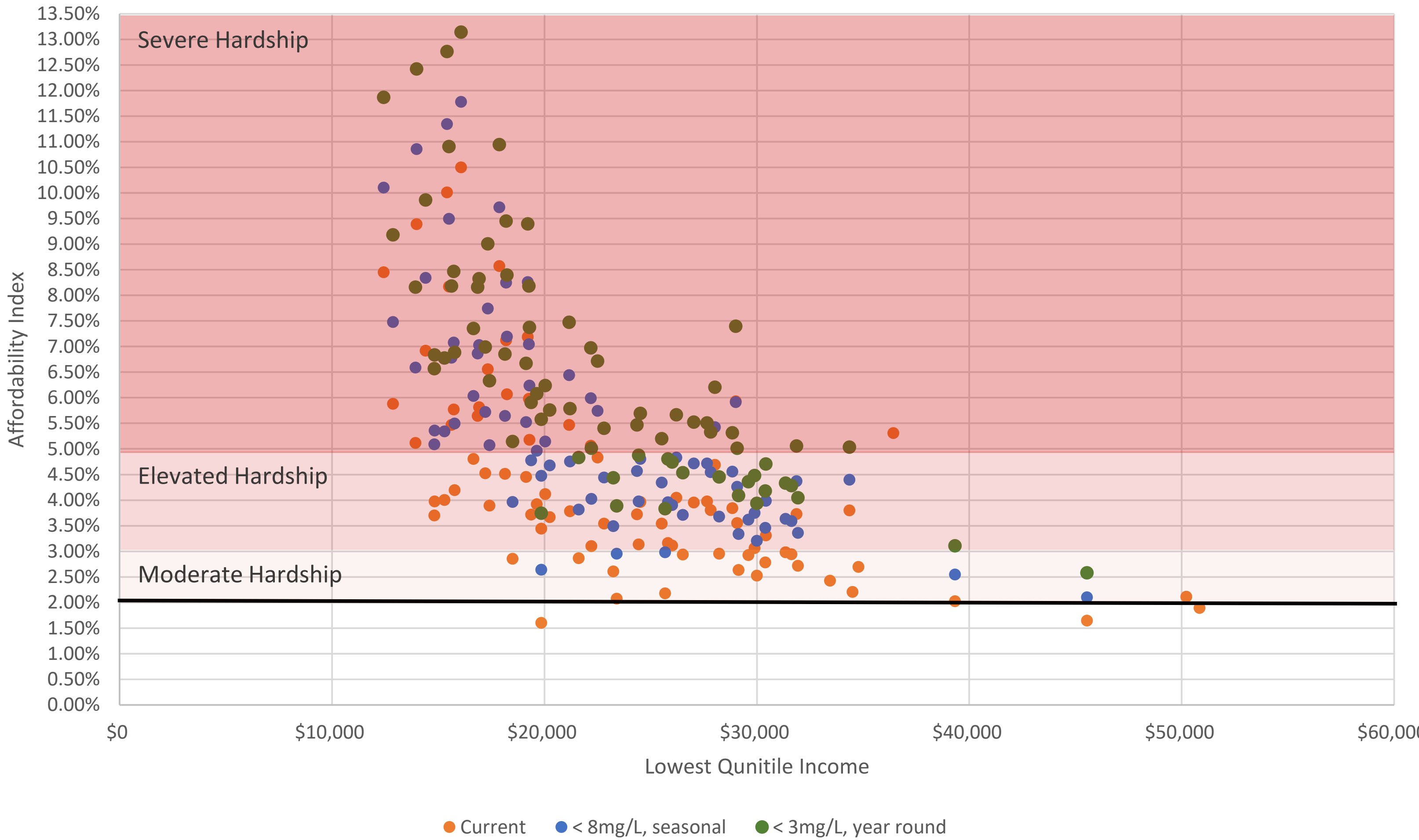


Current
4 hardship utilities (5%)

<8 mg/L seasonal
8 hardship utilities (10%)

<3 mg/L year round
18 hardship utilities (23%)

PSNGP-adjusted wastewater service costs as %LQI



Current
77 utilities >2% (96%)

<8 mg/L seasonal
80 utilities >2% (100%)

<3 mg/L year round
80 utilities >2% (100%)

Conclusion: The number of ratepayers at being billed >5% of their income for sewer service will increase with PSNGP requirements and potentially threaten the financial resiliency of wastewater service providers

Recommendation: Develop a state or region-wide low-income assistance program designed to reduce administrative burdens on and legal challenges to wastewater service providers. LIHWAP/ LIHEAP as model?

Recommendation: Consider a feasibility study on changing rate structures using a financial resilience model

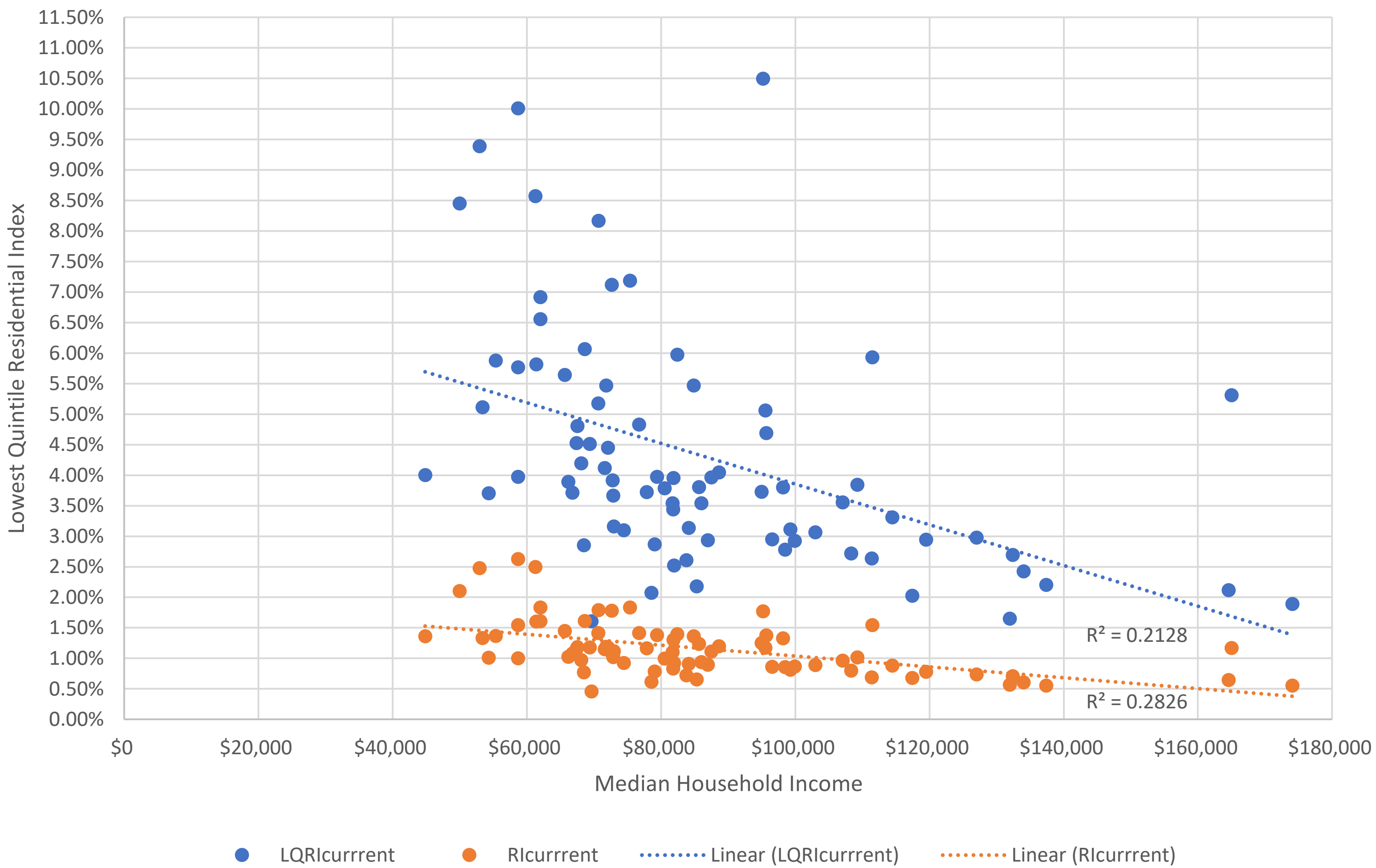

US Water Alliance

Recovering Stronger

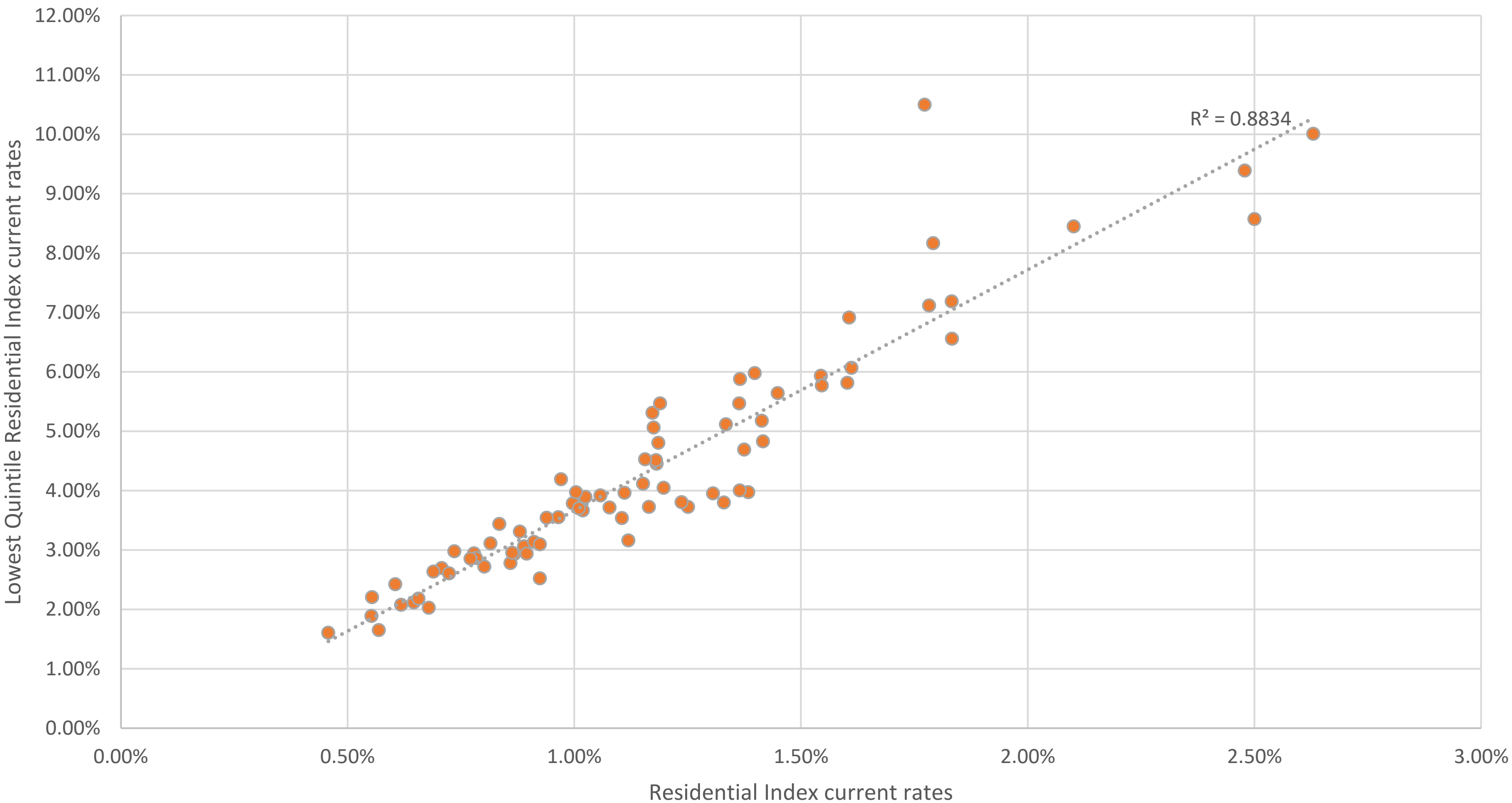
Pricing Water for Public Health and Financial Resilience: An Applied Modeling Pilot

Project Description

Is MHI good proxy for %MHI? NO



Is %MHI good proxy for %LQI?
YES



Conclusion: The criteria used by Ecology to make grant and hardship loan decisions don't fully address current affordability issues in the region

Recommendation: Use %MHI instead of MHI to allocate Puget Sound Nutrient Grant Program funding among jurisdictions.

Recommendation: Incorporate %LQI as a component of eligibility determinations for CWSRF additional subsidization.

Possible Next Steps?

- Develop a spatial data layer with accurate service area boundaries for all wastewater utilities
- Improve Census tract – service area correspondence methodology
- Compile utility-provided data on number of housing units served residential usage, and current sewer service cost
  - Multi-family housing units
  - Cost of drinking water service (and stormwater fees)
- Compile utility-provided data on already-planned rate increases and those that would be required to cover PSNGP upgrades

Tacoma Central Wastewater Treatment Plant (Photo: City of Tacoma)

Questions and discussion

burkes5@wwu.edu

aimeek@uw.edu

Q&A

Break


Overview of Modeling Results


Courtesy of Department of Ecology

DEPARTMENT OF ECOLOGY
State of Washington

Nutrient modeling includes:

- Model scenarios to refine nutrient limits
- Refine watershed modeling for nutrients (SPARROW)

Advance Model Interpretation, Capacity, & Access

- Launched Salish Sea Modeling Center
- Expanded computational capacity
- Increased access to model outputs by region with:
- Daily results
  - Concentrations
  - Other parameters
- Developed a volume-based metric
- Increased access to model and scripts

Applied modeling to inform utility decisions

PUGET SOUND INSTITUTE

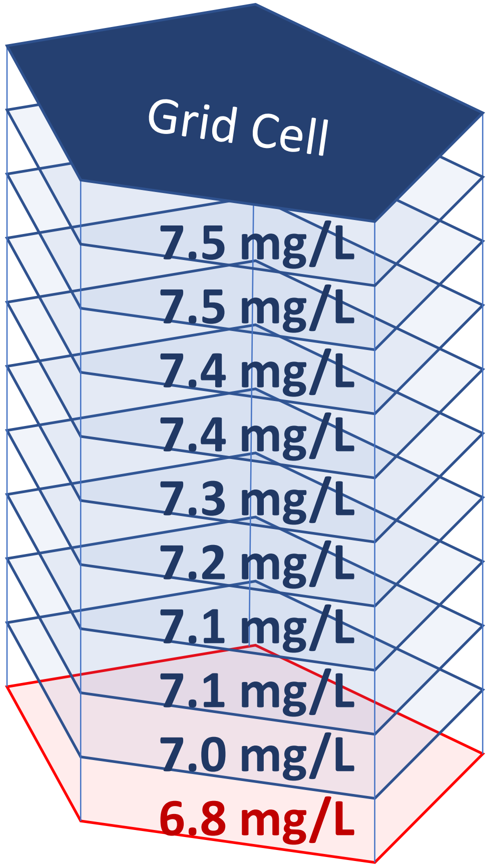
Develop Modeling Tools and Research

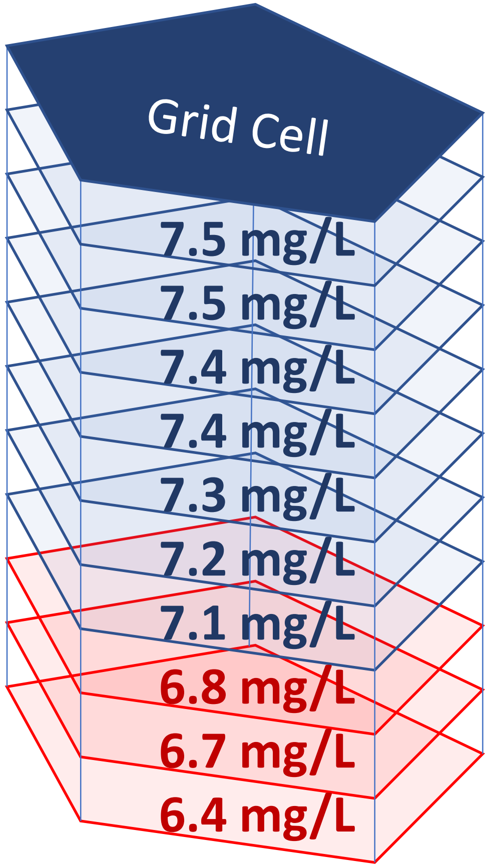
- Leading the Puget Sound Integrated Modeling Framework
- Developing a Toxics Fate and Transport Module
- Evaluating social-ecological outcomes using qualitative ecosystem models
- Coordinating the PSEMP Modeling Work Group
- Convening a Model Evaluation Group
- Facilitating workshops and communicating insights to inform decision making

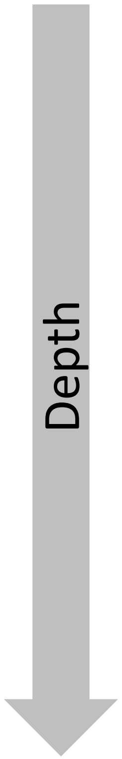
+ Puget Sound Institute's research allows for a more holistic and effective approach to water quality

Volume Days Refresher

	Day A	Day B
Day	Non-Compliant	Non-Compliant
Area	10 km^2	10 km^2
Volume	1 km^3	3 km^3

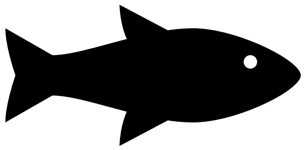






- Non-compliant area and days are the same
- Volume is more nuanced and relevant to biological impacts

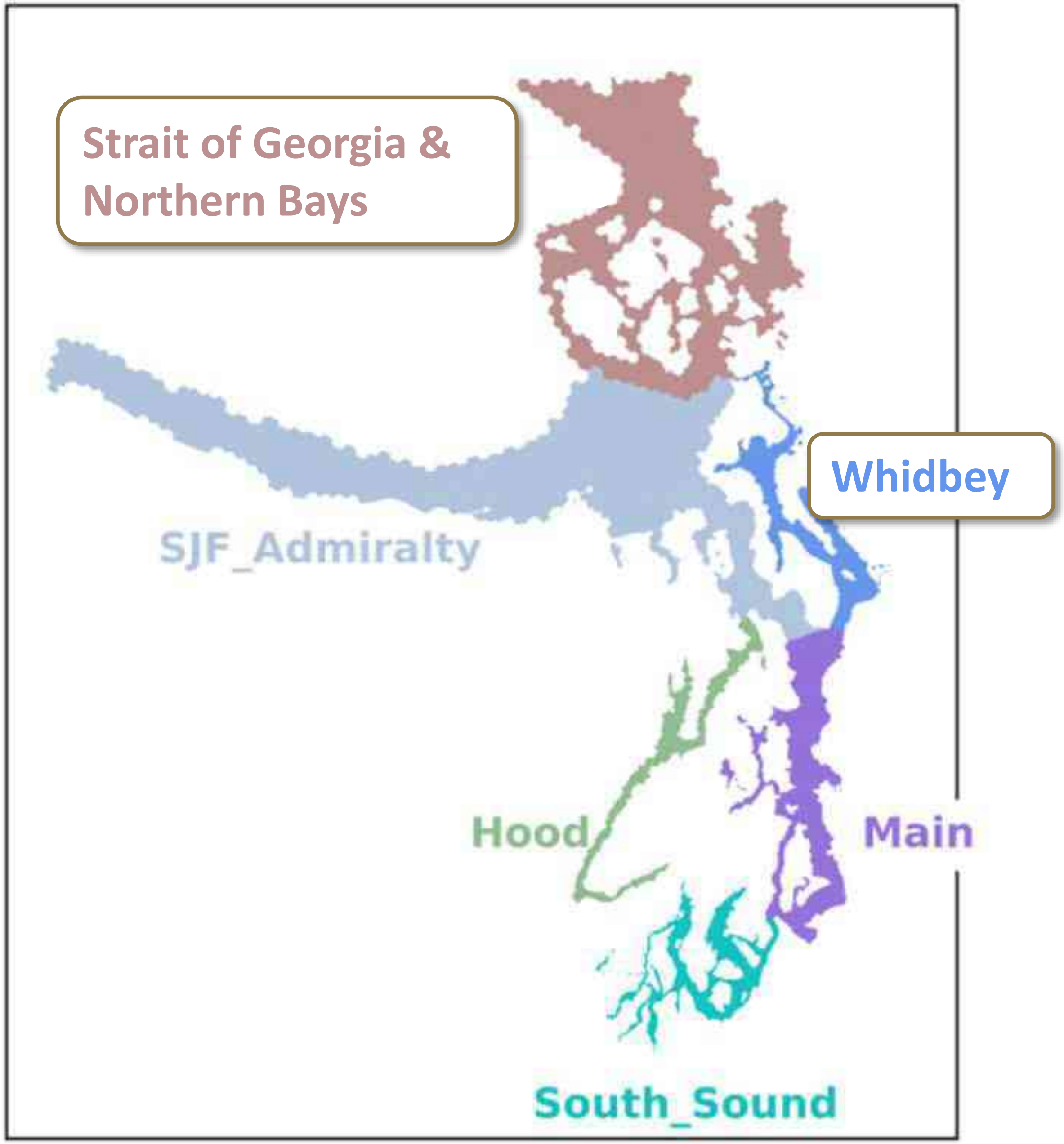
Standard: Excellent 7 mg/L



Red: Dissolved oxygen minimum does **not** meet the standard for any hour

Blue: Dissolved oxygen minimum meets the standard every hour

Regional Reports | Scenarios in 2014



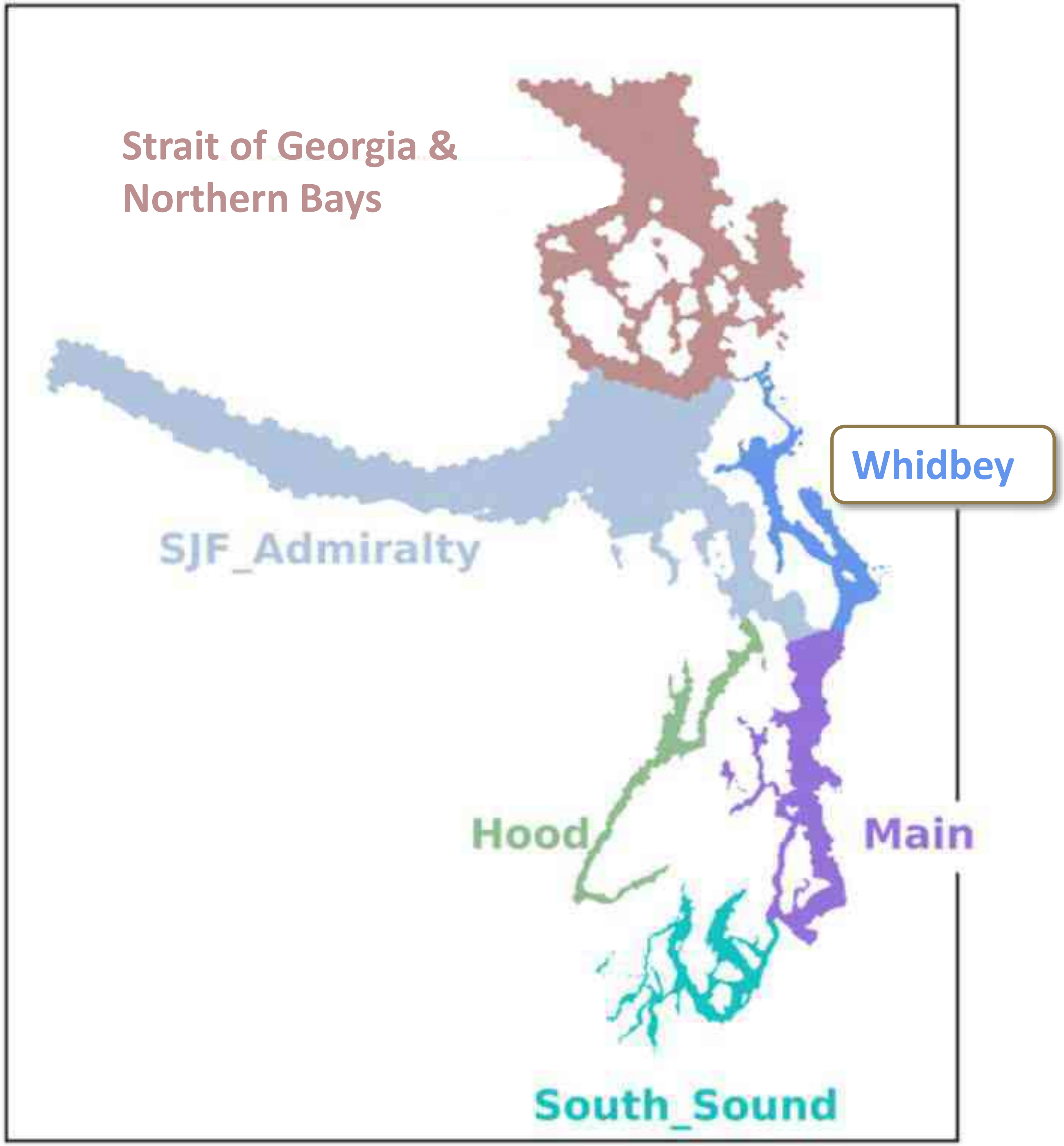
Alter nitrogen concentrations (both NO_2^-/NO_3^- and NH_4^+) for local wastewater treatment plants and rivers, but maintain flows

- Keep concentrations at 'current conditions' in other regions

Maintain other conditions (e.g., hydrodynamics, meteorology, biogeochemical kinetics, ocean exchange, etc.) at their 'current conditions'

Classify wastewater treatment plants as **small, moderate (medium), and dominant** in alignment with the State's permit documentation (issued 12/1/2021)

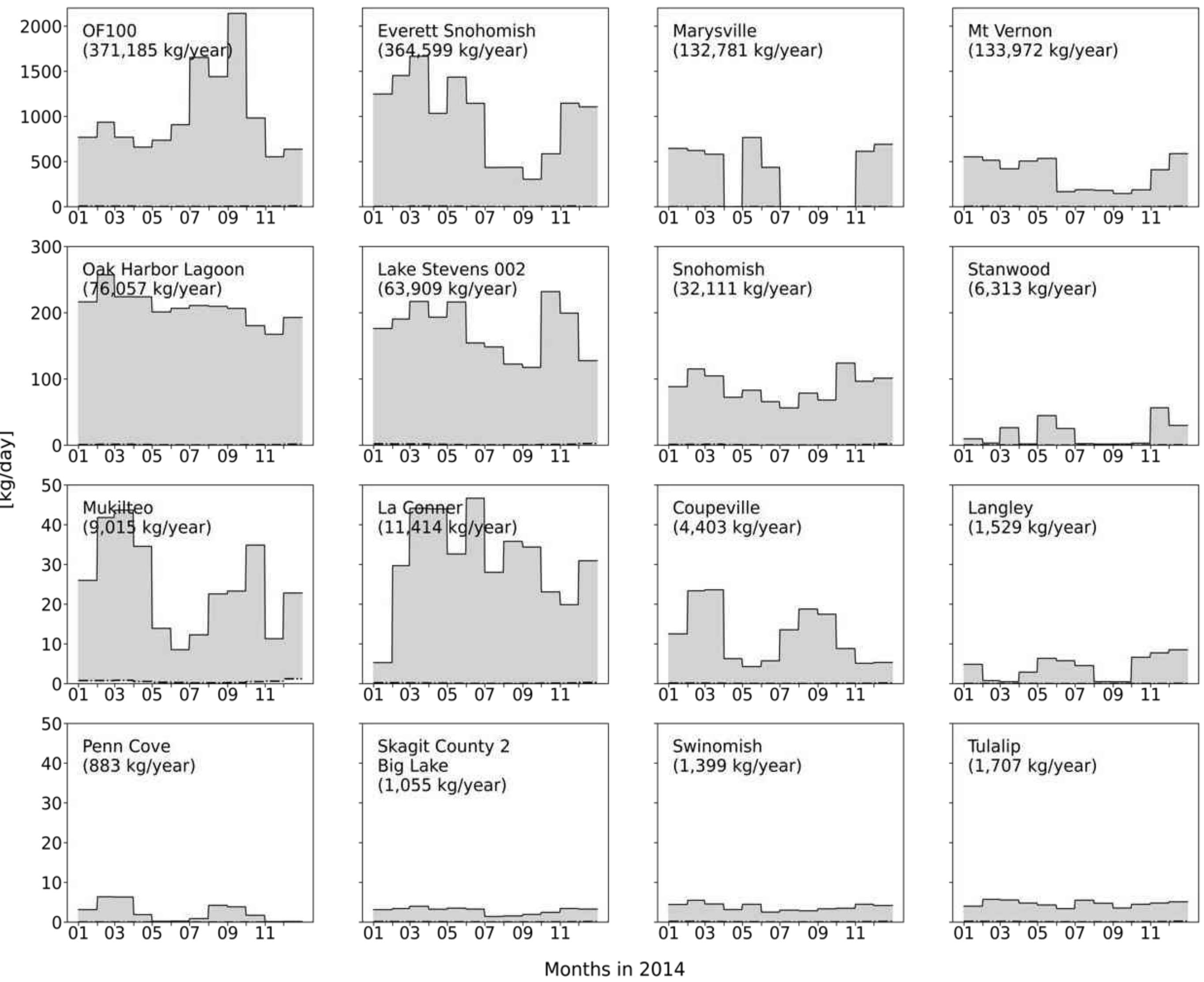
Whidbey Basin



Whidbey Basin| Local Nitrogen Loading in 2014

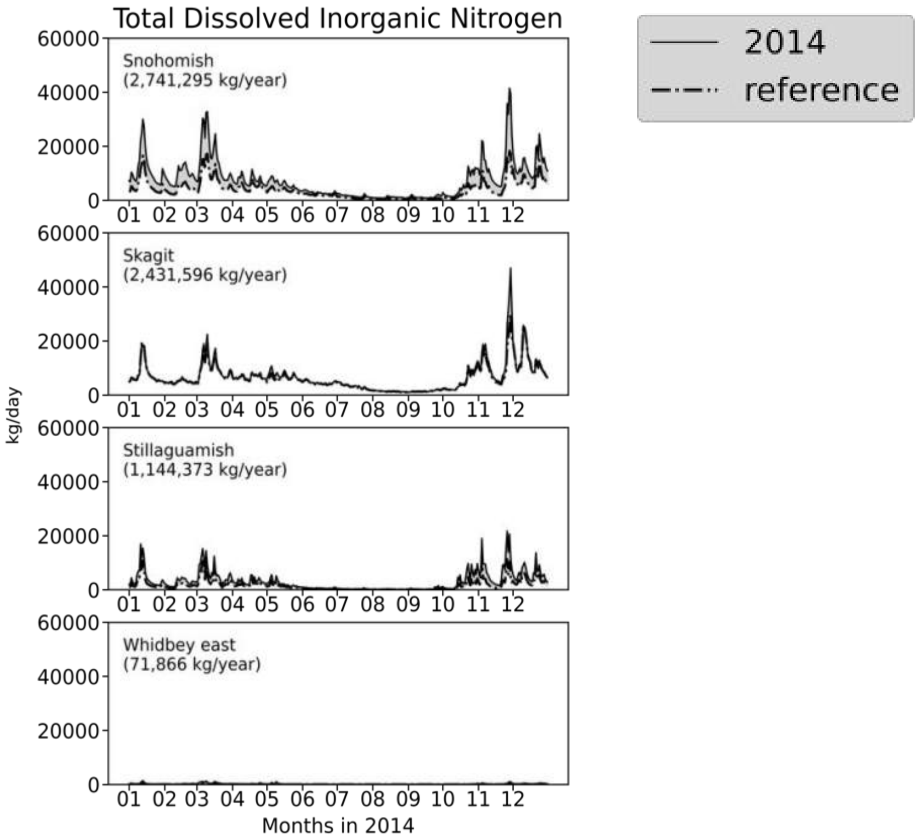
Wastewater Treatment Plants

Total Dissolved Inorganic Nitrogen



River Loading

Total Dissolved Inorganic Nitrogen



1.2 million kg/year wastewater

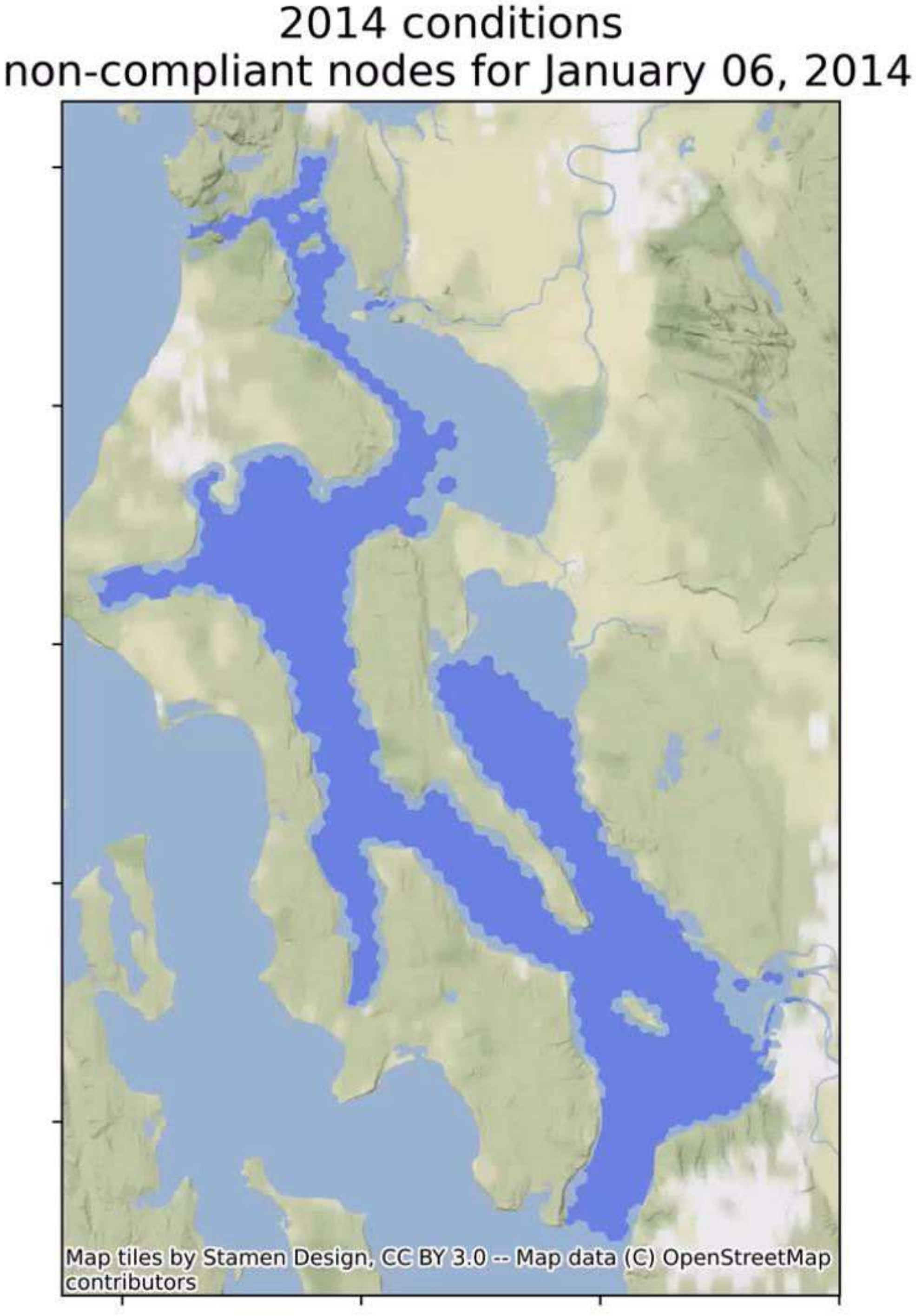
2.0 million kg/year rivers, human influence

4.4 million kg/year rivers, natural

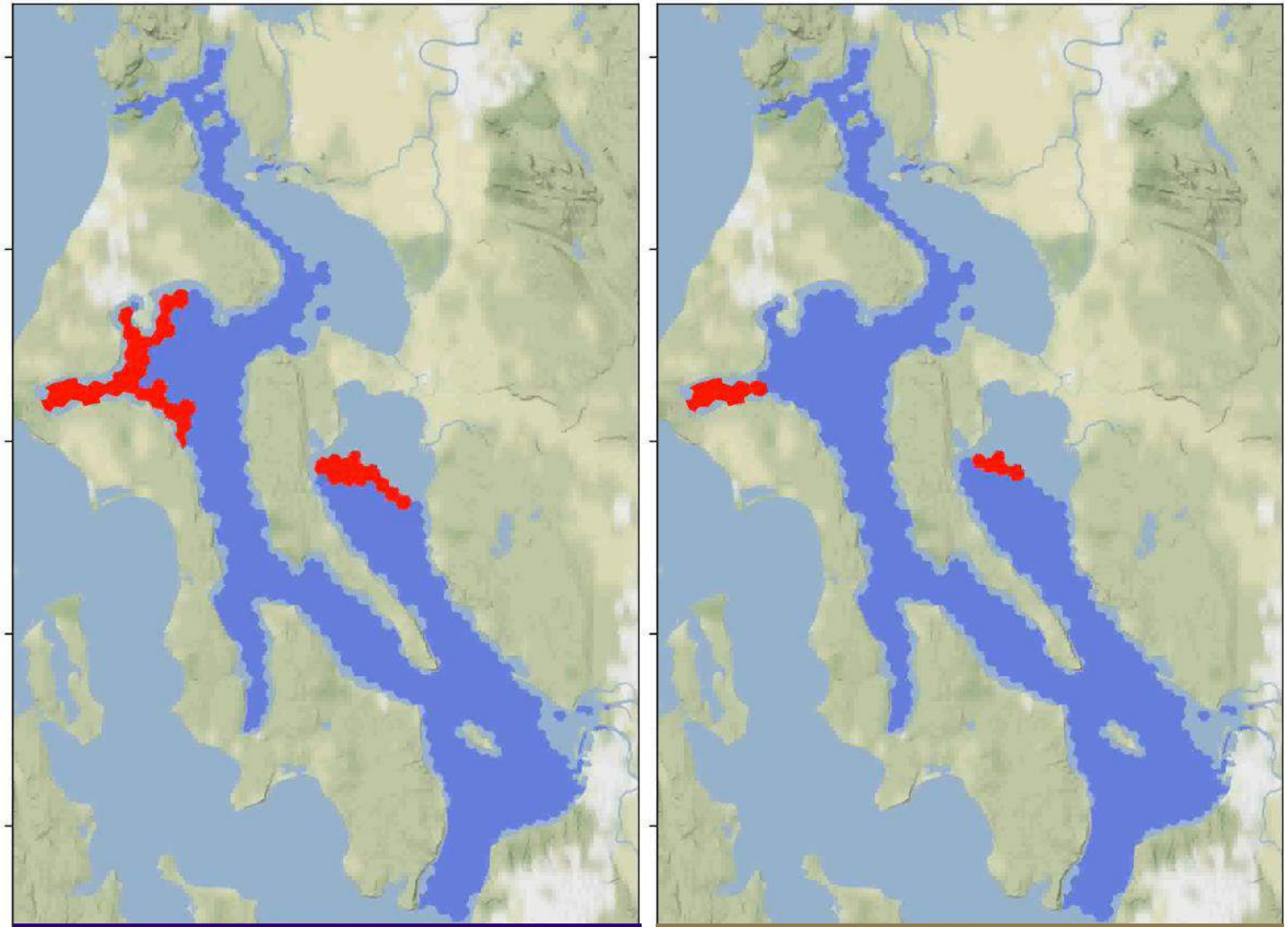
Whidbey Basin | Current Conditions in 2014

Within Whidbey Basin

- 174 days non-compliant
- Peak non-compliant volume is 3%
  - Non-compliant volume is sustained above 1% for 4 months, peaking in August and September



Whidbey Basin | Current vs. Reference

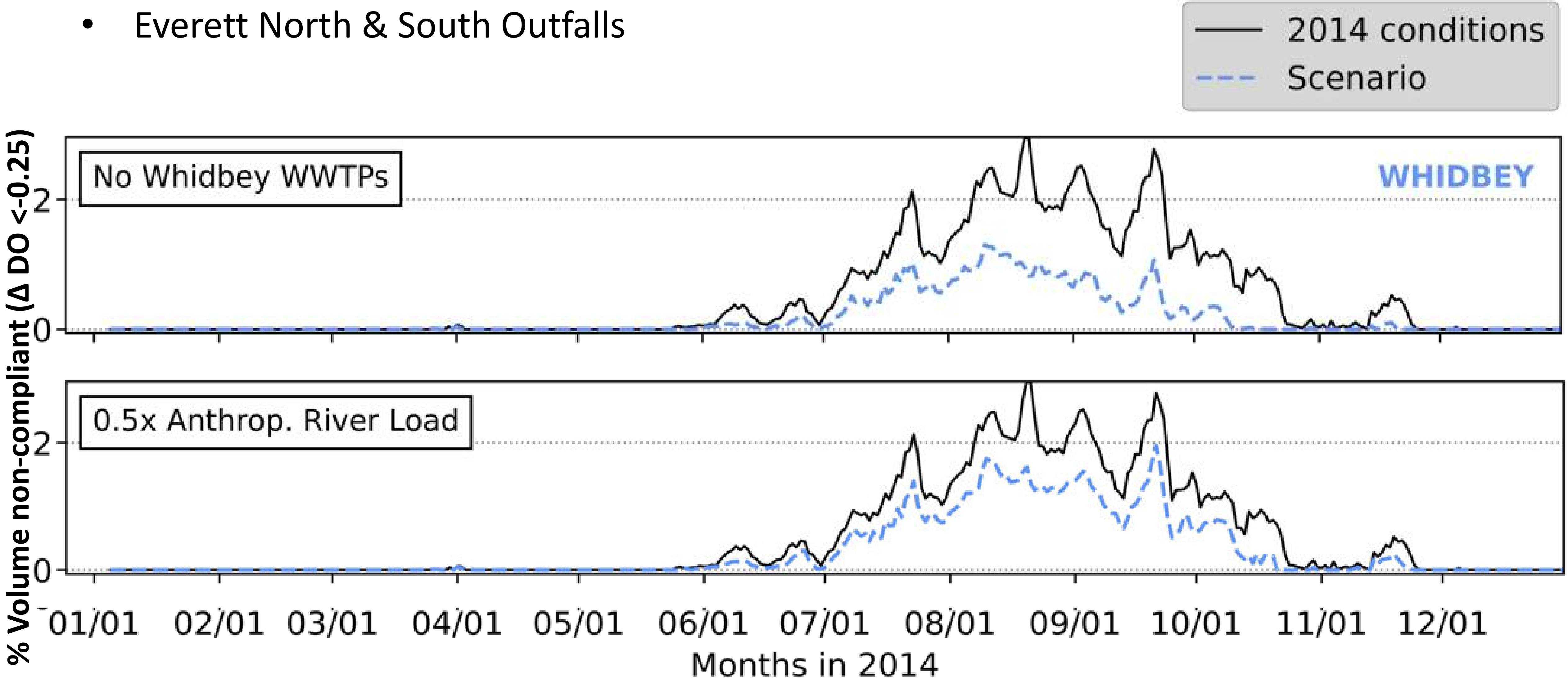


DO < 2 mg/L *Current Conditions*

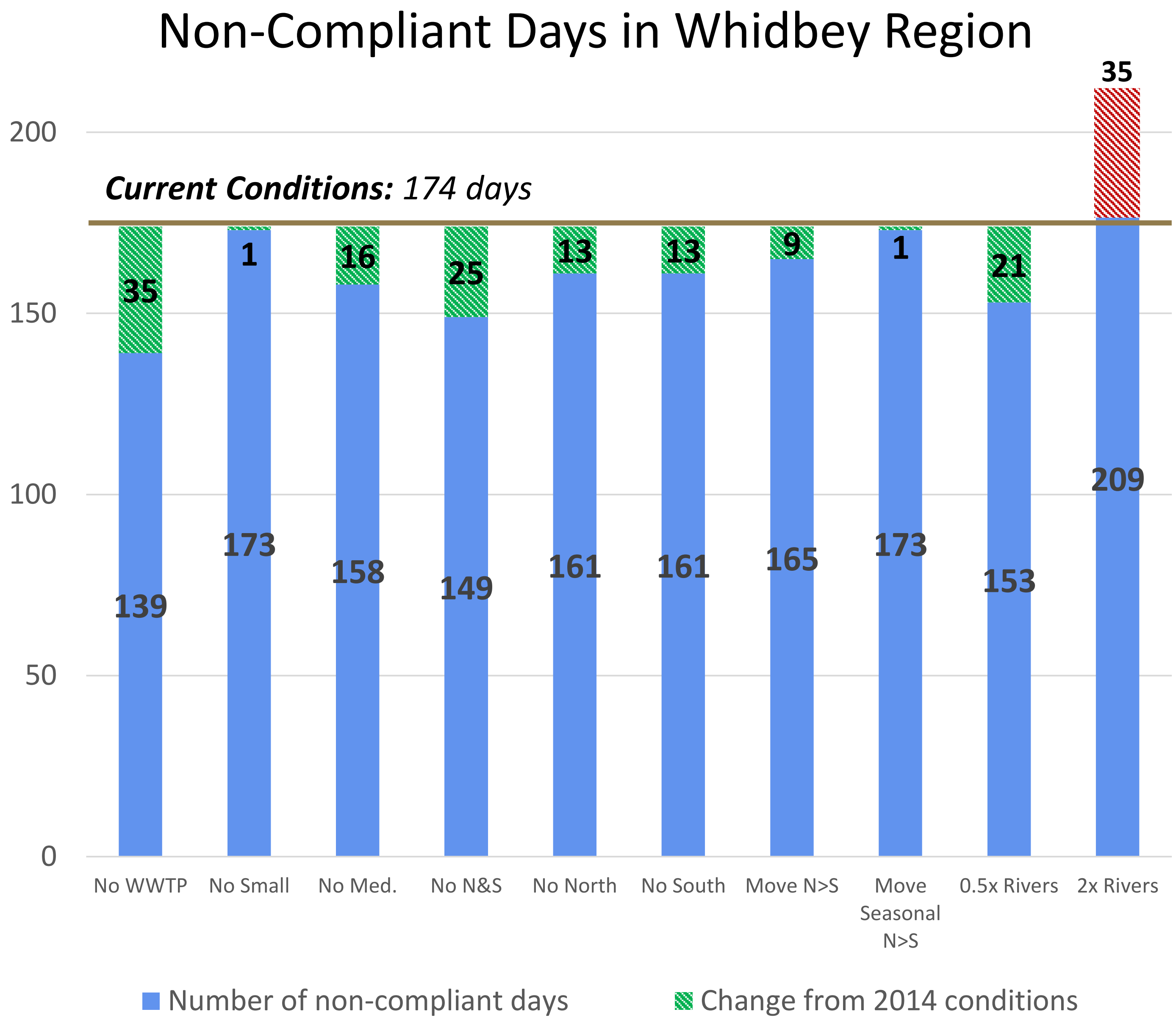
DO < 2 mg/L *Reference Conditions*

Whidbey Basin| Scenarios

- No small, medium, large, or any local wastewater treatment plants
- No local river loading, double river loading, and half the anthropogenic load
- Everett North & South Outfalls



Whidbey Basin| Within the Region



- Eliminating all **wastewater treatment plants:**
  - Reduces non-compliance from 174 to 139 days (↓ 35)
  - Decreases the max volume of non-compliant water from 3% to 1%
  - Shortens the duration of non-compliance by a few weeks
- No demonstrable impact from small plants
- Halving the human contribution to **river** loading:
  - Reduces non-compliance from 174 153 days (↓ 21)
  - Decreases the max volume of non-

Whidbey Basin| Everett North & South Outfalls

Number of Non-Compliant Days

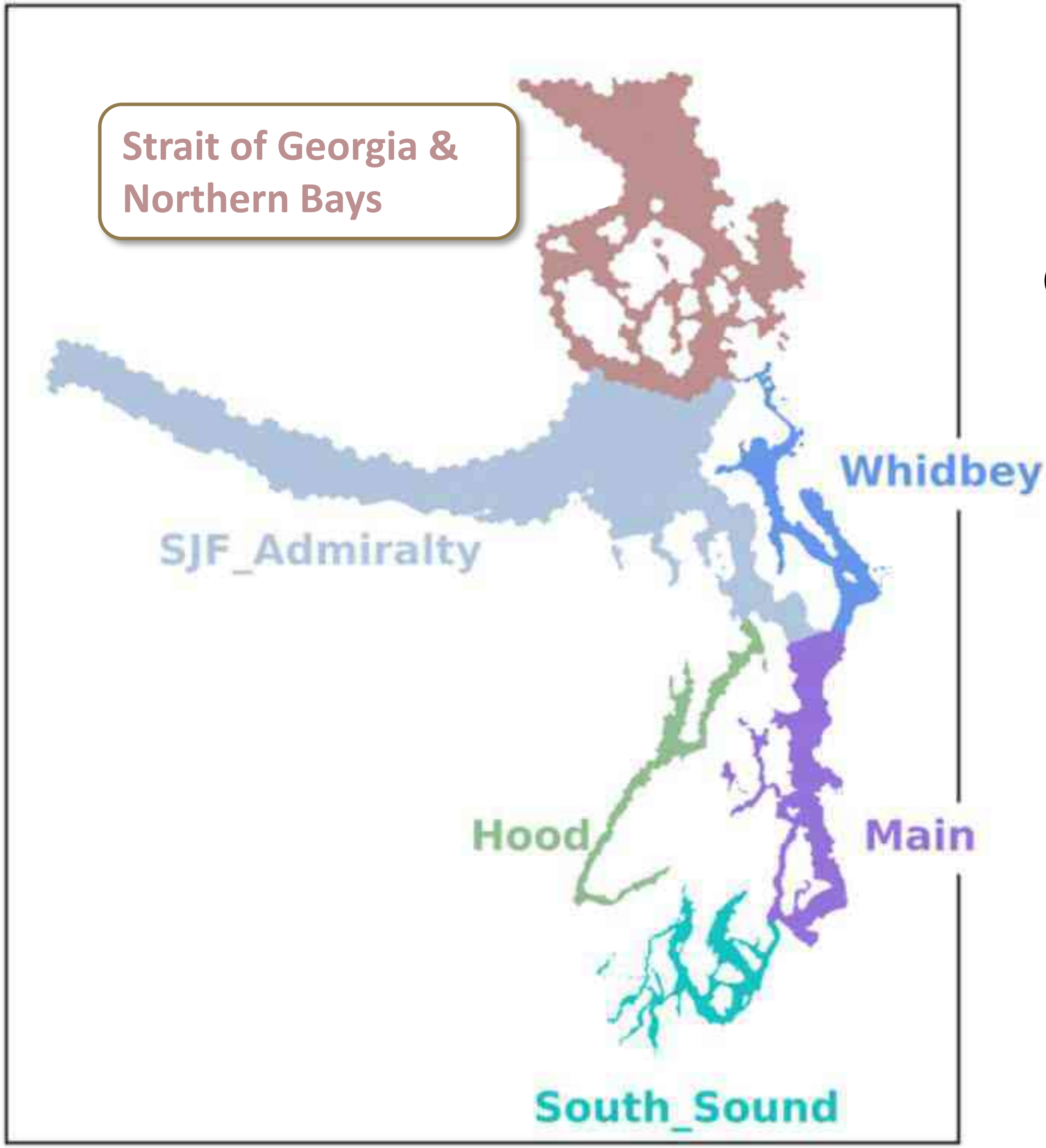
	2014 Conditions	**Wtp4** No N&S	**Wtp5** No North	**Wtp6** No South	**Wtp7** Move N>S	**Wtp8** Move Seas.N>S
Whidbey Basin	174	149	161	161	165	173
Hood Canal	146	134	135	142	138	145
Main Basin	162	153	156	160	160	162
Strait of Juan de Fuca & Admiralty	0	0	0	0	0	0
Strait of Georgia & Northern Bays	39	37	37	37	37	39
South Sound	176	176	176	176	176	176

- Everett North & South outfalls have a similar impact on Whidbey Basin
- Everett North & South outfalls, respectively, have a similar influence as all the medium plants collectively
- The North outfall may have a larger influence on Hood Canal and Main Basin despite having a similar load to the South outfall

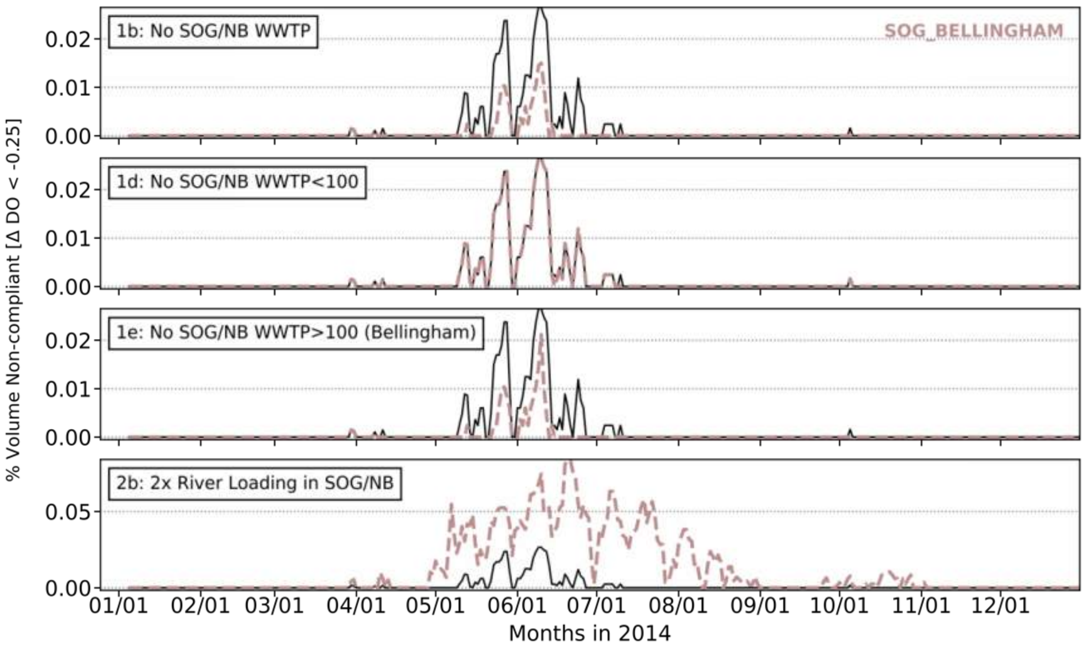
Whidbey Basin| Scenarios

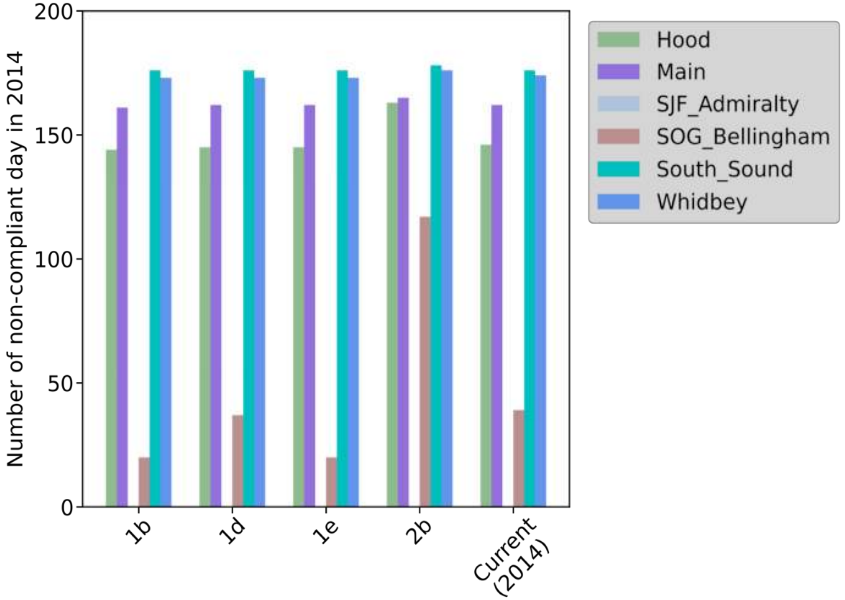
	2014 Conditions	Wtp1 No WWTP	Wtp2 No Small	Wtp3 No Med.	Wtp4 No N&S	Wtp5 No North	Wtp6 No South	Wtp7 Move N>S	Wtp8 Move Seas.N>S	Wr1 No Rivers	Wr2 0.5x Rivers	Wr3 2x Rivers
Days Non-Compliant												
Whidbey Basin	174	139	173	158	149	161	161	165	173	0	153	209
Hood Canal	146	130	145	137	134	135	142	138	145	41	133	207
Main Basin	162	147	162	158	153	156	160	160	162	38	153	185
Strait of Juan de Fuca & Admiralty	0	0	0	0	0	0	0	0	0	0	0	0
Strait of Georgia & Northern Bays	39	36	39	37	37	37	37	37	39	0	36	45
South Sound	176	175	176	176	176	176	176	176	176	103	176	183
ALL REGIONS	229	215	228	223	221	223	224	223	229	115	222	270
Percent Volume Days Non-Compliant												
Whidbey Basin	0.50	0.18	0.49	0.35	0.29	0.37	0.40	0.45	0.50	0.00	0.30	5.05
Hood Canal	0.05	0.04	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.01	0.04	0.25
Main Basin	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
Strait of Juan de Fuca & Admiralty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strait of Georgia & Northern Bays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
South Sound	1.15	1.02	1.14	1.10	1.06	1.09	1.12	1.11	1.14	0.05	1.06	1.79
ALL REGIONS	0.05	0.03	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.00	0.04	0.26

Strait of Georgia & Northern Bays



Strait of Georgia & Northern Bays | Recap





Within the Strait of Georgia & Northern Bays

- 0.5 million kg/year from local wastewater treatment plants and 2.4 million kg/year from local rivers
- Current conditions in 2014:
  - 52 days non-compliant
  - Peak non-compliant volume is 0.025%
  - Primarily in May & June
- Eliminating small wastewater treatment plant loads reduced the non-compliance from 39 to 37 days
- Eliminating the largest plant load, Bellingham, reduced non-compliance from 39 to 20 days
- Eliminating wastewater loads from the Strait of Georgia Northern Bays, did not substantially alter conditions in the other five regions (Δ ≤ 2 days)

Q&A

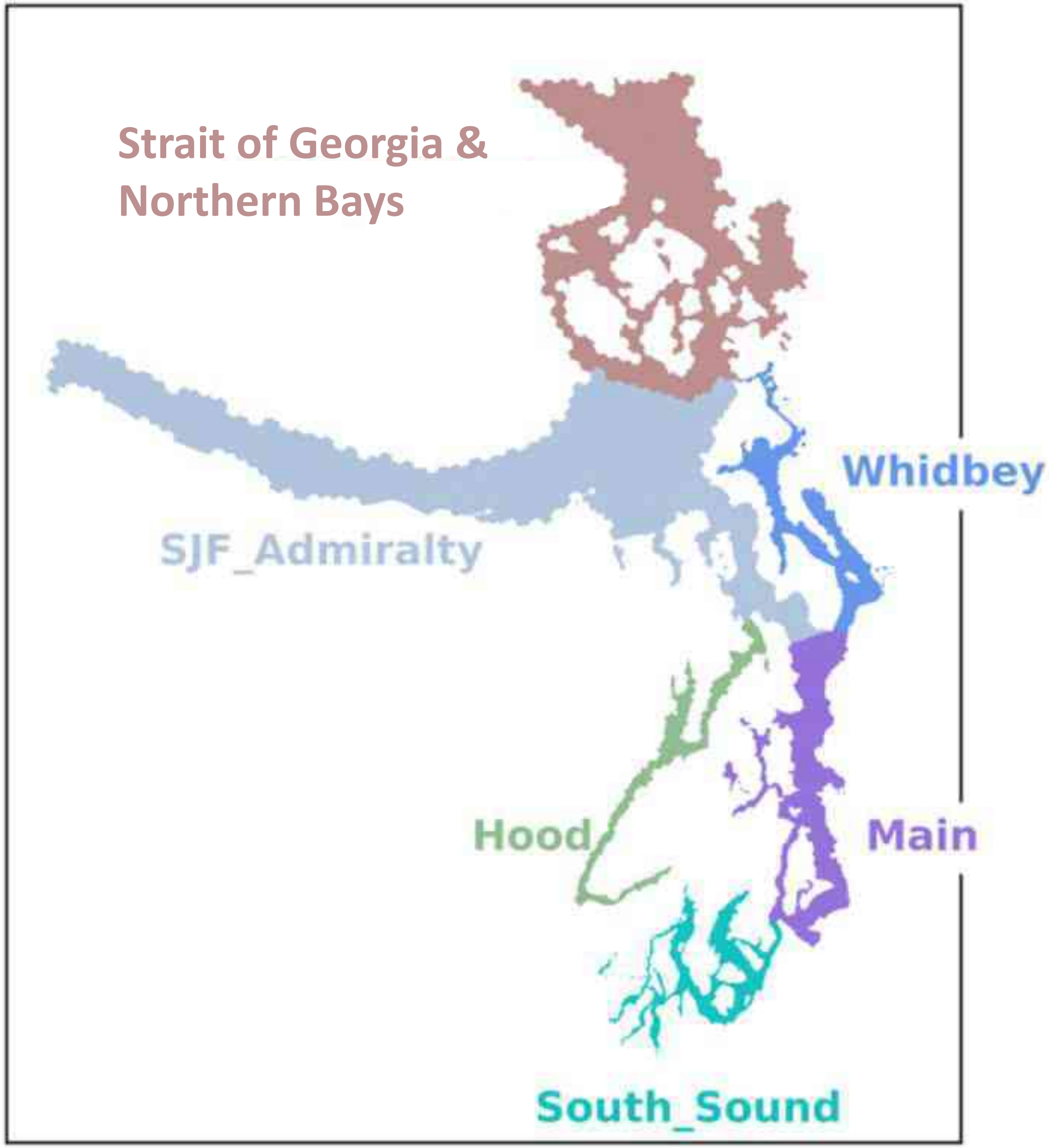
Draft Modeling Workplan

King County Scenarios

- West Point load reduced to 85%, South Plant and Brightwater TIN reduced to 3mg/l
- West Point, South Plant, Brightwater load reduced to 85%
- West Point load reduced to 50%
- West Point load reduced to 0%
- South Plant load reduced to 50%
- South Plant load reduced to 0%
- Brightwater load reduced to 50%
- Brightwater load reduced to 0%
- Green River 50% reduction in pre-anthropogenic loading
- *West Point, South Plant, Brightwater TIN reduced to 3mg/l (April – October only)*

Photo courtesy of King County

Draft Workplan | Regional Reports



- ❑ Main Basin (5 runs)
- ❑ South Sound (8 runs)
- ❑ Hood Canal (8 runs)
- ❑ Canadian treatment plants and river impact on Puget Sound (8 runs)
- ❑ ~~Strait of Juan de Fuca & Admiralty Inlet~~

Each Report Typically Includes

- Baseline (current conditions)
- Pre-anthropogenic (reference conditions)
- No small, medium, large, or any local wastewater treatment plants
- Half the anthropogenic load and double the current loads of local rivers
- + 2 customized scenarios

Draft Workplan | Scientific Engagement & Leadership

- Proactively address water quality issues in the Puget Sound (e.g., PFAS)
- This year, focus code development on dissolved oxygen available to organisms
  - Consider temperature and multiple stressors like climate change

[Presentation by Martha Sutula at The Science of Puget Sound Water Quality workshop on July 26, 2022]

May 26, 2023

WA Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

US Environmental Protection Agency
U.S. EPA, Region 10
1200 Sixth Avenue, Suite 155
Seattle, WA 98101

RE: The Marine Dissolved Oxygen Water Quality Criteria of WA State

Dear Sirs and Madams,

It is the view of the Stillaguamish Tribe that the Marine Dissolved Oxygen Water Quality Criteria (MDOWQC: Table 210 WAC 173-201A-210 (1)(d)) of WA State are in need of thoughtful, science-based revision. They are outdated, simplistic, and fail to consider the geography and hydrology of Puget Sound. Neither are they based on or referenced with scientific research. The Sound is a fjord-like estuary complex comprised of multiple deep-water basins separated by shallow sills, and many basins terminate in shallow inlets that may also include shallow brackish river deltas. The current marine dissolved oxygen standards are neither reasonable nor realistic and in many locations the standards will never be achieved due to these physical factors.

The State should rewrite the MDOWQC to address the natural seasonal conditions of various waterbodies in the Sound as they relate to the biological requirements of organisms using those habitats. Each type of waterbody (deep basin water, open water, shallow bay water, shallow intertidal, shallow estuary) need standards that match its natural condition for each season. The criteria should include minimums for 7-day and 30-day means in addition to instantaneous values, to address seasonal averages and trends. These conditions can be defined using the results of local science and monitoring efforts.

The state has identified waters not meeting the MDOWQC, yet that determination does not demonstrate the waters are truly impaired. Once appropriate standards are established, it is likely many of so-called water quality exceedances will cease to exist. Currently marine waters with 5

STILLAGUAMISH
TRIBE OF INDIANS

stuləgʷábš : People of the River
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mg/L dissolved oxygen in many deep-water basins are considered non-compliant, when in fact this oxygen level poses no threat to organisms that might be using it. Scientists in the region commonly acknowledge that the harm to a deep-water marine biological community does not occur until the water becomes hypoxic, that is, when oxygen levels drop below 2 mg/L.

Agencies are spending a great deal of focus, time, and money to determine nitrogen inputs and how they move around the Sound. Yet the models used to determine loading and circulation have inadequate inputs for important parameters such agricultural loading and shoreline septic systems. Even as Ecology plans to install nutrient monitoring devices in various watersheds, these devices will mostly be located upstream of agricultural lowlands and/or they will not be measuring total nitrogen. Shoreline residences of Puget Sound that are on septic systems are another potential source of nitrogen that is not measured. Some counties such as Snohomish do not even have regular required inspections and have inadequate inventories of their shoreline septic systems.

While nutrient loading in Puget Sound may be excessive and unhealthy in some locations, we feel that the amount of money, time, and resources spent on nutrients in the marine water are ignoring several other “elephants in the water” that harm wildlife and their habitat. The Tribe is concerned about preventing marine impacts from water quality issues that often lack required treatment and adequate source prevention: storm water, shoreline septics, persistent organic pollutants, and emerging contaminants.

The Stillaguamish Tribe urges the state and EPA to conduct a complete, science-based revision of the Washington Marine Dissolved Oxygen Water Quality Criteria. Because Marine Dissolved Oxygen Water Quality Criteria are driving the listing of impaired waters, these criteria must be based on scientifically defensible methods.

Sincerely,

Sara Thitipraserth, Director
Stillaguamish Tribe Natural Resources Department

3322 236th St NE, Arlington, WA 98223 :: stillaguamish.com

Supreme Court No. 102479-7

SUPREME COURT OF THE STATE OF WASHINGTON

CITY OF TACOMA, BIRCH BAY WATER AND SEWER DISTRICT, KITSAP COUNTY, SOUTHWEST SUBURBAN SEWER DISTRICT, and ALDERWOOD WATER & WASTEWATER DISTRICT,

Respondents,

v.

STATE OF WASHINGTON, DEPARTMENT OF ECOLOGY,

Petitioner.

AMICUS CURIAE BRIEF BY BUILDING INDUSTRY ASSOCIATION OF WASHINGTON

BUILDING INDUSTRY ASSOCIATION OF WASHINGTON
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I. INTRODUCTION

Affordable housing is a luxury in Washington, one which becomes more elusive to average citizens every day. Allowing the Washington State Department of Ecology ("Ecology") to require tertiary treatment at wastewater treatment plants ("WWTP") (or subject WWTP to total inorganic nitrogen ("TIN") load caps in the interim) without following the necessary procedures under the Administrative Procedure Act ("APA") will make owning and building homes in western Washington practically impossible.

The Building Industry Association of Washington ("BIAW" or the "Association") is the trade association for home builders and associated trades in Washington and has firsthand knowledge of the impact that additional wastewater and sewer bills will have upon Washingtonians. Without the Department following the requirements of the APA, and permitting the necessary stakeholders to meaningfully participate in discussions surrounding a requirement to add tertiary treatment, the following will happen: 1) Washington citizens, especially racial and social minorities, will be further unable to afford to purchase or rent homes in the communities where they currently live and work; 2) Washington citizens will not be permitted, nor will they be able to afford to build homes in western Washington counties; and 3) other private businesses and citizens will be detrimentally impacted when working with state agencies regarding rulemaking. For these reasons, this Court should affirm the decision of the lower court, and hold that the Department violated the APA when it issued its directive regarding the total inorganic nitrogen cap load.

II. FACTUAL AND PROCEDURAL BACKGROUND

In the interest of judicial economy, this brief defers to the thorough recitation of the facts and procedural background of this case as provided by the Court below, and the Respondent before this Court.

III. IDENTITY AND INTEREST OF AMICUS CURIAE

BIAW represents nearly 8,000 members of the Washington home-building industry. The Association is made up of fourteen affiliated local associations: the Central Washington Home Builders Association, the Building Industry Association of Clark County, the Jefferson County Home Builders Association, the Master Builders Association of King and Snohomish Counties, the Kitsap Building Association, the Lower Columbia Contractors Association, the North Peninsula Builders Association, the Olympia Master Builders, the Master Builders Association of Pierce County, the San Juan Building Association, the Skagit-Island Counties Builders Association, the Spokane Home Builders Association, the Home Builders Association of Tri-Cities, and the Building Industry Association of Whatcom County. BIAW is one of the largest home-building associations in America, championing the rights of its members and fighting for affordable home ownership at all levels of government. BIAW pursues these goals through several means including legal challenges, legislative and policy work, and through our research center, the Washington Center for Housing Studies ("WCHS"). Additionally, BIAW supports its members by providing awardwinning education, employee healthcare plans, and the state's largest, longest-operating Retro (Retrospective Rating) safety incentive program, ROII[1].

BIAW offers this brief to assist the Court in considering the harmful impacts of requiring tertiary treatment, and/or TIN load caps, at WWTP on homeowners in Washington, as well as the uncertainty created if government agencies are permitted to create rules outside of the APA process.

IV. ISSUES ADDRESSED

1. Whether requiring tertiary treatment, and/or TIN load caps, at WWTP will increase costs to homeowners and result in the denial of permits for affordable housing in Washington.

[1] Retro is a safety incentive program offered by the Washington State Department of Labor and Industries ("L&I"). In Retro a participating company can earn a partial refund of their workers' compensation premiums if the company can reduce workplace injuries and lower associated claim losses. *See* About Retrospective Rating (Retro), last viewed March 18, 2024, https://www.lni.wa.gov/insurance/rates-risk-classes/reducing-rates/about-retro.

2. Whether permitting Washington State agencies to create administrative rules and regulations outside of the APA process will create uncertainty in other regulatory agencies like the State Building Code Council ("SBCC") and L&I.

V. ARGUMENT

A. Requiring Tertiary Treatment Will Further Prevent Affordable Housing in Washington

If the Department of Ecology requires tertiary treatment at WWTP in Washington, then monthly housing-related bills will increase for homeowners and renters. Additionally, housing supply will inevitably decrease when this requirement, or a TIN load cap, leads to canceled development permits.[2]

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[2] Canceled and delayed building permits are not speculative hypotheticals, rather they present a very real risk to affordable housing. A delay in permitting can cost home builders and owners thousands of dollars. Statewide, the average permit delay is six and a half months, costing on average $31,375 in total holding cost. "For every $1,000 added to the cost of constructing a new home, 2,200 families lose their ability to purchase a new home." Andrea Smith, *Cost of Permitting Delays*, Washington Center for Housing Studies – BIAW, https://www.biaw.com/research-center/cost-of-permitting-delays/ (internal quotations omitted). Immediately following Ecology's denial letter stating it would "set nutrient loading limits at current levels…", the City of Tacoma placed "caveats in

Washingtonians, cannot afford additional bills – especially not an additional $500 added on to their monthly sewer bill. Nor can Washingtonians continue to be priced out of opportunities for home ownership, and rentals.

Data shows that Washington State is one of the most expensive states to live in and that the demand for affordable homes to rent and own is significantly greater than the supply.[3]

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building permits allowing the City to 'rescind the permit' in the event Ecology limited the City's treatment capacity by capping nitrogen discharges. This put several major projects in limbo, including multifamily housing developments, a behavioral health hospital, and an expansion at Bates Technical College Medical School." *City of Tacoma v. Dep't of Ecology*, 28 Wn. App. 2d 221, 233-34 (2023) (internal citation omitted).

[3] The expense of home ownership is apparent when viewing the increase in typical home value. Between 2000 and 2023 the increase in Washington was 216 percent. The only seven states higher were Hawaii (309 percent), California (259 percent), Idaho (258 percent), D.C. (254 percent), Florida (248 percent), Maine (240 percent), and Vermont (219 percent). Matt Brannon, *Home Prices vs. Inflation: Why Americans Can't Afford a House in 2024*, Clever (March 11, 2024), https://listwithclever.com/research/housing-inflation-2024/. Further, Washington is now home to 18 cities where the typical home is worth $1 million or more, ranking seventh in the nation for having the most million-dollar cities. King 5 Staff, *Report: Washington now home to 18 cities where the typical home is*

BIAW's research center, WCHS, has been working tirelessly to help inform decision-makers and politicians about the ever-rising costs and barriers to homebuilding, homeownership, and the rental market in Washington. BIAW and the National Association of Home Builders ("NAHB") estimate that a change of less than $1,000 to monthly bills would result in home ownership and renting being entirely unaffordable to most Americans, resulting in increased debt and homelessness. *See* Na Zhao, *NAHB Priced-Out Estimates for 2023*, National Association of Home Builders (March 2023), https://www.nahb.org/-/media/NAHB/news-and-economics/docs/housing-economics-plus/special-studies/2023/special-study-nahb-priced-out-estimates-for-2023-march-2023.pdf.

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worth $1 million or more, King 5 News (April 4, 2024 at 1:21 pm), https://www.king5.com/article/money/washington-home-to-18-cities-typical-home-worth-1-million-or-more/281-3225a860-e9a5-461a-9ab4-982211caabfc.

1. Cost is the greatest barrier for homes to own or rent in Washington.

The population growth in Washington State outpaces and outmatches the available, affordable homes. The Washington State Department of Commerce ("Commerce"), as well as WCHS, have determined, after reviewing the available data, that home ownership is nearly unattainable for most people in Washington. *See*, *Washington state will need more than 1 million homes in next 20 years*, Washington State Department of Commerce (March 2, 2023), https://www.commerce.wa.gov/news/washington-state-will-need-more-than-1-million-homes-in-next-20-years/, *see also,* Andrea Smith, *Housing Affordability In Washington*, Washington Center for Housing Studies - BIAW (March 1, 2024), https://www.biaw.com/research-center/washington-states-housing-affordability-index/. Inflation, an aging workforce, supply chain issues, rising construction costs, regulatory costs, and an ever-increasing cost of living all contribute to the barriers to home ownership and the ability to rent in Washington. The impact, however, of unaffordable housing ultimately lands upon low- and middle-income households, disproportionately affecting minorities - especially Black, Indigenous, and people of color ("BIPOC"), immigrants, LGBTQ2+ individuals, individuals with disabilities, first-time home buyers, and those living outside the nuclear family.[4]

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[4] *See, e.g.,* "Home ownership in Washington has followed a disturbing pattern […] 69% of White families are homeowners compared to only 34% of Black families. Fifty years ago, in 1970, 50% of Black families owned homes." The Racial Restrictive Covenants Project, *Homeownership by race 1970-2022 – Washington State*, Civil Rights and Labor History Consortium University of Washington (last viewed March 18, 2024), https://depts.washington.edu/covenants/homeownership_washington.shtml; "[…] Black, Indigenous, and people of color (BIPOC) would need to buy more than 140,000 houses in the state to achieve parity with white homeownership on a percentage basis. The housing gap is even more significant today than in the 1960s, when housing discrimination and redlining were legal." *Report: Black, Indigenous, and people of color (BIPOC) would need to buy more than 140,000 houses in the state to achieve parity with white homeownership in Washington State*, Washington Department of Commerce (last viewed on March 18, 2024), https://www.commerce.wa.gov/news/report-black-indigenous-and-people-of-color-bipoc-would-need-to-buy-more-than-140000-houses-to-achieve-parity-with-white-homeownership-in-washington-state/ (emphasis added); "According to a 2021 Public Health – Seattle & King County

survey […] 35% of LGBTQ respondents reported earning less than $30,000 per year, which isn't enough to live anywhere, let alone [Capitol Hill]." Rich Smith, *Seattle's LGBTQ Communities Demand Rent Stabilization*, The Stranger (February 22, 2024, 9:00 am), https://www.thestranger.com/olympia/2024/02/21/79395600/seattles-lgbtq-communities-demand-rent-stabilization; "Only 16% of [transgender] people owned their homes, in contrast to 63% in the U.S. population." James, S.E., *et al.*, *The Report of the U.S. Transgender Survey*, Washington, DC: National Center for Transgender Equality (last viewed March 19, 2024), https://calculators.io/national-transgender-discrimination-survey/; "One of the greatest priorities of the Legislature is the work to mitigate the impacts of the housing affordability crisis. […] the crisis remains acute and the barriers to housing are unacceptably high. This is just as true for those with intellectual and developmental disabilities in Washington as it is for everyone else. A recent grant program in the Housing Trust Fund received twice as many applications for more housing in Supported Living as expected, confirming an unmet need for housing continues." Jamila Taylor, *People with disabilities are part of the WA housing crisis, too*, Seattle Times (February 13, 2024, 4:23 pm), https://www.seattletimes.com/opinion/people-with-disabilities-are-part-of-the-wa-housing-crisis-too/; "Small, independently rented residential units with shared kitchen and common spaces may soon be allowed in cities and counties across Washington […] Co-living housing units are similar to dorm rooms, with each sleeping quarters independently rented and other parts of the building shared. […] Housing advocates say co-living is one of the best ways to increase the amount of affordable housing in Washington." Laurel Demkovich, *WA House approves bill to expand dormitory-like housing*, Washington State Standard (February 7, 2024, 12:10 pm), BIAW's Housing Affordability Index, a Washington-based resource for understanding the extent to which county-level housing markets are providing a range of choices that are affordable and attainable to Washingtonians found that "[h]ome ownership is unaffordable for 84 percent of Washington families, based on the median-priced home of $586,100." *See Housing Affordability In Washington*, *supra*. In less than a year, home prices in Washington have increased by 36 percent, rising from an average of $430,000 in June 2023 to an average of $586,100 in March 2024. *Housing Affordability Index: Homes less affordable today*, BIAW (March 11, 2024), https://www.biaw.com/housing-less-affordable/. To afford the current median home prices, BIAW's WCHS has determined that Washington homeowners need to earn approximately $165,100 per year, however, the statewide median income is $90,325 –

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https://washingtonstatestandard.com/2024/02/07/wa-house-approves-bill-to-expand-dormitory-like-housing/.

almost $75,000 less per year than the necessary income to afford a median-priced home.

WCHS's research shows that should a Washingtonian, making the median income, have the necessary downpayment, and qualify for the purchase of the current median-priced home this purchase will result in an average monthly payment of $3,862 (or 51 percent of their monthly gross income) – eking out 49 percent of their income to spend on every other bill a household may maintain including necessities such as food, electricity, water, as well as student loans, and medical debt. Personal finance experts only recommend a household spend 30 percent of their income on housing.[5] Only 16.2 percent of households in Washington can afford median-priced homes with

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[5] The NAHB adopts for purposes of its yearly "Priced-Out" report that the sum of the mortgage payment for a household (which includes principal, loan interest, property tax, as well as homeowners' property and private mortgage insurance premiums) is no more than 28 percent of the monthly gross household income. *See* Zhao, *supra*.

a conventional mortgage, and 83.8 percent of Washingtonians are not able to afford homes with a conventional mortgage.

Inflation also greatly impacts the affordability of homes. In a new study from Clever Real Estate, based on Redfin data, the cost of a typical home in the U.S. is $412,778 - 24 times more expensive than the cost of a home in the 1960s, while inflation is only 10 times more expensive since the 1960s. Ana Teresa Solá, *Home prices rose 2.4 times faster than inflation since 1960s, study finds. What that means for homebuyers*, CNBC (March 19, 2024, 2:12 pm), https://www.cnbc.com/2024/03/19/why-home-prices-have-risen-faster-than-inflation-since-the-1960s.html. This same study found that home prices have risen 2.4 times faster than inflation, pointing out that if home prices had kept pace with inflation since the 1960s, homes would on average only cost $177,500, not nearly half a million dollars. Matt Brannon, *Home Prices vs. Inflation: Why Americans Can't Afford a House in 2024*, Clever (March 11, 2024), https://listwithclever.com/research/housing-inflation-2024/.

Further, the study found that in the 1980s, it took about three and a half years' worth of household income to purchase the typical home. Now, in 2024, it takes six years and four months' worth of household income to purchase the same home. *Id.*

Across Washington, the shortage of affordable homes to own and rent impacts extremely low-income households ("ELI"), whose incomes are at or below the poverty guideline, or 30 percent of their area's median income. Many of these households are spending more than half of their income on housing, and these individuals are more likely than others to sacrifice necessities such as food and healthcare to continue to pay their mortgage or rent, and face the risk of eviction or foreclosure at a greater rate.

2. <u>The Cost of Adding Tertiary Treatment at WWTP Will Prevent More Washingtonians from Affording A Home.</u>

Division III understood the main barrier to the implementation of tertiary treatment – cost. As discussed *supra*, several factors play into housing affordability, however, the cost of monthly, recurring bills such as a sewer or wastewater bill can place housing in jeopardy if increased. The Court below acknowledged the unintended consequences of an interim TIN load cap while a WWTP raises the funds necessary to implement tertiary treatment – halting development, creating a de facto moratorium. *See City of Tacoma*, 28 Wn. App. 2d at 234. A City, such as Tacoma, would have to place conditions on the sewer availability notices leading to impaired lending, and effectively halting most developments including affordable housing, shelters, and accessory dwelling units. *Id.* The answer to many issues in western Washington is more affordable housing, not less. Preventing affordable homes from being built due to sewer limits from the addition of tertiary treatment (or TIN load caps) will force ELI families from urban communities, and further place the fragile Washington housing supply into a "tailspin."

BIAW's WCHS is currently working on a report to be published later this year regarding the cost of Washington water and sewer connections, and the data demonstrates that the average cost of hookups to homes in communities without tertiary treatment is already $5,601.86. This data is tied to new builds, but costs for sewage and other wastewater exist on a monthly and recurring basis, not including emergencies which are often the responsibility of the homeowner or renter. These costs can severely impact a household's ability to pay all its bills. Nearly all WWTP in Washington State do not currently have tertiary treatment available at their plant, and do not have the current infrastructure to add tertiary treatment without passing on significant costs to the customers they serve or the tax base as a whole.

One of the only WWTP in Washington to implement tertiary treatment, out of several hundred public WWTPs, is the Riverside Park Water Reclamation Facility ("Riverside") in Spokane. Riverside added tertiary treatment based on the Department of Ecology's requirement due to excess levels of phosphorus being released into the Spokane River. *The Riverside Park Water Reclamation Facility*, Spokane City (last viewed April 1, 2024), https://my.spokanecity.org/publicworks/wastewater/treatment-plant/. The addition of tertiary treatment to Riverside was estimated to cost $126 million for the construction alone. *Id.* This figure does not include additional maintenance, testing, and other costs associated with tertiary treatment. These costs must be borne by someone, and inevitably these costs will be borne by those with the least access to the funds necessary to cover these costs, resulting in increased homelessness, and individuals moving further from their work and communities to be able to afford to live.

The City of Tacoma estimates that the addition of tertiary treatment at its WWTPs connected to the Salish Sea will cost anywhere from $250 million to $750 million in construction costs alone. *See*, *City of Tacoma*, 28 Wn. App. 2d at 233, AR 620. The cost of constructing tertiary treatment for WWTPs in western Washington, without formal rule-making processes allowing stakeholders and the public to voice their concerns would render housing even more unaffordable to

Washingtonians. As mentioned *supra*, there are substantial costs to add tertiary treatment or to enforce TIN load caps, and the average Washingtonian cannot afford to cover that cost.

The APA provides the necessary procedures to prevent injustices in the administrative rule-making process – injustices such as allowing underprivileged individuals to bear the burden of cost for the decrease of nitrogen into the Salish Sea. There are alternative opportunities available to ensure the health of the environment while still providing affordable housing in Washington. However, without the salient opportunities for all necessary parties to raise their concerns, opinions, and solutions, there cannot be a world in which we can prioritize both of these goals.

B. Permitting Governmental Agencies to Create State Rules and Directives Without Engaging in Formal Rule Making Under the APA Harms the Citizens of Washington

The APA provides certainty and security to the citizens of Washington. The APA was enacted to "clarify the existing law of administrative procedure, to achieve greater consistency with other states and the federal government in administrative procedure, and to provide greater public and legislative access to administrative decision making. *See* RCW 34.05.001 (emphasis added).

The APA provides certainty to parties, and those participating in an agency's decision-making process, especially regarding the role the judiciary plays in reviewing decisions. For many, knowing that the Washington State Supreme Court sits in the same position as the superior court, applying the APA directly to the same record before the agency, provides great comfort by leveling the proverbial "playing field" for all parties and providing clear, administrable rules. *Dep't of Labor & Industries v. Rowley*, 185 Wn.2d 186, 200 (2016) (citing *Brown v. Dep't of Commerce*, 184 Wn.2d 509 (2015)). This Court has consistently stated that "[r]ules are invalid unless adopted in compliance with the APA." *Northwest Pulp & Paper Ass'n v. Dep't of Ecology*, 200 Wn.2d 666, 672 (2022) (citing *Hillis v. Dep't of Ecology*, 131 Wn.2d 373, 398 (1997)). This Court has acknowledged that “[r]ule making procedures under the APA involves providing the public with notice of the proposed rule and an opportunity to comment on the proposal. These procedures allow members of the public to meaningfully participate in the development of agency policies that affect them. *Id.* (internal citations omitted).

BIAW, and ROII, both participate closely with several State agencies including L&I and the SBCC. Should either of these agencies act similarly to Ecology and enact rules and directives without following the necessary steps under the APA, this decision would be detrimental to both BIAW and ROII’s work. Trade associations play a major role in advising members on how laws, regulations, and administrative rules impact their day-to-day operations.

For example, in the building industry, BIAW takes on the task of updating its members on all the changes to the building code when a new code cycle goes into effect. This communication is necessary for several reasons: 1) our members are dedicated to providing the highest quality of products to their clients and need to be aware of the newest regulations; 2) our members are leaders in the building industry and want to be ahead of the curve when it comes to health and safety; and 3) our members are dedicated to building affordable homes for Washingtonians. BIAW staff participate in every SBCC meeting, attend work groups, advise on proposed directives and regulations, and, if necessary, file litigation to protect the rights of our members. BIAW can participate in the rulemaking process because the APA provides the necessary procedures to do so. Similarly, ROII participates in all aspects of L&I regarding home building – everything from safety at work to ensuring that injured employees are appropriately assisted to ensure the greatest recovery possible. ROII staff can participate in these processes with L&I staff because of the APA process. It allows the ROII staff to have certainty in the relationship with L&I, and the manner in which L&I will handle all of their rules.

Should Ecology be permitted to issue directives regarding WWTP without following the APA rulemaking process, this decision will remove the voice of numerous private businesses in Washington that work closely with State agencies.

VI. CONCLUSION

Washingtonians cannot afford houses in Washington as it currently stands, let alone if required to pay for the addition of tertiary treatment, or a TIN load cap in the interim, to WWTP. This Court should affirm Division III's decision, and confirm that the Department of Ecology cannot issue a directive requiring the addition of tertiary treatment without following APA rules.

This document contains 3,611 words, excluding the parts of the document exempted from the word count by RAP 18.17.

Respectfully submitted this 12th day of April, 2024.

BUILDING INDUSTRY ASSOCIATION
OF WASHINGTON

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DECLARATION OF SERVICE

I declare under penalty of perjury under the laws of the State of Washington that on this date I caused the foregoing document to be served on the following parties via the Appellate Court filing portal as indicated below:

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Dated at Olympia, Washington, this 12th day of April, 2024.

s/ Sydney Phillips
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BUILDING INDUSTRY ASSOCIATION OF WASHINGTON

April 12, 2024 - 12:56 PM

Transmittal Information

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**IN THE SUPREME COURT
OF THE STATE OF WASHINGTON**

CITY OF TACOMA, BIRCH BAY WATER AND SEWER DISTRICT, KITSAP COUNTY, SOUTHWEST SUBURBAN SEWER DISTRICT, and ALDERWOOD WATER & WASTEWATER DISTRICT,

Respondents,

v.

STATE OF WASHINGTON, DEPARTMENT OF ECOLOGY,

Petitioner.

BRIEF OF AMICUS CURIAE KING COUNTY

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I. INTRODUCTION AND INTEREST OF AMICUS CURIAE

King County (the "County") is the largest wastewater utility in the Puget Sound (the "Sound"). Through operation of five municipal domestic wastewater treatment facilities ("WWTFs") – the Carnation, Brightwater, Vashon, South, and West Point facilities – the County provides wastewater treatment and disposal service to 18 cities, 15 sewer districts, and the Muckleshoot Tribe, serving approximately two million people in over a 424 square mile service area. Four of these facilities discharge treated wastewater pursuant to the Puget Sound Nutrient General Permit and an individual Clean Water Act National Pollutant Discharge Elimination System ("NPDES") permit issued by the Department of Ecology ("Ecology").

King County shares Ecology's goal of improving Puget Sound's water quality and is not opposed to the adoption of more stringent regulations to address low dissolved oxygen and any resulting harm to aquatic organisms. But those regulations must be science-based and adopted through a transparent rulemaking process that includes a cost-benefit analysis and a least cost alternative developed through a robust public comment period.

The County has committed to a robust set of actions to protect and restore water quality in Puget Sound. In 2020, the County projected it would invest $9.5 billion in the next decade, the vast majority of which will be directed to improving the quality of its wastewater discharges and combined sewer overflows. Additional investments will be used for stormwater management, toxic pollutant source control, legacy site-remediation and salmon restoration and recovery. Notably, the $9.5 billion projection does not reflect the significant additional expenditures the County must now earmark to comply with Ecology's nutrient regulation-- the subject of this appeal.

Every dollar spent is raised through rates paid by the public. For this reason, it is imperative that public investments of this magnitude, which include measures the County must take to comply with environmental rules, are informed by regulatory processes that fully consider the costs as well as the ecological outcomes and community impacts-- including effects on housing affordability-- of these investments.

In 2019, without satisfying the rulemaking requirements set out in RCW chapter 34.05, Ecology directed its permit writers to impose on *all* dischargers a nitrogen nutrient loading limit ("TIN Rule"). That limit effectively froze the amount of nitrogen discharged from each WWTF at then-current levels, without regard to the anticipated population growth or cost. In so doing, it purported to enact a new "rule" that required notice and comment. *City of Tacoma v. Dep't of Ecology* ("*Tacoma*"), 28 Wn.

App. 2d 221, 535 P.3d 462 (2023) (invalidating the rule). As a result of Ecology's violation of RCW chapter 34.05, the State Administrative Procedures Act ("APA"), in imposing the new TIN Rule, King County and the public were deprived of an opportunity to comment on this significant proposed change.

This is no small matter. To comply requires the County to spend between $25 and $50 million in the next five years, $100 to $200 million in the next 10 to 15 years, and between $9 billion and $14 billion on future nitrogen removal. This results in monthly sewer rate increases of between $20 and $130 per month *per household,* representing a 40% to 230% increase to residents' current monthly sewer rates. Rate increases of this staggering magnitude will impact housing affordability, especially for the communities least able to afford these increases.

Making matters worse, because Ecology failed to engage in the robust and deliberate rulemaking process required by RCW chapter 34.05, it blinded itself to the environmental and societal costs of imposing the one-size-fits-all TIN Rule.

Given that the County's WWTFs discharge 50% of all wastewater discharged to the Sound, the County is the local government that is most financially and operationally impacted by the illegally adopted rule that is the subject of this appeal. By submitting this amicus brief, the County seeks to assist the Court in appreciating the real-world impacts of Ecology's failure to conduct a rulemaking process that will yield robust information about the costs, benefits and real-world impacts of actions taken to address low dissolved oxygen that has a higher likelihood of leading to more impactful and less costly improvements for the Sound.

The Court of Appeals correctly ruled that Ecology was not free to dispense with notice and comment in imposing the new TIN Rule. *Tacoma*, Wn. App. 2d at 251. By *requiring* its permit writers to "[s]et nutrient loading limits at current levels from *all permitted dischargers* in Puget Sound," Ecology adopted a rule that must go through formal rulemaking. *Id*. at 232 (emphasis added) (a directive to staff to add new terms for reissuing a permit is a rule). Because the TIN Rule violated the APA, the decision below should be affirmed.

II. ARGUMENT

King County incorporates the Court of Appeals' statement of the case background. *Tacoma,* 28 Wn. App. 2d at 224-36. This brief will address the key issue of whether Ecology's TIN Rule is a "rule" under the APA, the Rule's likely effects on the regulated community, and why formal rulemaking is essential. *Id*. at 246 ("The precise issue presented in this appeal is whether a directive can be an internal directive, *e.g.,* a commitment by Ecology that its own staff will impose new requirements on permittees.”).

A. The Court of Appeals Should Be Affirmed

The APA defines a “rule” broadly as

> ***any*** agency order, ***directive***, or regulation ***of general applicability*** (a) ***the violation of which subjects a person to a penalty or administrative sanction***; (b) which establishes, alters, or revokes any procedure, practice, or requirement relating to agency hearings; ***(c) which establishes, alters, or revokes any qualification or requirement relating to the enjoyment of benefits or privileges conferred by law***; (d) which establishes, alters, or revokes any qualifications or standards for the issuance, suspension, or revocation of licenses to pursue any commercial activity, trade, or profession; or (e) which establishes, alters, or revokes any mandatory standards for any product or material which must be met before distribution or sale.

RCW 34.05.010(16) (emphasis added); *see also* RCW 34.05.001 (“[T]he courts should interpret provisions of [the APA] consistently with decisions of other courts interpreting similar provisions of other states, the federal government, and model acts.”); *Wells Fargo Bank, N.A. v. Dep’t of Revenue*, 166 Wn. App. 342, 354, 271 P.3d 268 (2012) (interpretation of the state act consistent with federal APA).

The test is one of substance, not labels preferred by the agency. *McGee Guest Home., Inc v. Dep’t of Soc. & Health Servs*., 142 Wn.2d 316, 322, 12 P.3d 144 (2000). It involves a two-step inquiry: first, the court determines whether the purported rule is an “‘order, ***directive***, or regulation of general applicability’; [s]econd, the court determines whether [it] ‘fall[s] into one of the five enumerated categories'" in RCW 34.05.010(16)(a) through (e). *Tacoma*, Wn. App. 2d at 237 (citations omitted).

A directive "impel[s] one to act." *Id*. at 238, 245-46. Further, a "directive" is of "general applicability" – and therefore a "rule" – where "'the challenge is to a policy applicable to all participants in a program, not its implementation under a single contract or assessment of individual benefits.'" *Id*. at 238 (quoting *Failor's Pharm. v. Dep't of Soc. Health & Health Servs.,* 125 Wn.2d 488, 886 P.2d 147 (1994)); *see also Simpson Tacoma Kraft Co. v. Dep't of Ecology*, 119 Wn.2d 640, 648, 835 P.2d 1030 (1992) (holding that "'the nature of a rule [is] that it [must] apply to individuals ***only as members of a class***,'" and ruling that the numeric standard was a directive of general applicability because it applied "***uniformly to the entire class*** of entities which discharges dioxin into the state's waters ..." (emphasis added; citation omitted)).

Contrary to statutory language, Ecology insists that for a directive to be a rule it must have "independent regulatory effect" directly binding the regulated community. Petitioner State of Washington, Department of Ecology's Supplemental Brief ("Ecology Supp. Br.") at 21, 23. But the APA explicitly defines agency actions that govern *internal agency procedures* as rules. RCW 34.05.010(16)(c) (action that alters requirements for privilege or benefit is rule), (d) (action that alters standards for issuance of license is rule).

In addition, RCW 34.05.413(3) requires formal rulemaking before agencies like Ecology can make any changes to the procedural form provided to aggrieved persons when seeking an adjudicative proceeding. Obviously, rules like this are not self-executing and have no independent regulatory or binding effect on the regulated community – until an applicant fills out the form and requests an adjudicative proceeding. Ecology's argument would render both RCW 34.05.413(3) and RCW 34.05.010(16)(c) and (d) meaningless. *See Hillis v. State, Dep't of Ecology*, 131 Wn. 2d 373, 399, 932 P.2d 139 (1997) (agency procedures for processing water rights applications were a rule).

Not only are Ecology's arguments contrary to the Washington APA, but they are also contrary to the federal APA and caselaw adjudicating this same issue. That caselaw is consistent with King County's interpretation and should be followed because the APA is modeled after the federal APA and because the permits that Ecology issues are part of a federally delegated program supervised by the Environmental Protection Agency ("EPA") under the CWA. RCW 34.05.010(16); 33 U.S.C. § 1342(b)-(d).

Under federal law, the key is whether the agency's action or statement binds private parties ***or the agency itself*** with the force of law.

See, e.g., CropLife Am. v. EPA, 329 F.3d 876, 881 (D.C. Cir. 2003) (EPA's statement that it would cease using third-party human study data in evaluating pesticide safety used "clear and unequivocal language, reflecting] an obvious change in established agency practice, creates a 'binding norm' that is 'finally determinative of the issues or rights to which it is addressed'" because the statement divested EPA staff of discretion, it was a binding rule that must go through notice and comment rulemaking (citation omitted)); *Nat. Res. Defense Counsel v. EPA*, 643 F.3d 311, 405 (D.C. Cir. 2011) (EPA's "guidance" purporting to interpret the Clean Air Act, was a rule that must go through notice and comment because it authorized EPA regional air division directors to accept alternative compliance plans for the regulation of particulate matter, where they previously did not have discretion to do so); *Gen. Elec. Co. v. EPA*, 290 F.3d 377, 384-85 (D.C. Cir. 2002) (EPA guidance addressing alternatives for evaluating risks from waste containing polychlorinated biphenyls was a rule because it "b[ou]nd the Agency to accept applications" using the identified toxicity factor and imposed "further obligation[] on EPA" to now categorically accept the use of the identified toxicity factor); *Am. Trucking Ass'ns v. Interstate Com. Comm'n,* 659 F.2d 452, 463-64 (5th Cir. 1981) (court looks to the language of the agency document to determine if it "'genuinely leaves the agency and its decision-makers free to exercise discretion'"; when "the specifics … are couched in terms of command" and the guidelines, while "decorated with words that appear to be carefully chosen to avert classification as rules … lead all applicants toward one course … these are not guidelines but normative rules, and must be evaluated as such." (citation omitted)).

In the case below, the Court of Appeals correctly applied a similar methodology. As in *Simpson* and the federal cases discussed above, internal agency guidance constitutes a rule that must go through notice and comment when "the agency's employees were directed to include a new standard in all renewed permits and, by doing so, the permittees were subject to punishment if they violated the new standard." *Tacoma*, 28 Wn. App. 2d at 247. "*Simpson* stands for the proposition that 'directive' includes an agency's ***internal directive to its staff*** for issuing permits." *Id*. (emphasis added); *see also Nat. Res. Defense Counsel,* 643 F.3d at 405.

Here, Ecology's rule took the form of a letter dated January 11, 2019 (the "NWEA denial letter"), denying a rulemaking petition filed by Northwest Environmental Advocates to require tertiary nitrogen treatment for all 79 Puget Sound WWTFs to satisfy the regulatory requirement[1] to employ "all known, available and reasonable treatment" ("AKART").

[1] WAC 173-201A-020.

Ecology issued the NWEA denial letter because AKART technologies must be economically feasible and cost-effective, and tertiary treatment was cost prohibitive. To satisfy its procedural obligation to identify an alternative action to address NWEA's concerns as required under the APA, RCW 34.05.330(1), Ecology committed to have its staff include nitrogen limits, based on current nitrogen loads, in ***all*** future individual permits:

> Ecology *will* through the individual permitting process:
>
> 1. Set nutrient loading limits at current levels from all permitted dischargers in Puget Sound and its key tributaries to prevent increases in loading that would continue to contribute to Puget Sound's impaired status.
>
> 2. Require permittees to initiate planning efforts to evaluate different effluent nutrient reduction targets.
>
> 3. For treatment plants that already use a nutrient removal process, require reissued discharge permits to reflect the treatment efficiency of the existing plant by implementing numeric effluent limits used as design parameters in facility specific engineering reports.

Nw. Env't Advocs. v. Dep't of Ecology ("*NWEA*"), 18 Wn. App. 2d 1005, 2021 WL 2556573, at *11 (2021) (unpublished). "The record indicates these requirements were nondiscretionary and were part and parcel of the commitments Ecology made to NWEA." *Tacoma*, 28 Wn. App. 2d at 248.

Ecology tries to distance itself from these commitments arguing that its staff "were not bound" by the alternative measures identified in the denial letter. Ecology Supp. Br. at 24. This is contrary to reality and Ecology cannot have it both ways. Having defended its rulemaking petition denial by relying on its commitment to employ the TIN Rule alternative, Ecology cannot disclaim that commitment here, especially because the Court of Appeals relied on that promise in upholding Ecology's petition denial. *NWEA,* 2021 WL 2556573*,* at *11-13 (finding that Ecology satisfied its procedural requirements in denying a rulemaking petition by listing the alternative measures it ***was taking*** to apply AKART to its individual treatment plant permitting process: "Ecology's denial letter … stated the alternative means by which it ***will*** address NWEA's concerns." (emphasis added)).

More to the point, Ecology should be judicially estopped from disclaiming that promise, given the Court of Appeals' reliance on those commitments. *New Hampshire v. Maine*, 532 U.S. 742, 749-50, 121 S.Ct. 1808 (2001) (judicial estoppel prevents a party from prevailing on an argument and then relying on a contradictory argument to prevail simply because the party's interests have changed). The doctrine is designed to prevent Ecology from doing what it is doing here – seeking an advantage by litigating on one theory and then pursuing a contrary theory to gain a litigation advantage.

Ecology's argument that it is simply using its "existing pollution control authority to regulate nutrient pollution" is equally deficient. Ecology Supp. Br. at 25. The TIN Rule does not allow permit writers to use their discretion to employ a facility-specific approach to address nutrients, as would be appropriate under existing regulations. Instead, the TIN Rule requires Ecology's permit writers to apply the same loading limit to *each* WWTF in the Puget Sound, regardless of "case-by-case" factors. The TIN Rule is directly binding on Ecology and imposes a new, substantive legal obligation not previously found in the statute or regulations for issuing discharge permits and was subject to notice and comment.

B. By Promulgating the TIN Rule Without Public Notice and Comment, the Agency Deprived Itself of Foundational Information That May Have Led to a More Cost-Effective and Environmentally Beneficial Alternative

The purpose of the rulemaking procedures established by the APA is "to ensure that members of the public can participate meaningfully in the development of agency policies which affect them." *Simpson*, 119 Wn.2d at 649. By promulgating the TIN Rule without public comment, Ecology not only violated the purpose and intent of the APA, it failed to account for the impacts of the TIN Rule or identify alternative, less burdensome means to achieve the same or similar result.

In 1995, the Legislature amended the APA to "ensure that the citizens and environment of this state receive the highest level of protection, *in an effective and efficient manner*, without stifling legitimate activities and responsible economic growth." H.B. 1010, Reg. Sess. § 1(2) (Wash. 1995) (emphasis added). The Regulatory Reform Act of 1995 added requirements for agencies to follow in promulgating significant legislative rules. *Id.* § 201; RCW 34.05.328. These additional requirements were designed to ensure that, when an agency adopted a substantive rule, it would do so "responsibly" so that the rule is "justified and reasonable" and "obligations imposed are truly in the public interest." H.B. 1010 § 1(2)(b).

The TIN Rule falls within the definition of "significant legislative rule," RCW 34.05.328(5)(c)(iii), yet Ecology undertook none of the analysis required to ensure that it was justified, cost-effective and reasonable, and that the obligations it imposed were in the public interest. Ecology's failure to follow APA rulemaking procedures has deprived County ratepayers and the public of the opportunity to meaningfully understand the impacts of, and provide comment on, the TIN Rule. More significantly, Ecology's procedural failings also deprived ***it*** of critical public input that may have led to a different decision that would ensure that ratepayers' funds were spent wisely given the inherent uncertainties in existing science concerning what is causing the dissolved oxygen impairments in the Sound.

Indeed, there is insufficient evidence that reducing nitrogen in wastewater effluent will be effective at increasing dissolved oxygen in impaired and sensitive areas of the Sound. As the Court of Appeals emphasized, it is currently unknown to what extent excess nitrogen in parts of the Sound is due to WWTF discharges. *Tacoma*, 28 Wn. App. 2d at 228. This is because, while nitrogen can be measured at the point of discharge, Ecology cannot determine where that nitrogen goes once it gets carried away with the currents and mixes with the rest of the Sound. *Id.* at 227. And, while the Salish Sea Model is an important tool for high-level water quality modeling, leading scientists at the University of Washington have criticized Ecology's heavy reliance on it for site-specific regulatory purposes, given its inability to isolate the water quality impacts of individual WWTFs. *Id.*

Given the gaps in the current scientific knowledge about the complex factors causing dissolved oxygen impairments in the shallow embayments of the Sound, coupled with the enormity of the costs associated with nitrogen removal, it was particularly important for Ecology to adhere to formal rulemaking requirements in promulgating the TIN Rule.

Had Ecology followed the process required by the APA, it would have 1) evaluated whether alternative methods were available for achieving the purpose of the TIN Rule; 2) conducted a cost-benefit analysis; 3) evaluated whether the TIN Rule was the least burdensome alternative for wastewater utilities in the Puget Sound; and 4) evaluated whether compliance with the TIN Rule would impede or prevent compliance with other competing NPDES permit obligations. RCW 34.05.328. Ecology would have also evaluated the environmental impacts of the TIN Rule and determined whether adoption of the Rule would have resulted in significant environmental impacts under the State Environmental Policy Act ("SEPA"). RCW 43.21C.030; WAC 197-11-960. Ecology's failure to comply with the APA and SEPA left the benefits and impacts of the TIN Rule unquantified and therefore unknown, even where, as here, EPA has cautioned that "careful consideration should be given to the benefits from lower nutrient levels compared to the potential environmental and economic costs associated with treatment processes used to achieve those levels."[2]

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[2] U.S. EPA, Life Cycle and Cost Assessments of Nutrient Removal Technologies in Wastewater Treatment Plants ("Life Cycle") at iii (Aug. 2021), https://www.epa.gov/system/files/documents/2023-06/life-cycle-nutrient-removal.pdf.

1. The Lack of Cost-Benefit Analysis Hampered Ecology's Decision-Making

The APA requires that Ecology prepare a cost-benefit analysis that determines the probable benefits of the rule are greater than its probable costs. RCW 34.05.328(1)(c), (d). By failing to quantify either the costs or the benefits of the TIN Rule, Ecology shielded itself from receiving and developing foundational information that may well have resulted in a very different outcome that would have provided County ratepayers with a greater public, and water quality, benefit at a fraction of the cost.

This failure is particularly acute considering what Ecology already knows about the significant costs of reducing nutrient loading in effluent from WWTFs. Ecology denied NWEA's rulemaking petition because of the enormous costs associated with installing and operating tertiary treatment to reduce nutrient loading. *NWEA,* 2021 WL 2556573, at *15. Although Ecology chose a different path to reduce nutrient loading, it promulgated the TIN Rule requiring WWTFs to newly install nutrient treatment technology without considering the associated costs. Given the magnitude of nutrient treatment costs, and knowing that some plants, including the County's West Point Facility, have no additional land on which to expand or build additional treatment infrastructure,[3] it is nothing

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[3] *Tacoma*, 28 Wn. App. 2d at 225-26.

short of remarkable that the agency decided to take the shortcut it took by forgoing the formal cost/benefit analysis.

Compounding this omission is the fact that the population of Puget Sound is rapidly growing and is projected to continue to grow into the future. This growth requires utility providers, such as King County, to plan for and provide additional wastewater treatment capacity. The County alone is on track to spend between $25 million to $50 million in the next five years to comply with the TIN Rule and hold nutrient discharges at current levels. Additional required nutrient removal projects will cost up to $200 million in the next 10 to 15 years.

As explained above, these additional costs will directly impact King County ratepayers, at a time when rates are already set to double over the next decade to meet non-TIN Rule obligations, capacity needs, and critical maintenance requirements. The City of Tacoma estimated that full-scale improvements required for it to meet the TIN Rule would cost between $250 million and over $750 million. *Tacoma*, 28 Wn. App. 2d at 234 (citing AR at 620). Tacoma and King County are but two examples of the significant costs the TIN Rule imposes on utilities, and more importantly, ratepayers, that were ignored by Ecology in issuing the rule.

Equally problematic, Ecology did not assess the potential benefits of the TIN Rule. As the Court of Appeals observed, the Salish Sea Model that Ecology used to develop the rule has been criticized as "not yet ready for prime time" and cannot "isolate the effect of individual WWT[Fs]" on water quality in the Puget Sound. *Id.* at 229. Accordingly, Ecology does not know what effect, if any, application of the TIN Rule will have on water quality in the Sound, and as Division III notes, the agency does not know to what extent the nitrogen discharged by WWTFs actually causes the Sound's dissolved oxygen impairment. *Id*. at 228. Without this information, it is not possible to reasonably regulate nitrogen discharges from WWTFs. *Id*.

2. Ecology Failed to Evaluate Alternative Methods of Reducing Nutrient Discharges and Failed to Determine if Less Burdensome Alternatives Were Available

In adopting the TIN Rule, Ecology did not use its underlying regulatory authority to develop facility-specific approaches that would have evaluated the technological feasibility of removing nutrients at meaningful levels. Nor did it analyze ratepayer impacts, and perhaps most importantly, effects to water quality from a facility-specific, data-driven and scientifically-tailored effluent limits. Instead, it took a shortcut by developing a one-size-fits-all rule and applied it irrespective of the impacts or alternatives.

By regulating nutrient loading through the TIN Rule as an unanalyzed stand-alone requirement, instead of an integrated suite of individual, facility-specific permit conditions, Ecology has prioritized nutrient load reduction at the potential expense of other CWA requirements. Had Ecology performed the least- burdensome alternatives analysis required by the APA, it might have found that a more flexible approach would allow utilities to experiment with phased treatment process changes over time to obtain more meaningful results.

Indeed, upgrading wastewater facilities that are as large as the County's is not unlike turning an aircraft carrier or stopping a train – it takes time. These are large, complex systems that have complicated processes that require multiple stages of careful planning and engineering, as well as technical and financial analyses before making significant upgrades. Changes to one aspect of the treatment or pollutant removal process often has rippling effects on other parts of the WWTF. Facilities as large as the County's cannot be re-engineered on a dime to address one factor without causing other externalities, which is why it often takes 10 to 15 years or more to implement significant capital improvements. For example, because the County's WWTFs were not designed for nitrogen removal, a more deliberate and flexible approach to managing TIN would have avoided the unintended consequences that occurred at the County's South Treatment Plant. Staff efforts to meet the TIN Rule resulted in changes to the pH level, another regulated parameter. This required the

County to incur significant labor costs in spending an additional $3 million to construct a chemical addition system to prevent pH violations of its individual NPDES permit.

Similarly, a more flexible approach might have also allowed utilities to conduct rigorous nutrient influent and effluent monitoring to better understand what the Court of Appeals found is currently missing from existing science – *i.e.,* the real-world water quality impacts of WWTFs' discharges. *Id.* at 228. While King County has developed a robust marine water quality science program and has spent millions of dollars collecting physical, chemical, and biological data in Puget Sound, including dissolved oxygen measurements, our collective understanding of how best to remedy the dissolved oxygen deficits impacting water quality is admittedly very limited. By failing to identify, let alone evaluate, alternatives to determine if there is a less burdensome approach than adoption of the TIN Rule, Ecology not only violated the APA, but more importantly blind-sighted itself to other alternatives that were much less expensive and much more environmentally beneficial to the Region.

3. Ecology Failed to Evaluate the Environmental Impacts of the TIN Rule

Ecology's SEPA regulations require all state agencies to consider the environmental impacts of a proposed rule.[4] *See* WAC 197-11-960. Yet, Ecology ignored its own regulations and failed to quantify the potential environmental impacts of the TIN Rule. This is particularly problematic considering that Ecology has previously recognized the potential environmental impacts of requiring WWTFs to adopt additional nutrient removal technology – including the likelihood that tertiary treatment will not only generate more effluent sludge that will require disposal but will also require two to three times the amount of electrical energy currently used in WWTFs. *NWEA,* 2021 WL 2556573, at *9. Ecology also ignored climate change impacts of its Rule, including the fact that nitrogen removal from wastewater converts some nitrogen in the wastewater to nitrous oxide, a greenhouse gas that is 300 times more potent than carbon dioxide.[5]

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[4] The County notes that, to the extent Ecology, or other *amici,* are concerned about the rate at which Ecology is addressing water quality concerns in the Puget Sound, the Superior Court held that Ecology was required to go through notice and comment rulemaking over two years ago. But instead of doing so, Ecology chose to appeal. In the time it has taken Ecology to arrive before this Court, it could have completed the rulemaking process and achieved a legally and scientifically defensible path to reducing nutrient loading to the Sound.
[5] *See* Life Cycle, *supra* note 2, at 4-7.

In addition to the above, the rule will lead to an increase in the cost of living for County residents. Affordability is not just an economic issue for our communities; it is an environmental issue. When rates and other expenses of living in urban areas increase, housing development sprawls to rural areas where urban sewer systems do not reach. On a per capita basis, rural septic is far more polluting and can result in untreated septic waste entering Puget Sound. *Tacoma*, 28 Wn. App. 2d at 234.

Finally, SEPA required Ecology to evaluate the impacts of the TIN Rule on low-income and environmental justice communities. Given the enormity of the costs associated with its implementation, Ecology ignored the TIN Rule's impact on housing affordability and increased utility rates for those who are least able to afford them.

III. CONCLUSION

Had Ecology gone through the rulemaking process, as required by the APA, King County would have actively participated to help identify workable and scientifically sound solutions. The County cares deeply about the health of Puget Sound and has worked for years to find scientifically sound ways to improve its water quality. The County, ratepayers, and public were denied the opportunity for meaningful public engagement and as a result, no one – not Ecology, the regulated community, this Court, nor the public – knows the true impacts of

Ecology's rule. For all these reasons and those set forth in Tacoma's Supplemental Brief, the Court of Appeals should be affirmed, and Ecology should be required to comply with the APA.

I certify that this document contains 4806 words, pursuant to RAP 18.17.

DATED: April 15, 2024.

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Supreme Court No. 1024797

**IN THE SUPREME COURT
OF THE STATE OF WASHINGTON**

CITY OF TACOMA, BIRCH BAY WATER AND SEWER DISTRICT, KITSAP COUNTY, SOUTHWEST SUBURBAN SEWER DISTRICT, and ALDERWOOD WATER & WASTEWATER DISTRICT,

Respondents,

v.

STATE OF WASHINGTON, DEPARTMENT OF ECOLOGY,

Petitioner.

WASHINGTON ASSOCIATION OF SEWER & WATER DISTRICTS' MOTION FOR LEAVE TO JOIN IN AMICUS BRIEF FILED BY KING COUNTY

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Attorneys for Washington Association of Sewer & Water Districts

Pursuant to Rules of Appellate Procedure 10.6, the Washington Association of Sewer & Water Districts ("WASWD") seeks this Court's permission to join in the *amicus curiae* brief filed by King County. [1]

I. IDENTITY AND INTEREST OF *AMICUS* PARTY

WASWD seeks to join King County's *amicus* brief since WASWD represents members that share substantially the same positions and concerns as those raised by King County due to the fact that approximately 26 of WASWD's members collect and/or discharge treated wastewater directly or indirectly into the waters of Puget Sound. In fact, 15 WASWD members

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[1] The undersigned counsel has requested the parties' position relating to WASWD's motion. As of the filing of this motion, the City of Tacoma, Kitsap County and Southwest Suburban Sewer District have indicated that they do not oppose and support WASWD's motion. The Department of Ecology, Alderwood Water & Wastewater District and Birch Bay Water and Sewer District have not yet responded. Although, Alderwood and Birch Bay both support King County's motion for leave to file an amicus brief and are not expected to take a different position on WASWD's motion. Further, King County has responded that it supports WASWD's motion.

receive wastewater treatment and disposal services from King County under wastewater treatment contracts. The impacts described by King County in its a*micus* brief will similarly affect these WASWD members and their respective customers.

Allowing WASWD to join in King County's *amicus* brief serves the underlying purposes of RAP 10.6, including providing access to the appellate court by those persons or groups who will be significantly affected by the outcome of issues on review which will materially assist the Court in the decision-making processing. *See* 3 Washington Practice, Rules Practice, RAP 10.6 at 110 (Task Force Comment).

A. WASWD'S Mission and Membership.

WASWD has been providing education, advocacy and collaboration for sewer and water districts throughout the State of Washington since 1961. WASWD supports sewer and water districts in providing environmentally responsible wastewater collection and treatment and safe drinking water in an informed, efficient and effective manner. WASWD strives to ensure that its members providing sewer and water services throughout the State of Washington remain at the forefront of these ever-evolving industries, while ensuring effective operations, and appropriate regulatory and legislative representation.

There are approximately 180 sewer and water districts located throughout the State of Washington, each governed by locally elected officials. These districts provide cost-effective sewer and water services ranging from the state's largest population centers to the smallest rural communities. WASWD regularly works with these sewer and water districts to ensure the districts have a voice in regulatory matters that impact the delivery of sewer and water services.

B. WASWD's Interests Relating to this Appeal.

WASWD has 15 members that receive wastewater treatment and disposal services under contracts with King County which is the largest wastewater utility in the Puget Sound region. Four of King County's wastewater treatment facilities discharge treated wastewater into Puget Sound pursuant to the Puget Sound Nutrient General Permit ("PSNGP") and an individual Clean Water Act National Pollutant Discharge Elimination System ("NPDES") permit issued by the Department of Ecology ("Ecology") to King County. County Brief at 1. The impacts described by King County relating to the issues on appeal will also affect WASWD's 15 members and their respective customers who reside throughout the greater Puget Sound area. In addition, WASWD has 11 members operating wastewater treatment facilities that discharge treated wastewater directly or indirectly into Puget Sound under the PSNGP and separate NPDES permits issued by Ecology.

WASWD desires to participate in this appeal on behalf of its members to make sure the Court understands fully the real-world impacts of this Court's decision. These impacts will similarly extend to WASWD's members located in the greater Puget Sound region. More broadly, ensuring that state agencies follow proper rulemaking procedures affects and benefits all of

WASWD's members that provide sewer or water services throughout the state, especially since the sewer and water industries are heavily regulated. If Ecology is allowed to set binding regulatory rules through staff directives like occurred here, then Ecology could do it in other situations that will affect WASWD members throughout the state. Therefore, WASWD has a strong interest and desire to actively participate in this appeal to weigh in on these important issues.

C. WASWD'S Involvement in the PSNGP Process.

WASWD has been actively involved in the regulatory development process and review of the potential impacts of Ecology's PSNGP given the potential impacts of the proposed PSNGP. In fact, WASWD had a seat at the regulatory table through the appointment of a WASWD representative to serve as a member of the General Permit Advisory Committee which was formed and convened by Ecology in March of 2020. The WASWD representative's role was to provide input on behalf of small to medium sized wastewater treatment plants covering the entire Puget Sound region. The stated purpose of the Advisory Committee was to advise Ecology in drafting general permit requirements for domestic wastewater treatment plants discharging to Puget Sound.

The Advisory Committee met throughout 2020 to develop recommendations for general permit conditions. Final Recommendations relating to the development of the PSNGP were completed in October of 2020 and were released in November of 2020.[2] The Final Recommendations reflect significant areas of disagreement between members of the Advisory Committee with Ecology's position on various matters relating to the PSNGP.

WASWD was also an active participant on behalf of its members when Ecology issued the preliminary draft of the

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[2]The Final Recommendations of the Advisory Committee are available at the following link: https://www.ezview.wa.gov/Portals/_1962/Documents/nutrients/PSNGP%20AC%20final%20recommendations%202020_10_21_Final.pdf.

PSGNP in January of 2021 and the formal draft of the PSGNP in June of 2021 by providing comments on the draft PSGNP and raising and documenting its members' concerns about various portions of the draft PSGNP before it was adopted.

While WASWD was able to participate in the rulemaking process relating to the PSNGP before it was adopted, Ecology provided no opportunity to WASWD, the regulated community, or the public to provide comments or raise concerns relating to Ecology's 2019 directive to its permit writers to impose on all wastewater treatment facilities (WWTFs) discharging to Puget Sound a nitrogen nutrient limit ("total inorganic nitrogen" or "TIN Rule") that froze the amount of nitrogen that could be discharged at current levels, without regard to the anticipated population growth or cost. Had Ecology engaged in the required rulemaking procedures before adopting its TIN Rule, WASWD would have been an active participant in that rulemaking process on behalf of its members, just as it was during the process of Ecology adopting the PSGNP. Having been denied by Ecology of the opportunity to participate in the required rulemaking process that should have occurred prior to the adoption and implementation of the TIN Rule, WASWD is committed to being actively engaged in this important appeal because of the significant implications this case will have on WASWD's members.

D. Relationship to and Support of King County's Arguments and Positions.

As stated in King County's *amicus* brief, Ecology's decision to adopt the TIN Rule without complying with formal rulemaking procedures significantly impacts King County's ability to affordably serve its growing population and thus presents an issue of critical importance to King County and the 2 million people it serves. County Brief at 1-3. Importantly, WASWD's members that either receive wastewater treatment and disposal services from King County under contracts or otherwise discharge directly or indirectly treated wastewater into Puget Sound are similarly impacted by Ecology's unlawful rulemaking and stand in substantially the same position as King County.

In its *amicus* brief, King County advises the Court that in order to comply with Ecology's directive King County will need to spend between $25 and $50 million in the next five years, $100 to $200 million in the next 10 to 15 years, and between $9 billion and $14 billion on future nitrogen removal. County Brief at 3. King County states that these expenditures will result in monthly sewer rate increases of between $20 and $130 per month per household, representing a 40% - 230% increase to residents' current monthly sewer rates. *Id.* Importantly, the magnitude of these rate increases will have a negative impact on housing affordability, including those communities or areas that are least able to afford these increases. *Id.*

Based on a review of the State Legislature's Detailed Legislative Reports Topical Index[3] for the 2019-20, 2021-22 and 2023-24 biennia, more than 30 separate pieces of legislation to address affordable housing issues have been adopted by the Legislature and signed into law during the referenced time periods. Therefore, it is clear that affordable housing issues are now a focal point of the State Legislature and local governments seeking to address the affordable housing concerns and mandates. The sewer rate increases that will naturally flow from Ecology's unlawful rulemaking process relating to the TIN Rule will be borne by both King County and WASWD's members, and their respective customers, which will make the affordable housing issues even more challenging.

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[3] The Topical Index can be found at the following location on the State Legislature website: https://app.leg.wa.gov/bi/topicalindex.

WASWD believes it is important for the Court to understand and appreciate that increases in costs to King County to comply with the TIN Rule will be paid by the County's customers and contract agencies, which includes 15 WASWD members that contract with King County for wastewater treatment services. In the utility industry, rates are established based on the cost of service. As King County's costs of complying with Ecology's directives increase, those costs will have to be recovered through higher rates charged to WASWD's 15 members. In turn, WASWD's members will then have to adopt higher rates which must be paid by their respective customers. In some cases, smaller districts with fewer customers end up being impacted more by increased regulatory costs because they have a smaller customer base over which to share the financial burden.

A representative sampling of the published sewer rates charged by 6 WASWD members that receive wastewater treatment services from King County reveals that their rates are already heavily influenced by treatment costs imposed on them by King County. For example, the published sewer rates for 6 of the 15 WASWD members that contract with King County for wastewater treatment services show that approximately 46.3% to 69.4% of the total sewer bills charged to the members' customers are directly attributable to the cost of wastewater treatment that gets paid to King County. The sewer rate schedules for these 6 WASWD members are publicly available on their official websites.[4] The rate schedules are offered to illustrate the point that these sewer districts lack the

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[4] Cedar River Water & Sewer District (https://www.crwsd.com/wp-content/uploads/2024/03/Rate-Fee-Schedule-Final-Rev.-03-2024.pdf); Coal Creek Utility District (https://www.ccud.org/uploads/1/0/3/0/10309811/2022_rate_sheet.pdf); Northeast Sammamish Sewer & Water District (https://www.nesswd.org/customer-rates-and-charges/); Sammamish Plateau Water & Sewer District (https://spwater.org/DocumentCenter/View/1718/12052023-Master-Fees-and-Charges-Schedule-PDF?bidId=); Skyway Water & Sewer District (https://www.skywayws.org/billing.php); Soos Creek Water & Sewer District (https://www.sooscreek.com/utility-rates-2024).

ability to control costs that are imposed on them by King County which make up approximately one-half or more of the cost of sewer service charged to their customers. Any increased costs incurred by King County to comply with the TIN Rule will get passed down to WASWD's members that contract with King County and will eventually get paid by their respective customers in the form of increased sewer rates. The increases in costs paid by these 15 WASWD members will put an additional financial strain on their funding capacity to address their other regulatory or facility repair and replacement requirements. As described by King County, these rate increases are going to be substantial given the projected costs of complying with the TIN Rule.

Given the nature of the current treatment technology utilized by most WWTFs, it is not an exaggeration to say that every resident within the greater Puget Sound region that is served by King County is going to experience substantial rate increases associated with the TIN Rule without Ecology ever having engaged in proper rulemaking. Such a result is contrary to the purposes of the Administrative Procedures Act (APA) which is "to provide greater public and legislative access to administrative decision making." RCW 34.05.001. The purpose of APA-required rulemaking procedures is to give notice to the public of the proposed rule and to allow it to comment on the proposal. *Hunter v. Univ. of Wash.*, 101 Wn. App. 283, 293, 2 P.3d 1022 (2000) (*citing Hillis v. Dep't of Ecology*, 131 Wn.2d 373, 399). Notice and comment rulemaking "ensure[s] that members of the public can participate meaningfully in the development of agency policies which affect them." *Hillis*, 131 Wn.2d at 399.

As stated by King County, Ecology failed to engage in the robust and deliberate rulemaking process required by chapter 34.05 RCW. By doing so, Ecology intentionally overlooked or ignored the environmental and societal costs and benefits of imposing the one-size-fits-all TIN Rule. Like King County, WASWD and its members care about the health of

Puget Sound and they acknowledge that further investment will have to be made in order to protect water quality, protect and restore habitat, and assist in salmon recovery. However, WASWD and its members have an interest in making sure that Ecology does not take short cuts when engaging in rulemaking, especially when the costs associated with a rule or directive are as substantial as those that will have to be incurred to comply with the TIN Rule.

II. WASWD'S FAMILIARITY WITH THE ISSUES

As discussed in Section I above, WASWD has been actively involved in Ecology's efforts to adopt the PSNGP since the beginning of the process. WASWD and many of its members that will be directly impacted by Ecology's unlawful rulemaking are very familiar with the issues involved in this appeal and WASWD has been closely monitoring this matter since the initial lawsuit challenging Ecology's TIN Rule was commenced in Superior Court. WASWD has regularly followed the legal proceedings because the outcome of this case could have a significant impact on many of WASWD's members.

Further, legal counsel for WASWD has reviewed the applicable pleadings and appellate briefs filed in this matter.

III. ISSUES ADDRESSED IN KING COUNTY'S *AMICUS* BRIEF WHICH WASWD SEEKS TO JOIN

As discussed above, WASWD's interests are closely aligned with King County's interests. Given the similarity of interests, WASWD seeks the Court's approval for WASWD to participate in this appeal by joining in King County's *amicus* brief which was well briefed and set forth compelling legal arguments which are fully endorsed and supported by WASWD. By joining in the legal arguments made by King County, WASWD believes it can achieve its goal of ensuring that the Court has the benefit of hearing from WASWD on the important issues affecting WASWD's members.

With respect to the merits of the appeal, King County addresses how Ecology's decision to impose a TIN cap on all

WWTFs discharging to Puget Sound was a significant legislative rule that required formal rulemaking pursuant to chapter 34.05 RCW. Specifically, King County presents two issues for the Court's consideration which are shared and supported by WASWD. First, King County responds to Ecology's argument that a directive is not a rule unless it has "independent regulatory effect" that directly binds the regulated community. County Brief at 6 (*citing* Ecology Supp. Br. at 21, 23). King County demonstrates that Ecology's argument is contrary to the plain text of the State Administrative Procedure Act, specifically rendering RCW 34.05.413(3) a nullity. King County further demonstrates that Ecology's argument is also contrary to the Federal Administrative Procedure Act and federal case law adjudicating this same issue. King County explains that this case law is particularly informative where, as here, the State APA was modeled after the federal APA, and where Ecology's permitting authority derives from authority the

Environmental Protection Agency granted it under a federally supervised program. County Brief at 7.

Second, King County demonstrates that formal commitments made by Ecology to satisfy Ecology's procedural obligations under RCW 34.05.330(1) in denying a petition for rulemaking filed by Northwest Environmental Advocates ("NWEA") were both promoted by Ecology in defending its denial and relied on by Division II in upholding Ecology's denial. Those commitments specifically included the TIN Rule (*i.e.*, capping TIN in WWTF discharges at current levels) which Ecology now attempts to disavows by insisting that its staff "were not bound" by the measures Ecology put forward as an alternative to the very costly "tertiary treatment" to remove TIN being advocated by NWEA. King County argues that Ecology should be judicially estopped from disclaiming that promise, given the Court of Appeals' reliance on those commitments in upholding Ecology's decision in *Nw. Env't Advocs. v. Dep't of Ecology*, 18 Wn. App. 2d 1005, 2021 WL 2556573, at *11

(2021). *See New Hampshire v. Maine*, 532 U.S. 742, 749-50 (2001) (judicial estoppel prevents a party from prevailing in one phase of a case on an argument and then relying on a contradictory argument to prevail in another phase simply because the party's interests have changed). County Brief at 10-11.

Beyond the merits, King County argues by promulgating the TIN Rule without public comment Ecology not only violated the purpose and intent of the APA, but Ecology also entirely failed to account for the impacts of the TIN Rule or to identify alternative, less burdensome means to achieve the same or similar result. County Brief at 12. King County demonstrates that Ecology's procedural failings also deprived Ecology of critical public input that may have led to a different decision that ensured that taxpayers' funds were spent wisely given the inherent uncertainties in existing science concerning what is causing the dissolved oxygen impairments in Puget Sound. King County argues that given the gaps in the current scientific knowledge about the complex factors causing dissolved oxygen impairments in the shallow embayments of Puget Sound, coupled with the enormity of the costs associated with nitrogen removal, it was particularly important for Ecology to adhere to formal rulemaking requirements in promulgating the TIN Rule. County Brief at 14.

By regulating nutrient loading through the TIN Rule as an unanalyzed stand-alone requirement, instead of an integrated suite of individual, facility-specific, permit conditions, King County shows that Ecology has prioritized nutrient load reduction at the potential expense of other Clean Water Act requirements. Had Ecology performed the "less burdensome analysis" required by the APA, Ecology might have found a more flexible approach that would allow utilities to experiment with phased treatment process changes over time to obtain more meaningful results. County Brief at 18.

King County also explains how upgrading wastewater facilities that are as large as King County's facilities is a complicated process which takes time. WWTFs are large complex systems that have complicated processes that require multiple stages of careful planning and engineering, as well as technical and financial analyses before making significant upgrades. Changes to one aspect of the treatment or pollutant removal process often has rippling effects on other parts of the WWTF. King County shows how facilities as large as the County's cannot be re-engineered on a dime to address one factor without causing other externalities which is why it often takes 10-15 years or more to implement significant capital improvements. County Brief at 19. These same issues apply to other wastewater treatment facilities owned or utilized by WASWD's members outside of areas served by King County.

Similarly, King County asserts that a more flexible approach might have allowed utilities to conduct rigorous nutrient influent and effluent monitoring to better understand what Division III found is currently missing from existing science - *i.e.*, the real-world water quality impacts of WWTFs' discharges. By failing to identify, let alone evaluate alternatives to determine if there is a less burdensome approach than adoption of the TIN Rule, Ecology not only violated the APA, but more importantly overlooked or ignored other alternatives that were both much less expensive and more environmentally beneficial to the greater Puget Sound region. County Brief at 19-20.

WASWD unequivocally supports and endorses all of the arguments made by King County. WASWD believes that these arguments will help the Court understand the real impact of Ecology's unlawful rulemaking when Ecology directed its staff to implement the TIN Rule.

IV. ADDITIONAL ARGUMENT IS NECESSARY TO INFORM THE COURT OF THE CONSEQUENCES OF THE TIN RULE

The additional arguments made by King County in its *amicus* brief which WASWD seeks to join are necessary to raise important arguments on the merits that have a different focus than were made by the named parties to the appeal.

Additional argument is also necessary to help educate the Court about the very real consequences of Ecology's decision to adopt the TIN Rule without adhering to formal rulemaking requirements.

Had Ecology gone through the rulemaking process, as required by the APA, WASWD would have actively participated in the rulemaking process to help identify workable and scientifically sound solutions. WASWD would have advocated on behalf of its members impacted by the TIN Rule for a more flexible approach that would require sewer utilities discharging treated wastewater directly or indirectly into Puget Sound to conduct rigorous nutrient influent and effluent monitoring to better understand the real-world water quality impacts of WWTFs' discharges.

Additional argument is also necessary to demonstrate the information that would have been gathered had Ecology followed the procedures mandated by the State Environmental Policy Act, including the environmental externalities that have and will continue to result from putting TIN removal above other water quality improvements and other impacts that have resulted from these actions. If Ecology had satisfied its SEPA mandate, that process would have also revealed the environmental justice ramifications of Ecology's decision to impose TIN caps across the board rather than on a case-by-case basis.

Like King County, WASWD's members desire to be good stewards of the environment and to protect the health of Puget Sound. However, WASWD and its members were denied the opportunity for meaningful public engagement regarding Ecology's TIN Rule directive. As a result, all interested parties have not had an opportunity to weigh in on the true impact of Ecology's TIN Rule.

V. CONCLUSION

For reasons discussed above, WASWD seeks permission from the Court to participate as an *amicus* party by joining in King County's *amicus* brief. WASWD and its members stand in a similar position as King County, but with a slightly different perspective. WASWD believes it is important for WASWD to participate in this appeal to advocate for its members since the TIN Rule will have significant ramifications to the districts providing wastewater collection and treatment services not only in the Puget Sound region, but throughout the state.

I certify that this document contains 3896 words, pursuant to RAP 18.17.

DATED: April 15, 2024

INSLEE, BEST, DOEZIE & RYDER, P.S.

s/ Eric C. Frimodt
ERIC C. FRIMODT, WSBA #21938

Attorneys for Washington Association of Sewer & Water Districts

DECLARATION OF SERVICE

I declare under penalty of perjury under the laws of the State of Washington that on this date I caused the foregoing document to be served on the following parties via the Appellate Court filing portal as indicated below:

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DATED this 15th day of April 2024 at Bellevue, Washington.

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Katia R. Perez, Legal Assistant

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April 15, 2024 - 2:18 PM

Transmittal Information

Filed with Court:	Supreme Court
Appellate Court Case Number:	102,479-7
Appellate Court Case Title:	Birch Bay Water and Sewer District, et al. v. State of WA, Dept. of Ecology
Superior Court Case Number:	20-2-02539-6

The following documents have been uploaded:

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Peterson, Teresa

From: James A. Tupper
Sent: Tuesday, July 2, 2024 10:40 AM
To: Emma L. Lautanen
Subject: FW: Thoughts regarding natural conditions criteria

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MARTEN LAW

From: Lincoln Loehr <lcloehr@yahoo.com>
Sent: Wednesday, April 17, 2024 4:07 PM
To: James A. Tupper <jtupper@martenlaw.com>
Subject: Fw: Thoughts regarding natural conditions criteria

Kalman's response

----- Forwarded Message -----
From: Bugica, Kalman (ECY) <kbug461@ecy.wa.gov>
To: Lincoln Loehr <lcloehr@yahoo.com>
Sent: Tuesday, April 16, 2024 at 06:42:37 PM PDT
Subject: Re: Thoughts regarding natural conditions criteria

Good afternoon Lincoln,

I appreciate your thoughts on natural conditions.

I'll talk more about our approach for this rulemaking next week to provide details, but in short, I'm not considering recommending changing the intent of WAC 173-201A-260(1)(a) regarding our approach to use of natural conditions. I.e., my recommendation is to keep our current approach, but tailor it to just aquatic life criteria.

Regarding DO criteria and those designated uses, I appreciate your thoughts. I would like to think that any DO criteria update may consider use updates as well, so perhaps there may be further distinctions between uses in the future.

Those changes might be necessary, as well, to avoid the scenario you identified below: where we would need to impair waters that aren't meeting 6 mg/l or 7 mg/L, but could still meet 5 mg/L.

Have a good afternoon, and I hope you plan on attending the preliminary decisions webinar for natural conditions next week.

Cheers,

Kalman

From: Lincoln Loehr <lcloehr@yahoo.com>
Sent: Friday, April 12, 2024 3:24 PM
To: Bugica, Kalman (ECY) <kbug461@ECY.WA.GOV>
Subject: Thoughts regarding natural conditions criteria

External Email

Kalman,

As you work on trying to satisfy EPA on a way to interpret natural conditions, I ask that the use of natural condition based approaches and the allowance for some human caused decrease should apply only when current numeric criteria are not met. (This is the current approach in our regulations.) The same allowance should also be available in the future when our marine DO criteria get a badly needed update to criteria similar to Chesapeake Bay's.

Given the explanation of our current numeric criteria, the natural condition trigger should only be when 5 mg/L (Good use) is not met. 5 mg/L is identified as protective *for most uses including, but not limited to, salmonid migration and rearing; other fish migration, rearing, and spawning; clam, oyster, and mussel rearing and spawning; crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing and spawning.*

True there are also criteria of 6 mg/L (Excellent use) and 7 mg/L (Extraordinary use), but the are identified as protecting all of the same uses that are protected by 5 mg/L (Good), and hence are unnecessary as triggers for natural condition considerations when not met. Granted, the Good use says "most uses" while the other uses have needless wording of "shall markedly and uniformly exceed the requirements for all uses including ...." and "shall meet or exceed the requirements for all uses including ...." When originally adopted in 1967, the list of uses included salmonid spawning for Excellent and Extraordinary, but did not include it for Good, hence the use of "most" in the list of uses protected by the Good classification. After 50 years, Ecology realized salmonids do not spawn in salt water, so that use was dropped, leaving three different classes (Extraordinary, Excellent, and Good) protecting all the same uses, without exceptions.

Given the common uses identified for 7, 6, and 5 mg/L, one cannot look to our criteria and assert there is impairment when DO is less than 7 or 6, but still meets 5 mg/L.

Please give these concerns consideration as you proceed with your rule-making task.

Lincoln Loehr

Preliminary Regulatory Analyses:

Including the:

- Preliminary Cost-Benefit Analysis
- Least-Burdensome Alternative Analysis
- Administrative Procedure Act Determinations
- Regulatory Fairness Act Compliance

Chapter 173-201A WAC

Water Quality Standards for Surface Waters of the State of Washington

By

Logan Blair, Ph.D.

Emma Diamond

For the

Water Quality Program

Washington State Department of Ecology

Olympia, Washington

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Website: Washington State Department of Ecology[1]

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Department of Ecology's Regional Offices

Map of Counties Served

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

Preliminary Regulatory Analyses

Including the:

Preliminary Cost-Benefit Analysis

Least-Burdensome Alternative Analysis

Administrative Procedure Act Determinations

Regulatory Fairness Act Compliance

Chapter 173-201A WAC, Water Quality Standards for Surface Waters of the State of Washington

Water Quality Program

Washington State Department of Ecology

Olympia, WA

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DEPARTMENT OF ECOLOGY
State of Washington

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Tables

Abbreviations and Acronyms

APA	Administrative Procedure Act
CBA	Cost Benefit Analysis
CFR	Code of Federal Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
ESA	Endangered Species Act
GP	General Permit
IP	Individual Permit
LBA	Least Burdensome Alternative
MGD	Million Gallons per Day
O&M	Operations and Maintenance
PPM	Parts Per Million
pH	potential of Hydrogen
RCW	Revised Code of Washington
RFA	Regulatory Fairness Act
SU	Standard Units
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
ug/L	Micrograms Per Liter
USFWS	United States Fish and Wildlife Service
WAC	Washington Administrative Code
WLA	Waste Load Allocations
WQ	Water Quality
WQS	Water Quality Standards

Executive Summary

This report presents the determinations made by the Washington State Department of Ecology as required under Chapters 34.05 RCW and 19.85 RCW, for the proposed amendments to the Water Quality Standards for the Surface Waters of the State of Washington rule (Chapter 173-201A WAC; the “rule”). This includes the:

- Preliminary Cost-Benefit Analysis (CBA)
- Least-Burdensome Alternative Analysis (LBA)
- Administrative Procedure Act Determinations
- Regulatory Fairness Act Compliance

why hasn't this been updated for DO since 1967?

Washington’s administrative code contains numeric water quality criteria for temperature, DO, and pH that are determined by designated use categories, as well as aquatic life toxics criteria such as copper, lead, and zinc. These numeric criteria are designed to protect designated uses and form the basis for water quality actions including permit limits.

However, numeric criteria do not always capture the unique chemical, physical, or biological characteristics that exist in any one system. Inconsistencies may be due to natural processes or seasonal conditions that vary across geography like water source, natural shading, and flow rate, among others. For example, a naturally low-flowing stream in a natural prairie without any human alteration may have seasonally higher temperatures than the numeric limit set to protect aquatic life. Here, a difficult situation may arise in which water bodies fail to meet water quality standards because of natural conditions, yet regulations require their improvement.

We are considering rule amendments to address EPA’s 2021 disapproval of previously-approved natural condition provisions in our standards, including for fresh and marine dissolved oxygen (DO) and temperature (excluding lakes). Nearly all states have some provision of this kind. Washington needs natural conditions provisions to recognizing that conditions in some surface waters naturally do not always meet water quality criteria throughout the year, and to effectively implement our Clean Water Act programs.

The proposed rule amendments consist of:

how is this defined? It wasn't detailed in the natural condition.

Proposed revisions to existing criteria:

- Updates to the natural conditions provision to limit use to aquatic life criteria.
- Updating allowances for human impacts to fresh and marine waters for dissolved oxygen and temperature when the natural conditions constitute the water quality criteria.

- Updates to the site-specific criteria process for an allowance for natural conditions to be used as a basis for developing these criteria.

Other proposed changes:

- Adding definitions for the performance-based approach and local and regional sources of human-caused pollution.
- Adding a new section detailing the use of the performance-based approach and applicable aquatic life criteria.
- Adding a rule document referenced in the water quality standards that details the methodology of the performance-based approach.

Minor non-substantive edits:

- One update to reflect the latest and current revision for a referenced EPA document

Costs from the proposed rule amendments would originate from any actions taken by permittees to comply with procedures or conditions that generate new capital expenses (e.g. technology, engineering solutions or land acquisition), labor cost (e.g. source control and monitoring), or other miscellaneous activities (scientific studies) compared to costs experienced under baseline conditions.

see EPA comment on costs (previous approval)

Based on guidance and conversations with Ecology staff, we determined that the most likely action to occur because of the proposed rule amendments taken together, would be meeting waste load allocations based on natural conditions criteria developed through the total maximum daily load (TMDL) process compared to meeting numeric temperature, DO, and / or pH criterion.[2] After filtering future TMDL studies for these criteria, with potential for natural conditions, and prioritized in the next 20 years, we identified 3,671 associated permits.

EPA previous approval concern...

no stakeholder process?

We cannot quantify the costs of the proposed rulemaking to associated permits because future TMDL studies have not been performed yet. Qualitatively, the most likely actions taken because of the proposed rulemaking are not likely to impose new costs, but rather produce benefits in the form of avoided costs. Historical TMDLs reviewed by the study team and the general logic of natural conditions provisions suggest that criteria considering local factors and seasonal variation would be more easily met through fewer actions or investments—up to avoiding paradoxical situations in which permittees need to improve the quality of the water they discharged to beyond what is achievable without any human influence.[3]

[2] See other potential actions and baseline comparisons detailed in Section 3.
[3] We note that if it were determined that for one part of the year natural conditions criteria are more stringent than the biologically based criteria (e.g. lower temperatures in winter months), permittees might face new cost during this period compared to baseline under the proposed rule. However, other aspects of the proposed rule like the human allowance and limiting allowances to local and regional sources, could mitigate these to an unknown degree. The net impact on costs would depend on the relative size of new costs and cost-savings. Ultimately, data

based on what?

We cannot fully quantify the extent of potential benefits of the proposed rulemaking because future TMDL studies have not been performed yet. However, through a pair of illustrative examples, we applied a small and arbitrary temperature and DO criteria change to a selection of potentially impacted permits—akin to just one scenario when meeting natural conditions under the proposed rulemaking. We estimated a total 20-year present value benefit of $675 million through this exercise, but stress that this represents partial benefits and should be considered a conservative lower bound. Additional, but unquantified, benefits include the avoided costs of meeting numeric criteria for freshwater pH compared to a natural condition based criteria, and any avoided cost of independent science by permittees in support of Ecology performing site-specific criteria and UAA in the baseline.

The baseline conditions and proposed rulemaking (if adopted) would be considered protective of aquatic life and designated uses. Therefore, we do not expect new costs or benefits from a material change in related ecosystem services.

We conclude, based on a reasonable understanding of the quantified and qualitative costs and benefits likely to arise from the proposed rule amendments, as compared to the baseline, that the benefits of the proposed rule amendments are greater than the costs.

After considering alternatives, within the context of the goals and objectives of the authorizing statute, we determined that the proposed rule represents the least-burdensome alternative of possible rule requirements meeting the goals and objectives.

Based on this analysis, Ecology is exempt from performing additional analyses under the Regulatory Fairness Act, under RCW 19.85.025(4) which states that, “This chapter does not apply to the adoption of a rule if an agency is able to demonstrate that the proposed rule does not affect small businesses.” Moreover, by not imposing compliance costs, the proposed rule amendments do not meet the RFA applicability standard under RCW 19.85.030(1)(a).

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limitations prevent us from quantifying a forecast of how often this might occur and the net cost of such a scenario.

Chapter 1: Background and Introduction

1.1 Introduction

This report presents the determinations made by the Washington State Department of Ecology, as required under Chapters 34.05 RCW and 19.85 RCW, for the proposed Water Quality Standards for the Surface Waters of the State of Washington rule (Chapter 173-201A WAC; the "rule"). This includes the:

- Preliminary Cost-Benefit Analysis (CBA)
- Least-Burdensome Alternative Analysis (LBA)
- Administrative Procedure Act Determinations
- Regulatory Fairness Act Compliance

The Washington Administrative Procedure Act (APA; RCW 34.05.328(1)(d)) requires Ecology to evaluate significant legislative rules to "determine that the probable benefits of the rule are greater than its probable costs, taking into account both the qualitative and quantitative benefits and costs and the specific directives of the law being implemented." Chapters 1 – 5 of this document describe that determination.

The APA also requires Ecology to "determine, after considering alternative versions of the rule…that the rule being adopted is the least burdensome alternative for those required to comply with it that will achieve the general goals and specific objectives" of the governing and authorizing statutes. Chapter 6 of this document describes that determination.

The APA also requires Ecology to make several other determinations (RCW 34.05.328(1)(a) – (c) and (f) – (h)) about the rule, including authorization, need, context, and coordination. Appendix A of this document provides the documentation for these determinations.

The Washington Regulatory Fairness Act (RFA; Chapter 19.85 RCW) requires Ecology to evaluate the relative impact of proposed rules that impose costs on businesses in an industry. It compares the relative compliance costs for small businesses to those of the largest businesses affected. Chapter 7 of this document documents that analysis, when applicable.

All determinations are based on the best available information at the time of publication. We encourage feedback (including specific data) that may improve the accuracy of this analysis.

1.1.1 Background

The distribution, health, and survival of many aquatic species in Washington directly or indirectly depend on the quality of the water in which they live. Changes in water temperature, for example, can materially impact the life of a salmonid given that cooler river water temperatures in the fall signal upstream migration. Human activities can directly contribute to thermal input to rivers, reduce groundwater that serves to moderate stream temperatures, or reduce the capacity of a river to absorb heat. Importantly, seasonal swings in temperature and variations in climatic conditions can also push temperatures outside the optimal range (USEPA, 2003).

DO, another important criterion, is the amount of oxygen that is present in water, which all aquatic animals need to breathe. Low levels of oxygen (hypoxia) or no oxygen levels (anoxia) can occur when excess organic materials, such as large algal blooms, are decomposed by microorganisms. As DO levels drop, some sensitive animals may move away, decline in health, or die (EPA, 2023). DO can be affected directly by local human actions such as contributing organic and inorganic materials that are metabolized by organisms (consuming available oxygen), and by actions that raise the temperature of waterbodies (thus reducing the solubility of oxygen). Like temperature, DO levels also fluctuate periodically, seasonally, and as part of the daily ecology of the aquatic resource (Ecology, 2018).

Variation in pH above (basic) or below (acidic) safe ranges may physiologically stress species and can result in decreased reproduction, decreased growth, disease, or death. While human activity can contribute to fluctuations in pH, pH levels vary naturally with the draining of wetlands or floodplains, substrate composition, and dissolved vegetative material or photosynthetic activity (EPA, 2024). Other toxic pollutants known to threaten aquatic life in a waterbody such as copper, lead, and zinc, may also come from human and natural contributors.

This rulemaking seeks to establish provisions that allow the use of natural conditions as a basis when setting aquatic life criteria through site-specific rulemaking or use attainability analysis (UAA). For temperature, DO and the potential of hydrogen ion concentration in freshwater (pH) specifically, this rulemaking provides a pathway for Ecology to set these criteria based on natural conditions without subsequent rulemaking through a performance-based approach. In waters where temperature and DO natural conditions apply, this rulemaking will limit human actions, or allowances. The rulemaking also includes definitions and methodological documentation supporting these proposed changes.

In this document, we predominantly focus our attention on describing and analyzing the proposed rule as it concerns temperature, DO and pH criteria given that establishing other criteria under this rulemaking will require additional rulemaking and regulatory analysis.

Numeric Criteria

Washington's administrative code contains numeric water quality criteria determined by designated use categories (see for example temperature in 173-201A-200(1)(c) WAC and 173-201A-210(1)(c) WAC, and DO in 173-201A-200(1)(d) WAC and 173-201A-210(1)(d) WAC), as well as a complete list of aquatic life toxics criteria in 173-201A-240 WAC.[4] Designated uses, sometimes called "beneficial uses," describe uses specified in Washington's water quality standards, and use designations are made for each surface water body or water body segment (see 173-201A-600 WAC and 173-201A-610 WAC).

Numeric criteria are designed to protect designated uses and form the basis for water quality actions including permit limits. There are six designated uses related to aquatic life for

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[4] Note that 173-201A-610 WAC contain all site-specific criteria where applicable.

freshwater bodies including: char spawning and rearing; core summer salmonid habitat; and salmonoid spawning, rearing, and migration. There are four marine water designated uses related to aquatic life ranging from extraordinary to fair quality. Each designated use is associated with a biologically-based numeric criterion ("numeric criteria" hereafter) determined to be protective of aquatic life. In the fresh water temperate criteria, for example, the numeric criterion for freshwater segments designated char spawning and rearing is 12 degrees Celsius (53.6 degrees Fahrenheit).[5]

Natural Condition Provisions at Ecology

Numeric criteria do not always capture the unique chemical, physical, or biological characteristics that exist in any one system. Inconsistencies may be due to natural processes or seasonal conditions that vary across geography like water source, natural shading, and flow rate among others. For example, a naturally low-flowing stream in a natural prairie without any human alteration may have seasonally higher temperatures than the numeric limit set to protect aquatic life.

In the example above, a difficult situation may arise in which water bodies fail to meet water quality standards because of natural conditions, yet regulations require their improvement. Permitting and enforcement would be costly if not impossible in this regulatory environment. Not only would dischargers need to curb their impacts, but they would be required to bring water quality to a state that is potentially unachievable, even in their collective absence.

To overcome these and similar challenges, the US Environmental Protection Agency (EPA) recommends that generalized aquatic life criteria be further refined through adoption of local criteria to protect unique characteristics inherent to a specific water (USEPA, 2015).[6] In this way, Ecology's regulatory work has relied on "natural condition provisions" to reconcile numeric criteria and local conditions before human alteration.[7]

Natural conditions provisions were adopted into the first water quality standards for the state in 1967 which placed limits on non-natural increases for temperature and allowed limited modifications when natural water quality conditions dropped due to "unusual and not reasonably foreseeable" natural causes.

The 1973 updates to the Water Quality Standards (WQS) introduced a general natural conditions provision, stating that "[w]henever the natural conditions are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria." This was further refined in 2003 and migrated to WAC 173-201A-260:

> "It is recognized that portions of many water bodies cannot meet the assigned criteria due to the natural conditions of the water body. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the natural conditions constitute the water quality criteria."

[5] See tables 200(1)(c), 200(1)(d), 210(1)(c), and 210(1)(d) in 173-201A WAC for additional details.
[6] https://www.epa.gov/sites/default/files/2015-02/documents/natural-conditions-framework-2015.pdf
[7] See WAC 173-201A-260(1); 173-201A-200(1)(c)(i); -210(1)(c)(i)); 173-201A-200(1)(d)(i); -210(1)(d)(i)).

Human action values were subsequently adopted to limit temperature (WAC 173-201A-200(1)(c)(i), -210(1)(c)(i))) and DO (WAC 173-201A-200(1)(d)(i), -210(1)(d)(i))) increases caused by human activity. For example, with respect to freshwater temperature (WAC 173-201A-200(1)(c)(i)):

> "When a water body's temperature is warmer than the criteria in Table 200 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F)"

EPA Disapproval

On Nov. 19, 2021, the EPA reconsidered and disapproved some of Ecology's previously approved natural conditions provisions and criteria in Surface Water Quality Standards (USEPA, 2021)[8] EPA disapproved the following WQS:

- A general provision that allows a water body's natural conditions to serve as the water quality standard. [WAC 173-201A-260(1)(a)]
- A specific provision that sets the temperature requirement to how cool a water body would be without human alterations. This provision also limits temperature increases caused by human activity cumulatively to less than 0.3 degrees Celsius. [WAC 173-201A-200(1)(c)(i), -210(1)(c)(i))]
- A specific provision that sets the dissolved oxygen requirement to the highest concentration a water body can achieve without human alterations. This provision also states that human activity cannot cumulatively cause dissolved oxygen in a water body to decrease more than 0.2 mg/L. [WAC 173-201A-200(1)(d)(i), -210(1)(d)(i)]

EPA stated in its justification of disapproving WAC 173-201A-260(1)(a) that the provision is broadly drafted and does not specify the types of criteria or pollutants to which it applies. Therefore, such a provision could apply to a wide range of naturally occurring pollutants, including toxic pollutants, and even allow an exception from otherwise applicable numeric human health criteria. This is not consistent with EPA's interpretation of the relationship between natural conditions and protection of designated human health uses. Washington's adopted provision did not limit in scope the natural conditions provision to aquatic life uses or specific pollutants.

EPA noted that there are no changes necessary to address the disapproval. Washington's WQS currently include applicable numeric criteria that EPA has determined to be protective of designated uses. EPA did, however, provide discretionary recommendations. EPA noted that it continues to believe an "appropriately drafted natural condition provision can serve an

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[8] In February 2014, the Northwest Environmental Advocates (NWEA) filed a complaint with the United States District Court for the Western District of Washington (Case No. 2:14-cv-0196-RSM) over EPA's 2008 CWA Section 303(c) approval. In October 2018, the Court issued an Order Granting a Stay (Dkt. 95) pending EPA's reconsideration of its prior determinations and subsequently granted an extension (Dkt. 118) for EPA to complete its reconsideration of these natural condition provisions by November 19, 2021. See https://fortress.wa.gov/ecy/ezshare/wq/standards/EPA_ActionsNCC_Nov192021.pdf for EPA's decisions.

important role in state WQS by reflecting a naturally occurring spatial and temporal variability in water quality that is protective of uses" (Opalski, 2021). EPA notes that a new provision for natural conditions narrowly tailored to aquatic life uses could be adopted. Alternative, the adoption of a performance-based approach could be used to establish aquatic life criteria reflecting the natural condition for specific pollutants.

In their justification for disapproving human allowance provisions in WAC 173-201A-200 and -210, EPA noted that it had disapproved the general provision in WAC 173-201A-260(1)(a) (as discussed above). Without an approved WQS that allows for natural conditions to constitute the applicable water quality criteria, then the applicable criteria for temperature and DO are the numeric criteria. The natural condition provisions for allowable human contribution are not based on these biologically based numeric criteria, but on the natural condition of the waterbody. Further, these provisions do not authorize human actions to cause insignificant exceedances to the applicable numeric criteria. Thus, EPA disapproved these provisions because such impacts are not tied to approved criteria that are in effect for Clean Water Act (CWA) purposes.

EPA noted again that no changes were necessary to address the disapproval, but that Washington could adopt new natural conditions criteria specific to temperature or DO. For instance, a performance-based approach for establishing these criteria representative of the natural condition of a waterbody could be adopted into the WQS. Another option would be for Washington to adopt numeric temperature and dissolved oxygen criteria that account for natural conditions using the best available relevant data. This could include site-specific criteria. EPA notes that Washington could also choose to adopt a new WQS provision that allows for human actions to cause insignificant decreases in DO or increases to temperature.

1.2 Reasons for the proposed rule amendments

We are considering rule amendments to address EPA's 2021 disapproval of previously-approved natural condition provisions in our standards, including for fresh and marine dissolved oxygen and temperature (excluding lakes).

It is important that we have a provision in the WQS recognizing that conditions in some surface waters naturally do not meet water quality criteria at all times throughout the year. Nearly all states have some provision of this kind. Washington needs natural conditions provisions to effectively implement our Clean Water Act programs.

1.3 Summary of the proposed rule amendments

In this rulemaking, we are using information from previous ESA consultations, prior EPA biological evaluations, EPA memorandums, EPA guidance documents, exploration of how other states address natural conditions, and the latest scientific information to propose natural conditions criteria that will protect designated and existing uses in Washington; while recognizing that some waters in Washington do not meet applicable biologically based numeric criteria due to natural or seasonal factors (see *inter alia* USEPA 2003, 2005, 2007, 2009, 2015b, 2021, 2023; USFWS, 2008).

The proposed rule amendments consist of:

Proposed revisions to existing criteria:

- Updates to the natural conditions provision to limit use to aquatic life criteria.
- Updating allowances for human impacts to fresh and marine waters for dissolved oxygen and temperature when the natural conditions constitute the water quality criteria
- Updates to the site-specific criteria process for an allowance for natural conditions to be used as a basis for developing these criteria.

Other proposed changes:

- Adding definitions for the performance-based approach and local and regional sources of human-caused pollution.
- Adding a new section detailing the use of the performance-based approach and applicable aquatic life criteria.
- Adding a rule document referenced in the water quality standards that details the methodology of the performance-based approach.

Minor non-substantive edits:

- One update to reflect the latest and current revision for a referenced EPA document

1.4 Document organization

The chapters of this document are organized as follows:

- **Chapter 2 - Baseline and the proposed rule amendments:** Description and comparison of the baseline (what would occur in the absence of the proposed rule amendments) and the proposed rule requirements.
- **Chapter 3 - Likely costs of the proposed rule amendments:** Analysis of the types and sizes of costs we expect impacted entities to incur as a result of the proposed rule amendments.
- **Chapter 4 - Likely benefits of the proposed rule amendments:** Analysis of the types and sizes of benefits we expect to result from the proposed rule amendments.
- **Chapter 5 - Cost-benefit comparison and conclusions:** Discussion of the complete implications of the CBA.
- **Chapter 6 - Least-Burdensome Alternative Analysis:** Analysis of considered alternatives to the contents of the proposed rule amendments.

- **Chapter 7 - Regulatory Fairness Act Compliance:** When applicable. Comparison of compliance costs for small and large businesses; mitigation; impact on jobs.
- **Appendix A - APA Determinations:** RCW 34.05.328 determinations not discussed in chapters 5 and 6.
- **Appendix B - Additional Tables and Figures**

Chapter 2: Baseline and Proposed Rule Amendments

2.1 Introduction

We analyzed the impacts of the proposed rule amendments relative to the existing rule, within the context of all existing requirements (federal and state laws and rules). This context for comparison is called the baseline and reflects the most likely regulatory circumstances that entities would face if Ecology does not adopt the proposed rule.

2.2 Baseline

The baseline is what allows us to make a consistent comparison between the state of the world with and without the proposed rule amendments. Should Ecology not adopt the proposed rulemaking, administering water quality actions are determined by existing laws and rules discussed in further detail in the remainder of this chapter.[9] Specifically, the baseline for this rulemaking includes:

- Clean Water Act
- Water Pollution Control Act
- Impaired Waterbody Listing and Cleanup Plan
- State Surface Water Quality Standards
- Permitting Guidelines and Compliance

The reminder of this section discusses the baseline in greater detail.

2.2.1 Clean Water Act

Section 303(c)(2)(A) states, about surface water quality standards:

> "…Such standards shall be such as to protect the public health or welfare, enhance the quality of the water and serve the purposes of this Chapter. Such standards shall be established taking into consideration their use and value for public water supplies, propagation of fish and wildlife, recreational purposes and agricultural, industrial and other purposes and also taking into consideration their use and value for navigation."

On standards, Section 304(a) cites that states should:

[9] Note again that we focus our attention predominantly on water quality actions related to temperature, DO and pH. That is because the proposed rule provides an option for these criteria to consider natural conditions through a performance-based approach. For all others, a site-specific study or UAA is needed, which will require a separate rulemaking and regulatory analysis.

(1) Establish numeric criteria values based on: 304(a) Guidance; 304(a) Guidance modified to reflect site-specific conditions; or other scientifically defensible methods.[10]

(2) Establish narrative criteria or criteria based upon biomonitoring methods where numerical criteria cannot be established or to supplement numerical criteria.

2.2.2 Water Pollution Control Act

RCW 90.48.010 states, about water quality standards:

> It is declared to be the public policy of the state of Washington **to maintain the highest possible standards to insure the purity of all waters of the state consistent with public health and public enjoyment thereof, the propagation and protection of wild life, birds, game, fish and other aquatic life, and the industrial development of the state,** and to that end require the use of all known available and reasonable methods by industries and others to prevent and control the pollution of the waters of the state of Washington. Consistent with this policy, the state of Washington will exercise its powers, as fully and as effectively as possible, to retain and secure high quality for all waters of the state. The state of Washington in recognition of the federal government's interest in the quality of the navigable waters of the United States, of which certain portions thereof are within the jurisdictional limits of this state, proclaims a public policy of working cooperatively with the federal government in a joint effort to extinguish the sources of water quality degradation, while at the same time preserving and vigorously exercising state powers to insure that present and future standards of water quality within the state shall be determined by the citizenry, through and by the efforts of state government, of the state of Washington.

RCW 90.48.035 states, about rule-making authority:

> The department shall have the authority to, and shall promulgate, amend, or rescind such rules and regulations as it shall deem necessary to carry out the provisions of this Chapter, including but not limited to rules and regulations relating to standards of quality for waters of the state and for substances discharged therein in order to maintain the highest possible standards of all waters of the state in accordance with the public policy as declared in RCW 90.48.010.

2.2.3 Impaired Waterbody Listing and Cleanup Plan

The CWA section 303(d) establishes a process to identify and clean up polluted waters. Every two years, all states are required to perform a water quality assessment of surface waters in

[10] Where other scientifically defensible methods include setting site-specific criteria equal to natural conditions (See https://www.epa.gov/sites/default/files/2015-02/documents/natural-conditions-framework-2015.pdf)

the state, including all the rivers, lakes, and marine waters where data are available. Ecology compiles its own water quality data and federal data and invites other groups to submit water quality data they have collected. All data submitted must be collected using appropriate scientific methods and follow an approved Quality Assurance Project Plan.[11] The assessed waters are placed in categories that describe the status of water quality. Once the assessment is complete, the public is given a chance to review and provide comments. The final assessment is formally submitted to the EPA for approval.

Waters with beneficial uses – such as aquatic habitat– that are impaired by pollutants are placed in the polluted water category in the water quality assessment 303(d) list. These water bodies fall short of state surface water quality standards and are not expected to improve within the next two years**.** , Waters placed on the 303(d) list require the preparation of a water cleanup plan (TMDL) or other approved water quality improvement project.[12] The improvement plan identifies how much pollution needs to be reduced or eliminated to achieve clean water and allocates that amount of required pollution reduction among the existing sources.

Ecology's assessment of which waters to place on the 303(d) list is guided by federal laws, state water quality standards, and the Policy on the Washington State Water Quality Assessment (Ecology 2023b). This policy describes how the standards are applied, requirements for the data used, and how to prioritize TMDLs, among other issues.[13] In addition, even before a TMDL is completed, the inclusion of a water body on the 303(d) list can reduce the amount of pollutants allowed to be released under permits issued by Ecology.

2.2.4 State Surface Water Quality Standards

State surface water quality standards form the initial basis for federal 303(d) listings and TMDLs described in section 2.2.2. Relevant rules that determine standards without this rulemaking include the following.[14]

Biologically based numeric criteria

Fresh water aquatic life designated uses and criteria WAC 173-201A-200, and marine water designated uses and criteria WAC 173-201A-210, establish Washington's biologically based numeric criteria for freshwater temperature, marine temperature, freshwater DO, saltwater

[11] See https://apps.ecology.wa.gov/publications/documents/2110032.pdf

[12] The term "TMDL" is often also applied to the process to determine a TMDL ("Ecology is doing a TMDL") and to the final documentation of the TMDL ("Ecology has submitted a TMDL").

[13] A TMDL is the sum of the Load Allocations and Wasteload Allocations, plus reserves for future growth and a margin of safety, which are equal to the Loading Capacity of the water body. This is a requirement of Section 303(d) of the federal Clean Water Act and is defined in 40 CFR 130.2(i). See https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Total-Maximum-Daily-Load-process for additional details on the TMDL process.

[14] Note that 90.48 RCW discussed above is the authorizing statute for opening WAC 173-201A discussed below.

DO, and freshwater pH—except for criteria applicable to specific waterbody segments found in Table 602 (173-201A-602).[15]

As discussed in Section 1.1.2, WAC 173-201A-260(1)(a), WAC 173-201A-200(1)(c)(i), -210(1)(c)(i)) and WAC 173-201A-200(1)(d)(i) -210(1)(d)(i) are not in effect for federal actions. This means that **without the proposed rulemaking, natural conditions cannot constitute water quality criteria for the purposes of federal actions, such as 303(d) listings and TMDLs.** Entities associated with water bodies that exceed numeric criteria in WAC 173-201A-200 & -210 for temperature, DO and pH will remain subject to numeric criteria.

Site-Specific Criteria and Use Attainability Analysis

Ecology can develop new site-specific criteria or change the designated use through a use attainability analysis (UAA). **Without the proposed rulemaking, natural conditions cannot form the basis for site-specific criteria, only biologically based numeric criteria determined from aquatic life species studies.[16]**

Currently, a private entity wishing to establish a site-specific criterion or to modify a use may evaluate, develop, and present the scientific support to Ecology for such an action. However, Ecology would carry out the full process of considering, proposing, and adoption through rulemaking.[17]

WAC 173-201A-430 states, about establishing site-specific criteria:

> (1) Where the attainable condition of existing and designated uses for the water body would be fully protected using an alternative criterion, site-specific criteria may be adopted. (a) The site-specific criterion must be consistent with the federal regulations on designating and protecting uses (currently 40 C.F.R. 131.10 and 131.11); and (b) The decision to approve a site-specific criterion must be subject to a public involvement and intergovernmental coordination process.
>
> (2) The site-specific analyses for the development of a new water quality criterion must be conducted in a manner that is scientifically justifiable and consistent with the assumptions and rationale in "Guidelines for Deriving National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses," EPA 1985; and conducted in accordance with the procedures established in the "Water Quality Standards Handbook," EPA 1994, as revised.
>
> (3) The decision to approve the site-specific criterion must be based on a demonstration that it will protect the existing and attainable uses of the water body.

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[15] Note that in addition to tables in 173-201A-200 and -210, 1 DADMax values and supplemental numeric spawning criteria described in subsequent subsections may also apply.

[16] Based on the scientific approach detailed in EPA (1985) guidelines.

[17] In this way, developing site-specific criteria or a UAA is a resource intensive process (Ecology, 2004). The need to balance resources with other water quality activities—such as permit management and TMDL work—means that site-specific criteria and UAA are taken on sparingly.

> (4) Site-specific criteria are not in effect until they have been incorporated into this chapter and approved by the USEPA."

WAC 173-201A-440 states, about use attainability analysis:

> (1) Removal of a designated use for a water body assigned in this chapter must be based on a use attainability analysis (UAA). A UAA is a structured scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, biological, and economic factors. A use can only be removed through a UAA if it is not existing or attainable.
>
> (2) A UAA proposing to remove a designated use on a water body must be submitted to the department in writing and include sufficient information to demonstrate that the use is neither existing nor attainable.
>
> (3) A UAA must be consistent with the federal regulations on designating and protecting uses (currently 40 C.F.R. 131.10).
>
> (4) Subcategories of use protection that reflect the lower physical potential of the water body for protecting designated uses must be based upon federal regulations (currently 40 C.F.R. 131.10(c)).
>
> (5) Allowing for seasonal uses where doing so would not harm existing or designated uses occurring in that or another season must be based upon federal regulations (currently 40 C.F.R. 131.10(f)).
>
> (6) After receiving a proposed UAA, the department will respond within sixty days of receipt with a decision on whether to proceed toward rule making.
>
> (7) The decision to approve a UAA is subject to a public involvement and intergovernmental coordination process, including tribal consultation.
>
> (8) The department will maintain a list of federally recognized tribes in the state of Washington. During all stages of development and review of UAA proposals, the department will provide notice and consult with representatives of the interested affected Indian tribes on a government-to-government basis, and carefully consider their recommendations.
>
> (9) The results of a UAA are not in effect until they have been incorporated into this chapter and approved by the USEPA. Any designated uses established through the UAA process are included in WAC 173-201A-602 and 173-201A-612.

2.2.5 Permitting Guidelines and Compliance

Permitting guidelines help determine how permit writers approach different permit scenarios. They assist permit writers in how to think through meeting water quality criteria for protection of aquatic life to permittee-specific requirements. While not a legal requirement, guidance informs how aquatic life criteria might impact permittees who discharge effluent to water bodies. Therefore, in describing the baseline for this analysis of the rule amendments, it is necessary to consider the permitting guidelines in the baseline and amended scenarios, as they will contribute to the cost and benefit estimates and the discussed impacts.

Ecology uses the Water Quality Program Permit Writer's Manual (Ecology, 2018) for technical guidance when developing wastewater discharge permits.[18] With respect to temperature, pH, and DO limits, permit writers would first determine if an applicable TMDL has been approved, or is in development before determining whether effluent will cause, or have reasonable potential to cause or contribute to, violation of water quality standards. If an approved TMDL exists, waste load allocations (WLA) described in the TMDL are used to determine appropriate water quality-based effluent limits.

If no TMDL exists, permit writers determine whether effluent will cause, or have reasonable potential to cause or contribute to, a violation of water quality standards. If so, then effluent limits are established using methods described in the permit writer's manual to meet biologically based numeric criteria.

Occasionally, the permit writer will have information that the receiving water concentration at the point of discharge during critical condition does not meet the aquatic life criteria and that the receiving water body is not listed on the 303(d) list.[19] In these cases, where the excursion is documented with data that meets the criteria for 303(d) listing, the permit writer should develop interim effluent limits based on existing performance (no increase in loading) to be placed in the permit.[20] The periodic Water Quality Assessment will evaluate the data and subsequently categorize the water body. If the water body is impaired, it will be put in Category 5 on the 303(d) list and prioritized for a TMDL.

Past or existing compliance

The baseline includes past or existing compliance behavior in response to federal and state laws, rules, permits, guidance, and policies. These include currently implemented TMDLs that set WLAs and other necessary actions to protect the natural conditions of the water, site-specific criteria, and criteria set through previous UAAs.[21] This behavior might include, but is not limited to, existing treatment technologies, production processes, and effluent volumes.

Future compliance

The baseline includes future compliance behavior without the proposed rulemaking. This includes response to in-development and future TMDL activity and permit actions related to temperature, DO and pH. In the absence of this proposed rulemaking, meeting temperature, pH, and DO on an impaired waterbody would eventually subject permits to a TMDL based on statewide numeric criteria (WAC 173-201A), criteria established under a biologically based site-specific study, or criteria established following a UAA.

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[18] https://apps.ecology.wa.gov/publications/documents/92109.pdf

[19] Critical condition refers to the time during which the combination of receiving water and waste discharge conditions have the highest potential for causing toxicity in the receiving water environment. This situation usually occurs when the flow within a water body is low, thus, its ability to dilute effluent is reduced.

[20] Where loading refers to the mass of a substance that passes particular point in a specified amount of time.

[21] Note that Washington has only performed one UAA, which is still with the EPA for review.

2.3 Proposed rule amendments

The proposed rule amendments consist of:

Proposed revisions to existing criteria:

- Updates to the natural conditions provision to limit use to aquatic life criteria.
- Updating allowances for human impacts to fresh and marine waters for dissolved oxygen and temperature when the natural conditions constitute the water quality criteria
- Updates to the site-specific criteria process for an allowance for natural conditions to be used as a basis for developing these criteria.

Other proposed changes:

- Adding definitions for the performance-based approach and local and regional sources of human-caused pollution.
- Adding a new section detailing the use of the performance-based approach and applicable aquatic life criteria.
- Adding a rule document referenced in the water quality standards that details the methodology of the performance-based approach.

Minor non-substantive edits:

- One update to reflect the latest and current revision for a referenced EPA document

2.4 Regulatory Impacts by Component

2.4.1 Updates to the natural conditions provision to limit use to aquatic life criteria

Baseline

State

On account of EPA's disapproval, there is no state baseline associated with natural conditions currently approved for federal actions (USEPA, 2021). Previous EPA-approved state regulations at WAC 173-201A-260(1)(a) states that:

"…portions of many water bodies cannot meet the assigned criteria due to the natural conditions of the water body. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the natural conditions constitute the water quality criteria."

Federal

The EPA's interpretation of the Clean Water Act allows for site-specific criteria to be set to natural conditions (see 2015 guidance on site-specific conditions and EPA's Action on Revisions to the Washington State Department of Ecology's Surface Water Quality Standards for Natural Conditions Provisions).[22,23]

Proposed

The proposed rule would:

- Change "assigned criteria" to "assigned aquatic life criteria" in WAC 173-201A-260(1)(a) to clarify that natural conditions apply only to aquatic life.
- Add WAC 173-201A-260(1)(a)(i) to provide information to determine natural conditions criteria values, which reflect EPA's requirement that there is a binding procedure in a state's WQS to determine natural background (Davies, 1997).[24]

Expected impact

This proposed amendment, in combination with others in this rulemaking, is expected to restore Ecology's ability to establish site-specific criteria equal to the natural conditions of a water body, in water quality standards. In particular, the proposed amendments will allow future TMDL studies and those currently under development to consider the natural conditions of a water body in the context of aquatic life.

Site-specific aquatic life criteria based on natural conditions are typically pursued when a water body does not meet statewide numeric criteria and the natural conditions of the water body are suspected of contributing to the failure to meet the water quality standard. In this rulemaking, applying natural conditions provisions to water bodies with insignificant human allowances, would provide protection for aquatic life while recognizing the characteristics and seasonal attributes unique to a specific water body. This likely constitutes a **benefit** because criteria set through natural conditions provisions will typically be more achievable by permittees than those based on numeric criteria.

Without the proposed rulemaking, permittees discharging to water bodies that exceed numeric criteria, but suspect exceedance is in part due to natural conditions, will be subject to the applicable numeric criteria unless a site-specific criterion or a UAA is adopted through rule making. Site-specific criteria or a UAA are rarely pursued by Ecology, but private entities may evaluate, develop, and present the science support to Ecology for such an action (see section 2.2.4). Independently conducted science must be evaluated by Ecology and the EPA and does not guarantee agreement or adoption. In this way, the proposed rulemaking constitutes an additional **benefit** to the degree that it would lessen the need for privately conducted scientific support of site-specific criteria or designated use changes and associated cost.

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[22] https://www.epa.gov/sites/default/files/2015-02/documents/natural-conditions-framework-2015.pdf

[23] https://fortress.wa.gov/ecy/ezshare/wq/standards/EPA_ActionsNCC_Nov192021.pdf.

[24] Where natural background is defined as "background concentration due only to non-anthropogenic sources, i.e., non-manmade sources."

Note that the costs of TMDL studies and associated data collection, labor, and other resources are borne by Ecology. Therefore, amending the TMDL process through this rulemaking to include natural conditions provisions does not represent new costs to private entities.

Also note that biologically based numeric criteria, site-specific criteria, or criteria established based on natural conditions of a water body proposed in this rulemaking are fully protective of aquatic life. Thus, the proposed amendments are not expected to materially impact ecosystem services or cultural values otherwise associated with changes to aquatic life.

2.4.2 Updating allowances for human impacts to fresh and marine waters for dissolved oxygen and temperature when the natural conditions constitute the water quality criteria

Baseline

State

On account of EPA's disapproval, there is no state baseline associated with natural conditions currently approved for federal actions (EPA, 2021). The previously EPA-approved state laws regulating human impacts when the natural conditions constitute the water quality criteria are: WAC 173-201A-200(1)(c)(i), 173-201A-200(1)(d)(i), WAC 173-201A-210(1)(c)(i), WAC 173-201A-210(1)(d)(i) and for specific waterbody segments listed under 173-201A-602.

In the disapproved sections above, "human actions" considered cumulatively may not cause the DO of that water body to decrease [from natural conditions] more than 0.2 mg/L, or the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F) for both fresh waters and marine waters.

Federal

The EPA's interpretation of the Clean Water Act allows for site-specific criteria to be set equal to the natural conditions of a water body. EPA guidance further suggest adopting a provision that allows for human actions to cause insignificant decreases in DO or increases to temperature (see 2015 guidance on site-specific conditions, EPA's Action on Revisions to the Washington State Department of Ecology's Surface Water Quality Standards for Natural Conditions Provisions).[25,26]

Proposed

(1) Change "human actions" to "local and regional sources of human-caused pollution".[27]

(2) Add that DO allowances may not cause the DO of that water body to decrease more than 10% or 0.2 mg/L below natural conditions, whichever decrease is smaller.

[25] https://www.epa.gov/sites/default/files/2015-02/documents/natural-conditions-framework-2015.pdf

[26] https://fortress.wa.gov/ecy/ezshare/wq/standards/EPA_ActionsNCC_Nov192021.pdf.

[27] See proposed definition of "local and regional sources of human-caused pollution" below

(3) Insert “below natural condition” referring to DO allowances and “above natural condition” for temperature allowance, to clarify they are given from the natural conditions criteria.

Expected impact

This proposed amendment, in combination with others in this rulemaking, is expected to restore Ecology’s ability to establish site-specific criteria equal to the natural conditions of a water body, as amended, in water quality standards. In particular, the proposed amendments will allow future TMDL studies and those currently under development to consider protecting aquatic life by requiring actions that would allow the water to meet site-specific criteria set equal to the natural conditions of a water body.

The proposed change (1) to the human action allowances will provide Ecology with the tools to regulate insignificant allowances when natural conditions criteria apply to a water body without the cumulative human action allowance being partially or fully allocated to impacts that are outside of Ecology’s regulatory authority (e.g., point source discharges in upstream Canadian waters, global climate change impacts). Amending DO allowance (2) provides additional protections in hypoxic waters, as otherwise a 0.2 mg/L decrease when waters are <2 mg/L DO may cause harm to aquatic life. Proposed language in (3) is purely for clarification.

If compared to EPA-disapproved state language, proposed amendments in (1) would allow for more achievable water quality by permittees while remaining protective of aquatic life, thus representing a benefit. Amendment (2) would be more stringent in some instances representing a cost to permittees and benefit to society by improving aquatic life. Amendment 3 has no impact.

Note that these proposed amendments are only impactful in the context of Ecology re-establishing the use of natural conditions provisions in water quality standards (i.e. WAC 173-201A-260(1)(a)). From the current baseline, the proposed amendments in this section will provide **benefits** as part of the broader collection of amendments establishing natural condition described in section 2.4.1.

2.4.3 Updates to the site-specific criteria process for an allowance for natural conditions to be used as a basis for developing criteria

Baseline

State

WAC 173-201A-430(2) says, of developing a new site-specific criteria, that it must be consistent with assumptions and rationale in “Guidelines for Deriving National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses” (USEPA, 1985).

The 1985 guidelines from the EPA were incorporated by reference and provide a mechanism for developing protective biologically based criteria, but these guidelines rule out the possibility of developing protective natural conditions criteria.

Federal

The EPA's interpretation of the CWA allows for site-specific criteria to be set equal to the natural conditions of a water body. Communication with the EPA guided Ecology to adopt 40 CFR 131.11 for simplicity and to cite federal regulations rather than guidance documents. This allowed Ecology to incorporate the ability to use the natural conditions of a water body as the basis for developing site-specific aquatic life criteria.

Proposed

To replace the 1985 EPA guidance references in WAC 173-201A-430(2) with 40 CFR 131.11.

Expected impact

This proposed amendment, in combination with others in this rulemaking, will restore Ecology's ability to establish site-specific criteria equal to the natural conditions of a water body, in water quality standards. This proposed amendment specifically allows the use of natural conditions as justification for site-specific criteria development. Adopting 40 CFR 131.11 broadens what approaches can be used to scientifically support site-specific criteria development. Under the proposed rulemaking, site-specific criteria development would become particularly useful when data, parameter, or site constraints prevent use of the performance-based approaches described elsewhere in this proposed rulemaking. On the margin where other approaches are not pursued (e.g. performance-based), and private entities wish to develop scientific support for site-specific criteria, the additional options and flexibility afforded by the proposed amendment likely translates to a **benefit.**

As with other means of establishing WQ criteria, note that site-specific criteria pursued through this amendment are also expected to be fully protective of aquatic life and the designated uses of the water body. Thus, the proposed amendment is not expected to impact ecosystem services or cultural values associated with changes to aquatic life compared to the baseline.

2.4.4 Adding definitions for the performance-based approach and local and regional sources of human-caused pollution

Baseline

Proposed

Add the following definitions to WAC 173-201A-020:

"Performance-based Approach" means a water quality standard that is a transparent process (i.e., methodology) which is sufficiently detailed and has suitable safeguards that ensures predictable and repeatable outcomes, rather than a specific outcome (i.e., concentration limit for a pollutant), consistent with 40 C.F.R. 131.11 and 40 C.F.R. 131.13.

"Local and regional sources of human-caused pollution" means sources of pollution caused by human actions, and the pollution originates from: (1) within the boundaries of the State; or (2) within the boundaries of a U.S. jurisdiction abutting to the State that impacts surface waters of the State.

Expected impact

Definition. No direct impact outside of where the defined terms are used in the proposed rule, discussed above and below in this Section.

2.4.5 Adding a new section detailing the use of the performance-based approach and applicable aquatic life criteria

Baseline

Federal

The EPA's interpretation of the Clean Water Act allows for site-specific criteria to be set equal to the natural conditions of a water body. The EPA guidance has identified two general approaches states and authorized tribes can use when adopting site-specific water quality criteria: determining a specific outcome (i.e., concentration limit for a pollutant) through the development of an individual numeric criterion, and adopting a criteria derivation process through the performance-based approach (see USEPA, 2021, 2023).[28,29]

Proposed

Add a new section to the WAC (173-201A-470) detailing performance-based approach as a tool that Ecology can choose to use for implementing aquatic life criteria in its state and federal CWA actions. In this proposed rule, the performance-based approach applies to dissolved oxygen (fresh water and marine water), pH (fresh water), and temperature (fresh water and marine water) only. Ecology does not propose a requirement that the tool must be used.

Expected impact

This proposed amendment, in combination with others in this rulemaking, is expected to restore Ecology's ability to establish site-specific criteria equal to the natural conditions of a water body, as amended, in water quality standards. In particular, the proposed amendments will allow future TMDL studies and those currently under development to consider protecting aquatic life by requiring actions that would allow the water to meet site-specific criteria set equal to the natural conditions of a water body without additional rulemakings.

From the current baseline, the proposed amendment in this section is part of a broader natural condition provision that will **provide benefits** described above in section 2.4.1.

2.4.6 Adding a rule document referenced in the water quality standards that details the methodology of the performance-based approach

Baseline

Federal

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[28] https://www.epa.gov/sites/default/files/2015-02/documents/natural-conditions-framework-2015.pdf
[29] https://fortress.wa.gov/ecy/ezshare/wq/standards/EPA_ActionsNCC_Nov192021.pdf.

The EPA's interpretation of the Clean Water Act allows for site-specific criteria to be set equal to the natural conditions of a water body The EPA guidance has identified two general approaches states and authorized tribes can use when adopting site-specific water quality criteria: determining a specific outcome (i.e., concentration limit for a pollutant) through the development of an individual numeric criterion, and adopting a criteria derivation process through the performance-based approach (see 2015 guidance on site-specific conditions and EPA's Action on Revisions to the Washington State Department of Ecology's Surface Water Quality Standards for Natural Conditions Provisions).[30,31]

Proposed

Due to the information required for the performance-based approach, we propose having a separate rule document, Ecology publication 24-10-017 "A Performance-Based Approach for Developing Site-Specific Natural Conditions Criteria for Aquatic Life in Washington", that provides details and requirements of the performance-based approach as noted in the proposed section WAC 173-201A-470(1)(b).

Expected impact

This proposed amendment, in combination with others in this rulemaking, will restore Ecology's ability to establish site-specific criteria equal to the natural conditions of a water body, as amended, in water quality standards. In particular, the proposed amendments will allow future TMDL studies and those currently under development to protect aquatic life by considering required actions that would allow the water to meet site-specific criteria equal to the natural conditions of a water body without additional rulemakings.

From the current baseline the proposed amendment in this section is part of a broader natural condition provision that will provide **benefits** described above in section 2.4.1, along with operational clarity and understanding.

2.4.7 One update to reflect the latest and current revision for a referenced EPA document

Baseline

State

WAC 173-201A-430(2) cites "*Water Quality Standards Handbook*," EPA 1994, as revised.

Proposed

Update WAC 173-201A-430(2) to "*Water Quality Standards Handbook*," EPA 2023, as revised.

Expected impact

This revision is required by current state law. No impact.

[30] https://www.epa.gov/sites/default/files/2015-02/documents/natural-conditions-framework-2015.pdf
[31] https://fortress.wa.gov/ecy/ezshare/wq/standards/EPA_ActionsNCC_Nov192021.pdf.

Chapter 3: Likely Costs of the Proposed Rule Amendments

3.1 Introduction

We analyzed the likely costs associated with the proposed rule amendments, as compared to the baseline. The proposed rule amendments and the baseline are discussed in detail in Chapter 2 of this document.

3.2 Cost analysis

As discussed in Chapter 2, the collective proposed rule amendments interact and work together to generate impacts. Given that the baseline has no federally-approved natural conditions provisions, it is not practical to analyze every component of the rulemaking individually. We proceed instead by describing the impacts of the following amendments on the behavior of affected parties **as implemented together** (e.g. restoring natural conditions, as amended, for the purposed of federal actions):

Proposed revisions to existing criteria:

- Updates to the natural conditions provision to limit use to aquatic life criteria.
- Updating allowances for human impacts to fresh and marine waters for dissolved oxygen and temperature when the natural conditions constitute the water quality criteria
- Updates to the site-specific criteria process for an allowance for natural conditions to be used as a basis for developing these criteria.

Other proposed changes:

- Adding definitions for the performance-based approach and local and regional sources of human-caused pollution.
- Adding a new section detailing the use of the performance-based approach and applicable aquatic life criteria.
- Adding a rule document referenced in the water quality standards that details the methodology of the performance-based approach.

Minor non-substantive edits:

- One update to reflect the latest and current revision for a referenced EPA document
- Update to reflect the latest and current revision for a referenced EPA document

3.2.1 Impacted Permits

The proposed rulemaking would primarily impact current and future permits associated with surface waters on the 303(d) list as currently impaired (Category 5) for temperature, pH, and/or DO. To illustrate the scope of potentially impacted permits, we queried proposed TMDL projects listed from Ecology's latest water quality assessment (Ecology, 2023a) that have the potential for natural conditions based on temperature, DO, and or pH.[32, 33]

Ecology ranks projects based on the severity of the pollution problem, risks to public health, risk to threatened and endangered species, and vulnerability of water bodies to degradation among other factors (2023a, 2023b). Projects fall under one of four priorities:

- High: projects that have already been vetted and are actively being worked on,
- Medium: projects that should begin in the next 1 to 5 years,
- Medium-Low: projects that should begin in the next 5 to 15 years, and,
- Low: Projects that do not warrant starting before the higher prioritized projects.

We narrowed our initial list to only high, medium, and medium-high priority TMDL projects to describe those that will likely be complete or nearly complete within the 20-year timeframe of this analysis. Through the filtering process, 42 TMDLs were identified across all four of Ecology's regions (Eastern, Central, Northwestern, and Southwestern) and the Puget Sound.[34]

Table 1 provides a description of the top 5 out of 18 affected permit categories associated with potentially affected TMDLs by listing criteria (see Table 3 in Appendix B for full permit list). Note that among 3,671 unique permits identified, any single permit can fall within a TMDL listed for one or multiple criteria. Therefore, permits described across columns in Table 1 are not mutually exclusive. An individual permit is for a specific discharger, while general permits cover multiple dischargers performing similar activities.

Table 1. Number of potentially impacted dischargers, Top 5 Potentially Impacted Permit Categories, by Criteria

Permit Type	Temp	DO	pH
Construction SW GP	2,263	2,549	1,163
Sand and Gravel GP	218	256	201
Industrial SW GP	182	258	176
Fruit Packer GP	70	54	54
Municipal NPDES IP	46	58	49
Total (Top 5)	**2,779**	**3,175**	**1,643**
Total Including bottom 11 (not shown)	**2,926**	**3,360**	**1,792**

[32] https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d
[33] Based on conversations with Ecology staff, 3-5 years is an average time period for completing most TMDL studies assuming current staff capacity and omitting extreme and unpredictable cases.
[34] TMDLS in this analysis typically represent a full or partial watershed with one or multiple rivers and its tributaries. Impacts of a TMDL also potentially include upstream reaches of listed segments.

Note: GP is “General Permit” and IP “Individual Permit”, SW is “Storm Water”

3.2.2 Potential Actions

From the prospective of a permittee, amendments taken collectively in this rulemaking would result in one of the following actions (behaviors):

1. Meet waste load allocations based on natural conditions criteria developed through the TMDL process using the performance-based approach,
2. Meet site-specific criteria based on natural conditions (supported by a separate Ecology rulemaking),
3. Meet site-specific criteria based on natural conditions (supported by permittee science, followed by a separate Ecology rulemaking).

Compared to an action that would take place without the proposed rule (baseline):

a) Meet waste load allocations based on numeric criteria through the TMDL process,

b) Meet site-specific criteria based on biological study (supported by a separate Ecology rulemaking)

c) Meet site-specific criteria based on biological study (supported by permittee science, followed by a separate Ecology rulemaking)

d) Meet criteria identified through a UAA (supported by a separate Ecology rulemaking)

e) Meet criteria identified through a UAA (supported by permittee science, followed by a separate Ecology rulemaking)

Costs from the proposed rule could originate from any actions taken by permittees to comply with procedures or conditions that generate new capital expenses (e.g. technology, engineering solutions or land acquisition), labor cost (e.g. source control and monitoring), or other miscellaneous activities (studies) compared to costs experienced under baseline conditions.[35] In the face of multiple potential outcomes from the rule and baseline scenarios, this amounts to the costs for any “action pair”, made up of a numbered (1, 2, or 3) potential action taken under the proposed rule, compared to a series of potential baseline states (a, b, c, d, or e) above. There are 3 × 5 = 15 such pairs.

Based on guidance and conversations with Ecology staff (Ecology, 2004), the most likely action pair is meeting waste load allocations based on natural conditions criteria developed through the TMDL process using the performance-based approach compared to a numeric criterion, or action pair 1a. This is because establishing site-specific criteria or a UAA (with or without permittee science) is a very resource intensive process. The need to balance these resources with other water quality activities—such as permit management and TMDL work—means that site-specific criteria and UAA are taken on sparingly, and if so, on significantly extended

[35] Recognizing that the new rule still carries a non-zero cost.

timelines.[36] Actions 2 and 3 under the proposed rule will require a separate rulemaking and regulatory analysis.

For these reasons, we narrow the following analysis to action pair 1a, and briefly discuss 1b-e for completeness.

3.2.3 Costs by Action Pair

Action Pair 1a

Action pair 1a (discussed in Section 3.2.2) would lead to meeting natural conditions criteria through the TMDL study process using a performance-based approach compared to the same process using statewide numeric criteria. From a practical perspective, Ecology would only use natural conditions provisions under the rulemaking for waters that already cannot meet numeric criteria, and suspect that natural conditions, among other things, may be the cause (e.g. waters represented in Table 1).

It is reasonable to assume that alternative criteria that consider local natural conditions and seasonal variation within these waters should be more easily met through fewer actions or investments. That is, there would be no new costs associated with meeting water quality requirements that allows for equal or higher temperature criteria, and/or equal or lower DO criteria (less dissolved oxygen required in the system) compared to the baseline. Since correcting pH up *or* down in effluent may require action, values set higher or lower (or both) than baseline to consider local natural conditions and seasonal variation should also by the same logic result in no new costs.

While the argument that no (new) costs would accrue from the proposed rule is logical, we cannot quantify potential costs of this rulemaking to permits in Table 1 directly because associated TMDL studies have not yet been performed. As a proxy for future TMDL development, Ecology reviewed 8 historical TMDLs developed to protect natural conditions of the water.[37] We summarize their general differences between natural and numeric criteria, the drivers of those differences, and their use in refining standards below.

- From **temperature** modeling scenarios in the reviewed TMDLs, a few degrees Celsius typically made up the difference between natural conditions targets and numeric criteria when applicable. Though it does not reflect the general trend of a few degrees, natural conditions ranged up to 13°C higher than numeric statewide criteria in outlier cases. Natural temperatures, higher than statewide standards, were commonly attributed to limits in vegetative growth, high air temperature, and naturally low flow periods. In most instances, temperature TMDLs were written in such a way that allowed for natural conditions of the system to constitute water quality criteria during parts of

[36] Only one UAA has been completed in Washington and is still under review by the EPA.
[37] Historical TMDLs natural conditions models vary widely by geographic scale (e.g. by stream segment within a watershed), time interval, and seasonal granularity. Modeling techniques also vary over time and space with technology, site access, and available historical data. This makes a systematic review impractical.

the year when exceedances were triggered, and the numeric criterion under naturally cooler periods, so long as they were determined to remain protective.[38]

- Among **DO** modeling scenarios, the difference between numeric criteria and natural DO conditions ranged from a fraction of a mg/L to over 3 mg/L. Natural levels of DO lower than numeric standards were commonly attributed to local rates of stream bank erosion, groundwater with low DO concentrations, aquatic vegetation such as algae and elodea, and storm events. Also note that higher water temperature can have indirect effects on DO through vegetation growth and other natural processes. Like temperature, numeric criteria and the natural conditions were commonly used to develop the TMDL in such a way that refined DO limits to reflect the naturally lower DO concentrations when and where appropriate.
- From **pH** modeling scenarios in the reviewed TMDLs, natural pH values varied as much as 1.5 standard units (SU) beyond the highest/lowest numeric standards.[39] Natural variances in pH were attributed to factors and processes similar to DO such as algal productivity and groundwater contributions. Also, like temperature and DO, pH criteria in these systems were set and allocated in such a way to meet natural conditions in the system.

In historical cases reviewed by the study team, allowing for natural conditions provided the flexibility necessary to avoid paradoxical situations in which permittees would need to improve the quality of the water they discharged to beyond what is achievable without any human influence. Criteria based on natural conditions would require fewer actions or technologies to achieve and maintain protective levels of water quality compared to this reality.

We note that because of this rulemaking, future natural conditions values could be calculated differently than the historical TMDLs reviewed above. Differences come primarily from amended human impact allowances (see Section 2.4.2) and the introduction of the performance-based approach (see Sections 2.4.5 and 2.4.6).

Natural conditions calculated through this process will make up the criteria for the entire duration of the year where data allow, rather than only during periods in which exceedances occurred (e.g., due to seasonal factors like flow and air temperature). If it were determined that for one part of the year natural conditions criteria are more stringent than the biologically based criteria (e.g. lower temperatures in winter months), permittees could face new cost during this period compared to baseline.

Data limitations prevent quantifying a forecast of how often this might occur and to what degree. Bear in mind that criteria set through natural conditions would be technically

[38] In historical TMDL reviewed in this section, the natural condition of temperature was approximated by the system potential through an evaluation of the combined effect of hypothetical natural conditions of site potential riparian vegetation, microclimate improvements, and improved channel widths. The modeling software QUAL2Kw was frequently used in these settings.

[39] Standard units are given on a logarithmic scale. Each number represents a 10-fold change in the acidity/basicness of the water, where 7 is neutral. For example, a pH of five is ten times more acidic than water having a pH of six.

achievable during these periods, while numeric criteria in other parts of the year may not have been without the proposed rulemaking. [40] Compared to zero allowance in the baseline, human allowance in the proposed rule would also work to reduce cost, as would limiting allowances to local and regional sources such that they would not be absorbed by global climate change and cross-border polluters.

Outside of these caveats, evidence suggests that this proposed rulemaking would **not likely impose new costs to potentially impacted permits.** Rather, it is likely that the rulemaking represents a **cost savings (benefit),** as described further below in Chapter 4.

Impacts to Aquatic Life

A material loss in aquatic life in a water body from the proposed rulemaking would constitute a loss of ecosystem services and cost to society. This is especially true for impacts to ESA listed species with uniquely high market and cultural value such as salmonoids. It is important to note that the proposed rulemaking is intended to refine water quality criteria, whilst remaining protective of aquatic life and endangered species. This means that so long as this holds true, there is no cost expected from the proposed rule compared to the baseline. Once adopted, both would be considered protective of aquatic life and designated uses.

To ensure this is the case, Ecology utilized information from previous ESA consultations, prior EPA biological evaluations, EPA memorandums, EPA guidance documents, exploration of how other states and tribes address natural conditions, and the latest scientific information to support the proposed rule (WAC 173-201A-470) (see *inter alia* USEPA 2003, 2005, 2007, 2009, 2015b, 2021, 2023; USFWS, 2008). From similar documentation and consultation with federal agencies, Ecology also ensured that other aspects of the proposed rulemaking, such as human allowances, are *de minimis*. For example:

- The EPA determined the allowable 0.3° C increase in temperature for fresh waters under natural condition scenarios is consistent with recommendations in EPA's Temperature Guidance (EPA, 2003). This provision allows for an insignificant level of heat from human actions when natural conditions are the applicable criteria or where waters are exceeding the biologically based numeric criteria. The EPA has also noted that absent such a provision, no heat would be allowed from humans when the natural conditions criteria are the applicable criteria. The EPA believed that a 0.3° C or less temperature increase about the natural condition temperature is insignificant because monitoring measurement error for recording instruments typically used in field studies are approximately 0.2° C to 0.3°.
- The EPA determined the allowable 0.2 mg/L decrease of DO for fresh waters and lakes under natural condition scenarios are considered insignificant decreases. EPA noted that DO is a characteristic of the waterbody that can be affected by several parameters (e.g., temperature). Further, 0.2 mg/L is within the monitoring measurement error for

[40] Historical TMDLs typically focus on times of year where waters were impaired. On the extreme end, natural conditions criteria could be more stringent than numeric criteria at all times of the year. However, to our knowledge there is no historical evidence that this condition exists, or would exist in future TMDLs.

recording instruments typically used to monitor dissolved oxygen. Ecology's rule requires that a decrease in DO from natural conditions equal 10% of the water body's DO or 0.2 mg/L, whichever is lower. This amendment provides additional safeguards in naturally hypoxic waters (<2 mg/L of DO).

Action Pair 1b-c

Action pair 1b-c amounts to meeting natural conditions criteria through the TMDL study process using the performance-based approach, compared to criteria developed using biological data collected in site-specific studies.

Both alternatives in these action pairs are intended to allow for a departure from statewide numeric criteria based on local conditions. However, criteria in the baseline scenario, despite being site-specific, must still be biologically based. Like 1a, criteria considering natural conditions and seasonal variation within that system are likely to be more easily met by permittees through fewer actions or investments and present no new costs.

Beyond this general logic, to our knowledge there are no examples to draw from in which a site-specific study established biologically based criteria without natural conditions (a proxy for baseline action a); then later for the same water body, established natural conditions criteria through the TMDL process (proxy for action 1 in the proposed rule).

Because Ecology would carry out the full process of considering, proposing, and adopting site-specific criteria, there would be no administrative costs differences to permittees under 1b. If a permittee were to elect to privately fund science in support of the site-specific criteria (1c), the proposed rulemaking represents an avoided cost of such a study (i.e. a benefit, see Chapter 4).

Action Pair 1d-e

Action pair 1d-e amounts to meeting natural conditions criteria through the TMDL study process using the performance-based approach, compared to meeting a different designated use through UAA.

As with site-specific criteria discussed in 1b and 1c, there is insufficient historic data to analyze potential permittee behavior in terms of meeting natural conditions criteria, compared to meeting a different designated use through UAA.[41]

Because Ecology would carry out the full process of considering, proposing, and adopting criteria based on UAA, there would be no administrative costs differences to permittees under 1d. If a permittee were to elect to privately fund science in support of a UAA (1e), the proposed rulemaking represents an avoided cost of such a study (i.e. a benefit, see Chapter 4).

3.2.4 Cost Summary

In this section, we considered the likely costs associated with the proposed rule amendments as implemented together.

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[41] Only one UAA has been completed in Washington and is still under review by the EPA.

We determined that the most likely action to occur because of this rulemaking—that would not require additional rulemaking—is meeting waste load allocations based on natural conditions criteria developed through the TMDL process using the performance-based approach compared to numeric temperature, DO, and / or pH criterion. After filtering future TMDL studies for these criteria, with potential for natural conditions, and prioritized in the next 20 years, we identified 3,671 associated permits (see Table 1).

We cannot quantify the costs of the proposed rulemaking to associated permits because future TMDL studies have not been performed yet. Historical TMDLs reviewed by the study team and the general logic of natural conditions provisions suggest that criteria considering local factors and seasonal variation would be more easily met through fewer actions or investments up to avoiding paradoxical situations in which permittees need to improve the quality of the water they discharged to beyond what is achievable without any human influence. In other words, the most likely actions, taken because of the proposed rulemaking, are **not likely to impose new costs.**[42] Rather, the proposed rulemaking likely represents a **cost savings (benefit),** as described further below in Chapter 4.

Meeting waste load allocations based on natural conditions criteria developed through the TMDL process compared to other, but unlikely, baseline scenarios such as developing site-specific criteria, or UAA, also likely carry no new costs.

The baseline conditions and proposed rulemaking (if adopted) would be considered protective of aquatic life and designated uses. Therefore, we do not expect new costs or benefits from a material change in related ecosystem services.

Chapter 4: Likely Benefits of the Proposed Rule Amendments

4.1 Introduction

We analyzed the likely benefits associated with the proposed rule amendments, as compared to the baseline. The proposed rule amendments and the baseline are discussed in detail in Chapter 2 of this document.

4.2 Benefits analysis

As discussed in Chapter 2, and reprinted from Chapter 3, the collective proposed rule amendments interact and work in tandem to generate impacts. Given that the baseline has no

[42] We note that if it were determined that for one part of the year natural conditions criteria are more stringent than the biologically based criteria (e.g. lower temperatures in winter months), permittees might face new cost during this period compared to baseline under the proposed rule. However, other aspects of the proposed rule like the human allowance and limiting allowances to local and regional sources, could mitigate these to an unknown degree. The net impact on costs would depend on the relative size of new costs and cost-savings. Ultimately, data limitations prevent us from quantifying a forecast of how often this might occur and the net cost if such a scenario.

federally-approved natural conditions provisions, it is not practical to analyze every component of the rulemaking individually. We proceed instead by describing the impacts of the following amendments on the behavior of affected parties **as implemented together** (e.g. restoring natural conditions, as amended, for the purposed of federal actions):

Proposed revisions to existing criteria:

- Updates to the natural conditions provision to limit use to aquatic life criteria.
- Updating allowances for human impacts to fresh and marine waters for dissolved oxygen and temperature when the natural conditions constitute the water quality criteria
- Updates to the site-specific criteria process for an allowance for natural conditions to be used as a basis for developing these criteria.

Other proposed changes:

- Adding definitions for the performance-based approach and local and regional sources of human-caused pollution.
- Adding a new section detailing the use of the performance-based approach and applicable aquatic life criteria.
- Adding a rule document referenced in the water quality standards that details the methodology of the performance-based approach.

Minor non-substantive edits:

- One update to reflect the latest and current revision for a referenced EPA document

4.2.1 Benefits by Action Pairs

Benefits from this rulemaking would be borne from avoiding the cost of compliance with baseline scenarios in the absence of the proposed rulemaking. This includes any additional capital expenses (e.g. technology, engineering solutions or land acquisition), labor cost (e.g. source control and monitoring), or other miscellaneous activities (e.g. scientific study) required compared to those expected under the proposed rule. Table 1 in Chapter 3 summarizes permits potentially affected by this rulemaking. Various outcomes of the proposed rulemaking and baseline alternatives, or “action pairs”, can be reviewed in Section 3.2.1.

Action Pair 1a

As noted in Section 3, action pair 1a—meeting natural conditions criteria developed through the TMDL study process using the performance-based approach compared to the same process using statewide numeric criteria—is the most likely action in this analysis and would apply in some fashion to most permits in Table 1.

Based on the general logic and intent of natural conditions criteria to refine criteria values, and Ecology’s review of historical TMDLs, this scenario is likely to generate benefits.

1. Because natural conditions are suspected to be part of the driving force behind permits exceeding numeric criteria in Table 1, it is reasonable to assume that considering local variation in temperate, DO and pH would result in fewer actions and investments required to comply with refined criteria limits.
2. Almost all historical TMDLs that develop WLA based on natural conditions (see Section 3.2.3) reviewed by the study team allowed some flexibility to permittee compliance. This amounted to small allowances for higher temperature (e.g. a couple degrees Celsius), DO (e.g. a fraction of a mg/L), and pH variation (e.g. fraction of a standard unit) in parts of the year for some segments of a water body, compared to their statewide numerical equivalents.
3. In other historic TMDLs that develop WLA based on natural conditions, naturally occurring temperature, DO, and pH, varied from numeric criteria by as much as 13°C, 3 mg/L, and 1.5 standard units respectively. To the degree that similar or larger differences exist in future TMDLs, permittees in Table 1 could face a paradoxical situation under the baseline in which they must improve the quality of the water they discharged to well beyond what is achievable, even without human influence. The proposed rulemaking could prevent major engineering solutions otherwise needed to remain in compliance, or at the extreme end, prevent ceasing operations for part of the year or all together.

Outside of likely being non-zero, we are unable to identify the exact magnitude of these benefits (avoided costs) by potentially affected permittees (Table 1). This is because WLAs under the baseline or proposed rulemaking for these are currently unknown. In addition behavior would depend on a wide variety of facility types, with potentially multiple discharges, all taking different actions in response to compliance.

Benefits – Temperature

To illustrate just one select benefit pathway, we provide a stylized example of a small adjustment to effluent temperature required in the absence of the proposed rule (i.e. a benefit of this action pair under proposed rulemaking).

In this example, we only consider permits in the top 5 permit types likely impacted to be conservative in our assessment of benefits (see Table 1). From the highest to lowest number of impacted permittees, this includes 2,263 Construction Stormwater general permittees, 218 Sand and Gravel general permittees, 182 Industrial Stormwater general permittees, 70 Fruit Packing general permittees, and 46 municipal wastewater treatment plants.

We assume that all affected permits, regardless of type, would be required to cool their discharge by at least 1 degree Fahrenheit (0.56 Celsius) for at least part of the year to meet numeric standards in the absence of the proposed rulemaking. We recognize that several of these permit types, such as construction stormwater and sand and gravel, are not commonly responsible for raising the temperature of water, nor are commonly required to cool effluent. But in a hypothetical waterbody for this analysis, it is the fact that site conditions are naturally higher (hotter) than numeric criteria that would lead all associated permits under the TMDL to be responsible for lowering effluent temperature.

The cost of a thermal reduction to surface water from effluent can vary greatly depending on application and volume. Table 2 contains a non-exhaustive list of methods recommended to decrease the temperature impacts to surface water. Values in Table 2 are presented as industrial or water treatment plant solutions, broken out by component in such a way that allows for generalization to other applications (Jenkins, 2007).

Table 2. Common Surface Water Cooling Techniques and Costs

Effluent Cooling Modifications	Description	Cost
Clarifier Covers	This method provides shade over clarifiers to reduce the amount of solar radiation reaching the wastewater before discharge.	Approximately $180,000 for a 50' diameter clarifier
Seasonal Storage	Holding treated effluent in a reservoir until stream temperature has decreased.	$0.18 to $2.60 per cubic foot of storage volume
Move Discharge Location	Discharging effluent to a different portion of the stream or to a different surface water body altogether.	$180 - $1800 per linear foot of pipeline
Multiple Port Diffusers	Releasing effluent through multi-port diffuser systems in several locations simultaneously into the receiving water.	$370 - $2800 per foot of diffuser
Effluent Blending	Mixing treated effluent with cooler groundwater or surface water prior to discharge.	$140 - $275 per foot for a well or $180 - $275 per lineal foot for a pipeline
Unlined Ponds	Contain treated effluent and allow it to percolate into the subsurface.	$0.45 - $0.90 per gallon of storage
Riparian Shading	Establishing streamside forests to provide shade over receiving water.	Example cost: Property purchase = $36,750 per acre, Plant starts = $4.60 per plant, Density = 2,614 plants per acre
Cooling Ponds	A shallow reservoir designed to receive warm water and discharge cool water, relying on evaporative and radiative heat loss.	$0.18 to $0.40 per cubic foot of storage volume

Effluent Cooling Modifications	Description	Cost
Cooling Towers	An evaporative cooling method used to dissipate heat from process water.	Example cost: $237,150 for a 0.05 MGD plant
Chillers	Devices that employ an evaporator, compressor, condenser, and refrigerant to remove heat from a liquid.	$46,000 - $110,300 per MGD per degree Fahrenheit and an additional $9,200 - $18,400 per MGD per degree Fahrenheit per year in operating costs

Note: Values in table range from 2001 to 2005 dollars depending on technology.

For construction stormwater, sand and gravel, and fruit packer general permits we estimated the price to install a small cooling pond as a low-cost option to comply to the baseline scenario. These shallow reservoirs are designed to receive warm water and discharge cool water through evaporative and radiative heat loss. Note in Table 2 that ponds may double as holding tanks for effluent until stream temperature has decreased. We assume an average engineered cooling pond, with the ability to hold 40,000 cubic feet of water, can be constructed for a fixed cost of $14,946 in 2024 dollars.[43]

Industrial stormwater general permits include air and seaports, large manufacturing facilities, refineries, and commercial food processors, with the potential of treating and discharging millions of gallons of effluent per day. Together with municipal wastewater treatment permits, more sophisticated methods of cooling would likely be required for these facilities to meet marginal cooling requirements necessary without the proposed rule. To estimate the cost of cooling effluent in these facilities, we assumed the need for more advanced technology such as cooling towers or chillers. Using information from Jenkins (2007) we estimated the cost to a mid-sized 3 million gallons per day (MGD) system using these technologies to lower effluent temperatures 1 degree Fahrenheit is $686,923 in capital costs and $114,591 per year in operating and maintenance (O&M) in 2024 dollars.[44,45]

Benefits described above will not accrue all at once upon the adoption of this rulemaking; rather, they would be staggered across time depending on TMDL priority and where the receiving permit is within its 5-year renewal cycle. To calculate the net present value over a 20-

[43] Adjusted upward from initial estimates of $7,200 from 2005 data in Jenkins, 2007. Adjustments were made using Producer Price Index by Commodity: Machinery and Equipment: Domestic Water Systems (https://fred.stlouisfed.org/series/WPU11411311). Does not include the cost of any land acquisition that, if avoided under the proposed rule, would increase this benefit.

[44] Note that in many cases these estimates are conservative with respect to facility size. For example, very large water treatment plants (upwards of 90 MGD), could require as much as $10 million in infrastructure alone and $1.6 million per year in O&M for a single plant to cool effluent by 1 degree Fahrenheit.

[45] Adjusted upward from initial capital and O&M estimates of $330,900 and $114,591 from 2005 data in Jenkins, 2007. Adjustments were made using Producer Price Index by Commodity: Machinery and Equipment: Domestic Water Systems (https://fred.stlouisfed.org/series/WPU11411311)

year period, we consider again Ecology's TMDL priority rankings (discussed in Section 3.2.1) and add 5 years to the latest date that the TMDL might begin to allow for research time and idiosyncratic lags in permit renewal. That is:

- Permittees under high priority TMDLs for temperature (1,299) receive benefits 5 years after adoption.
- Permittees under medium priority TMDLs for temperature (1,197) would begin receiving benefits 10 years after adoption.
- Permittees under medium-low priority TMDLs for temperature (283) would begin receiving benefits 20 years after adoption.

Conditional on assumptions discussed above in this exercise (e.g. a 1 degree Fahrenheit reduction, required by all permittees in the top 5 permit in the next 20 years) the total net present value of benefits from the proposed rule over a 20 year horizon would be just over $356 million.[46,47]

Benefit – DO

When high levels of nutrients fuel excessive marine plant life, such as algae, oxygen is consumed when plants later die and decompose. Nutrient removal is therefore one of the main, and potentially costly, strategies used when mitigating dissolved oxygen depletion in fresh and marine water.

We emphasize that the proposed rulemaking would not absolve impacted permittees from treating nutrients in their effluent. However, any marginal refinements to DO criteria based on natural conditions provisions could provide financial relief to facilities otherwise facing the need for additional technologies to meet numeric standards. In this way, setting DO criteria values based on natural conditions represents a potential benefit under the proposed rule.

Reiterated from above, it is not possible to know how natural conditions criteria will differ from numeric DO criteria for permits in Table 1, or how those differences would translate to nutrient requirements in TMDL waste load allocations. Available data on nutrient treatment costs are also not commonly presented in marginal units of removed nutrients (e.g. a dollar amount for every unit of nitrogen or phosphorus), making such an analysis additionally impractical.

Under these caveats, the most conservative assumption we can make with available data is that the lowest known facility cost of treatment would be sufficient to satisfy an arbitrary difference between numeric based DO requirements in the baseline and natural conditions provisions under the proposed rule. As another illustrative example, this time focused on nutrient

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[46] Discounted at 0.9%, the 20-year average of fixed real annual rates. Fixed rate of return to inflation-indexed I-Bonds by US Treasury Department (https://www.treasurydirect.gov/savings-bonds/i-bonds/i-bonds-interest-rates/).

[47] Without considering modifications by construction permits, this estimate is just under $325 million (after making assumptions discussed elsewhere in this section such as a 1 degree Fahrenheit reduction, required by all remaining permittees in the next 20 years).

removal, we apply these arbitrary facility and operational changes to permits in the top 5 likely impacted permit types (see Table 1).

Considering impacts wastewater treatment, we assume again an average municipal treatment facility size of 3 MGD. In 2011, Ecology produced a technical report identifying cost estimates for a suite of wastewater treatment technologies to achieve a range of different effluent quality performance targets with respect to nutrients (Ecology, 2011). This report, as summarized by the EPA (2015a), finds constructed or retrofitted treatment technologies for removing nutrients, such as inorganic nitrogen, come at a capital cost ranging from $0.1/MGD/year to nearly $100/MGD/year, with typical costs cited as averaging $25/MGD/year. Annual O&M for these systems ranged from $0.01/MGD/year to $1.85/MGD/year.[48,49] Applying $0.1/MGD and $0.01/MGD for capital and O&M cost, and adjusting to current price levels, the estimated cost to remove an arbitrarily small amount of nitrogen is $488,790 per facility in capital costs, and $48,879 in annual O&M.[50]

For the treatment of nutrients in industrial and agricultural applications the USEPA (2015a) points to publications that primarily draw from foodstuffs, beverages, livestock, and agricultural producers. Technologies used in these industries include enhanced aeration, modified Ludzack-Ettinger process, and chemical treatment that would apply to Fruit Packer general permits, and generalizable to many other large-footprint facilities found in Industrial stormwater general permits not directly included in the aforementioned industries. While unable to recover unit costs, the minimum estimated total cost for these technologies used to achieve a reduction in nutrients at the facility level was $241,570 in upfront capital and $119,164 annually for O&M in 2024 dollars.

Potential costs borne by construction wastewater and sand and gravel permits are even less clear. For the purposes of this exercise, we assume that complying with a small arbitrary reduction in nutrients would include moving materials such as fertilizers and landscaping material out of the path of stormwater, ensuring proper operation and maintenance of any treatments already installed, and updating plans to minimize unnecessary land disturbance. Assuming 40 hours of labor per year for these activities by existing staff, and the Bureau of Labor Statistics median pay for Environmental Engineering Technicians, ($24.51 per hour), we estimated $980.04 annually (BLS, 2023).

As with temperature, we applied benefits at the permit level over time based on permit type and TMDL priority over a 20-year horizon. We again limit this analysis to the top 5 affected permit categories described in Table 1 to be consistent and additionally conservative.

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[48] Employed technologies range from activated sludge, lagoons, membrane bioreactors, rotating biological contactors, sequencing batch reactors, and trickling filters.
[49] 2012 dollars.
[50] Adjustments made using Producer Price Index by Commodity: Machinery and Equipment: Domestic Water Systems (https://fred.stlouisfed.org/series/WPU11411311).

Conditional on assumptions discussed above (e.g. an arbitrary reduction in nutrients, required by all permittees in the top 5 permit categories over 20 years), the net present value of this stream of benefits is estimated to be just over $319 million.

Benefit – pH

As with Temperature and DO requirements, benefits of avoided compliance cost with numeric pH criteria, compared to those based on an applicable natural condition criterion, would likely be positive. Due to a lack of publicly available data on the cost of pH neutralization, the study team is currently unable to illustrate these benefits quantitatively.

Action Pair 1b-c

Action pair 1b-c amounts to meeting natural conditions criteria through the TMDL study process using the performance-based approach, compared to criteria developed using biological data collected in site-specific studies.

Both alternatives in the action pair are intended to allow for a departure from statewide numeric criteria based on local conditions. However, criteria in the baseline scenario, despite being site-specific, must still be biologically based. Like in action 1a, criteria considering natural conditions and seasonal variation within that system are likely to be more easily met by permittees through fewer actions or investments, representing an avoided cost (benefit).

If a permittee were to elect to privately fund science in support of the site-specific criteria (action 1c), the proposed rulemaking represents an additional benefit in the form of avoided costs of such a study. The benefit of this avoided study component could range from tens to hundreds of thousands of dollars depending on the size, complexity, and detail needed to effectively substantiate site-specific criteria .

Action Pair 1d-e

Action pair 1d-e amounts to meeting natural conditions criteria through the TMDL study process using the performance-based approach, compared to meeting a different designated use through UAA.

There is insufficient historic data to analyze potential permittee behavior in terms of meeting natural conditions criteria, compared to meeting a different designated use through UAA. If a permittee were to elect to privately fund science in support of a UAA (1e), the proposed rulemaking represents an additional benefit in the form of avoided costs of such a study. However, there is very little data to estimate a range quantitatively. [51]

4.2.2 Benefits Summary

In this section, we considered the likely benefits associated with the proposed rule amendments as implemented together.

[51] Only one UAA has been completed in Washington and is still under review by the EPA.

As described in Section 3, we assumed that the most likely action to occur because of this rulemaking—that would not undergo additional rulemaking—is meeting waste load allocations based on natural conditions criteria developed through the TMDL process using the performance-based approach compared to a numeric temperature, DO, and or pH criterion.

Based on historical TMDLs reviewed by the study team, and the general logic of natural conditions provisions, we expect a potentially wide range of benefits associated with the proposed rule amendments. For many, criteria considering local factors and seasonal variation under this proposed rulemaking will be more easily met through fewer actions or investments on the margin. For others, benefits would include avoiding the need to eliminate discharge and associated economic activity completely for all or part of the year completely to avoid paradoxical situations in which permittees must improve the quality of the water they discharged to beyond what is achievable without any human influence.

We cannot fully quantify the extent of potential benefits of the proposed rulemaking because future TMDL studies have not been performed yet. However, through a pair of illustrative examples, we applied a small and arbitrary temperature and DO criteria change to potentially impacted permits—akin to just one scenario when meeting natural conditions under the proposed rulemaking. We estimated a total 20-year present value benefit of $675 million through this exercise, but stress that this represents partial benefits and should be considered a conservative lower bound.

Additional, but unquantified, benefits include avoided costs of meeting numeric criteria for freshwater pH compared to a natural condition based criteria, and any avoided cost of independent science by permittees in support of Ecology performing site-specific criteria and UAA in the baseline.

The baseline conditions and proposed rulemaking (if adopted) would be considered protective of aquatic life and designated uses. Therefore, we do not expect new costs or benefits from a material change in related ecosystem services.

Chapter 5: Cost-Benefit Comparison and Conclusions

5.1 Summary of costs and benefits of the proposed rule amendments

Due to data limitations, we cannot quantify the costs of the proposed rulemaking to associated permits (see Section 3.2). However, the most likely actions taken because of the proposed rulemaking are not likely to impose new costs, but rather produce benefits in the form of avoided costs. Historical TMDLs reviewed by the study team and the general logic of natural conditions provisions suggest that criteria considering local factors and seasonal variation would be more easily met through fewer actions or investments—up to avoiding paradoxical situations in which permittees need to improve the quality of the water they discharged to beyond what is achievable without any human influence. In this way, the proposed rulemaking is not likely to impose new costs, but rater cost savings (benefit).

Due to data limitations, we cannot fully quantify the extent of potential benefits of the proposed rulemaking. However, through a pair of illustrative examples, we applied a small and arbitrary temperature and DO criteria change to a selection of potentially impacted permits—akin to just one scenario when meeting natural conditions under the proposed rulemaking. Through this exercise, we estimated a total 20-year present value benefit of $675 million, but stress that this represents partial benefits and should be considered a conservative lower bound. Additional, but unquantified, benefits include avoided costs of meeting numeric criteria for freshwater pH compared to a natural condition based criteria, and any avoided cost of independent science by permittees in support of Ecology performing site-specific criteria and UAA in the baseline.

The baseline conditions and proposed rulemaking (if adopted) would be considered protective of aquatic life and designated uses. Therefore, we do not expect new costs or benefits from a material change in related ecosystem services.

5.2 Conclusion

We conclude, based on a reasonable understanding of the quantified and qualitative costs and benefits likely to arise from the proposed rule amendments, as compared to the baseline, that the benefits of the proposed rule amendments are greater than the costs.

Chapter 6: Least-Burdensome Alternative Analysis

6.1 Introduction

RCW 34.05.328(1)(c) requires Ecology to "…[d]etermine, after considering alternative versions of the rule and the analysis required under (b), (c), and (d) of this subsection, that the rule being adopted is the least burdensome alternative for those required to comply with it that will achieve the general goals and specific objectives stated under (a) of this subsection." The referenced subsections are:

> (a) Clearly state in detail the general goals and specific objectives of the statute that the rule implements;
>
> (b) Determine that the rule is needed to achieve the general goals and specific objectives stated under (a) of this subsection, and analyze alternatives to rule making and the consequences of not adopting the rule;
>
> (c) Provide notification in the notice of proposed rulemaking under RCW 34.05.320 that a preliminary cost-benefit analysis is available. The preliminary cost-benefit analysis must fulfill the requirements of the cost-benefit analysis under (d) of this subsection. If the agency files a supplemental notice under RCW 34.05.340, the supplemental notice must include notification that a revised preliminary cost-benefit analysis is available. A final cost-benefit analysis must be available when the rule is adopted under RCW 34.05.360;
>
> (d) Determine that the probable benefits of the rule are greater than its probable costs, taking into account both the qualitative and quantitative benefits and costs and the specific directives of the statute being implemented.

In other words, to be able to adopt the rule, we must determine that the requirements of the rule are the least burdensome set of requirements that achieve the goals and objectives of the authorizing statute(s).

We assessed alternative proposed rule content and determined whether they met the goals and objectives of the authorizing statute(s). Of those that would meet the goals and objectives, we determined whether those chosen for inclusion in the proposed rule amendments were the least burdensome to those required to comply with them.

6.2 Goals and objectives of the authorizing statute

The authorizing statute for this rule is Chapter 90.48 RCW, Water Pollution Control. Its goals and objectives include the state of Washington's policy of maintaining the highest possible standards to ensure the purity of all waters of the state consistent with public health, public enjoyment, the protection of wildlife, and the industrial development of the state. This requires the use of all known available and reasonable methods to prevent and control the pollution of the waters of the state of Washington.

RCW 90.48.035, Rule-making authority, specifically authorizes Ecology to promulgate, amend, or rescind rules and regulations as deemed necessary to maintain the highest possible standards of all waters in the state. Its goals and objectives include but are not limited to rules relating to standards of quality of waters of the state and regulating substances discharged into them.

6.3 Alternatives considered and why they were excluded

We considered the following alternative rule requirements and did not include them in the proposed rule amendments. This list includes alternatives that were suggested by the public during development of the rule, with the intent of mitigating negative impacts, including environmental harms, on vulnerable populations and overburdened communities, and equitably distributing benefits. Each section below explains why we did not include these alternatives.

- Updating human allowance and natural condition provisions only (i.e., no performance-based approach).
- Updating natural condition provision only (i.e., no human allowance or performance-based approach).
- No natural condition updates

6.3.1 Updating human allowance and natural condition provisions only

We considered updating only the human allowance and natural conditions provisions in the proposed rule, but not including a performance-based approach. This alternative would potentially be more burdensome for permittees. If a water is not meeting biologically based numeric criteria, and that is due in part to natural conditions, then there would only be two pathways for determining protective criteria based on natural conditions: a use change through a Use Attainability Analysis (which could result in different criteria values); or criteria change through site-specific criteria development. Both approaches would require separate WQ Standards rulemaking and would need to undergo EPA review (including any ESA consultation with NOAA NMFS and USFWS) and approval prior to being in effect for CWA purposes.

6.3.2 Updating natural condition provision only

We considered updating only the natural condition provision in the proposed rule, but not including the human allowance or the performance-based approach. This alternative would potentially be more burdensome for permittees. If a water is not meeting biologically based numeric criteria, and that is due in part to natural conditions, then there would only be two pathways for determining protective criteria based on natural conditions if no performance-based approach exists: a use change through a Use Attainability Analysis (which could result in different criteria values); or criteria change through site-specific criteria development. Both approaches would require separate WQ Standards rulemaking and would need to undergo EPA review (including any ESA consultation with NOAA and USFWS) and approval prior to being in effect for CWA purposes.

In addition, if no human allowance is provided in rule, then when natural conditions are the applicable criteria, NO degradation for temperature or DO would be allowed. This would be unnecessary for protection of aquatic life and unnecessarily costly. See rulemaking Technical Support Document for further details.

6.3.3 No Rulemaking

We considered not doing this rulemaking. Without natural conditions criteria, the applicable biologically based numeric criteria would apply and must be met to protect existing and designated aquatic life uses. Some waters during some periods of the year may not be able to meet these criteria due to natural and seasonal variations. This could be the case even if all human impact was reversed and removed from this determination. Thus, it would be more burdensome to covered parties as applicable criteria would not be able to be met regardless of any actions taken (See Appendix A(B)(2) for additional details).

6.6.4 Alternative DO Allowance 1

We considered an alternative DO allowance that states when natural conditions constitute the water quality criteria for a site, local and regional sources of human-caused pollution considered cumulatively may not decrease DO more than 0.2 mg/L.

We excluded this possibility as we determined it would not be protective of aquatic life when waters were naturally low in DO (i.e., <2 mg/L), and therefore does not meet goals and objectives. For instance, if waters were naturally 1.0 mg/L for DO Concentration, a 0.2 mg/L decrease to 0.8 mg/L would have negative impact on aquatic life; therefore, this would not be protective and would not represent a de minimis amount of degradation.

6.6.5 Alternative DO Allowance 2

We considered an alternative DO allowance that states when natural conditions constitute the water quality criteria for a site, local and regional sources of human-caused pollution considered cumulatively may not decrease DO more than 0.2 mg/L only if the natural condition criteria of the water is > or = 2.0 mg/L. Otherwise, no further degradation of the waters are allowed.

We excluded this possibility because it would be unnecessarily stringent, and thus overly burdensome for permittees, compared to what is needed for protection of aquatic life (see EPA's 2007 Biological Evaluation regarding 0.2 mg/L for fresh water systems). Additionally, because we may be using water quality models to estimate natural condition values, there will inherently be some error associated with estimation. Trying to meet no degradation (i.e., 0) is difficult when you must account for associated model error. Thus, no allowance in this alternative prevents accounting for natural condition estimation error in our modeling process in TMDLs.

6.4 Conclusion

After considering alternatives, within the context of the goals and objectives of the authorizing statute, we determined that the proposed rule represents the least-burdensome alternative of possible rule requirements meeting the goals and objectives.

Chapter 7: Regulatory Fairness Act Compliance

We analyzed the compliance costs of the proposed rule amendments in Chapter 3 of this document. We conclude that the proposed rule amendments are not likely to result in compliance costs for any businesses. The proposed rule is likely to result only in cost-savings for dischargers, as compared to the baseline. Based on this analysis, Ecology is exempt from performing additional analyses under the Regulatory Fairness Act, under RCW 19.85.025(4) which states that, "This chapter does not apply to the adoption of a rule if an agency is able to demonstrate that the proposed rule does not affect small businesses." Moreover, by not imposing compliance costs, the proposed rule amendments do not meet the RFA applicability standard under RCW 19.85.030(1)(a).

References

RCW 34.05.272 requires Ecology to categorize sources of information used in significant agency actions made in the Water Quality Program.

Independent peer review

Review is overseen by an independent third party.

n/a

Internal peer review

Review by staff internal to Ecology.

Jenkins, Pam. 2007. Methods to Reduce or Avoid Thermal Impacts to Surface Water (Publication 07-10-088). Available at: https://apps.ecology.wa.gov/publications/SummaryPages/0710088.html

External peer review

Review by persons that are external to and selected by Ecology.

n/a

Open review

Documented open public review process that is not limited to invited organizations or individuals.

n/a

Legal and policy documents

Documents related to the legal framework for the significant agency action, including but not limited to: federal and state statutes, court and hearings board decisions, federal and state administrative rules and regulations, and policy and regulatory documents adopted by local governments.

40 CFR Section 131.

Chapter 90.48 RCW: Water Pollution Control.

Chapter 173-201A WAC: Water quality standards for surface waters of the state of Washington.

Davies, Tudor T. 1997. Establishing Site Specific Aquatic Life Criteria Equal to Natural Background. Memorandum to Water Management Division Directors, EPA Regions 1-10, and State and Tribal Water Quality Management Program Directors. Dated 5 November 1997. Office of Water, Office of Science and Technology. Washington, D.C. Available at: http://water.epa.gov/scitech/swguidance/standards/upload/2009_01_29_criteria_naturalback.pdf

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United States Environmental Protection Agency (USEPA). 2024. Causal Analysis/Diagnosis Decision Information System (CADDIS).

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Washington Department of Ecology (Ecology). 2018. Water Quality Program Permit Writer's Manual (Publication 92-109). Available at: https://apps.ecology.wa.gov/publications/summarypages/92109.html

Washington Department of Ecology (Ecology). 2023a. 2021 TMDL Workload Assessment- Analysis of Category 5 Listings from 2018 Water Quality Assessment (*Publication 23-10-026*).

Washington Department of Ecology (Ecology). 2023b. Water Quality Program Policy 1-11. Washington's Water Quality Assessment Listing Methodology to Meet Clean Water Act Requirements (*Publication 18-10-035*). Available at: https://apps.ecology.wa.gov/publications/SummaryPages/1810035.html

Independent data

Data from primary research, monitoring activities, or other sources, but that has not been incorporated as part of documents reviewed under independent, internal, or external peer review.

Bureau of Labor Statistics (BLS). 2023. "Occupational Outlook Handbook, 2023 – 2024, Environmental Engineering Technicians." Bureau of Labor Statistics, U.S. Department of Labor. Available at: http://www.bls.gov/ooh/architecture-and-engineering/environmental-engineering-technicians.htm.

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Records of the best professional judgment of Ecology employees or other individuals.

n/a

Other

Sources of information that do not fit into other categories.

United States Environmental Protection Agency (USEPA). 2024. Causal Analysis/Diagnosis Decision Information System (CADDIS).

Appendix A: Administrative Procedure Act (RCW 34.05.328) Determinations

A. RCW 34.05.328(1)(a) – Clearly state in detail the general goals and specific objectives of the statute that this rule implements.

See Chapter 6.

B. RCW 34.05.328(1)(b) –

1. Determine that the rule is needed to achieve the general goals and specific objectives of the statute.

See chapters 1 and 2.

2. Analyze alternatives to rulemaking and the consequences of not adopting this rule.

A rulemaking is the only way to adopt natural conditions provisions and criteria. If we do not adopt this rule, then waters would need to meet applicable biologically based numeric aquatic life criteria. As some waters cannot meet these aquatic life numeric criteria due to natural or seasonal variations, then without this rule, these waters would not meet applicable water quality standards and may be considered impaired, even if fully protecting all existing and designated uses. In addition, if natural conditions are the sole cause of a violation of the applicable biologically based aquatic life criteria, then listing these waters as impaired would go against the intent of the legislature (RCW 90.48.570(3)).

If we do not adopt a performance-based approach during this rulemaking, then any site-specific criteria development for determining natural conditions criteria would need to go through rulemaking, including EPA review, prior to being used for state and federal Clean Water Act purposes. A consequence of such approach would be a possibly lengthy delay between developing a protective site-specific criterion based on natural conditions of the water body and the ability to use such criterion in a Clean Water Act action (e.g., TMDLs).

If we do not adopt human-use allowances for temperature and dissolved oxygen, then when natural conditions constitute the criteria for a water, there would be no allowance for any degradation by human actions. EPA has previously determined, and Ecology agrees, that such approach would be unnecessary for the protection of existing and designated uses and would be unnecessarily costly for entities with stake in those waters.

Please see the Least Burdensome Alternative Analysis, Chapter 6 of this document, for discussion of alternative rule content considered.

C. RCW 34.05.328(1)(c) - A preliminary cost-benefit analysis was made available.

When filing a rule proposal (CR-102) under RCW 34.05.320, Ecology provides notice that a preliminary cost-benefit analysis is available. At adoption (CR-103 filing) under RCW 34.05.360, Ecology provides notice of the availability of the final cost-benefit analysis.

D. RCW 34.05.328(1)(d) – Determine that probable benefits of this rule are greater than its probable costs, taking into account both the qualitative and quantitative benefits and costs and the specific directives of the statute being implemented.

See Chapters 1 – 5.

E. RCW 34.05.328 (1)(e) - Determine, after considering alternative versions of the analysis required under RCW 34.05.328 (b), (c) and (d) that the rule being adopted is the least burdensome alternative for those required to comply with it that will achieve the general goals and specific objectives stated in Chapter 6.

Please see Chapter 6.

F. RCW 34.05.328(1)(f) - Determine that the rule does not require those to whom it applies to take an action that violates requirements of another federal or state law.

Under the Federal Clean Water Act, states are required to adopt water quality standards that consist of designated uses, water quality criteria that protect those uses, and an antidegradation policy. These standards must protect the public health or welfare, enhance the quality of the water, and serve the purposes of the Act. States must adopt water quality criteria that protect designated uses. States adopt EPA recommended CWA Section 304(a) criteria, modified CWA Section 304(a) criteria that reflect site-specific conditions, or other criteria so long as they are based on sound scientific rationale and protect the designated uses of the water (40 CFR 131.11).

EPA's policy on natural conditions states that site-specific numeric aquatic life criteria can be set equal to natural background, where natural background is defined as "background concentration due only to non-anthropogenic sources, i.e., non-manmade sources." States that wish to set criteria equal to natural background must include, at minimum, in their water quality standards: (a) a definition of natural background; (b) a provision that allows setting site-specific criteria equal to natural background; and (c) a binding procedure for determining natural background.

Ecology amended and introduced new natural conditions provisions and criteria in 2003 and 2006 to be consistent with federal requirements for use of natural conditions in effect at the time. Since then, certain natural condition provisions have been reconsidered by EPA and disapproved. Any new or updated natural conditions criteria will be consistent with current federal requirements and policy for use of natural conditions, and these criteria and associated provisions are reviewed and approved by EPA before becoming effective for Clean Water Act actions.

G. RCW 34.05.328 (1)(g) - Determine that the rule does not impose more stringent performance requirements on private entities than on public entities unless required to do so by federal or state law.

No. The rule does not impose more stringent performance requirements on private entities than on public entities. Any entity, private or public, must adhere to the rules protecting water quality in the state of Washington.

H. RCW 34.05.328 (1)(h) Determine if the rule differs from any federal regulation or statute applicable to the same activity or subject matter.

No.

- If **yes**, the difference is justified because of the following:

☐ (i) A state statute explicitly allows Ecology to differ from federal standards.

☐ (ii) Substantial evidence that the difference is necessary to achieve the general goals and specific objectives stated in Chapter 6.

I. RCW 34.05.328 (1)(i) – Coordinate the rule, to the maximum extent practicable, with other federal, state, and local laws applicable to the same subject matter.

We will work with EPA to ensure that the proposed rules are approvable.

Appendix B: Additional Tables and Figures

Table 3. Potentially Impacted Permit Categories, by Criteria

Permit Type	Temp	DO	pH
Construction SW GP	2,263	2,549	1,163
Sand and Gravel GP	218	256	201
Industrial SW GP	182	258	176
Fruit Packer GP	70	54	54
Municipal NPDES IP	46	58	49
Industrial (IU) to POTW/PRIVATE SWDP IP	30	45	36
Industrial NPDES IP	22	25	24
Bridge Washing GP	16	15	11
Upland Fish Hatchery GP	15	17	13
Industrial to ground SWDP IP	14	20	17
Municipal to ground SWDP IP	11	16	18
AP Irrigation System Aquatic Weed Control GP	10	14	14
Water Treatment Plant GP	8	8	6
Puget Sound Nutrient GP	6	9	3
Boatyard GP	5	6	1
Net Pens NPDES IP	3	3	0
Reclaimed Water IP	3	3	2
Winery GP	3	3	3
Total	2,926	3,360	1,792

Note: GP is “General Permit” and IP “Individual Permit”

Washington State's Marine Dissolved Oxygen (DO) Criteria: Application to Nutrients

Bryson Finch
Watershed Management Unit
Water Quality Program

DEPARTMENT OF ECOLOGY
State of Washington

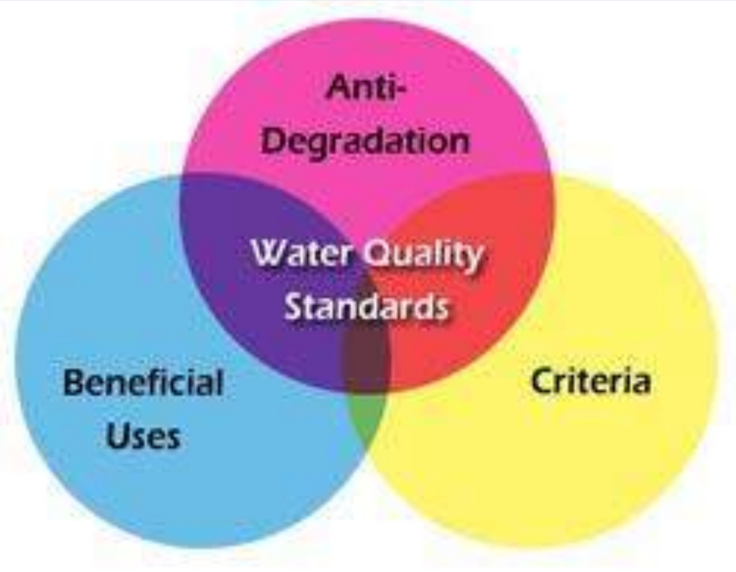
Overview

- Water Quality Standards
  - Numeric DO Criteria
  - Aesthetic Narrative Criteria
  - Anthropogenic Allowance
- History and Rationale for Marine DO Criteria
- Nutrient Criteria Alternatives
- Application of Marine DO Criteria
  - Water Column
  - Site Specific Locations
  - Anthropogenic Allowance

Water Quality Standards

Water Quality Standards

- The water quality standards set limits on pollution in our lakes, rivers and marine waters in order to protect beneficial uses, such as aquatic life and swimming.



DO Criteria

- DO criteria in the water quality standards are intended to set levels that protect healthy, robust aquatic communities, including the most sensitive species
- Assumption: if numeric criteria are met for the most sensitive organisms of each habitat, then the waterbody will protect all other species
- Criteria: **magnitude, duration,** & **frequency** component

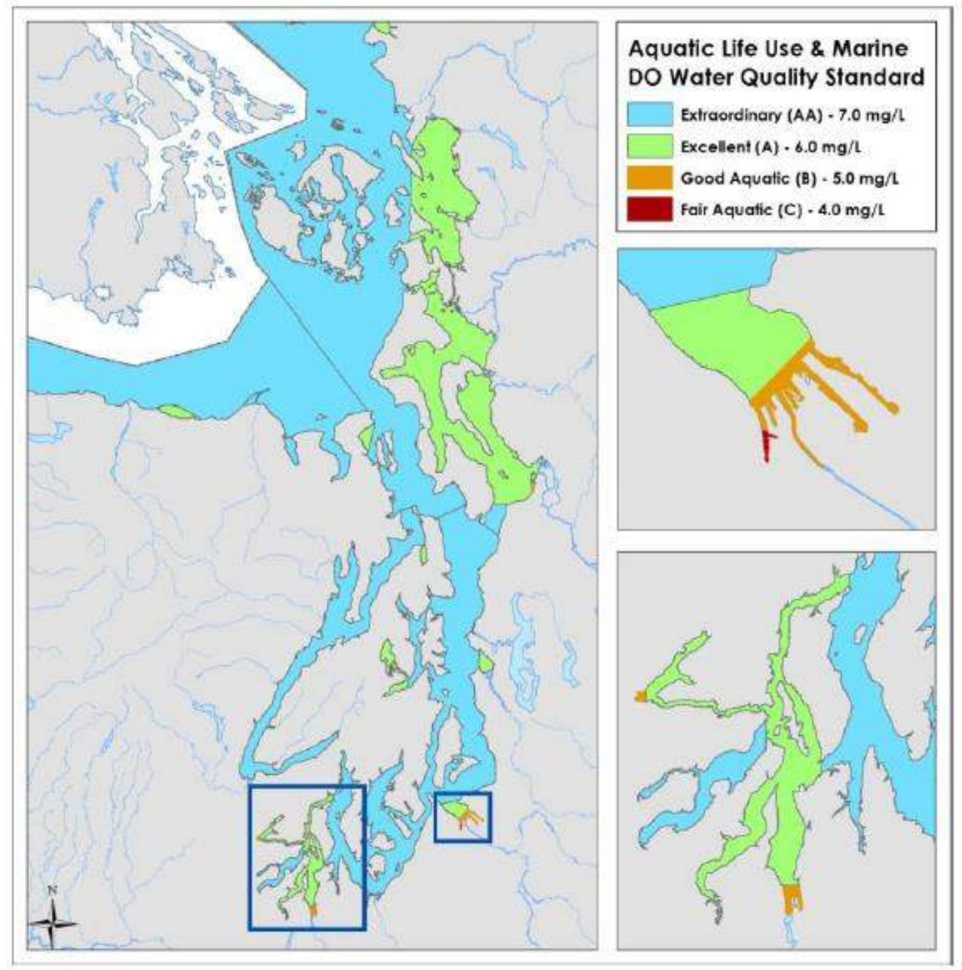
DO Numeric Criteria

Aquatic Life Use	DO Criteria (1-day min.)	General Description
Extraordinary quality	7.0 mg/L	Extraordinary quality salmonid and other fish migration, rearing, and spawning; clam, oyster, and mussel rearing and spawning; crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing and spawning.
Excellent quality	6.0 mg/L	Excellent quality salmonid and other fish migration, rearing, and spawning; clam, oyster, and mussel rearing and spawning; crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing and spawning.
Good quality	5.0 mg/L	Good quality salmonid migration and rearing; other fish migration, rearing, and spawning; clam, oyster, and mussel rearing and spawning; crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing and spawning.
Fair quality	4.0 mg/L	Fair quality salmonid and other fish migration.

Criteria exceedances may occur once every ten years on average.

WQ Dissolved Oxygen Standards in Puget Sound

- **7.0** mg/L - most of Puget Sound and the Straits
- **6.0** mg/L – Bellingham Bay, Samish Bay, Skagit Bay, around Whidbey, other inlets/bays
- **5.0** mg/L - Commencement Bay, Budd Inlet, and portions of some inlets
- **4.0** mg/L –finger of Commencement Bay



Aesthetics Criteria

- Aesthetic values must not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of light, smell, touch, or taste.
  - Used when numeric criteria are insufficient

Anthropogenic Allowance

- Allowance: 0.2 mg/L DO

- Based on concept of a measurable change
  - Measurable change: change in physical, chemical, or biological quality of the water to determine that a lowering of water quality occurred

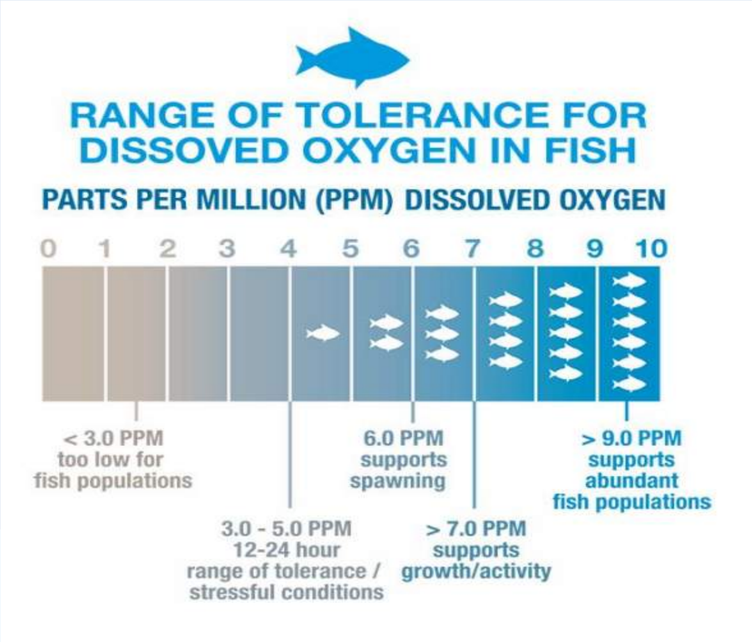
  - Represents a detectable change in water quality based on precision of the instrument

  - **Not a biologically derived value**

Marine DO Criteria Rationale

History of Marine DO Criteria

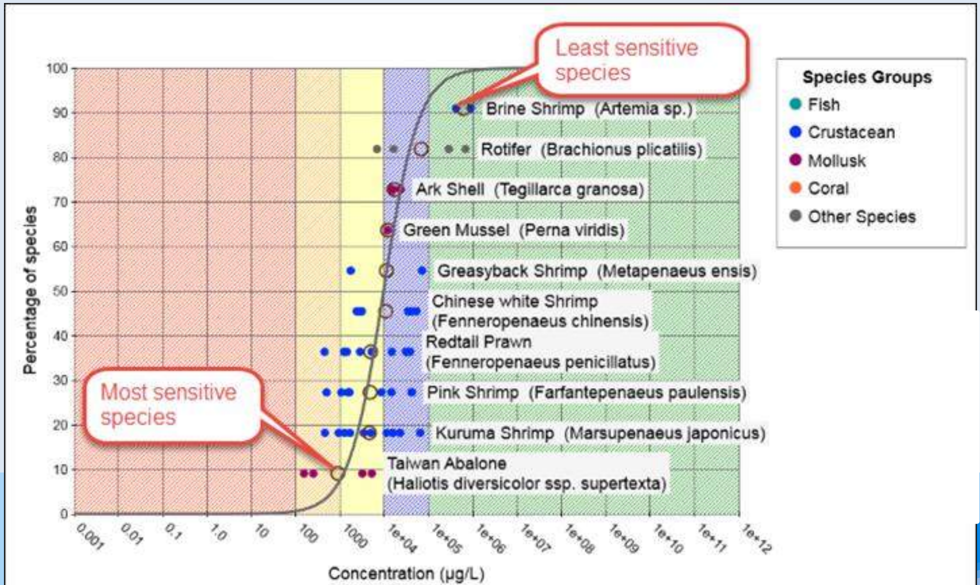
- <u>1968 Dept. of Interior recommendations</u>:
  - DO levels between **5 and 8 mg/L** protect survival and growth of fish
  - Coastal wasters shall not be <5.0 mg/L
  - Estuaries & tidal tributaries shall not be <4.0 mg/L



Supporting Scientific Data

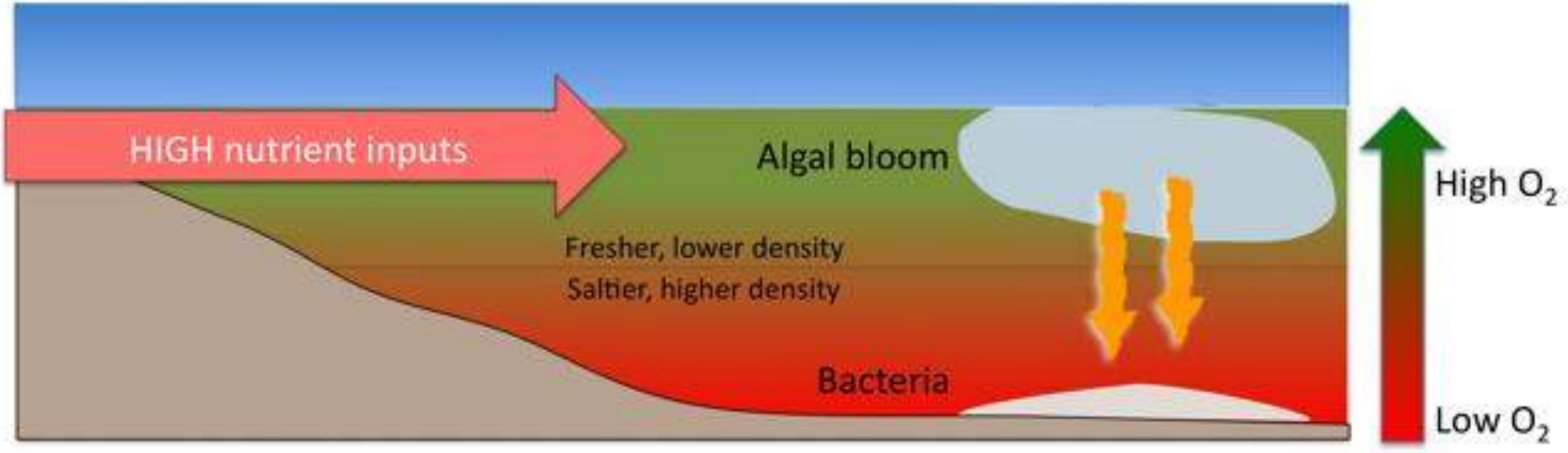
- Vaquer-Sunyer & Duarte (2008):
  - Reviewed 872 experiments spanning 206 species
    - <u>4.6 mg/L DO</u>: maintain <u>most</u> populations & biodiversity
    - <u>5.0 mg/L DO</u>: protective of sub-lethal effects for <u>most</u> species
      - ➢ 4.6 and 5.0 mg/L values represent 90th percentile of LC50s
      - ➢ Most sensitive species <u>not</u> protected at these levels

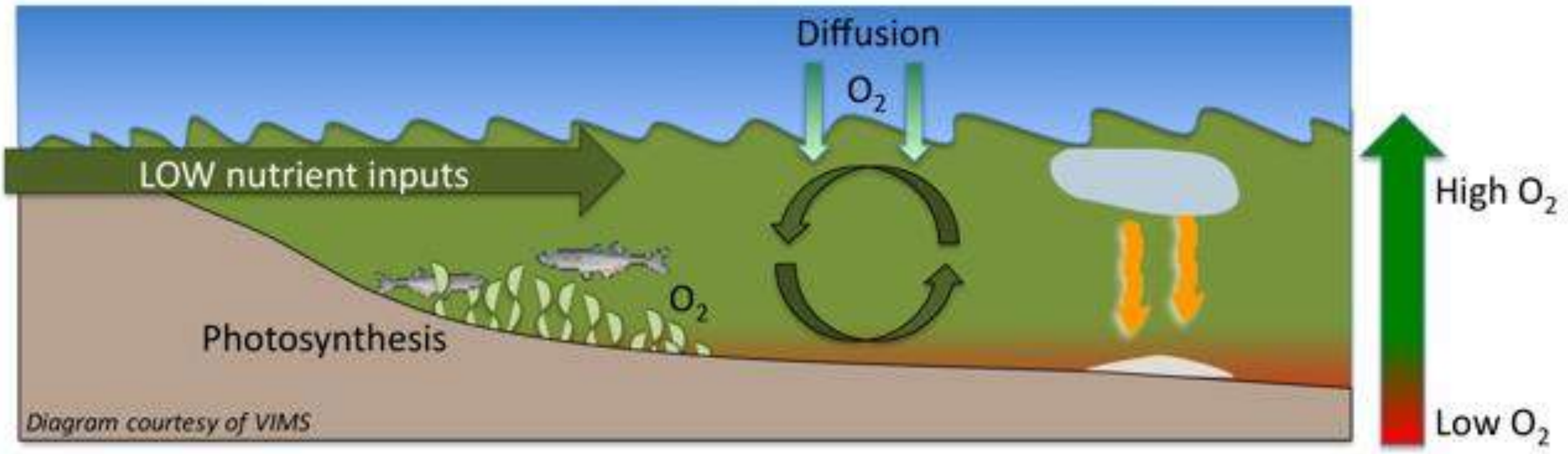
- Conclusion:
  - Full protection >>>5.0 mg/L DO



Nutrient Criteria Alternatives

DO : Nutrient Dynamics





Translating Numeric Criteria to Nutrients

<u>Dissolved Oxygen</u>

- Interrelationships between DO and nutrients
- Variations in DO can be associated with excessive nutrient inputs
- Marine models used to demonstrate relationships
  - Develop nutrient reduction volumes to achieve goals
  - Initiate actions to protect aquatic life

Translating Narrative Criteria to Nutrients

- Aesthetics narrative applies to effects of presence or offense to senses (light, smell, touch, taste)

- Various measures:
  - Percent oxygen saturation
  - Chlorophyll levels
  - Photographic evidence of algal mats/blooms
  - Others…

- Relationships between nutrient over-enrichment and aesthetics can be established

Application of DO Criteria

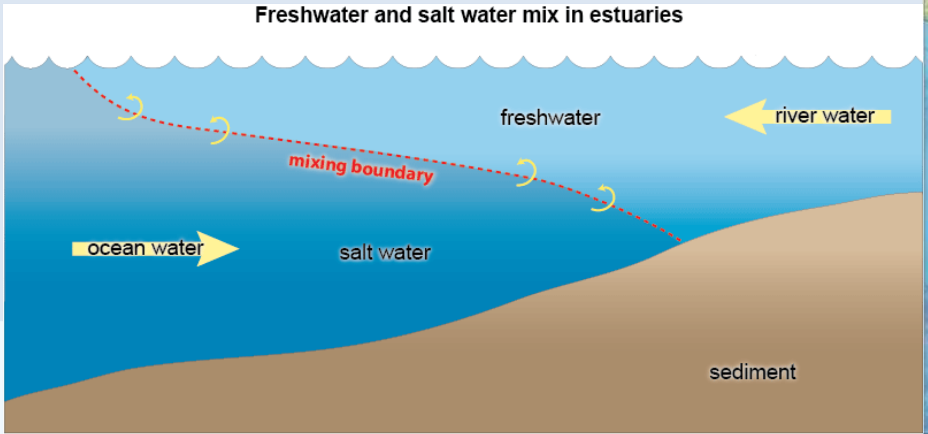
Application of DO Criteria:
Water Column

- DO measurements should represent the dominant aquatic habitat of the monitoring site
  - Samples should not be collected from shallow stagnant backwater areas, within isolated thermal refuges, at the surface or at the water's edge

- Deep waters:
  - Water samples should be assessed within:
    - Relatively <u>homogenous conditions</u> (e.g. euphotic zone; below or above the pycnocline; bottom waters)
    - Various <u>dominant aquatic habitat</u> of communities (e.g. benthic, fish, phytoplankton, zooplankton communities)

Application of DO Criteria:
Site-Specific Locations

- Water boundaries are established in the water quality standards
- Surface waters are required to be in compliance year-round at all assessment sites
- Fresh/marine water boundaries are determined by salinity measurements



Application of DO Criteria:
Anthropogenic Allowance

- Human actions considered cumulatively may not cause DO concentrations to decrease by >0.2 mg/L
  - Does not apply if water body is in compliance

- Based on 1-day minimum concentrations

- Applies year-round at all locations unless otherwise noted in WAC 173-201A

Nutrient Criteria

- EPA provides national strategies for developing nutrient criteria
  - Nationally recommended numeric criteria not available
  - Chesapeake Bay guidance document for various refugia
    - Serves as a good template when robust data is available

- WA has elected to use water quality responses for excessive nutrients to protect aquatic life

Questions?

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Puget Sound Wastewater Service Affordability Analysis: Implications for Implementation Strategies

2022 CRITICAL ANALYSIS SUMMARY REPORT

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May 17, 2023

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WESTERN WASHINGTON UNIVERSITY

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Lastly, we want to highlight the efforts of two student interns, Audrey Barber and Nate Jo. They made this study possible as we could not have compiled the large amount of data needed to complete the study without them. Their efforts, diligence and good humor in combing the web for data and managing US Census Bureau data tools are deeply appreciated. Any errors or misrepresentations are solely the fault of S. Burke and A. Kinney.

Recommended citation:
Burke, S., A. Kinney, K. Bogue, A. Barber, and N. Jo. 2023. Puget Sound Wastewater Service Affordability Analysis: Implications for Implementation Strategies. Critical Analysis Summary Report prepared by ECO Resource Group and Puget Sound Institute for the Stormwater Strategic Initiative and Puget Sound Partnership.

EXECUTIVE SUMMARY

Background and Objectives

In 2018, regional nutrient management efforts were initiated in response to monitoring data that revealed worrisome trends in Puget Sound's water quality. Wastewater treatment plants (WWTPs) are the largest anthropogenic source of nutrients to Puget Sound and were therefore an early focus of both nutrient management efforts. Puget Sound National Estuary Program Marine Water Quality Implementation Strategy (MWQ IS) planning efforts identified current funding levels as a barrier to reducing wastewater nutrient loads and recommended development of a funding pathway to identify new/expanded sources of local, state, and federal funding. In 2021, the Department of Ecology issued a Puget Sound Nutrient General Permit (PSNGP) requiring operators of facilities that discharge into Puget Sound marine waters to begin long-term planning for upgrades that would be needed to comply with total inorganic nitrogen (TIN) numeric effluent limits expected in future PSNGP cycles.

This analysis was initiated because participants in the MWQ IS development process expressed concerns about the impact of costly upgrades on their ratepayers. Since nutrient reduction upgrades have the potential to exacerbate existing affordability issues, additional data collection/analysis was recommended.

Research Questions

This report answers the following research questions as to whether current and PSNGP-adjusted sewer service costs:

1. Raise affordability concerns for Puget Sound households that are connected to sewer utilities? Affordability is measured using two indices, sewer bills as a percent of median household income (%MHI) and sewer bills as a percent of lowest quintile income (%LQI).
2. Contribute to equity and efficiency concerns of the MWQ IS if current and future sewer bills constitute a larger percentage of income of low-income households than high-income households?

And if the answer to these questions is yes, then can the data for this study help:

- Calculate the amount of federal and state monies needed to maintain %MHI or %LQI indices below a specified affordability threshold for individual Puget Sound utilities.
- Improve the equity outcomes when prioritizing the distribution of grant funds.

Study Methods

This analysis utilizes publicly available data to estimate the current annual household sewer bills and potential future nutrient-adjusted sewer bills for 80 Puget Sound regional sewer utilities.[1] Data compilation and analysis steps are listed below. The full database is available open access via UW libraries (Barber et al. 2022).

- Current sewer rates were obtained from utilities web pages to estimate current (2022) sewer bills.
- Nutrient-adjusted sewer bills were estimated for two different nutrient removal objectives; total inorganic nitrogen (TIN) < 8 mg/L seasonally and TIN < 3 mg/L and total phosphorus (TP) < 0.1mg/L year-round. These two objectives bookend the estimated costs of regulatory standards that were reported by the Washington Department of Ecology (Ecology) and Tetra Tech in the June 2011, *Technical Evaluation of Nitrogen and Phosphorus Removal at Municipal Wastewater Treatment Facilities*.
- Household income data was obtained from the U.S. Census Bureau American Community Survey (ACS). The lowest geographic unit for which household income by quintile and population data is available is the Census Tract.
- Census tracts were corresponded to sewer district boundaries or city boundaries where utilities are operated by municipalities. This allowed us to estimate a population-weighted income for each of the 80 local wastewater service providers in the study.

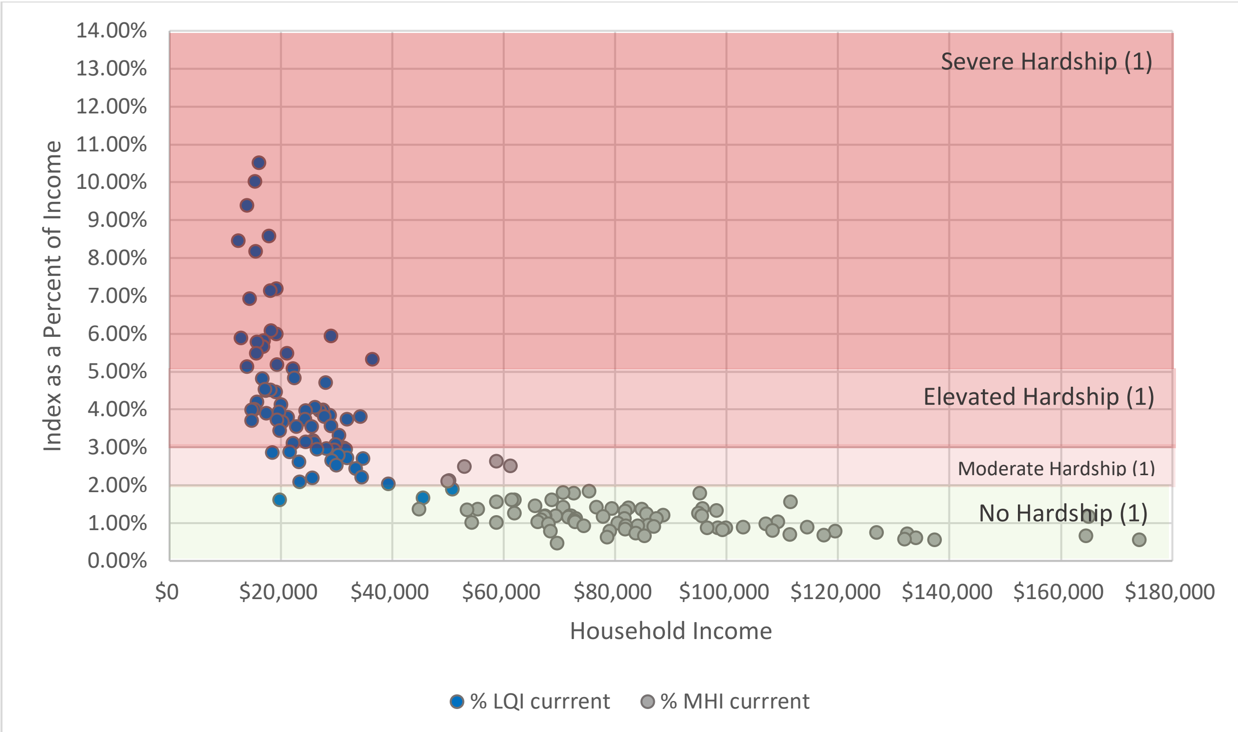
Summary Results

Current monthly sewer bills range from $27 to $161. Estimated PSNGP-adjusted monthly sewer bills ranged from $44 to $196, depending on the utility and the nutrient-reduction scenario. Estimated household income ranges widely across the region. MHI ranges from $174,078 to $44,844. LQI ranges from $50,831 to $12,425 and is, on average, 28% of MHI.

As shown in Figure ES-1, affordability metric results indicate that current sewer rates are likely:

- Not creating affordability concerns for households earning the median household income (MHI). Sewer bills were generally below 2 percent of MHI (%MHI).
- **Creating affordability concerns for households earning the lowest quintile income (LQI).** Sewer bills were often above 2 percent of LQI (%LQI), ranging between 1.61 percent of lowest quintile income (LQI) to 10.5 percent of LQI, with an average of 4.38 percent of LQI. For reference, the US Economic Research Service reports that in 2021, U.S. households spent an average of 10.3 percent of their disposable personal income on food, so on average sewer bills are a little less than half a lower quintile households' food budget.

[1] Wastewater/sewage services in the region are provided by a mix of county or municipal governments, Special Purpose Districts, and Public Utility Districts. For simplicity, we call all these local wastewater service providers utilities. Some of these utilities operate WWTPs and are PSNGP permittees, and the others are wholesale customers of those WWTP operators.

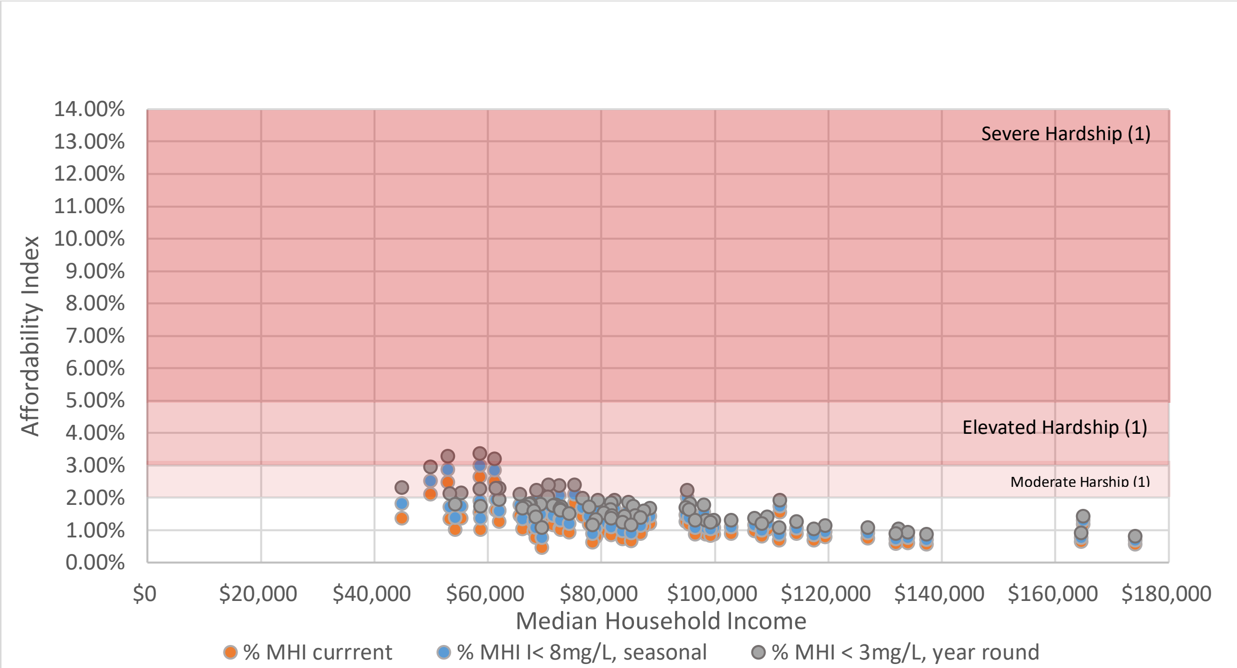


(1) Hardship categories taken from WAC 173-98-300 and apply to MHI% but not LQI%.

Figure ES-1. %MHI and %LQI Values of Estimated Current Sewer Rates for 80 Puget Sound Sewer Utilities, 2020 dollars

However, as shown in Figure ES-2, the estimated PSNGP-adjusted rates could result in sewer bills that:

- **Create affordability concerns for households earning the MHI and served by between 7 and 17** of the utilities in the study, depending on the nutrient-removal objective, e.g., %MHI values greater than 2 percent (Figure ES-2).
- **Continue to create hardship for households earning the lowest quintile income (LQI),** e.g., above 2 percent of LQI (%LQI), %LQI values greater than 2 percent for all 80 utilities ranging from 2.1 percent of LQI to 13.14 percent of LQI (Figure ES-3).



(1) Hardship categories taken from WAC 173-98-300.

Figure ES-2. Estimated current and nutrient-adjusted utility-district specific %MHI

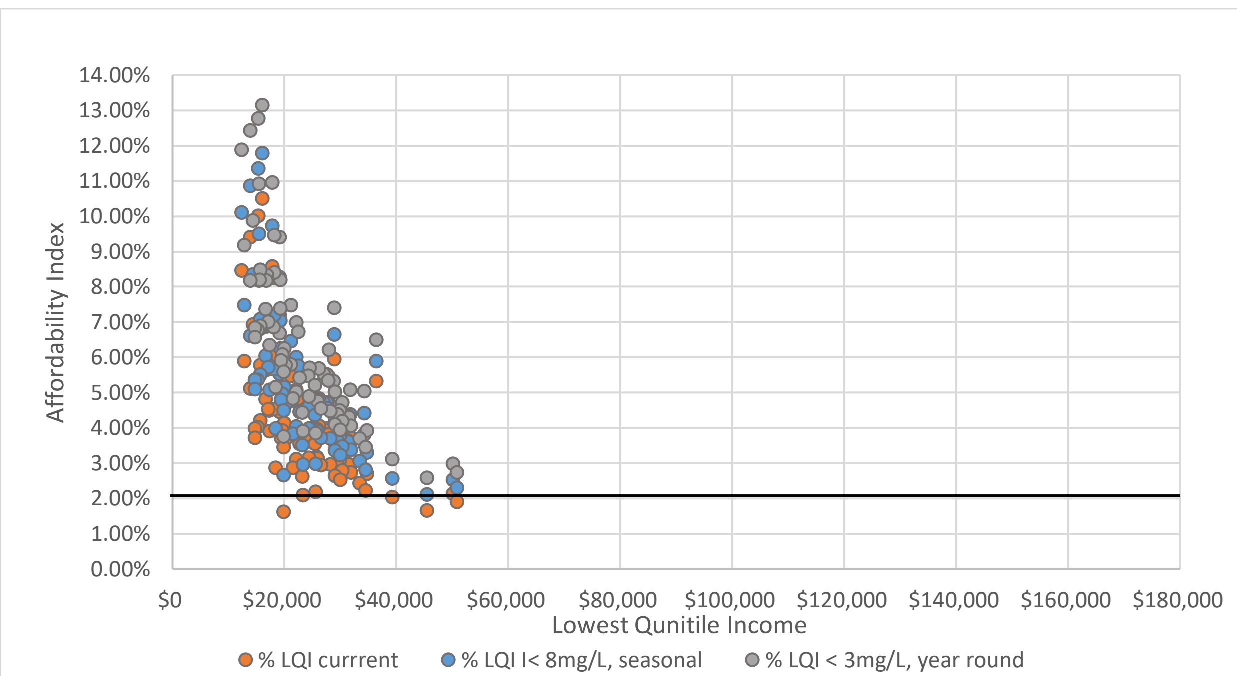


Figure ES-3. Estimated current and nutrient-adjusted utility-district specific %LQI

The range of the index values for both MHI and LQI vary widely in part because both income levels and sewer rates vary widely among the 80 utilities in the study.

With a high degree of variability in incomes and sewer bills, neither relatively high sewer bills, nor relatively low income alone predict the districts that have the highest impact index values. Rather, the %MHI and/or %LQI provides more information about the greatest need for grant funds than simply looking at the MHI levels (Figure ES-6). The correlation of both %MHI index value and %LHI index value to MHI is relatively low (R^2 of 0.2746 for %MHI and R^2 of 0.205 for %LQI). This low correlation suggests that MHI does predict the utilities that have the highest index values and therefore potentially households with the greatest need.

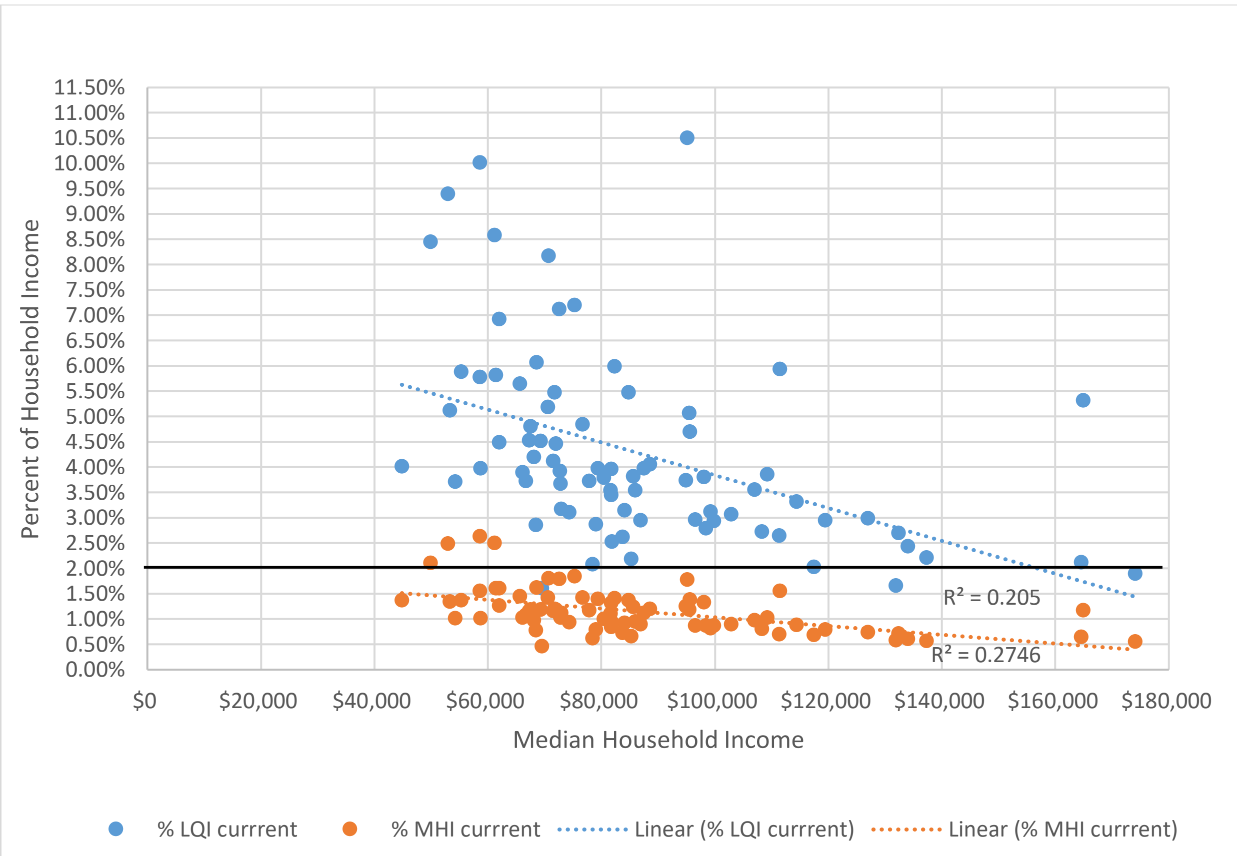


Figure ES-4. Correlation of %MHI and %LQI values to MHI

Recommendations

Our recommendations focus on identifying steps to take toward an equitable and efficient funding pathway for the MWQ IS reduce wastewater nutrient loads strategy. Non-utility public funding can contribute to the provision of a public good, in this case clean water, and help keep utility %MHI values within Ecology's "no hardship" range (below 2 percent of MHI). As funding is limited, this research helps direct available funding towards the places where it is needed most and may be used as efficiently as possible.

Four recommendations that might improve both efficiency and equity outcomes for the available grant and loans monies are:

- Utilize the data from this study to estimate the amount of federal and state capital grant monies would be needed to maintain %MHI or %LQI indices below a specified affordability threshold for individual Puget Sound utilities.
- Investigate the possibility of using the %MHI or %LQI metric in addition to other metrics used to determine financial hardship in Ecology's Grants and Loans Programs.
- Study the feasibility of a regional or state-wide low-income assistance program to aid those with the greatest need. In contrast to providing federal and state monies to pay for nutrient-related capital improvements, which could lower rates for all rate payers, a low-income assistance program would target funds to those households in greatest need of assistance.
- Consider funding a feasibility study to assess the potential benefits of restructuring rates following the model developed by the US Water Alliance's report, *A Promising Water Pricing Model for Equity and Financial Resilience* (Hara and Take 2022).

CONTENTS

TABLES AND FIGURES

LIST OF ABBREVIATIONS

CCWP	Centennial Clean Water Program
CWSRF	Clean Water State Revolving Fund
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FCA	EPA's Financial Capability Assessment
HEAL Act	Healthy Environments for All Act
IS	Implementation Strategy
LQI	Lowest Quintile Household Income
MHI	Median Household Income
MSRC	Municipal Research and Services Center
MWQ	Marine Water Quality
NPDES	National Pollutant Discharge Elimination System
PSNGP	Puget Sound Nutrient General Permit
PSP	Puget Sound Partnership
TIN	Total Inorganic Nitrogen
WAC	Washington Administrative Code
WWTP	Wastewater Treatment Plant

1. INTRODUCTION

This summary report describes methods, reports results, and discusses implications of a wastewater service affordability analysis conducted in support of Puget Sound National Estuary Program Marine Water Quality Implementation Strategy planning efforts. Associated data files and a data description with detailed metadata can be viewed in the companion *Puget Sound Wastewater Service Affordability Analysis Data Collection* (Barber et al. 2022), available at https://digital.lib.washington.edu/researchworks/handle/1773/49467.

Eutrophication is a process that occurs when anthropogenic nutrient inputs promote excessive growth of phytoplankton and macroalgae in water bodies, which can then cascade into other physical, chemical, and biological changes. Symptoms of eutrophication—low dissolved oxygen, loss of submerged aquatic vegetation, changes in nutrient ratios that alter planktonic species composition, and blooms of algae that produce harmful biotoxins—can intensify as the process progresses (Bricker et al. 2007).

In 2018, two regional nutrient management efforts were initiated in response to monitoring data that revealed worrisome trends in Puget Sound's water quality:

- Reporting for the Puget Sound Partnership's (PSP) "Marine Water Quality Vital Sign" implied a progression of eutrophication symptoms.[2] These findings led to development of a Marine Water Quality Implementation Strategy (MWQ IS) to provide a ***non-regulatory*** road map intended to align nutrient management efforts across agencies and programs. It was created using a collaborative process developed by PSP and is being implemented by the Stormwater Strategic Initiative.

- The Washington Department of Ecology's (Ecology) Water Quality Assessment identified 102 waterbody segments in Puget Sound that don't meet marine dissolved oxygen Water Quality Standards (i.e., they were placed on the 303(d) list of impaired waterbodies). As a result, Ecology began the Puget Sound Nutrient Reduction Project as a ***regulatory*** process to quantify needed pollutant reductions and identify management actions necessary to bring impaired waters back into compliance with the state's legally enforceable water quality standards.

Wastewater treatment plants (WWTPs) are the largest anthropogenic source of nutrients to Puget Sound and were therefore an early focus of both nutrient management efforts. Since most WWTPs in the region do not currently utilize advanced nutrient removal technologies, without facility upgrades nitrogen loading will continue to increase as the region's population grows. In 2021, Ecology issued a Puget Sound Nutrient General Permit (PSNGP) requiring operators of facilities that discharge into Puget Sound marine waters to begin long-term planning for upgrades that would be needed to comply with total inorganic nitrogen (TIN) numeric effluent limits expected in future PSNGP cycles.

[2] See PSP (2020) for the latest update on this recently replaced set of metrics.

WWTP upgrades needed to reduce TIN loading as population grows will be expensive. Capital costs associated with adding advanced nutrient removal technologies to all the municipal WWTPs subject to the PSNGP are likely to exceed $2 billion, based on a preliminary economic evaluation of potential nutrient limits by Ecology and Tetra Tech (2011) escalated to 2022 dollars. The MWQ IS identified current funding levels as a barrier to WWTP upgrades and recommended development of a funding pathway strategy to encourage alignment of federal, state, and local funding sources.

1.1 Critical Analysis Purpose

Critical analyses are a component of the Puget Sound National Estuary Program's implementation strategies (IS) framework. During development of these strategies, participants identify uncertainties that limit understanding of problems and potential solutions related to regional recovery targets. These uncertainties are catalogued by Puget Sound Institute. Each year some Environmental Protection Agency (EPA) and PSP implementation strategy assistance agreement funding is allocated for "critical analysis" to answer key questions with a targeted data collection and analysis effort.

This critical analysis was initiated because participants in the IS development process expressed concerns about the impact of costly upgrades on ratepayers. Northern Economics (2019) similarly raised questions about equitable distribution of nutrient reduction costs, and potential political implications if a subset of the region's population is to bear a disproportionate share of costs needed to achieve public benefits enjoyed by all residents. In addition, Kinney et al. (2021) and Kinney et al. (2023) had documented existing water utility service affordability challenges in the region. Since nutrient reduction upgrades have the potential to exacerbate existing affordability issues, additional data collection/analysis was recommended.

Results of this analysis are intended to inform and contribute to the discussion of how to "develop a funding pathway" strategy in the MWQ IS. Choices made about how the region is to pay for WWTP upgrades may have implications for growth management as well as equity outcomes receiving greater attention due to the White House's Justice40 Initiative and Washington's Healthy Environment for All (HEAL) Act. We hope this analysis can support development of funding strategies that improve water quality while minimizing unintended consequences for other elements of Puget Sound's socioecological system.

1.2 Critical Analysis Approach

We approach the analysis in two steps. First, we estimate and analyze the financial impact that sewer bills have on Puget Sound communities and households with municipal sewer service. Second, we discuss ways the impact analysis results could be used to develop a funding pathway strategy for the MWQ IS, specifically focused on the potential to improve economic efficiency and equity outcomes.

SEWER BILL IMPACT ANALYSIS

The impact analysis answers two questions:

- How affordable are current sewer service costs in the Puget Sound region?
- How does affordability change when projected rate increases attributable to PSNGP-required upgrades are added to current service costs?

We assessed **"affordability"** by calculating sewer service costs for single family residential households as a percentage of Median Household Income (MHI) and Lowest Quintile Income (LQI). There is no single universally accepted threshold for water utility affordability, but consistent with existing literature and practice we flag results above 2% as relatively less affordable. **A %MHI value exceeding 2% begins to raise concerns at the utility/community scale and a %LQI value exceeding 2% is a potential red flag for individual households.** These generalizations were derived from two sources:

- EPA Financial Capability Assessment Guidance considers %MHI in combination with other factors when determining implementation schedules for control measures needed to meet Clean Water Act regulatory obligations.[3] Past EPA (2014) guidance suggested that wastewater costs exceeding 2% of MHI have a **"high impact"** on residents. Reliance on MHI as a measure of affordability was criticized because it understates financial impacts to low-income households (Congressional Research Service 2017, Teodoro 2018). EPA (2022a) responded by proposing new indicator metrics that incorporate LQI in their revised financial capability assessment guidance.
- WAC 173-98-300 4(b) and WAC 173-98-320 delineate three categories of **"hardship"** for Ecology to use when determining interest rates and forgivable principal eligibility for clean water loans. Moderate hardship occurs when %MHI is above <2% but less than 3%; elevated hardship is defined as %MHI between 3% and 5%; and severe hardship occurs when %MHI is above 5%.

FUNDING STRATEGY DISCUSSION

Next, we discuss how the sewer bill impact analysis data and results could contribute to the development of a funding strategy for the MWQ IS. There is little debate that the needed nutrient-related capital infrastructure upgrades are costly and the demands for capital funds, whether from local, state, or federal sources, are limited. We focus our discussion on how the results of the impact analysis could help maximize the efficiency of state grant and loan

[3] EPA points out that their Financial Capability Assessment "is not a methodology for defining water affordability." **In this report we use the umbrella term "affordability" to encompass the general idea that water rates may be a financial burden on some households and utilities may face hardship when some of their ratepayers are unable to pay their bills.** As EPA points out, we do not intend to infer that the rates are unreasonable for the level of environmental protection that they offer.

spending, where efficiency is measured as prioritizing financial assistance to utilities and/or households with the greatest need.

The funding strategy discussion includes a brief background on the history of federal investment in water infrastructure and continues with a description of the state's grant and loan programs, specifically focused on prioritization methods. The prioritization discussion provides a basis to consider using the results of this study to improve the efficiency and equity of future grant funding.

Specifically, two potential equity issues are:

- Concerns over a subset of the region's population incurring a large portion of the expenditures needed to achieve broad public benefits.
- Whether increasing sewer rates cause lower income households to pay a disproportionate share of their incomes on sewer bills.

At the conclusion of the funding strategy discussion, we list recommendations and potential next steps.

2. SEWER BILL IMPACT ANALYSIS

The impact analysis describes the methods used to estimate the utility-specific %MHI and %LQI metrics for current and potential PSNGP-related sewer bills as well as data limitations we encountered during the analysis. We conclude the impact analysis with a description of the results. Additional information about data sources and analysis methodology can be found in the study's data collection (Barber et al. 2022).

2.1 Methods

Here we summarize the data compilation and analysis steps taken to estimate current and PSNGP-adjusted annual sewer service costs and income metrics used to calculate %MHI and %LQI.

2.1.1 Utilities Impacted by Puget Sound Nutrient General Permit

The first step was to identify all utilities[4] directly and indirectly affected by PSNGP requirements. The list of WWTP operators covered by the permit (the permittees) was obtained from Ecology (2021a and 2021b). Forty utilities operate 58 municipal WWTPs that discharge directly to Puget Sound marine waters. These utilities are directly impacted by the PSGNP because they operate the facilities that will need to be upgraded to comply with expected future TIN effluent limits.

Several permittees are wholesale providers of treatment services to neighboring utilities that do not own and operate a WWTP. The permittee charges wholesale customers a uniform rate to cover treatment costs (capital, operations, maintenance). The wholesale customer is also a retailer that bills their customers for the wholesaler's services plus the cost to operate their local collection systems (e.g., pipelines and pump stations) and convey wastewater to the wholesaler's system. These 43 utilities are impacted indirectly by the PSNGP, as they do not have to invest in treatment options, however the contract rates they pay for treatment services will likely increase. The total number of utilities that will be affected by the PSNGP is nearly twice the number of permittees.

King County is an example of a regional entity that owns/operates WWTPs and contracts treatment services to 29 local utilities. King County does not bill individual property owners; each of the 29 local utilities that King County provides services are the entities that bill individual customers. Because each of these local utilities have a unique rate structure and set their individual rates, this study calculated %MHI and %LQI for each of the local utilities.

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[4] Wastewater/sewage services in the region are provided by a mix of county or municipal governments, Special Purpose Districts, and Public Utility Districts. For simplicity, we call all these different types of service providers sewer utilities.

In total this study estimated sewer bills and utility-specific household incomes for 80 Puget Sound municipal sewer utilities.[5] State agency permittees (Department of Corrections, Washington State Parks) and non-municipal customers (Washington State Ferries, Puget Sound Naval Shipyard, Ft. Warden, Manchester Naval Fuel Depot, and Tribes) were excluded from the study. Appendix A lists the permitee and the utility district to which they provide treatment services.

2.1.2 Monthly Sewer Service Cost

CURRENT COST

We estimated monthly sewer bills for 80 utilities in Puget Sound. Rate data was obtained from the utilities' webpages. Two assumptions were used to estimate the monthly sewer bills for each utility. First, the rates are based on a ¾" residential pipe size. Second, where a variable rate was charged based on water usage, the usage was assumed to be a constant 5.5 ccf per household per month across all utilities. Assuming a constant usage rate allows for comparisons across rates that are solely based on the variable rate and not a difference in water usage. For a detailed description of the calculations see Barber et al. (2022).

The project team emailed utilities that utilize a variable rate structure, where bills are based entirely or partially on the volume of water used, to verify the estimated rates. Of 26 utilities contacted, we received responses from 12 (46% response rate). Minor corrections to our initial estimates were made where errors were identified by utilities.

PSNGP-ADJUSTED COST

In addition to estimating the current sewer bills, we also estimated potential sewer rates once PSNGP-required upgrades are added to current sewer rates. We added estimates of the nutrient-related increase in sewer rates (Table 1), published in *Technical and Economic Evaluation of Nitrogen and Phosphorus Removal at Municipal Wastewater Treatment Facilities,* (Ecology and Tetra Tech 2011) to our estimates of current sewer rates to arrive at these PSNGP-adjusted sewer costs.

Ecology and Tetra Tech (2011) show the estimated increase in monthly sewer rates for 4 different potential nitrogen effluent limits in 2010 dollars, which are displayed in Table 1. We choose to project costs for the most (<3 mg/L TIN year-round) and least (<8mg/L dry-season) stringent limits, which coincide with the most and least expensive upgrade scenarios, to provide an idea of the full range of potential impacts on sewer bills. We adjusted the estimates to 2022 dollars using the US Producer Price Index for Construction Materials.[6]

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[5] We identified 89 municipal sewer utilities the discharge into Puget Sound marine waters, however only 80 are included in the study because we were unable to find service area maps or sewer rates for 9 utilities.

[6] Federal Reserve Bank of St. Louis, Economic Research, PPI by Commodity: Special Indexes: Construction Materials.

It bears mentioning that the PSNGP-adjusted sewer rates assume utilities will pay the full amount of the necessary upgrades without state or federal grants.[7] Thus, the nutrient adjusted sewer rates may be overstated if significant grant funding is made available. At the same time, the estimated upgrade costs may be understated. The expected accuracy range of the estimated monthly rate increases was +100 percent to – 50 Percent (Tetra Tech, 2011). Additionally, our PSNGP-adjusted sewer rates do not account for any other increases in service costs required for any other type of planned upgrades, for example to replace aging infrastructure. Actual future sewer costs will be even higher than our PSNGP-adjusted rates. A reminder that this analysis, the first of its kind, is intended to estimate the potential magnitude of impacts the PSNGP may have on Puget Sound utilities and households in the absence of significant new sources of state or federal funding.

Table 1. Estimated Monthly Household Sewer Rate Increase For Nutrient Removal of Puget Sound Water Resource Inventory Areas, Adjusted to 2022 dollars.

	TIN <8mg/L year-round	TIN <3 mg/L year-round	TIN <8 mg/L dry season	TIN <3 mg/L dry season
2010 (a)	$ 16.00	$ 19.48	$ 9.43	$ 11.41
2022 (b)	$ 29.05	$ 35.36	$ 17.12	$ 20.71

Sources: (a) Table ES-3 in *Technical and Economic Evaluation of Nitrogen and Phosphorus Removal at Municipal Wastewater Treatment Facilities* (Ecology and Tetra Tech 2011) (b) Costs adjusted by factor of 182 percent based on PPI by Commodity: Special Indexes, Construction Materials.

2.1.3 Household Income

Household income and population data was obtained from the 2019 U.S. Census Bureau American Community Survey (ACS). The lowest geographic unit for which household income by quintile and population data is available is the Census Tract. We downloaded data associated with 941 unique census tracts for the twelve Puget Sound counties.

Census tracts were corresponded to sewer district boundaries or city boundaries where utilities are operated by municipalities. This allowed us to estimate a population-weighted income for each of the 80 local wastewater service providers in the study. The full database is available open access via UW libraries (see Barber et al. 2022).

[7] This assumption is based on the methodology described in Tetra Tech and Ecology's 2010 report entitled Technical Evaluation of Nitrogen and Phosphorus Removal at Municipal Wastewater Treatment Facilities, 2011. See Section 17.2 that describes how the weighted average monthly household sewer rate increase for nutrient removal upgrades was calculated.

2.1.4 Affordability Metrics

Using the numerators (estimated sewer bills) and denominators (estimated utility-specific household income) generated in the previous steps, we calculated six affordability metrics for each of the 80 utilities in the study:

- Current annual sewer service cost as a percent of MHI
- Current annual sewer service cost as a percent of LQI
- Annual cost of sewer service with a year-round 3 mg/L TIN limit as a percent of MHI
- Annual cost of sewer service with a year-round 3 mg/L TIN limit as a percent of LQI
- Annual cost of sewer service with a seasonal 8 mg/L TIN limit as a percent of MHI
- Annual cost of sewer service with a seasonal 8 mg/L TIN limit as a percent of LQI

Results were evaluated based on their value relative to the commonly applied 2% benchmark.

2.2 Data Limitations

The geographic scale of this evaluation is broader than an individual utility would undertake for a financial capability assessment. Results represent a snapshot in time and are intended to inform development of a regional-scale funding strategy. Here we provide a list of potential sources of error that should be considered when using this data and/or our analysis results. A more detailed description of the assumptions and the impacts that these assumptions had on our estimates can be found in Barber et al. (2022).

- Not all Puget Sound region households are included in the study. PSNGP-impacted utilities discharge directly to Puget Sound marine waters. WWTPs that discharge to rivers that flow into Puget Sound are not included. Likewise, on-site sewage treatment (septic systems) and utilities that discharge via groundwater are not included. Multifamily households were excluded from the analysis due to the differences in the ways utilities and building managers sub-meter and bill individual units.
- Corresponding the census tracts to utility district service areas required several assumptions that resulted in a lower level of confidence about than we would have liked.
- Households that use on-site sewage treatment (septic systems) but are located within the service area boundaries of a wastewater utilities were not excluded when calculating the Median Household Income and Lowest Quintile Income for those utilities.
- Our 5.5 ccf/month (4,114 gallons) water usage assumption does not explicitly include consideration of household size and seasonal variation. We decided to calculate service costs based on a standardized usage, rather that collecting data on actual usage, so that cost estimates were normalized to enable direct comparison. The standardized usage we

selected is based on a commonly applied estimate of average winter quarter usage in the region (D. Thompson, City of Tacoma Wastewater Operations Division Manager, pers. comm.). Using a rainy season average excludes outdoor/irrigation use thereby more closely approximating the generally accepted "basic use" estimate of 50 gallons per capita per day (gpcd) (approximately 6.6 ccf). Several utilities contacted to verify our service cost calculations responded that their actual annual average household usage volume was higher than 5.5 ccf/month.

- Some service providers incorporate state and local utility taxes into their rates, and some do not. We used published rates and did not account for inclusion/exclusion of taxes.
- More recent estimates of potential PSNGP compliance costs (e.g., Brown and Caldwell 2020) indicate that cost estimates provided in Ecology and Tetra Tech (2011) are very low, even adjusted to 2022 dollars.

2.3 Results

2.3.1 Utilities Impacted by the PSNGP

See Appendix A for a list of the sewer utilities included in the study. The list includes 85 utilities, 80 of which were included in the study. Five utilities were excluded because we were unable to locate a detailed map of the provider's service area or the district's web page did not report sewer rates. Two utilities, King County and LOTT, are exclusively wholesalers that do not bill any households for sewer treatment services.

2.3.2 Monthly Sewer Service Cost

Figure 1 shows our estimates for current monthly sewer bills of 80 local sewer providers. Current estimated monthly sewer cost ranges from $26.55 per month to $161.21 per month. The average across all 80 utilities was $78.36 per month with a standard deviation of $23.91. As discussed in Section 2.1.2, these costs assume 5.5 ccf of water usage for the 25 utilities with rates based on volume of water used. The remaining 55 utilities utilize a flat rate structure.

Figure 2 shows our estimates for potential future PSNGP-related sewer bills of 80 local sewer districts. The two PSNGP-related sewer bills were calculated by adding $17.12 (8mg/L seasonal scenario) and $35.36 (3mg/L year-round scenario) to estimated current sewer bills. Potential future PSNGP-adjusted monthly sewer bills associated with the 8mg/L seasonal scenario range from $43.76 per month to $178.33 per month. Potential future PSNGP-adjusted monthly sewer bills associated with the 3mg/L year-round scenario range from $62.01 per month to $196.57 per month.

This large range of estimated monthly sewer bills was curious but beyond the scope of this study to attempt to explain. A possible future study could attempt to correlate costs to factors such as number of connections, topography, underlying geology, length of pipes, number of pump stations, location (e.g., island), existing removal nutrient technology, etc.

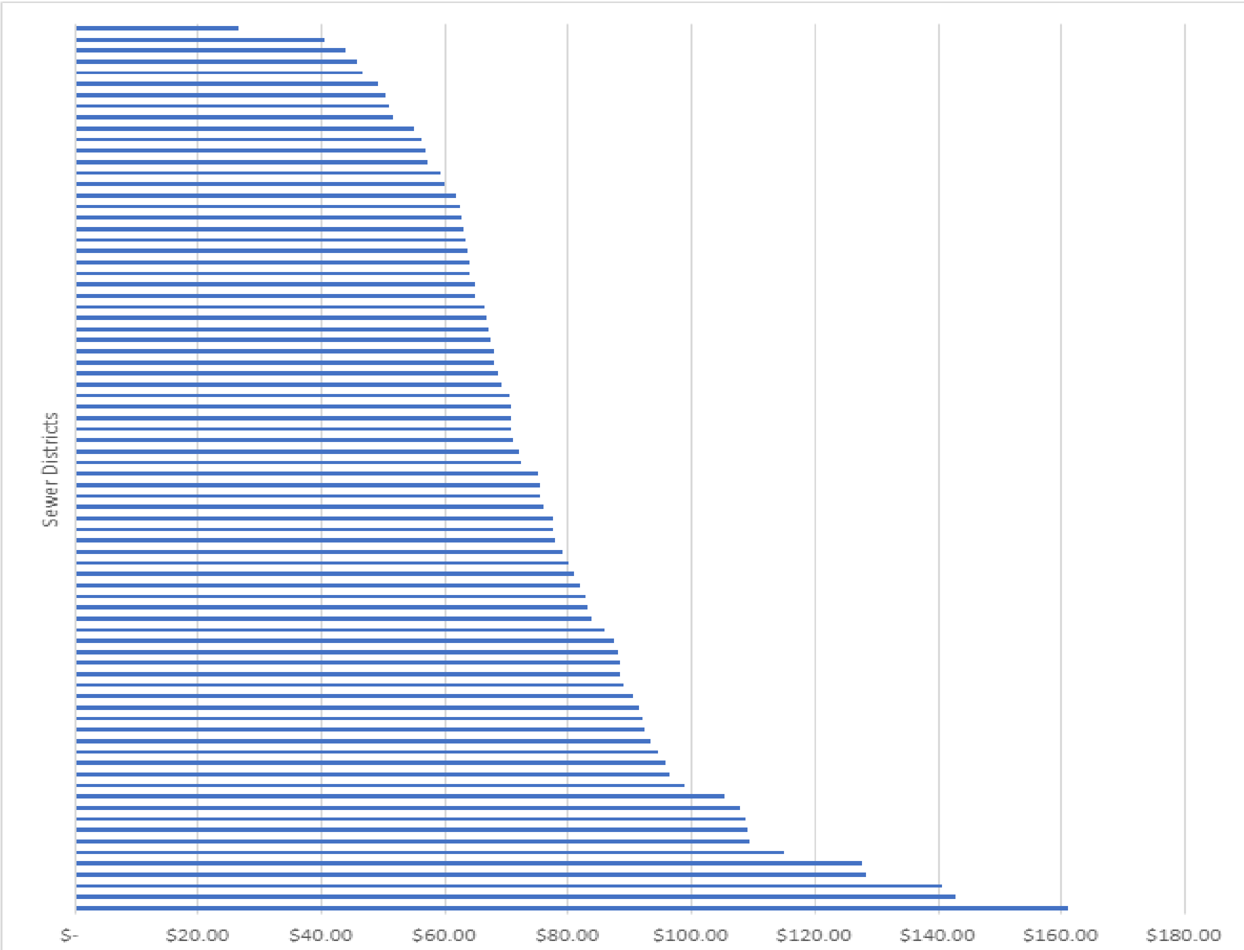


Figure 1. Estimated Current Monthly Sewer Service Costs, 80 Puget Sound Utilities

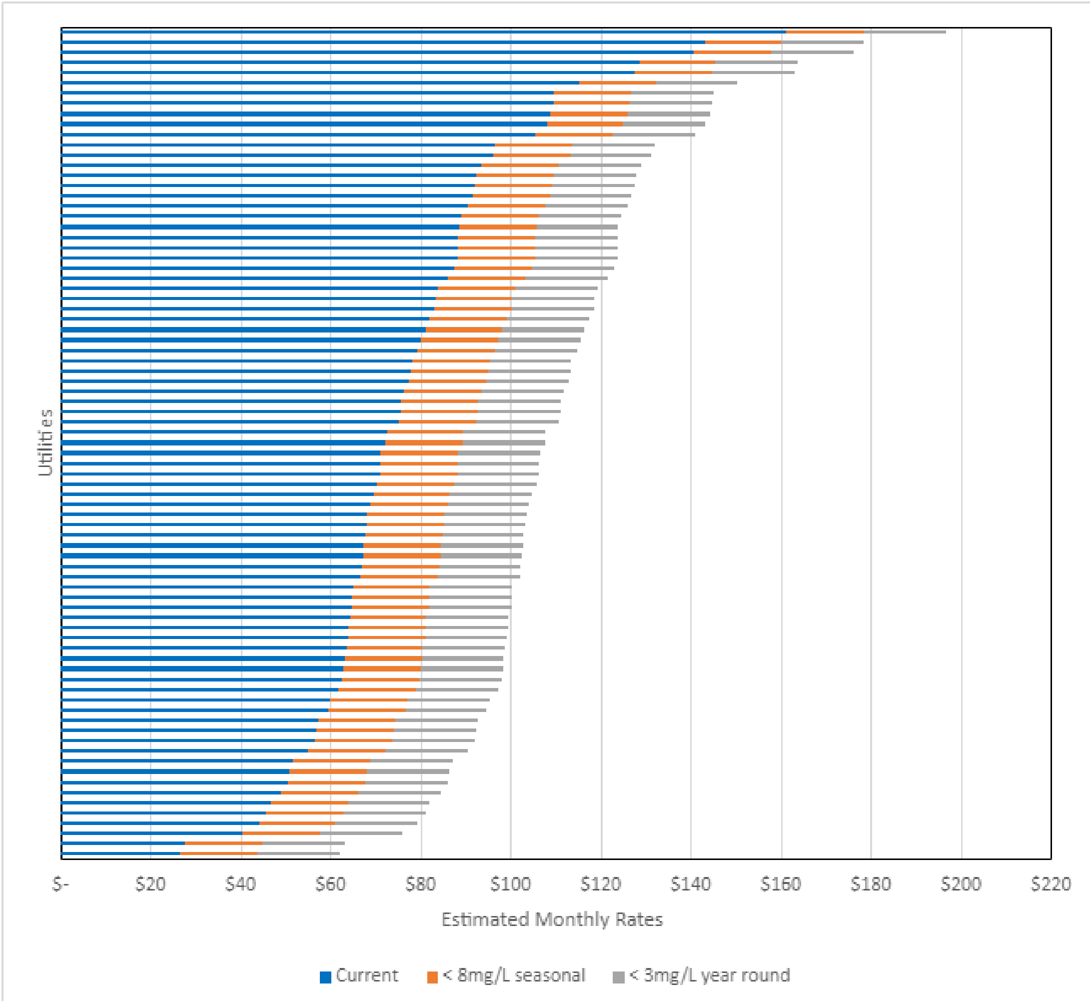


Figure 2. Estimated PSNGP-Related Monthly Sewer Service Costs, 80 Puget Sound Utilities

2.3.3 Household Income

Figure 3 shows estimated MHI and LQI in the service areas of 80 local wastewater providers. MHI ranges from a low of $44,844/year to a high of $174,078/year, with an average of $86,323/year. The estimated LQI ranges from a low of $12,425/year to a high of $50,831/year, with an average of $23,953/year. In general, the LQI is approximately 30 percent of the MHI, illustrating the extent of income disparity in the Puget Sound region (Figure 4).

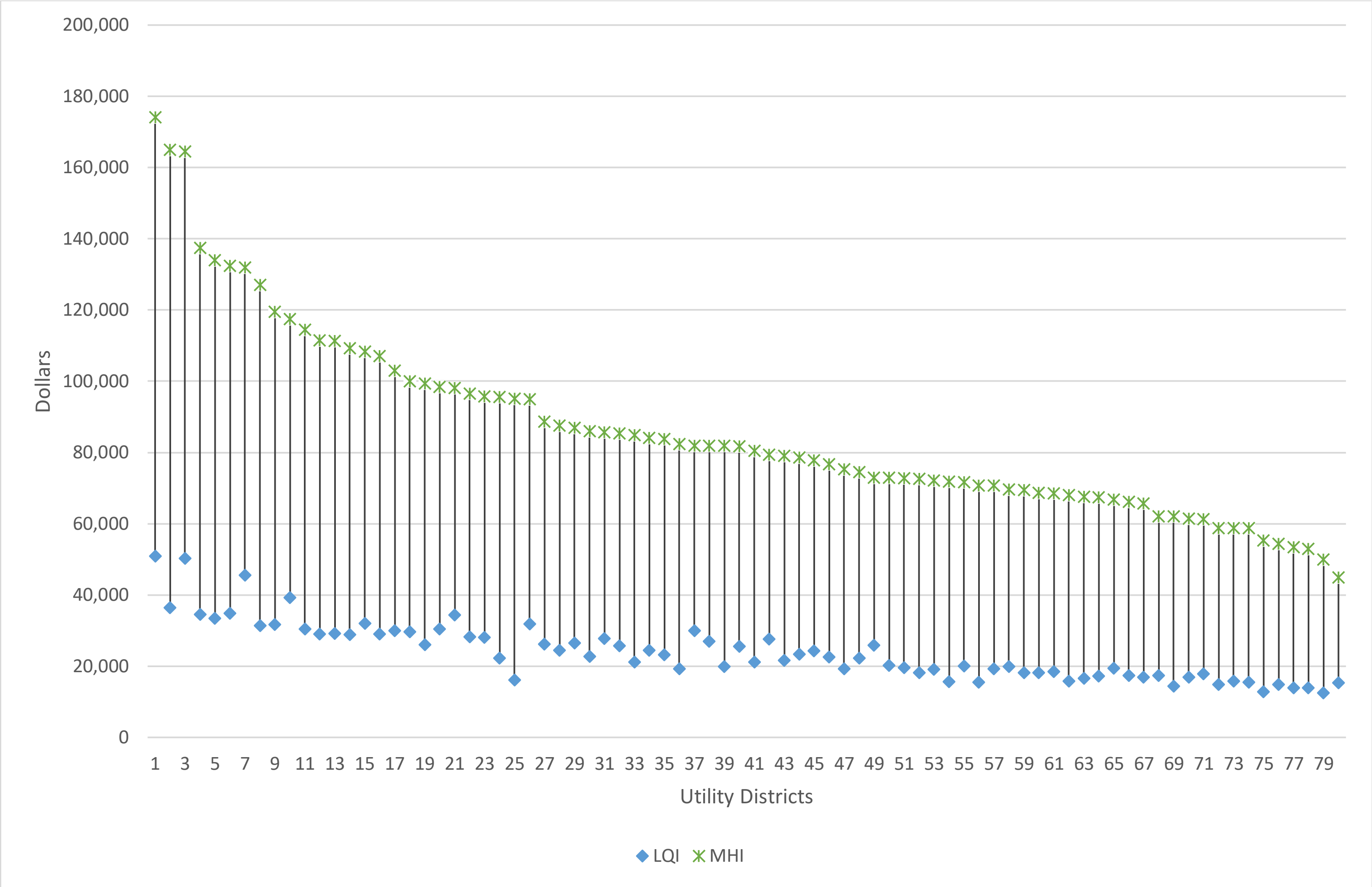


Figure 3. Estimated Household Income for 80 Puget Sound Sewer Utilities, 2020 dollars

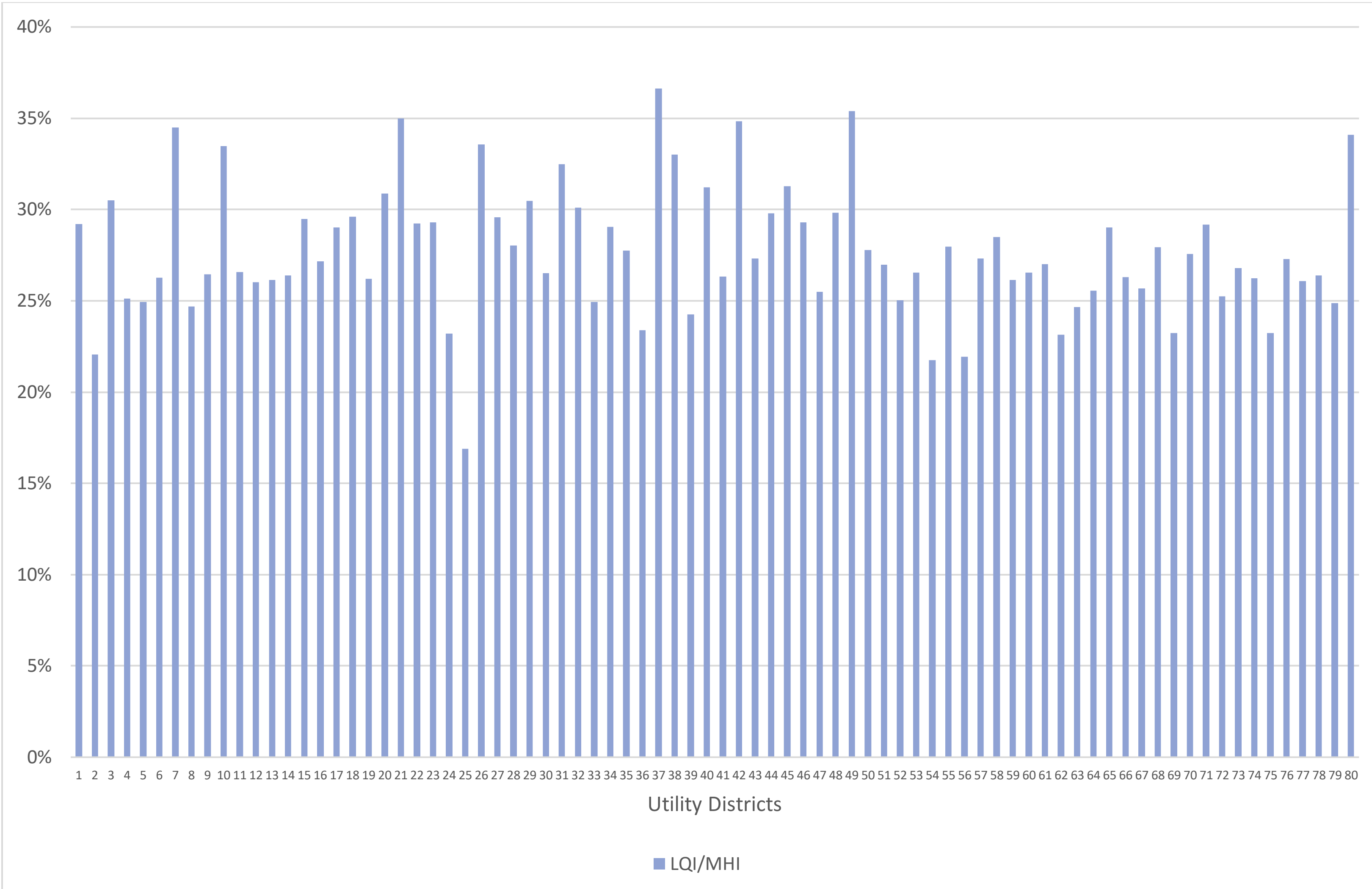


Figure 4. Lowest Quintile Income as a Percent of Median Household Income for 80 Puget Sound Sewer Utilities, 2020 dollars

2.3.4 Indicators of "Affordability"

The %MHI and %LQI results were calculated by dividing the estimated sewer costs by the utility specific MHI and LQI, respectively. Two sets of %MHI values and %LQI values were estimated, one set for current sewer costs and a second set for PSNGP-adjusted sewer costs.

Estimated %MHI and %LQI results for current sewer costs are shown in Figure 5. Values range from 0.5 %MHI to 2.6 %MHI, averaging 1.2 %MHI. These values suggest current rates are reasonably affordable when calculated using MHI. However, the %LQI results indicate sewer service costs are burdening low-income households. %LQI values range from 1.6 %LQI to 10.5 %LQI. This wide disparity in index values demonstrates one reason EPA's FCA guidance document includes utilizing LQI in some metrics. For reference, the US Economic Research Service reports that in 2021, U.S. consumers spent an average of 10.3 percent of their disposable personal income on food.

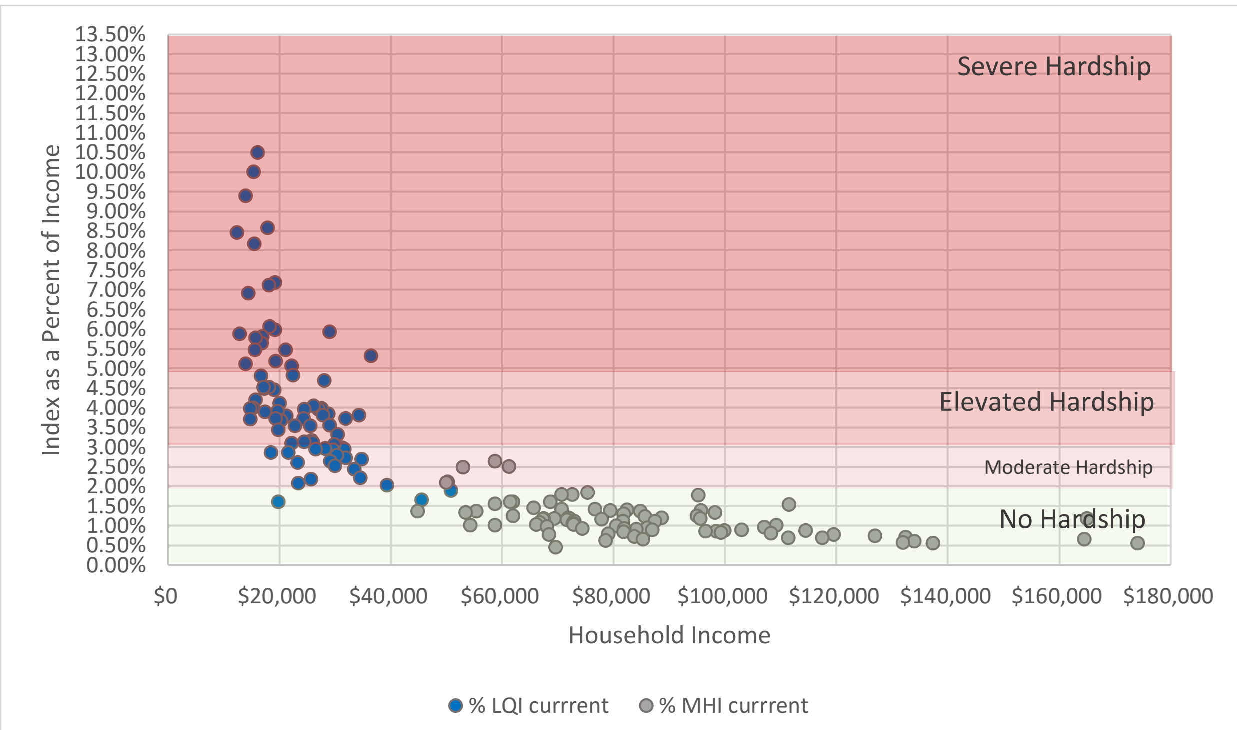


Figure 5. %MHI and %LQI Values Using Estimated Current Sewer Costs for 80 Puget Sound Sewer Utilities, 2020 dollars

The summary information presented in Figure 5 demonstrates several areas of potential concern. First, the scatter plot demonstrates the income disparity in Puget Sound, even between MHI and LQI. Where MHI ranges from approximately $40,000 to a high of $180,000. Whereas LQI range is much narrower, with the majority of households around $20,000 LQI. Second, current sewer rates may not have a high impact on Puget Sounds' household's budget using MHI, however sewer bills do have a relatively high impact, or create hardship, on low-income households. The next question to address is how might PSNGP-adjusted sewer rates impact households? This question and a detailed description of the both sets of indices (the %MHI and the %LQI) using both current and nutrient-adjusted sewer rates are discussed below.

CURRENT AND PSNGP-ADJUSTED COSTS AS A PERCENT OF MHI

The utility-specific %MHI values using current sewer rates are less than two percent in 76 of the 80 Puget Sound sewer utilities included in the analysis (Table 2). The %MHI values range between 0.46 percent of MHI and 2.63 percent of MHI, with an average of 1.16 percent of MHI, and a standard deviation of 0.44. These results indicate that for most utilities in the region current sewer costs are not high impact or causing hardship as defined by EPA and Washington State, respectively.

However, estimated %MHI values using PSNGP-adjusted sewer rates suggest that over 20 percent of Puget Sound utilities' sewer bills would cause hardship to their rate payers, absent federal or state investment in nutrient reduction upgrades (Table 2). %MHI values were estimated for two potential regulatory scenarios: <8.0mg/L TIN during dry season-only, and <3.0mg/L TIN year-round. These two scenarios bookend the potential sewer rates increases, representing both the least expensive (<8.0mg/L TIN) and most (<3.0mg/L TIN) expensive approaches to nutrient reduction.

Under the 8.0mg/L TIN scenario, 8 utilities (10%) have %MHI values greater than two percent and less than 3 percent of MHI. This %MHI range is defined by Ecology as "moderate hardship." EPA considers %MHI above 2.0 percent as high impact. The %MHI values range from 0.67 percent of MHI to 2.98 percent of MHI.

Under the 3.0mg/L effluent limit scenario, 18 utilities (23%) exceed the 2% affordability benchmark. Three of those utilities have %MHI values in the "elevated hardship" range. The %MHI values range from 0.80 %MHI to 3.35 %MHI.

In summary, the range of %MHI values indicate that current sewer bills cause moderate hardship on households served by 4 (5% of the total) Puget Sound utilities. Absent additional state or federal funding, PSNGP-required upgrades could cause moderate to severe hardship for 18 of the 80 Puget Sound sewer utilities.

Table 2. Summary of Current and PSNGP-Adjusted %MHI Values

Metric	Current	PSNGP-Adjusted (a)	
		< 8.0mg/L TIN dry season	< 3.0mg/L TIN year round
Total number of districts/utilities	80	80	80
Moderate Hardship, (e.g. index > 2.0 % and < 3%)			
Number of utilities	4	8	15
Percent of utilities	5.0%	10%	19%
Elevated Hardship, (e.g. index > 3.0 % and < 5%)			
Number of utilities	0	0	3
Percent of utilities	0.0%	0.0%	4.0%
Severe Hardship, (e.g. index > 5.0 %)			
Number of utilities	0	0	0
Percent of utilities	0.0%	0.0%	0.0%
Minimum %MHI value	0.46%	0.67%	0.80%
Maximum %MHI value	2.63%	2.98%	3.35%
Average %MHI value	1.16%	1.41%	1.69%
Std Deviation	0.44%	0.49%	0.54%

(a) **Nutrient-adjusted rates estimated using data from Technical and Economic Evaluation of Nitrogen and Phosphorus Removal at Municipal Wastewater Treatment Facilities. Publication 11-10-060, WA Dept of Ecology and Tetra Tech, 2011.**

(b) **See the Data Limitations section of the analysis for a discussion on the limitations of the population data**

Source: Barber, A., K. Bogue, S. Burke, N. Jo, and A. Kinney. 2022. Puget Sound Wastewater Service Affordability Analysis Data Collection [Data files]. 1st Version. Prepared by College of Business and Economics, Western Washington University; ECO Resources Group; and Puget Sound Institute, University of Washington Tacoma. Distributed by ResearchWorks, University of Washington Libraries.

Figure 6. presents a scatter plot of current and estimated nutrient-adjusted %MHI values and delineates the 2.0 percent benchmark for EPA's high impact and Ecology's hardship metric. The %MHI values are plotted against household income for all 80 utilities in the study, showing a correlation between higher income households and lower %MHI values (i.e., there are more utilities with higher %MHI at the low end of the MHI axis). However, the correlation is not as strong as might have been expected. For example, there are utility districts below $60,000 MHI and that still have %MHI values below 2.0% and there are utility districts above $60,000 MHI that have %MHI values above 2.0 percent. This suggests that using an MHI metric to prioritize grant funds may provide money to districts that need it less than another district with a higher %MHI value. This finding is addressed in more depth in Section 5, Implications for MWQ IS.

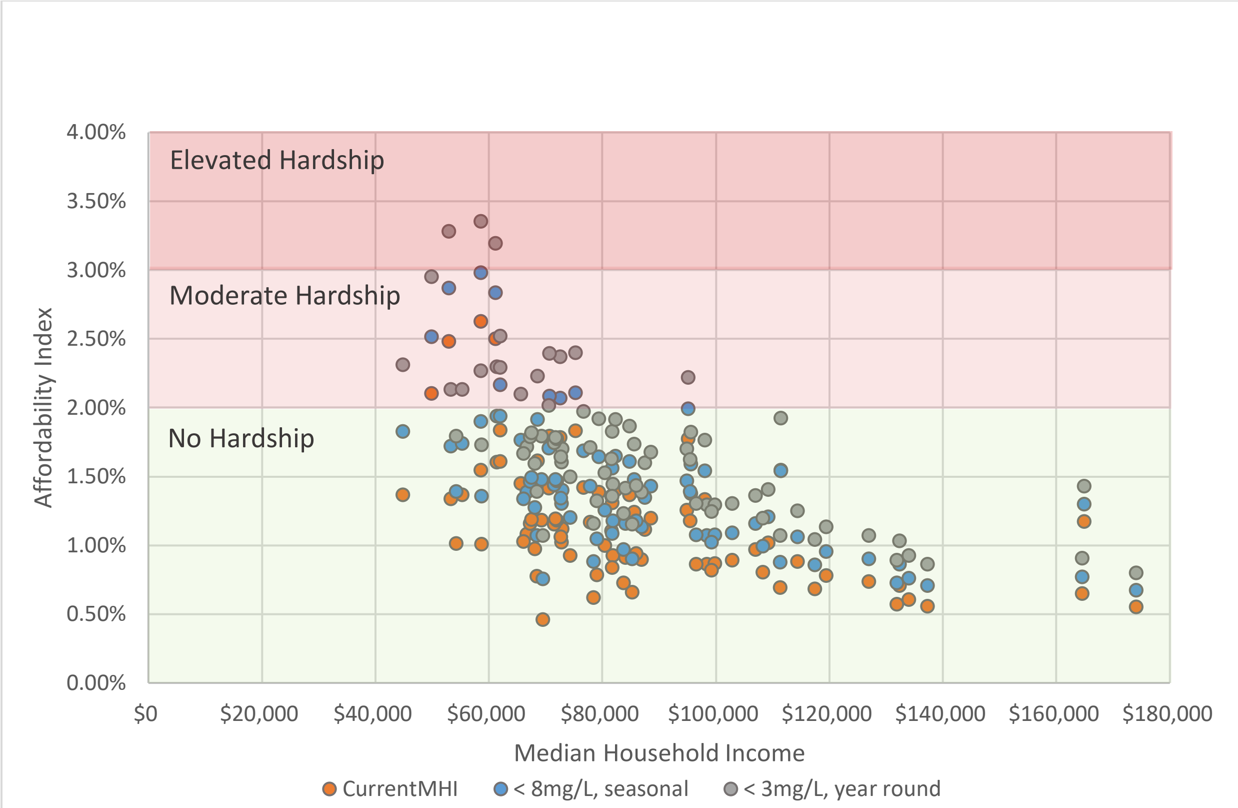


Figure 6. Estimated current and nutrient-adjusted utility-district specific %MHI

CURRENT AND PSNGP-ADJUSTED COSTS AS A PERCENT OF LQI

77 of the 80 Puget Sound sewer utilities had values exceeding 2%LQI (Table 3). 19 utilities' %LQI values were between 2% and 3%; 35 utilities' %LQI values were between 3% and 5%; and 23 utilities' %LQI values were above 5%. Current %LQI values range from 1.97% LQI to a high of 10.5% LQI, with an average of 4.4%LQI and a standard deviation of 1.97.

These estimated %LQI values suggest that approximately twenty percent of Puget Sound households served by a sewer utility are paying on average approximately 4.4% of their income on sewer bills. The lowest quintile of households in this study may spend almost half of a households' estimated food budget (per ERS 2021) on sewer bills.

Table 3. Summary of Current and PSNGP-Adjusted %LQI Values

Metric	Current	PSNGP-Adjusted (a)	
		< 8.0mg/L TIN dry season	< 3.0mg/L TIN year round
Total number of districts/utilities	80	80	80
Index > 2.0 % and < 3%			
Number of utilities	19	8	3
Percent of utilities	24.0%	10%	4%
Index > 3.0 % and < 5%			
Number of utilities	35	37	23
Percent of utilities	44.0%	46.0%	29.0%
Index > 5.0 %			
Number of utilities	23	35	54
Percent of utilities	29.0%	44.0%	68.0%
Minimum %LQI value	1.61%	2.80%	3.44%
Maximum %LQI value	10.50%	11.78%	13.14%
Average %LQI value	4.38%	5.47%	6.52%
Std Deviation	1.86%	2.05%	2.27%

(a) **Nutrient-adjusted rates estimated using data from Technical and Economic Evaluation of Nitrogen and Phosphorus Removal at Municipal Wastewater Treatment Facilities. Publication 11-10-060, WA Dept of Ecology and Tetra Tech, 2011.**

(b) **See the Data Limitations section of the analysis for a discussion on the limitations of the population data**

Source: Barber, A., K. Bogue, S. Burke, N. Jo, and A. Kinney. 2022. Puget Sound Wastewater Service Affordability Analysis Data Collection [Data files]. 1st Version. Prepared by College of Business and Economics, Western Washington University; ECO Resources Group; and Puget Sound Institute, University of Washington Tacoma. Distributed by ResearchWorks, University of Washington Libraries.

All PSNGP-adjusted costs had %LQI values above 2.0%. Under the 8.0 mg/L scenario, 8 utilities' %LQI values are between 2 percent and 3 percent of LQI; 37 utilities' %LQI values are between 3 percent and 5 percent; and 35 utilities' %LQI values are above 5 percent of LQI. Under the 3.0mg/L scenario, 3 utilities' %LQI values are between 2 percent and 3 percent of LQI; 37 utilities' %LQI values are between 3 percent and 5 percent; and 54 utilities' %LQI values are above 5 percent of LQI.

For the 8.0mg/L scenario, %LQI values range between 2.8 percent of LQI and 11.8 percent of LQI with an average of 5.47 percent of LQI. Under the 3.0mg/L scenario, %LQI values range from 3.4 percent of LQI to 13.1 percent of LQI, with an average %LQI of 6.5 percent of LQI.

Figure 7 presents a scatter plot of current and PSNGP-adjusted %LQI values. The %LQI values are plotted against household income for all 80 utilities in the study, showing a correlation between higher income households and lower %LQIs, e.g. there are more utilities with higher %LQIs at the low end of the LQI axis.

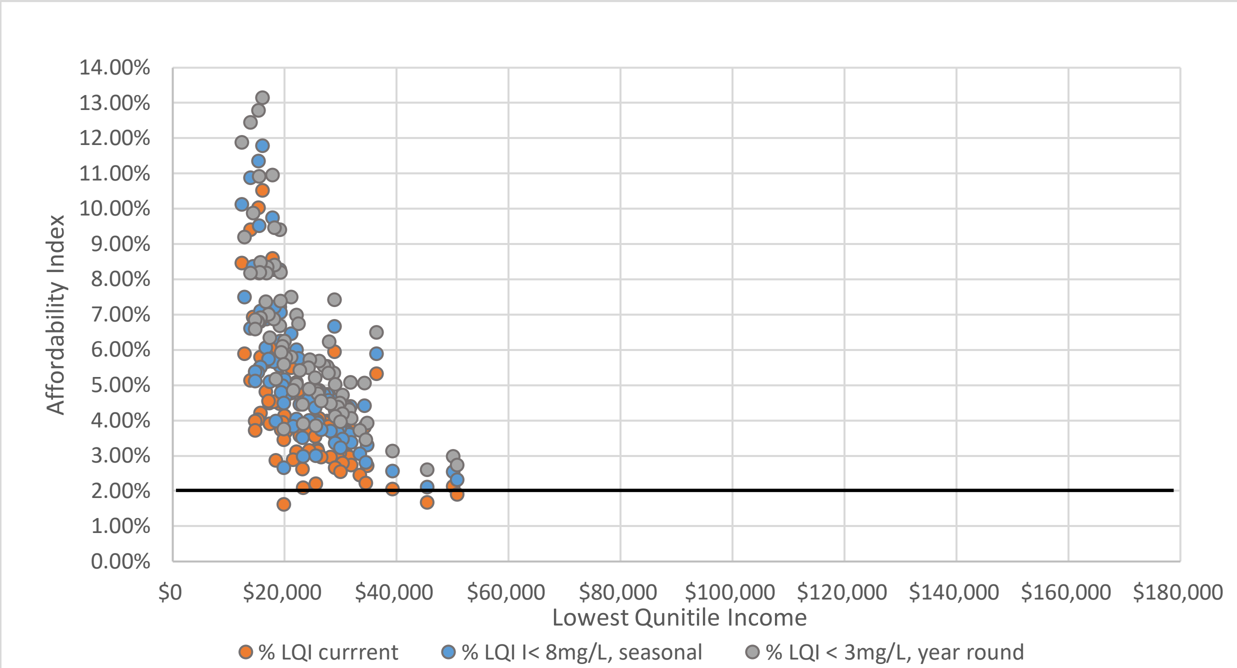


Figure 7. PSNGP-adjusted service cost as %LQI

3. FUNDING STRATEGY DISCUSSION

The findings of the impact analysis may help inform policy in in two areas:

- **Funding of public benefits**: Some industry experts and resource managers argue that sewer services provide a public benefit. We discuss this concept and the potential concern over a subset of the region's population incurring a large portion of the expenditures needed to achieve those public benefits.

- **Environmental justice/equity consequences**: Utility bills are regressive in nature and cause lower income households to pay a disproportionate share of their incomes on sewer bills. We discuss this issue using the findings of the impact analysis.

Both potential concerns are well described by the US Water Alliance in a recent publication (Hara and Take 2022) which states (emphasis added):

> For every community in our country, the availability of **wastewater services is a precondition for public health and prosperity. It is in our collective national interest** that everyone has access to clean water and sanitation. Yet, the reality is that maintaining and operating water systems is incredibly costly, **and both people who cannot pay water bills and utilities who cannot cover costs** can face severe consequences…

Lastly, we close with a discussion of implications this study has for the MWQ IS funding strategy and potentially for the Land Development and Cover IS.

3.1 Funding the Public Benefit of Sewer Services

Sewer Services as a Public Good

Some categories of public goods, like public education systems are funded in ways that aim to accrue and distribute the benefits of those goods to all people. For example, higher education, for which the student pays a portion of the cost, is subsidized through student loans, acknowledging the benefit to society of a well-educated population. To the extent that some of the benefits of wastewater services accrue to the public, an argument can be made for public funding for a portion of the costs of providing those services.

When public benefits do not receive appropriate levels of public funding the consequences can be under production of the public good, in this case clean water. And public funding for water infrastructure has been complicated by the fact that the federal government's funding has not kept pace with the need. The US Water Alliance estimates that, at the national level, in 2019 the gap between spending from all sources and investment needs as $81 billion (US Water Alliance, undated). This gap in federal funding places added pressure on local and state governments to bridge the gap and increases the urgency to distribute available funds to utilities with the greatest need and equity concerns (see Box 1). And the standard locally reliant utility revenue model is a precarious way to fund essential public goods that benefits more than just rate payers (Beecher, 2020).

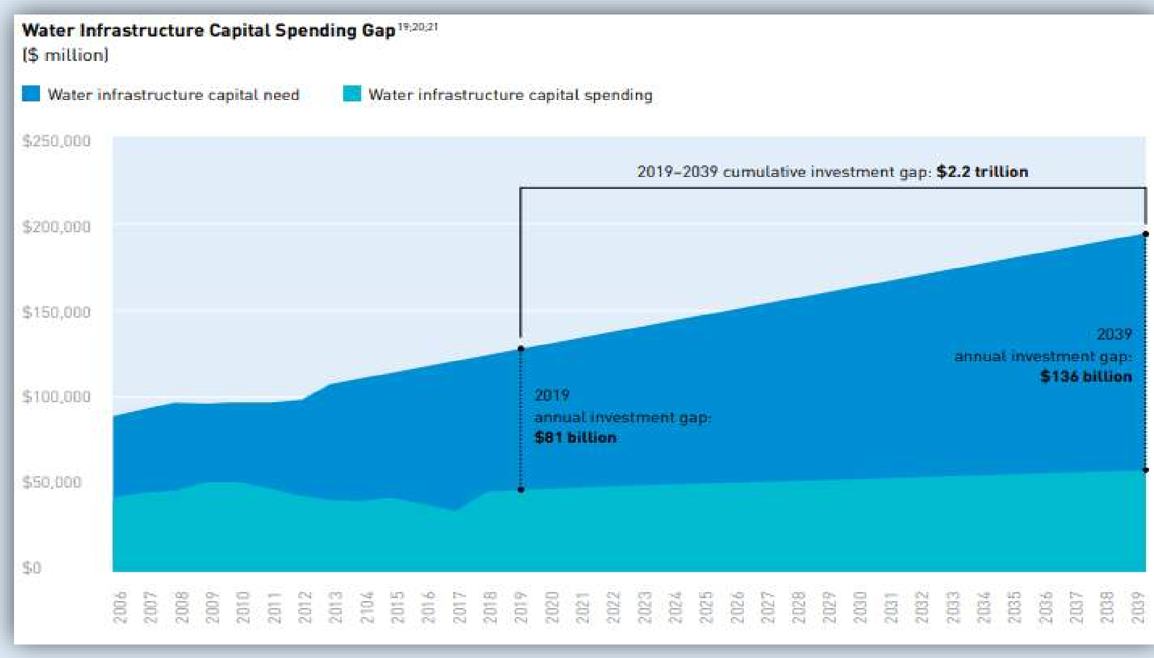
Another consequence of a gap of public funding is the negative equity outcomes that occur if a subset of the region's households bears the greatest responsibility for paying for nutrient-related infrastructure investments. Questions have been raised about the equitable cost distribution associated with a subset of the region's population incurring a large portion of the expenditures needed to achieve public benefits (Northern Economics, 2019). Those expenditures come from households when they pay their sewer bills. Households with on-site sewage systems (septic) do not pay monthly sewage bills.

Box 1

The Economic Benefits of Investing in Water infrastructure

US Water Alliance National Water Infrastructure Spending Gap

"Meeting the drinking water and wastewater capital needs for communities across the United States will require coordinated investment at the federal, state, and local levels. Despite the growing need for water infrastructure, the federal government's share of capital investment has fallen from 31 percent in 1977 to a mere four percent in 2017. ... As federal support for water infrastructure capital needs has declined, local and state spending has provided a much greater share. Across the country, water rates are climbing to meet the costs of upgrading, expanding, and replacing water infrastructure. As costs, however, continue to rise, many communities will struggle to cover them through local rates and fees." (Page 14)



Source: US Water Alliance, The Economic Benefits of Investing in Water infrastructure, undated.

Ability to Pay

A second potential unintended equity outcome of over-reliance on sewer ratepayers to fund wastewater treatment involves the potential for lower income households to either pay a disproportionate share of their income on sewer bills or be unable to pay those bills. Utility bills are regressive—they take a relatively larger share of low-income households' budgets compared to middle- and high-income households' budgets—and are therefore a form of structural inequity (Beecher 2020).

Our findings suggest that currently only three Puget Sound utilities' sewer rates result in sewer bills less than 2.0 percent of LQI. PSNGP-adjusted rates resulted in %LQI values ranging between 2.64 percent of LQI and 12.76 percent of LQI. These relatively high values indicate that sewer bills exacerbate the already regressive nature of Washington State's tax structure.

Box 2. Sewer Utilities' Income-Based Assistance Programs

Discounted utilities rates for low-income senior citizens or disabled residents are offered by many Puget Sound utilities districts. However, utility-based programs that offer low-income households - other than seniors or disabled citizens - have not been widely adopted. Furthermore, previous studies indicates that enrollment levels tend to be low compared to eligible populations (Kinney, 2022). Multiple challenges administering these programs, such as imprecise eligibility rules; extensive time and effort required for customers to apply; and a lack of trust to share income information are common (Pierce et al. 2021, Teodoro 2021).

Additional research on the effectiveness of customer assistance programs, as well as legal constraints related to such programs in Washington may be warranted (see footnote 6). For a thorough exposition of Washington State's grant, loan and assistance programs see the Marine Water Quality Base Program Analysis (Kinney and Wright, 2022). For examples of how utilities in other states are approaching these equity-based challenges see the US Water Alliance's recent study, A Promising Water Pricing Model for Equity and Financial Resilience (Hara and Take, 2023).

Although customer assistance programs for low-income households exist in Washington,[8] utility managers note that these programs are undersubscribed in their districts (see Box 2). This result is borne out in research on low-income assistance programs nationwide (Pierce, et.al, 2021 and Teodoro, 2021). Multiple challenges to administering these programs include: imprecise eligibility rules, extensive time and effort required for customers to apply, and a lack of trust to share income information.

This concern—overburdening disadvantaged or low-income households—is addressed in the Washington State Environmental Justice (EJ) Task Force Recommendations for Prioritizing EJ in Washington State Government. The recommendations of the task force resulted in the adoption of Chapter 70A.02 RCW which states, "an equitable distribution means a fair and just, but not necessarily equal, allocation intended to mitigate disparities in benefits and burdens". Washington State's concern over these equity issues is well justified, as the State ranks highest

[8] RCW 35.92.020 and RCW 35.67.020 confer authority to construct systems and *fix rates and charges* to Counties and Cities, respectively stating "the rates charged shall be uniform for the same class of customers or service" where the "factors" used to classify customers do not include low-income households. However, both RCWs do allow *assistance to aid* low-income persons in connection with services. RCW 57.08.014 provides authority to adjust or delay rates for low-income persons provided that "information on cost shifts caused by establishment of the special rates or charges shall be included in the notification of same." RCW 74.38.070 further discusses reducing rates for low-income senior citizens and other low-income citizens provided that the definitions of same are defined by appropriate ordinance or resolution adopted by the governing body of the county, city, town, public utility district or other municipal corporation. For example, Edmonds has adopted rate reductions for low-income citizens utilizing the definition of low-income established in RCW 84.36.381(5)(b)(i), Property tax exemptions, which includes a statement that to qualify individuals must be 61 years or older or disabled.

in the Tax Inequality Index (ITEP, 2018), which measures the regressive nature of states' tax structures.

Demonstrating similar concern about overburdening low-income households, EPA (2022b) instructed states to review, refine and improve as necessary their CWSRF affordability criteria to ensure that criteria are reflective of current affordability issues in the state. This instruction is an opportunity to incorporate newer thinking regarding use of LQI versus MHI in prioritizing funding decisions. These affordability metrics influence a utilities' access to grants and loans.

In addition to federal and State concerns of overburdening low-income households the industry also writes about these concerns. The US Water Alliance recently commented on the impact that the user-fee based funding structure has more broadly on communities and the environment, noting:

> *"This type of funding model exposes both individuals and communities to health and economic risks. Households that cannot pay their water bills face consequences like service shutoffs, property tax liens, and additional penalties and fees. This can push struggling customers into deeper debt, making it even harder to get current on bills. Meanwhile, utilities that cannot collect adequate revenue from rates run the risk of financial instability, putting vital operations and system maintenance at risk. Utilities that struggle financially may not be able to secure loans with favorable terms, which raises costs, leads to deferred maintenance, and drives the need for further rate increases to maintain quality levels of service. Utilities' financial dependence on customers makes them highly vulnerable to economic crises and growing income inequality." (Hara, 2022 for the US Water Alliance)*

3.2 Implications for the Land Development and Cover Implementation Strategy

The work is also relevant to the Land Cover and Development Implementation Strategy and 2022-2026 Action Agenda Strategy #1 (Advance smart development and protect intact habitats and processes by channeling population growth into attractive, transit-oriented centers with easy access to natural spaces). The high cost of living in urban centers, relative to rural communities, has been identified as a barrier to the regional goal of directing population growth into urban centers. Residents of these urban areas fund clean water services through Stormwater Utility Fees and sewer bills, while rural residents on septic systems in areas without NPDES Municipal Stormwater Permit coverage do not. This is likely one component of the "rural cost subsidy" described in the Land Cover and Development Implementation Strategy.

4. RECOMMENDATIONS

Our recommendations combine the findings of the impact analysis with the funding strategy discussion to help identify steps to take toward an efficient funding pathway for the MWQ IS. Public (i.e., non-utility) funding is required if resource managers agree that sewer services provide a public good. Additional public funding would also be required if resource managers set a target to keep utilities' %MHI values within Ecology's "no hardship" range (below 2 percent of MHI). The %MHI values of between 8 and 18 individual utilities were in either the moderate hardship range or the elevated hardship range when using the PSNGP-adjusted sewer rates. And over half the %LQI values exceeded 5%, indicating a significant impact on low-income households.

Demand for public funding, whether state or federal, frequently exceeds the supply of funding. Public funding is a finite resource. As such, developing a plan to utilize the available funding as efficiently as possible is an admirable goal. In the following four subsections, we provide recommendations that might improve both efficiency and equity outcomes for the available grant and loans monies. They are:

- Use the data collected for this study, plus newer estimates of PSNGP-related capital costs currently being developed as a PSNGP requirement, to calculate a Capital Investment Gap metric. The gap would be the amount of state/federal funding needed to maintain %MHI indices values below a specified percentage and/or the funding needed for low-income assistance programs to ensure households don't pay more for sewer service than a specified percentage of their income (Section 4.1).
- Investigate the possibility of using the %MHI or %LQI metric in addition to other metrics used to determine financial hardship in Ecology's Grants and Loans Programs (Section 4.2).
- Consider development of a regional or state-wide low-income assistance program for sewer utilities (Section 4.3).
- Consider funding a study to assess the potential equity benefits of restructuring wastewater rates using the Resilient Rate Structure model developed by the US Water Alliance (Section 4.4).

4.1 Estimate the Capital Investment Gap to maintain index values below target levels

Ecology and Tetra Tech's (2011) initial estimates of the total capital investment required to upgrade all Puget Sound WWTP for nitrogen and phosphorus removal was estimated to be between \$1.4 billion and \$5.9 billion depending on the level of nitrogen removal required.[9] Current estimates being completed by individual utilities are higher, but the exact amount of capital investment required to meet regulatory requirements cannot be known until nutrient effluent limits are determined by Ecology. While the final capital cost estimates are being completed by each utility, we recommend developing a methodological approach for distributing federal or state grant funds (assuming such grant funding is available) to maximize the equity outcomes and efficiency of those investments.

[9] See Tables ES-3 and Table ES-4 of the 2011 Technical and Economic Evaluation of Nitrogen and Phosphorus Removal at Municipal Wastewater Treatment Facilities, WA Dept of Ecology and Tetra Tech, adjusted for 2022 dollars.

We propose developing a Capital Investment Gap metric as shown in green on the bar chart in Figure 8. Assume for this hypothetical example that the State and/or Puget Sound regional recovery partners set a target of a 2%MHI for all Puget Sound utilities and endeavors to provide grant funds to utilities that would exceed that target due to PSNGP-required upgrades. The first bar shows a current (before nutrient removal upgrades are implemented) index value. The second bar shows how the index value would change assuming that the utility receives no state or federal grant funding and increases rates to pay for all PSNGP-required upgrade costs. The third bar shows a local share up to 2 percent, with the green stripped area above 2 percent indicating the hypothetical state or federal contribution needed to keep the %MHI index below the 2 percent threshold.

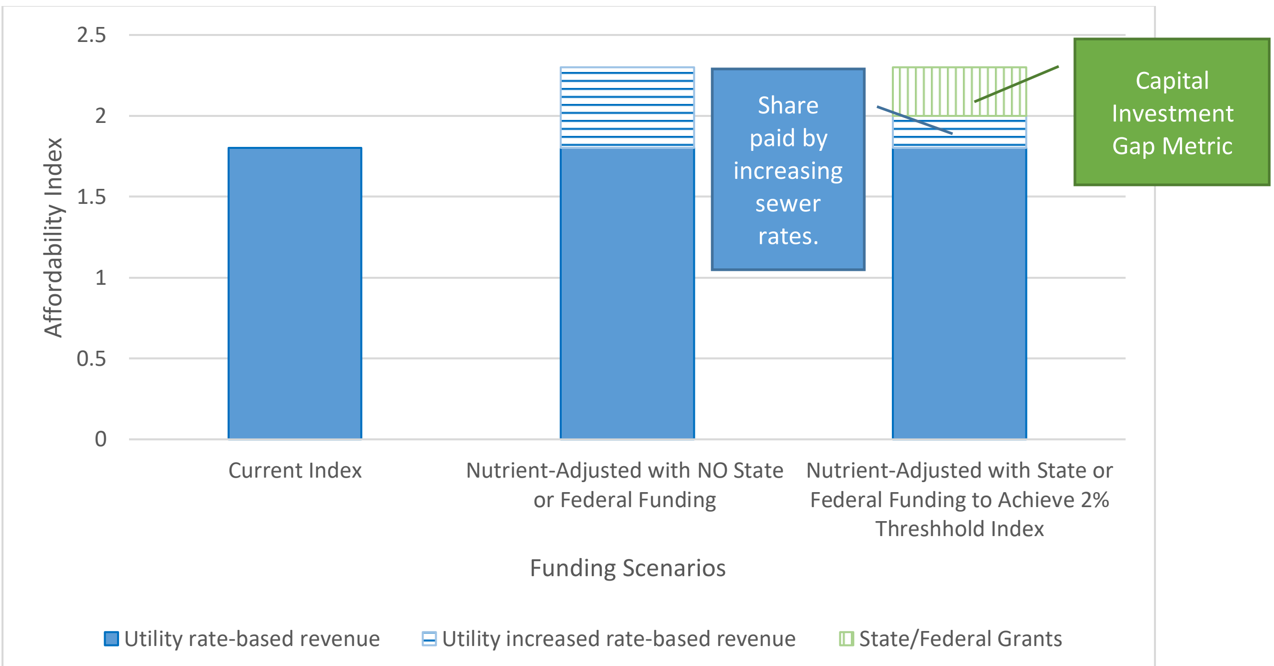


Figure 8. Proposed method to derive a Capital Investment Gap metric for quantifying state and federal funding requests to support PSNGP-required upgrades

This method would help estimate the amount of state/federal funding that could keep sewer bills below a target threshold. In this example the threshold was 2% but results could be calculated for other thresholds, such as other state hardship benchmarks like 3% and 5%. Note that this method assumes that utilities raise rates to pay for the difference between the index value under current rates and the rates up to the selected threshold. The funding need above that threshold would provide a target for state and federal funding requests.

Using utility-specific index thresholds to prioritize grant funding would help increase the economic efficiency of grant distribution. Additionally using utility specific index thresholds would help estimate how much grant money might be needed to fill the gap between what utilities can pay at a 2 percent index threshold and how much grant money might be needed to keep indices below that threshold level. In other words, utilities that have index values below 2 percent, even after the nutrient upgrades would receive a lower priority for grant funds. Instead, scarce grant funds would be prioritized to those utilities to close a gap and maintain a 2 percent index threshold.

Applying this same method using %LQI instead of %MHI could be used to estimate the annual budget needed to implement a regional low-income assistance program. Ideally, a customer assistance program would be sufficiently funded to ensure households don't pay more for sewer service than a specified percentage of their income.

Using this method to estimate the gap in capital spending, the annual budget for a low-income assistance program, or a combination of the two would help the advance the MWQ IS funding pathway strategy and increase understanding of the magnitude of the funding challenge associated with adding advanced nutrient reduction technologies to WWTPs in the region.

4.2 Utilize %MHI or %LQI in place of MHI when allocating grant/loan funding

Ecology manages grants and loans under both the Water Quality Combined Funding Programs[10] as well as the Puget Sound nutrient reduction grants program. Each of the funding programs described in Table 4 uses either %MHI or MHI as part of the prioritization process. The Ecology Water Combined Funding program, which oversees the Centennial Clean Water Program (CCWP) and the Clean Water State Revolving Fund (CWSRF), utilizes %MHI for its hardship determination. The 2022 Puget Sound Nutrient Reduction Grant Program (PSNRGP) included consideration for the average MHI of permitees.

If one of goals of a grants and loan program includes reducing hardship on those households most affected, incorporating %LQI in the hardship determination could potentially increase the efficiency and equity of the programs. However, if MHI (used for the PSNGP grant program) and %MHI (used for the CWSRF and the CCWP) values are close proxies for %LQI values then a program change would not be warranted.

[10] See Ecology's Grants and Loans web page.

Table 4. Washington State Grant and Loan Programs Available for Wastewater Infrastructure Improvements in Puget Sound

Program Name	Phase	Eligible Utilities	Current Hardship/Prioritization Metrics
Clean Water State Revolving Fund (a)	Pre-construction	All	• The existing residential population of the service area for the proposed project is 25,000 or less at the time of application. • The MHI for the proposed service area is less than 80 percent of the state MHI.
	Construction	All	• The existing residential population of the service area for the proposed project is 25,000 or less at the time of application. • Financing the project without subsidy would cause existing residential sewer fees to be two percent or more of the MHI for the service area. Hardship categories: Moderate 2% < RI < 3%; elevated 3% < RI < 5%; severe RI >5%
Centennial Clean Water Program (a)	Pre-construction & construction	All	• Managed in accordance to Chapter 70A.135RCW and Chapter 173-95A WAC where: • 70A.135 RCW give preference to Puget Sound partners (defined in 90.71.010 RCW as an entity that has been recognized by the partnership as having consistently achieved outstanding progress in implementing the 2020 action agenda • 173-95A WAC define hardship (in WAC 173-98-300) as MHI > 2%, categories as listed above under CWSRF.
Puget Sound Nutrient Reduction Grant Program (b)	Planning	43 utilities that own and operate the 58 WWTPs discharging to Puget Sound	From page 1, from legislative language for the $9M of the 2021-23 biennium: • Location of wastewater treatment facility, prioritizing facilities that are not located within a city with a population of 760,000 or more, • Age of wastewater treatment facility, prioritizing the oldest eligible facilities; and • Immediacy of need for grant funding to avoid system failure and higher magnitude of contamination. From page 3, under prioritization factors all of the above and: • Economic Status: Facilities serving populations with lower Median Household Incomes receiving higher priority.

Sources: (a) Washington State Department of Ecology, 2022. State Fiscal Year 2024 Funding Guidelines Water Quality Combined Funding Program, Pub 22-10-016 (b) Washington State Department of Ecology, 2021. 2021-2023 Puget Sound Nutrient Reduction Program Funding Guidelines, Pub 21-10-042

Figure 9 shows the correlation between MHI and %MHI values and %LQI values. The correlation between either index and MHI is moderate at best. Meaning, MHI may not be a good proxy for hardship. This demonstrates that the MHI does not identify the utilities with the highest %MHI values or %LQI values. The reason that MHI is not strongly correlated with hardship is due to the wide variability of sewer rates (Figure 1). The information suggests that, at a minimum incorporating the %MHI index into the hardship determination for the PSNRGP would increase equity outcomes significantly.

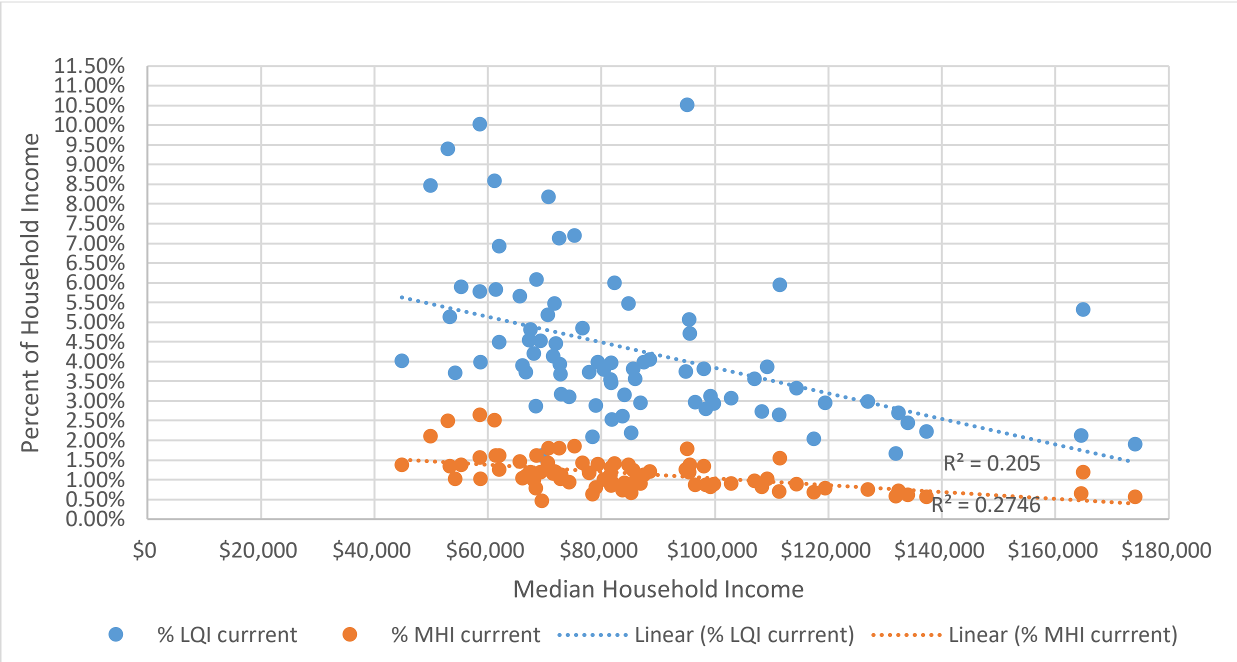


Figure 9. Correlation of %MHI and %LQI values to MHI

Figure 10 shows the correlation between %LQI values and %MHI values. Here the correlation is strong. Meaning, %MHI value may be a good proxy for hardship. There would be room for an equity improvement if %LQI was used in place of %MHI in determining hardship, but the improvement may be relatively small. The reason that %MHI values are correlated with hardship is because %MHI incorporates variability in sewer rates. The information suggests that, incorporating the %LQI value into the hardship determination for the CWSRF and CCWP may increase equity outcomes slightly.

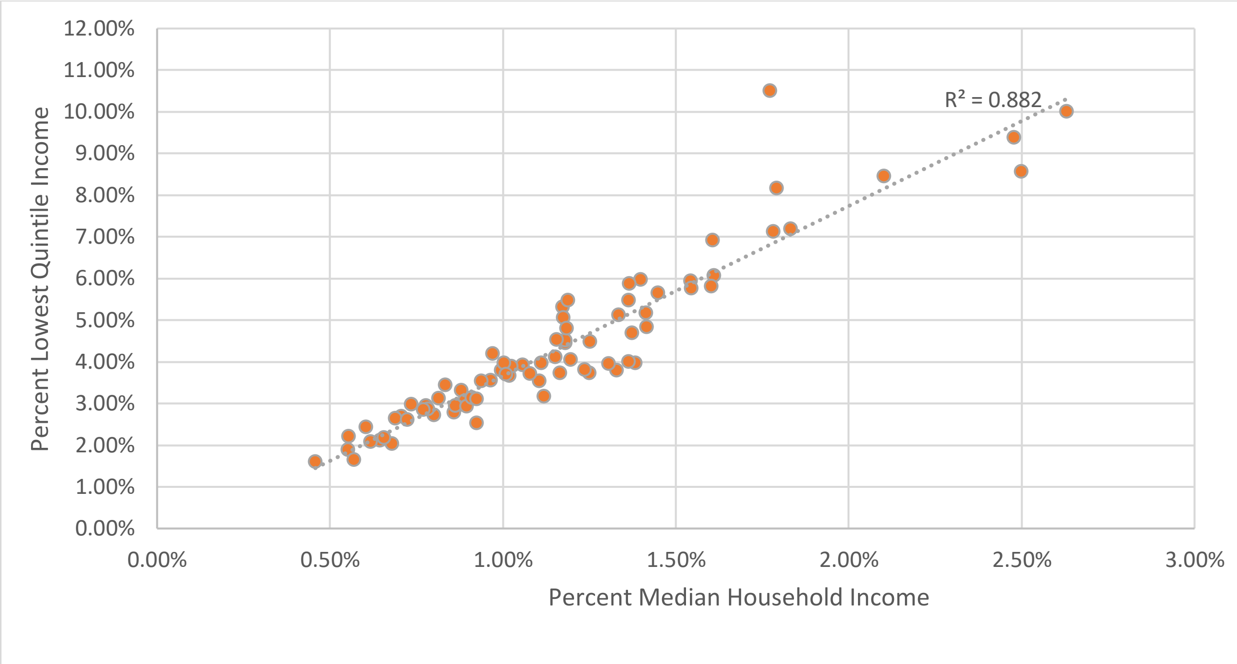


Figure 10. Correlation of %LQI to %MHI

4.3 Consider developing a regional or statewide low-income assistance program

The results of this study show that our conservatively low PSNGP-adjusted sewer service cost estimates would exceed 2% LQI for 76 of the utilities included in the study and pose a financial risk to both people who cannot pay water bills and utilities who cannot cover costs if bills are not paid. One possible improvement to equity outcomes of state grant programs would be development of a statewide or region wide low-income assistance program. Developing this program at a state or region level would lower the financial risk and administrative burden that utilities face in developing a low-income assistance program. In addition, a state-wide or region-wide program may reduce some impacts of Washington State's regressive tax system.

Several of Washington's codes provide authority for utilities to develop low-income assistance programs/rates (see footnote 6). However low-income assistance programs have not been widely adopted by utilities, except for programs for seniors and disabled individuals (see Box 2). The US Water Alliance observes this phenomenon among utilities nationwide. Utilities facing administrative burdens and legal ambiguities have errored on the side of caution with regard to low-income rates. The Municipal Research and Services Center (MRSC) describes how utilities could define eligibility on a utility-by-utility basis, emphasis added:[11]

> *Eligibility requirements for low-income and senior* ***low-income assistance are not defined by statute,*** *so agencies are free to define these as they see fit. Some only*

[11] MRSC's website at: https://mrsc.org/explore-topics/public-works/general-utility-topics/senior-and-low-income-utility-rate-discounts.

provide these assistance programs to low-income seniors, while others include persons with disabilities as well, generally defining people with disabilities to be those people who qualify for special parking privileges under chapter 46.19 RCW (formerly RCW 46.16.381) and people who are blind as defined in RCW 74.18.020.

However, ***there are a range of definitions****. Some jurisdictions may include individuals with developmental disabilities and mental illnesses, while others require proof of disability from the Social Security Administration. Some may even exempt all low-income individuals.*

In some cases, the utility requires that qualified persons be the head of household, while in other cases there may be a restriction on the income level of any co-tenant. To ensure that ***eligibility determinations are made fairly and uniformly****, the utility's legislative body should establish, by ordinance or resolution, policies or programs for utility staff to follow.*

This description provides an example of some of the administrative challenges that an individual utility may face in developing a low-income rate. Seeing similar challenges nationwide the US Water Alliance recommends:

- Establish affordability criteria to better target state funding.
- Remove legal barriers to affordability solutions.
- Create a statewide program for water bill assistance for low-income residents, citing California's programs.

A program to aid low-income sewer rate payers could be modeled after existing programs like Washington Low Income Home Energy Assistance Program (LIHEAP) (See Box 3). Additionally, a program may be able to be created with a modification to the existing Low Income Household Water Assistance Program (LIHWAP). The LIHWAP provides assistance to low-income households with water and wastewater bills that are disconnected or are in imminent threat of disconnection. A modification to the program that includes payment of monthly sewer bills may want to be considered in order to offset unintended equity outcomes that may arise from the needed investment in nutrient reduction infrastructure.

Box 3. Low Income Assistance Programs

Washington Low Income Home Energy Assistance Program (LIHEAP) (see https://www.benefits.gov/benefit/1586) Washington Low Income Home Energy Assistance Program (LIHEAP) services are provided to the public through a network of 26 local community-based nonprofit organizations and local municipalities. Services include energy assistance, client conservation education, furnace repair and replacement, and weatherization. Energy assistance benefits are paid directly to energy providers and are based on a portion of a household's annual home heating costs.

Low Income Household Water Assistance Program (LIHWAP) (see https://www.commerce.wa.gov/growing-the-economy/energy/low-income-home-energy-assistance/lihwap/) LIHWAP provides emergency assistance to low-income households who are disconnected or are in imminent threat of disconnection. LIHWAP provides water assistance to households in Washington through the same network of community action agencies and local partners that provide the Low-Income Home Energy Assistance Program (LIHEAP). These local organizations will help you determine if you're eligible and how much assistance you might receive. If you qualify, your local agency will send a payment directly to your water utility on behalf of your household. Households eligible for water assistance are also qualified for the Low-Income Home Energy Assistance Program.

4.4 Consider the feasibility of the Resilient Rate Structure

The US Water Alliance's recent publication, *Pricing Water for Public Health and Financial Resilience: An Applied Modeling Pilot, Project Description* (US Water Alliance, 2021) proposes an alternative type of rate structure to address shortcomings of a usage-only based rate structures, enhance revenue stability, and integrate equity considerations. Models of this Resilient Rate Structure are already being developed in Minnesota and Cincinnati for water bills. From the paper:

> *The water sector and community advocates need to reimagine the utility revenue model and available pricing structures to reflect water's fundamental role in a thriving society and the true costs and value of providing safe, reliable water and wastewater service. Of course, federal funding is crucial and should contribute a larger share of utility revenue than it presently does. However, utilities can use the tools at hand to begin* ***billing for water in a more sensible, equitable way while advocating for change at the federal level****. The time is right to develop innovative new ways to price and fund water that supports system sustainability, equity, and public health.*

The outcome of the feasibility study would suggest whether innovative pricing models could make sewer bills more affordable and equitable while preserving utility revenue. The resilient rate structure model would seek to allow certain amounts of costs and an associated level of sewer service for all residents to be paid for by property taxes or some other similar property-based cost recovery mechanism.

5. NEXT STEPS

When developing a funding strategy for WWTP upgrades, we encourage policy makers to consider tradeoffs between water quality and other regional recovery goals. Choices made about how the region is to pay for WWTP upgrades may have implications for growth management as well as equity outcomes receiving greater attention due to the White House's Justice40 Initiative and Washington's Healthy Environment for All (HEAL) Act. We hope this analysis can support development of funding strategies that improve water quality while minimizing unintended consequences of Puget Sound's socioecological system.

Possible next steps for this research beyond the recommendations described in the preceding section could include:

- **Addressing know data gaps and challenges**. For example: improve the accuracy of the correspondence table that links the income data (at the census tract level) with the utility district boundaries. Improving the correspondence table would not only increase the certainty of the individual utilities' households' MHI and LQI but also increase our confidence about stating the number of households effected within each income quintile. Another known data challenge is the method with which we averaged LQI. We utilized a population weighting, which does not accurately estimate the median value of the lowest quintile income. For a complete list of know data challenges see Barber et.al (2022).
- **Explore the usefulness of making the household income data easily available to Puget Sound utilities and Ecology**. While this study was done at a relatively coarse scale, the data is useful in identifying potential hardships faced by utility providers. However, this data can become quickly outdated as data on incomes is updated at least annually. Should utilities and Ecology find this data useful it could be updated annually for very little cost. If the database proved useful, updating it could become an annual exercise for student interns under the supervision of a senior researcher. For example, the income data that was gathered for this study was collected using student interns located at the Center for Business and Economic Research at Western Washington University. The cost of data collection was low and the students received invaluable work experience, that ultimately lead to permanent employment in the consulting and public sectors.
- **Explore implications of the extremely wide variation in what Puget Sound residents pay to treat a gallon of sewage**. More research is needed to characterize the distribution of clean water costs and benefits across the region's population. This effort could include analyzing the proportionality of costs among utility ratepayers in neighboring jurisdictions as well as compared to on-site sewage system users who incur sewage treatment costs on a different timeframe (i.e., system maintenance or replacement costs are usually not paid monthly).

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APPENDIX: DATA TABLES

Table A-1 lists all 89 local wastewater service providers directly and indirectly affected by the PSNGP. Those on the left are directly impacted by the PSNGP because they operate WWTPs covered by the permit. Those on the right include additional utilities indirectly impacted by the permit because they retail wastewater treatment services provided by permittees.

Table A-2 provides individual sewer cost, MHI, LQI, %MHI, and %LQI results for the 80 service providers included in the study.

Table A-3 provides summary statistics for the 80 service providers included in the study.

All data is from Barber et al. (2022).

Table A-1. Local Wastewater Service Providers Direct and Indirectly Affected by the PSNGP

WWTP Operator / PSNGP Permittee	Utility District Billing Individual Property Owners	Included in study?
Alderwood Water District	Alderwood Water District	Yes
	Silver Lake Water & Sewer District	Yes
Anacortes, City Of	Anacortes, City of	Yes
Bainbridge Island City of	Bainbridge Island City of	Yes
Bellingham-Water Division City of	Bellingham-Water Division City of	Yes
	Lake Whatcom Water and Sewer District	Yes
Birch Bay Water & Sewer District	Birch Bay Water & Sewer District	Yes
Blaine City of	Blaine City of	Yes
Bremerton City of	Bremerton City of	Yes
Clallam Bay Sekiu (Clallam County PUD)	Clallam Bay Sekiu (Clallam County PUD)	Yes
Coupeville Town of	Coupeville Town of	Yes
Eastsound Sewer and Water District	Eastsound Sewer and Water District	Yes
Edmonds, City of	Edmonds, City of	Yes
	Mountlake Terrace, City of	Yes
Everett Public Works Dept. City of	Everett Public Works Dept. City of	Yes
Fisherman Bay Water Association	Fisherman Bay Water Association	Yes
Friday Harbor Town of	Friday Harbor Town of	Yes
Gig Harbor Sanitary Sewer	Gig Harbor Sanitary Sewer	Yes
King County	King County Does Not Bill Individual Property Owners	No (1)
	Algona Water Dept	Yes
	Auburn, City of	Yes
	Bellevue City of	Yes
	Black Diamond Water Dept	Yes
	Bothell Water City of	Yes

WWTP Operator / PSNGP Permittee	Utility District Billing Individual Property Owners	Included in study?
	Brier, City of	Yes
	Cedar River Water & Sewer District	Yes
	Coal Creek Utility District	Yes
	Cross Valley Water District	Yes
	Issaquah Water System	Yes
	Kent Water Department	Yes
	Kirkland, City of	Yes
	Lake Forest Park Water District	Yes
	Lakehaven Water and Sewer District	Yes
	Mercer Island City of	Yes
	NE Sammamish Sewer & Water District	Yes
	Northshore Utility District	Yes
	Olympic View Water & Sewer District	Yes
	Pacific, City of	Yes
	Redmond Water System City of	Yes
	Renton City of	Yes
	Sammamish Plateau Water & Sewer	Yes
	Seattle Public Utilities	Yes
	Shoreline Waste Water, City of	Yes
	Skyway Water & Sewer	Yes
	Soos Creek Water & Sewer District	Yes
	Tukwila Water Department	Yes
	Valley View Sewer District	Yes
	Woodinville Water District	Yes
	Highlands Sewer District	No (2)
	Vashon Sewer District	No (2)
Kitsap County	Kitsap County	Yes
	Poulsbo City of	Yes
Kitsap County Sewer District #7	Kitsap County Sewer District #7	Yes
La Conner Water Dept	La Conner Water Dept	Yes
Lake Stevens Sewer District	Lake Stevens Sewer District	Yes
Langley City of	Langley City of	Yes
LOTT	LOTT Does Not Bill Individual Property Owners	No (1)
	Lacey Water Department	Yes
	Olympia City of	Yes
	Tumwater City of	Yes
Lynnwood, City of	Lynnwood, City of	Yes
Marysville Utilities	Marysville Utilities	Yes
Mason County	Mason County	Yes
Midway Sewer District	Midway Sewer District	Yes

WWTP Operator / PSNGP Permittee	Utility District Billing Individual Property Owners	Included in study?
Mount Vernon, City of	Mount Vernon, City of	No (2)
Mukilteo Water & Wastewater District	Mukilteo Water & Wastewater District	Yes
Oak Harbor City of	Oak Harbor City of	Yes
Penn Cove Water and Sewer District	Penn Cove Water and Sewer District	No (2)
Pierce County	Pierce County	Yes
	Steilacoom Town of	Yes
Port Angeles City of	Port Angeles City of	Yes
Port Townsend City of	Port Townsend City of	Yes
Sequim City of	Sequim City of	Yes
Shelton City of	Shelton City of	Yes
Skagit County Sewer District #2	Skagit County Sewer District #2	No (2)
Snohomish, City of	Snohomish, City of	Yes
Stanwood Water Dept City of	Stanwood Water Dept City of	Yes
SW Suburban Sewer District	SW Suburban Sewer District	Yes
Tacoma Water	Tacoma Water	Yes
	Fife Dept of Public Works	Yes
	Fircrest City of	Yes
	Ruston, City of	Yes
Thurston County	Thurston County Boston Harbor	Yes
	Thurston County Tamoshan	Yes
West Sound Utility District	West Sound Utility District	Yes

(1) King County and LOTT do not provide retail services to households, therefore do not have retail rates, and as such %MHI and %LQI cannot be calculated

(2) Barber et al. (2022) were unable to locate a detailed map of the provider's service area or the district's web page did not report sewer rates

Table A-2. Individual Results for 80 Puget Sound Wastewater Service Provider

Permitee Serving	Utility Name	Est Annual Sewer Bill	Est. Utility District Income Metric		%MHI Index			%LQI Index		
			MHI	LQI	Current	< 8mg/L, seasonal	< 3mg/L, year round	Current	< 8mg/L, seasonal	< 3mg/L, year round
Alderwood Water District	Alderwood Water District	$866	$99,925	$29,596	0.87%	1.07%	1.29%	2.93%	3.62%	4.36%
Alderwood Water District	Silver Lake Water & Sewer District	$797	$117,439	$39,324	0.68%	0.85%	1.04%	2.03%	2.55%	3.11%
Anacortes, City of	Anacortes, City of	$742	$72,862	$20,246	1.02%	1.30%	1.60%	3.67%	4.68%	5.76%
Bainbridge Island, City of	Bainbridge Island, City of	$1,007	$114,451	$30,415	0.88%	1.06%	1.25%	3.31%	3.99%	4.71%
Bellingham Water Division	Bellingham Water Division	$589	$58,703	$14,826	1.00%	1.35%	1.73%	3.97%	5.36%	6.84%
Bellingham Water Division	Lake Whatcom Water and Sewer District	$1,069	$81,832	$27,023	1.31%	1.56%	1.82%	3.95%	4.72%	5.53%
Birch Bay Sewage Treatment Plant (STP)	Birch Bay Water & Sewer District	$319	$69,617	$19,839	0.46%	0.75%	1.07%	1.61%	2.64%	3.74%
Blaine, City of	Blaine, City of	$1,381	$75,356	$19,208	1.83%	2.11%	2.40%	7.19%	8.26%	9.40%
Bremerton, City of	Bremerton, City of	$777	$62,011	$17,332	1.25%	1.58%	1.94%	4.48%	5.67%	6.93%
Clallam Bay PUD	Clallam Bay Sekiu (Clallam County PUD)	$612	$44,844	$15,291	1.36%	1.82%	2.31%	4.00%	5.35%	6.78%
Coupeville, Town of	Coupeville, Town of	$661	$68,102	$15,759	0.97%	1.27%	1.59%	4.19%	5.50%	6.89%
Eastsound Sewer and Water District	Eastsound Sewer and Water District	$756	$55,350	$12,858	1.37%	1.74%	2.13%	5.88%	7.48%	9.18%
Edmonds, City of	Edmonds, City of	$606	$83,751	$23,236	0.72%	0.97%	1.23%	2.61%	3.49%	4.44%
Edmonds, City of	Mountlake Terrace, City of	$766	$84,112	$24,426	0.91%	1.16%	1.42%	3.14%	3.98%	4.87%
Everett Public Works Dept., City of	Everett Public Works Dept., City of	$999	$70,649	$19,293	1.41%	1.70%	2.01%	5.18%	6.24%	7.38%
Fisherman Bay Water Assoc	Fisherman Bay Water Assoc	$996	$62,008	$14,400	1.61%	1.94%	2.29%	6.92%	8.34%	9.86%
Friday Harbor, Town of	Friday Harbor, Town of	$1,542	$58,690	$15,405	2.63%	2.98%	3.35%	10.01%	11.34%	12.76%
Gig Harbor Sanitary Sewer	Gig Harbor Sanitary Sewer	$810	$99,284	$26,004	0.82%	1.02%	1.24%	3.11%	3.90%	4.75%
King County	Algona Water Dept	$816	$72,942	$25,804	1.12%	1.40%	1.70%	3.16%	3.96%	4.81%
King County	Auburn, City of	$903	$81,719	$25,517	1.11%	1.36%	1.62%	3.54%	4.34%	5.20%

Permitee Serving	Utility Name	Est Annual Sewer Bill	Est. Utility District Income Metric		%MHI Index			%LQI Index		
			MHI	LQI	Current	< 8mg/L, seasonal	< 3mg/L, year round	Current	< 8mg/L, seasonal	< 3mg/L, year round
King County	Bellevue, City of	$934	$126,996	$31,343	**0.74%**	**0.90%**	**1.07%**	**2.98%**	**3.64%**	**4.33%**
King County	Black Diamond Water Dept	$868	$108,333	$31,932	**0.80%**	**0.99%**	**1.19%**	**2.72%**	**3.36%**	**4.05%**
King County	Bothell Water City of	$1,033	$107,072	$29,071	**0.96%**	**1.16%**	**1.36%**	**3.55%**	**4.26%**	**5.01%**
King County	Brier, City of	$683	$81,817	$19,841	**0.83%**	**1.09%**	**1.35%**	**3.44%**	**4.48%**	**5.58%**
King County	Cedar River Water & Sewer District	$915	$102,967	$29,889	**0.89%**	**1.09%**	**1.30%**	**3.06%**	**3.75%**	**4.48%**
King County	Coal Creek Utility District	$1,721	$111,493	$29,005	**1.54%**	**1.54%**	**1.92%**	**5.93%**	**5.92%**	**7.40%**
King County	Cross Valley Water District	$1,109	$109,257	$28,839	**1.02%**	**1.20%**	**1.40%**	**3.85%**	**4.56%**	**5.32%**
King County	Issaquah Water System	$812	$134,035	$33,442	**0.61%**	**0.76%**	**0.92%**	**2.43%**	**3.04%**	**3.70%**
King County	Kent Water Dept	$907	$77,856	$24,343	**1.16%**	**1.43%**	**1.71%**	**3.73%**	**4.57%**	**5.47%**
King County	Kirkland, City of	$931	$119,490	$31,621	**0.78%**	**0.95%**	**1.13%**	**2.94%**	**3.59%**	**4.29%**
King County	Lake Forest Park Water District	$833	$96,555	$28,221	**0.86%**	**1.08%**	**1.30%**	**2.95%**	**3.68%**	**4.46%**
King County	Lakehaven Water & Sewer District	$486	$78,554	$23,401	**0.62%**	**0.88%**	**1.16%**	**2.08%**	**2.95%**	**3.89%**
King County	Mercer Island, City of	$1,935	$165,001	$36,417	**1.17%**	**1.30%**	**1.43%**	**5.31%**	**5.88%**	**6.48%**
King County	NE Sammamish Sewer & Water District	$962	$174,078	$50,831	**0.55%**	**0.67%**	**0.80%**	**1.89%**	**2.30%**	**2.73%**
King County	Northshore Utility District	$768	$111,384	$29,127	**0.69%**	**0.87%**	**1.07%**	**2.64%**	**3.34%**	**4.09%**
King County	Olympic View Water & Sewer District	$1,061	$88,612	$26,206	**1.20%**	**1.43%**	**1.68%**	**4.05%**	**4.83%**	**5.67%**
King County	Pacific, City of	$1,099	$79,412	$27,652	**1.38%**	**1.64%**	**1.92%**	**3.97%**	**4.72%**	**5.51%**
King County	Redmond Water System, City of	$761	$137,373	$34,494	**0.55%**	**0.70%**	**0.86%**	**2.21%**	**2.80%**	**3.44%**
King County	Renton, City of	$972	$87,494	$24,511	**1.11%**	**1.35%**	**1.60%**	**3.97%**	**4.80%**	**5.70%**
King County	Sammamish Plateau Water & Sewer	$1,063	$164,576	$50,206	**0.65%**	**0.77%**	**0.90%**	**2.12%**	**2.53%**	**2.96%**
King County	Seattle Public Utilities	$1,123	$95,537	$22,177	**1.18%**	**1.39%**	**1.62%**	**5.06%**	**5.99%**	**6.98%**
King County	Shoreline Waste Water, City of	$807	$85,987	$22,798	**0.94%**	**1.18%**	**1.43%**	**3.54%**	**4.44%**	**5.40%**

Permitee Serving	Utility Name	Est Annual Sewer Bill	Est. Utility District Income Metric		%MHI Index			%LQI Index		
			MHI	LQI	Current	< 8mg/L, seasonal	< 3mg/L, year round	Current	< 8mg/L, seasonal	< 3mg/L, year round
King County	Skyway Water & Sewer	$1,295	$72,635	$18,186	1.78%	2.07%	2.37%	7.12%	8.25%	9.45%
King County	Soos Creek Water & Sewer District	$846	$98,460	$30,392	0.86%	1.07%	1.29%	2.78%	3.46%	4.18%
King County	Tukwila Water Dept	$951	$65,657	$16,851	1.45%	1.76%	2.10%	5.65%	6.86%	8.16%
King County	Valley View Sewer District	$984	$61,420	$16,922	1.60%	1.94%	2.29%	5.82%	7.03%	8.32%
King County	Woodinville Water District	$937	$132,419	$34,770	0.71%	0.86%	1.03%	2.69%	3.29%	3.91%
Kitsap County	Kitsap County	$1,059	$85,655	$27,823	1.24%	1.48%	1.73%	3.81%	4.55%	5.33%
Kitsap County Sewer Dist #7	Kitsap County Sewer Dist #7	$751	$131,979	$45,527	0.57%	0.72%	0.89%	1.65%	2.10%	2.58%
Kitsap County	Poulsbo, City of	$852	$72,083	$19,131	1.18%	1.47%	1.77%	4.45%	5.53%	6.67%
La Conner Water Dept	La Conner Water Dept	$800	$67,518	$16,657	1.19%	1.49%	1.81%	4.80%	6.04%	7.35%
Lake Stevens Sewer District	Lake Stevens Sewer District	$1,188	$94,973	$31,866	1.25%	1.47%	1.70%	3.73%	4.37%	5.06%
Langley, City of	Langley, City of	$854	$71,835	$15,624	1.19%	1.48%	1.78%	5.47%	6.78%	8.18%
LOTT	Lacey Water Dept	$825	$71,606	$20,026	1.15%	1.44%	1.74%	4.12%	5.14%	6.24%
LOTT	Olympia, City of	$819	$69,385	$18,139	1.18%	1.48%	1.79%	4.51%	5.65%	6.85%
LOTT	Thurston County Boston Harbor	$1,315	$95,664	$28,023	1.37%	1.59%	1.82%	4.69%	5.43%	6.21%
LOTT	Thurston County Olympic View	$1,266	$70,695	$15,502	1.79%	2.08%	2.39%	8.17%	9.49%	10.91%
LOTT	Tumwater City of	$770	$72,769	$19,640	1.06%	1.34%	1.64%	3.92%	4.96%	6.08%
Lynnwood, City of	Lynnwood, City of	$619	$79,032	$21,602	0.78%	1.04%	1.32%	2.87%	3.82%	4.83%
Marysville Utilities	Marysville Utilities	$560	$85,294	$25,673	0.66%	0.90%	1.15%	2.18%	2.98%	3.83%
Rustlewood, North Bay/Case Inlet, Belfair WR/Sewer	Mason County	$1,306	$98,169	$34,349	1.33%	1.54%	1.76%	3.80%	4.40%	5.04%
Midway Sewer District	Midway Sewer District	$720	$66,787	$19,372	1.08%	1.39%	1.71%	3.72%	4.78%	5.91%
Mukilteo Water & Wastewater Distr	Mukilteo Water & Wastewater Dist	$779	$86,968	$26,510	0.90%	1.13%	1.38%	2.94%	3.71%	4.54%
OAK HARBOR City of	Oak Harbor, City of	$1,532	$61,278	$17,872	2.50%	2.84%	3.19%	8.57%	9.72%	10.95%

Permitee Serving	Utility Name	Est Annual Sewer Bill	Est. Utility District Income Metric		%MHI Index			%LQI Index		
			MHI	LQI	Current	< 8mg/L, seasonal	< 3mg/L, year round	Current	< 8mg/L, seasonal	< 3mg/L, year round
Pierce County Chambers Creek Regional WWTP	Pierce County	$688	$74,435	$22,197	0.92%	1.20%	1.49%	3.10%	4.03%	5.01%
Pierce County Chambers Creek Regional WWTP	Steilacoom, Town of	$757	$81,915	$29,994	0.92%	1.18%	1.44%	2.52%	3.21%	3.94%
Port Angeles, City of	Port Angeles, City of	$1,050	$49,965	$12,425	2.10%	2.51%	2.95%	8.45%	10.10%	11.87%
Port Townsend, City of	Port Townsend, City of	$549	$54,320	$14,818	1.01%	1.39%	1.79%	3.70%	5.09%	6.57%
Sequim City of	Sequim City of	$713	$53,400	$13,928	1.33%	1.72%	2.13%	5.12%	6.59%	8.16%
Shelton City of	Shelton, City of	$1,312	$52,947	$13,978	2.48%	2.87%	3.28%	9.39%	10.86%	12.42%
Snohomish, City of	Snohomish, City of	$803	$80,539	$21,203	1.00%	1.25%	1.52%	3.79%	4.76%	5.79%
Stanwood Water Dept	Stanwood Water Dept	$1,152	$82,394	$19,269	1.40%	1.65%	1.91%	5.98%	7.04%	8.18%
SW Suburban Sewer District	SW Suburban Sewer District	$528	$68,471	$18,501	0.77%	1.07%	1.39%	2.85%	3.96%	5.15%
Tacoma Water	Fife Dept of Public Works	$1,087	$76,735	$22,490	1.42%	1.68%	1.97%	4.83%	5.75%	6.72%
Tacoma Water	Fircrest, City of	$907	$58,694	$15,722	1.55%	1.90%	2.27%	5.77%	7.08%	8.47%
Tacoma Water	Ruston, City of	$1,157	$84,868	$21,158	1.36%	1.61%	1.86%	5.47%	6.44%	7.47%
Tacoma Water	Tacoma Water	$678	$66,183	$17,410	1.02%	1.33%	1.67%	3.89%	5.07%	6.33%
Thurston County	Thurston County Ground Mound	$1,106	$68,631	$18,227	1.61%	1.91%	2.23%	6.07%	7.19%	8.39%
Thurston County	Thurston County Tamoshan	$1,688	$95,188	$16,074	1.77%	1.99%	2.22%	10.50%	11.78%	13.14%
West Sound Utility District (South Kitsap WRF)	West Sound Utility District	$779	$67,388	$17,211	1.16%	1.46%	1.79%	4.53%	5.72%	6.99%

Color Codes:

Income Metric
Lowest
Midpoint

Annual Sewer Bill
Highest
Midpoint
Lowest

Indices
Severe hardship (greater than 5%)
Elevated hardship (greater than 3% and less than 5%)
Moderate hardship (greater than 2% and less than 3%)
No hardship (less than 2%)

Table A-3. Summary Statistics for 80 Puget Sound Wastewater Service Providers

Summary Statistics:	Population weighted MHI	Population weighted LQI	%MHI Current	%MHI 8mg/L, seasonal	%MHI 3mg/L, year-round	%LQI Current	%LQI 8mg/L, seasonal	%LQI 3mg/L, year-round
Total number of utilities	80	80	80	80	80	80	80	80
utilities with index > 2% and < 3%, e.g., moderate hardship			4	7	14	19	8	3
% Utilities with index > 2% and < 3%			*5%*	*9%*	*18%*	*24%*	*10%*	*4%*
utilities with index > 3% and < 5% e.g., elevated hardship			0	0	3	35	37	23
% Utilities with index > 3% and < 5%			*0%*	*0%*	*4%*	*44%*	*46%*	*29%*
utilities with index > 5% e.g., severe hardship			0	0	0	22	35	54
% Utilities with index > 5			*0%*	*0%*	*0%*	*29%*	*44%*	*68%*
Total utilities with index > 2%						77	80	80
Minimum	$44,844	$12,425	0.46%	0.67%	0.80%	1.61%	2.10%	2.58%
Maximum	$174,078	$50,831	2.63%	2.98%	3.35%	10.50%	11.78%	13.14%
Average	$86,324	$23,953	1.16%	1.42%	1.69%	4.31%	5.25%	6.27%
Correlation to MHI			-0.5316			-0.4613		
Correlation to %MHI			NA			0.9399		

rental rights should it conclude the Department has not adequately explored a viable guardianship option.

¶48 Here, a Department caseworker testified that a guardianship was not a viable alternative to termination because the children were thriving in their current placement, and a guardianship would keep them "in limbo" with negative "consequences." The children's guardian ad litem also testified about her opinion on "guardianship versus adoption." She concluded that "adoption would be in their best interest" because of the children's ages and the "lack of stability for seven years." She reiterated that R.B. did not see his children for five of those years, has no relationship or bond with them, and has shown no "ability to parent." And the current caregiver to both children testified that her family "discussed the potential for guardianship or adoption with the Department." She said that her family preferred adoption and that their home had already "been approved for adoption." Substantial evidence supports the trial court's findings that the children's caregivers were "not interested" in being guardians and that a guardianship would diminish the children's integration into a stable and permanent home.

¶49 Because the trial court did not err when it allowed R.B. to proceed pro se and substantial evidence supports the court's findings, we affirm termination of his parental rights to G.C.B. and M.J.B.-L.

WE CONCUR:

Hazelrigg, A.C.J.

Dwyer, J.

CITY OF TACOMA, Birch Bay Water and Sewer District, Kitsap County, Southwest Suburban Sewer District, and Alderwood Water & Wastewater District, Municipal Corporations and Political Subdivisions of the State of Washington Respondents,

v.

State of Washington, DEPARTMENT OF ECOLOGY, Appellant.

No. 39494-8-III

Court of Appeals of Washington, Division 3.

Filed September 14, 2023

Background: City, along with other local governments and special purpose districts that owned or operated public sewer systems and associated wastewater treatment plants, filed petition for judicial review of two documents issued by Department of Ecology recommending and committing to action to regulate nitrogen discharges into Puget Sound, contending that documents improperly adopted three new rules in violation of rulemaking procedures under Administrative Procedure Act (APA). The Superior Court, Thurston County, Sharonda D. Amamilo, J., granted petition. Ecology appealed.

Holdings: The Court of Appeals, Lawrence-Berrey, J., held that:

(1) judicial deference to Ecology's statutory interpretation concerning its authority to promulgate rules was unwarranted;

(2) portion of water quality report discussing portions of waterway that did not meet dissolved oxygen (DO) standard did not constitute "rule" under APA;

(3) pages in report discussing human causes of DO depletion did not constitute "rule" under APA;

(4) Ecology's commitments to certain actions to reduce nitrogen discharges from wastewater treatment plants

were "of general applicability" within meaning of APA's definition of "rule";

(5) Ecology's internal directive to its staff to include new requirements for National Pollutant Discharge Elimination System (NPDES) permits constituted "directive" within meaning of APA's definition of "rule"; and

(6) new nitrogen-discharge limitations for NPDES permittees altered qualifications or requirements relating to enjoyment of privileges conferred by law.

Affirmed in part and reversed in part.

1. Environmental Law ⚷708

Whether certain provisions of documents issued by Department of Ecology discussing nitrogen pollution constituted "rules" as defined by Washington Administrative Procedure Act (APA) presented questions of statutory interpretation which Court of Appeals would review de novo. Wash. Rev. Code Ann. § 34.05.010(16).

2. Administrative Law and Procedure ⚷2288

Environmental Law ⚷708

In determining whether provisions of report issued by Department of Ecology relating to dissolved oxygen (DO) testing and sampling, as well as new limitations Ecology allegedly placed on National Pollutant Discharge Elimination System (NPDES) permits, constituted "rules" within meaning of Administrative Procedure Act (APA), such that Ecology could not adopt such provisions and limitations without going through formal rulemaking procedures, Court of Appeals would not defer to Ecology's interpretation of statutes at issue, even though Ecology was agency designated to regulate water pollution; Court of Appeals was tasked with determining scope of Ecology's authority to promulgate rules, which was improper subject for judicial deference. Wash. Rev. Code Ann. §§ 34.05.010(16), 34.05.570.

3. Administrative Law and Procedure ⚷1842

Courts do not defer to an agency the power to determine the scope of its own authority.

4. Administrative Law and Procedure ⚷1164

The label that an agency assigns to its activities does not determine whether those activities constitute rulemaking under the Administrative Procedure Act (APA). Wash. Rev. Code Ann. §§ 34.05.010(16), 34.05.570.

5. Administrative Law and Procedure ⚷1162, 1167

In order to determine whether an agency's statement or other activity constitutes a "rule" within the meaning of the Administrative Procedure Act (APA), a court first determines whether the purported rule is an "order, directive, or regulation of general applicability," and second, the court determines whether the purported rule falls into one of the five categories enumerated in the APA provision defining "rule"; if the purported rule fails the first part of the inquiry, the court need not address whether it falls within one of the enumerated categories in satisfaction of the second element. Wash. Rev. Code Ann. § 34.05.010(16).

6. Administrative Law and Procedure ⚷1162

Licenses ⚷3

Although an action is "of general applicability" if applied uniformly to all members of a class, for purposes of determining whether the action is a "rule" under the Administrative Procedure Act (APA), it is a logical fallacy to imply that an action is not of general applicability if not applied uniformly to all members of a class; implying this logical fallacy would make it easy for an agency to skirt the rulemaking requirements of the APA simply by imposing incremental standards on members of a class, such as permittees, rather than a single standard. Wash. Rev. Code Ann. §§ 34.05.010(16), 34.05.570.

7. Statutes ⚷1123, 1181

Undefined terms in statutes are given their ordinary dictionary definition.

8. Environmental Law ⚷217

Portion of water quality report issued by Department of Ecology depicting regions of Puget Sound that did not meet dissolved oxygen (DO) standard at certain levels of water column did not constitute "directive," as necessary to constitute "rule" subject to rulemaking requirements of Administrative Procedure Act (APA); portion of report only explained how report's authors reported their results and did not impel anyone to act, and there was no indication that Ecology planned to use anything other than existing rule for measuring DO levels or for deciding whether wastewater treatment plants (WWTPs) were in violation of applicable National Pollutant Discharge Elimination System (NPDES) permits. Wash. Rev. Code Ann. §§ 34.05.010(16), 34.05.570(2)(c); Wash. Admin. Code 173.201(1).

9. Environmental Law ⚷217

Pages of water quality report issued by Department of Ecology which stated that predictive computer model projected every basin but one in Puget Sound had at least one layer in water column that failed to meet dissolved oxygen (DO) standards, discussed human causes of DO depletion, and represented Puget Sound's DO levels at reference levels without human influence and at existing levels did not state any directive, and thus, did not constitute "rule" subject to Administrative Procedure Act (APA) rulemaking requirements, even if report identified noncompliant areas beyond those already subject to more stringent National Pollutant Discharge Elimination System (NPDES) permit requirements under federal law; such pages merely stated authors' conclusions and did not impel anyone to act. Federal Water Pollution Control Act § 303, 33 U.S.C.A. § 1313(d); Wash. Rev. Code Ann. §§ 34.05.010(16), 34.05.570(2)(c).

10. Environmental Law ⚷217

Department of Ecology's commitments in letter denying rulemaking request, namely that Ecology would set nutrient loading limits at current levels for all National Pollutant Discharge Elimination System (NPDES) permittees, require NPDES permittees to initiate planning efforts to evaluate different effluent nutrient reduction targets, and require reissued NPDES permits for wastewater treatment plants to reflect plants' treatment efficiency, were of general applicability, as necessary for such commitments to constitute "rules" that Ecology could only promulgate through rulemaking procedures of Administrative Procedure Act (APA); commitments applied to all wastewater treatment plants. Wash. Rev. Code Ann. §§ 34.05.010(16), 34.05.570(2)(c).

11. Administrative Law and Procedure ⚷1162

Where a party challenges an administrative policy applicable to all participants in a program, not its implementation under a single contract or assessment of individual benefits, the action is one of general applicability, within the Administrative Procedure Act's (APA) definition of a "rule." Wash. Rev. Code Ann. § 34.05.010(16).

12. Administrative Law and Procedure ⚷1162

A "directive," within the meaning of the Administrative Procedure Act (APA) provision defining a "rule" as an "order, directive, or regulation of general applicability" that falls within one of five enumerated categories, is something that impels action. Wash. Rev. Code Ann. § 34.05.010(16).

See publication Words and Phrases for other judicial constructions and definitions.

13. Environmental Law ⚷217

Department of Ecology's internal instruction to its staff to impose certain new restrictions on reissued individual permits and newly-created general permit under National Pollutant Discharge Elimination System (NPDES) with goal of reducing total inorganic nitrogen (TIN) discharged into Puget Sound by wastewater treatment plants constituted "directive" within meaning of Administrative Procedure Act's (APA) definition of "rule" as "order, directive, or regulation of general applicability" falling into one of five statutory categories; internal directive to add new terms for reissuing permits was nondiscretionary and had same effect as a promulgated rule governing terms of permit renewal, and Ecology could not bypass APA's rulemaking requirements by adopting renewal criteria internally. Wash. Rev. Code Ann. §§ 34.05.010(16), 34.05.570(2)(c).

See publication Words and Phrases for other judicial constructions and definitions.

14. Courts ⚷92

Statements in a case that do not relate to an issue before the court and are unnecessary to decide the case constitute "obiter dictum" and need not be followed.

See publication Words and Phrases for other judicial constructions and definitions.

15. Environmental Law ⚷217

New nitrogen-discharge limitations that Department of Ecology committed to imposing as requirement for National Pollutant Discharge Elimination System (NPDES) permits issued to wastewater treatment plants in Puget Sound, as Ecology stated in letter and implemented when renewing two individual permits and creating new general permit, altered qualifications or requirements relating to the enjoyment of benefits or privileges conferred by law, as necessary for limitations to constitute "rule" subject to rulemaking procedures of Administrative Procedure Act (APA); issuance of NPDES permit was privilege conferred by law, discharging any substance into Puget Sound was prohibited without permit, and existing water quality standards did not directly regulate nitrogen, whereas new limitations did. Wash. Rev. Code Ann. §§ 34.05.010(16), 34.05.570(2)(c), 90.48.160, 90.48.162.

See publication Words and Phrases for other judicial constructions and definitions.

16. Environmental Law ⚷708

On Department of Ecology's appeal from superior court's grant of city's petition for judicial review of certain statements and actions taken by Ecology, which city contended constituted "rules" that Ecology was required to adopt through rulemaking procedures of Administrative Procedure Act (APA), Court of Appeals would decline to consider whether city had standing to file petition in superior court, where issue was solely raised by amici curiae. Wash. Rev. Code Ann. §§ 34.05.010(16), 34.05.570(2)(c).

Appeal from Thurston Superior Court, Docket No:20-2-02539-6, Honorable Sharonda Amamilo, Judge.

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Amalia R. Walton, Squaxin Island Tribe Legal Department, 3711 Se Old Olympic Hwy., Shelton, WA, 98584-7734, for Amicus Curiae on behalf of Squaxin Island Tribe.

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PUBLISHED OPINION

Lawrence-Berrey, J.

¶ 1 Respondents are all either local governments or special purpose districts that own and operate public sewer systems and associated wastewater treatment plants

(WWTPs) discharging into Puget Sound (Sound). In 2019, the Department of Ecology (Ecology) generated two documents discussing nitrogen pollution in Puget Sound. One document recommended action to regulate nitrogen discharges to the Sound and the other committed to doing so.

¶ 2 The respondents (hereafter Tacoma) sued to block regulation of their nitrogen discharges by arguing that these two documents improperly adopted three new rules in violation of the rulemaking provisions of chapter 34.05 RCW, the Administrative Procedure Act (APA). The superior court agreed with Tacoma. Ecology appeals.

¶ 3 We clarify the APA's definition of "rule" and conclude that "directive," for purposes of one APA component of "rule," includes an agency's directive to its staff to include new terms in permits. We conclude that the first and second purported rules are not "rules" within the APA's definition, but we conclude that the third purported rule is.

¶ 4 We affirm in part and reverse in part.

FACTS

¶ 5 The waters of Puget Sound extend from Olympia and the inside of the Olympic Peninsula north through the San Juan Islands up to Bellingham. Puget Sound is itself part of a greater body of water, known as the Salish Sea. The Salish Sea extends from the northern tip of Vancouver Island in British Columbia, south through the Strait of Georgia and the Strait of Juan de Fuca, continuing through the entirety of Puget Sound along the inside of the Olympic Peninsula. Some maps extend the Salish Sea further south along the Oregon Coast and include the mouth of the Columbia River.

¶ 6 Puget Sound and the Salish Sea are polluted. Some pollution is naturally caused. Other pollution is anthropogenic (i.e., human caused). Some of the human-caused sources of water pollution include shipping, fishing, fisheries, other forms of aquaculture, agricultural runoff, stormwater runoff, industrial waste, medical waste, garbage, oil and gas production, and discharges from WWTPs. This case concerns attempts to control pollution from WWTPs.

¶ 7 Since enactment of the Federal Water Pollution Control Act of 1972 (Clean Water Act or CWA), 33 U.S.C. § 1251 et seq., the United States has attempted to mitigate human-caused water pollution. Some of the mitigation tools adopted by the CWA, its amendments, and implementing regulations were monitoring and limiting discharges of biological oxygen-demanding pollutants, suspended solids, fecal coliform, pH (hydrogen ion concentration) impairing pollutants, and thermal impairing pollutants. *See* 33 U.S.C. § 1314(a). Another tool was requiring point source emitters of pollution to obtain a permit for the continued right to discharge pollutants into the waters of the United States. *See* 33 U.S.C. § 1342. These permits are known as "National Pollutant Discharge Elimination System (NPDES)" permits. Another tool was requiring industrial polluters to adopt "pretreatment" and requiring WWTPs to adopt "secondary treatment." *See* 33 U.S.C. § 1317(b), § 1311(b)(1)(B). Pretreatment seeks to reduce or eliminate nonstandard pollutants prior to the pollutant entering a WWTP.[1] 40 C.F.R. § 403.3(s). Secondary treatment typically consists of activated sludge, trickling filters, and/or biological contactors intended to remove biodegradable organic pollutants. Primary treatment typically consists of screening, skimming, and settling to remove large solids that sink, and oils and lighter solids that float to the surface. Wastewater treatment also typically includes some form of disinfection, such as application of chlorine, ozone, or ultraviolet light.

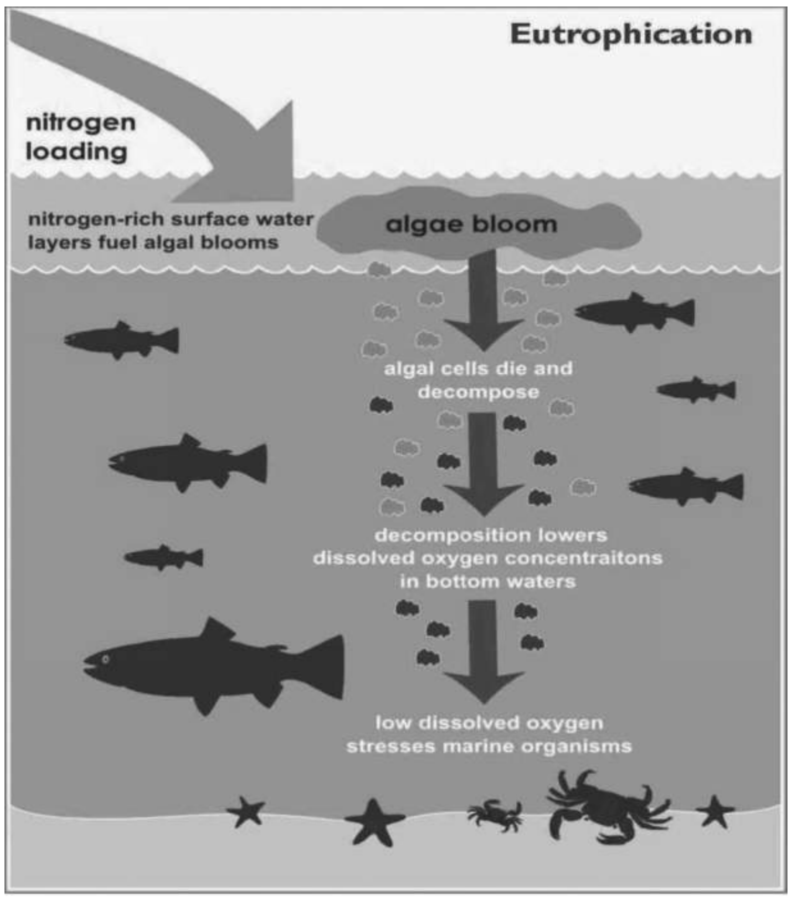
¶ 8 Despite all these forms of treatment, many pollutants still remain in wastewater discharged into the waters of the United States. As technology and scientific knowledge have continued to advance, additional forms of treatment have emerged. Additional treatment is often referred to as tertiary treatment, final treatment, or advanced secondary treatment. This additional treatment may refer to technology and agents that

1. Most WWTPs were originally designed to handle typical household and light commercial waste.

remove pharmaceutical waste, micropollutants such as plastics, phosphorus, nitrogen, or any other remaining unwanted substance. In this case, tertiary treatment is used to refer to nitrogen removal.

¶ 9 Some WWTPs in Washington already incorporate nitrogen removal, such as the Spokane Regional Water Reclamation Facility and the Budd Inlet Treatment Plant. Despite having been technologically feasible for several decades, tertiary treatment is not yet required for all WWTPs.

¶ 10 One of the primary impediments to wider adoption of tertiary treatment is cost. In 2017, the Chambers Creek Regional Wastewater Treatment Plant in Pierce County finished installation of a nitrogen removal system at a cost of $342 million. Individual plants may also be impeded by a lack of available land on which to construct new infrastructure or insufficient access to additional electricity. Other impediments are gaps in our knowledge.



¶ 11 Nitrogen, while commonly thought of as a beneficial nutrient, is also a pollutant. Simplified, excess nitrogen results in excess algal growth. Algae generate organic carbon. When carbon decomposes, it consumes oxygen. Depleted oxygen, or eutrophication, can render water incapable of supporting many forms of aquatic life.

¶ 12 Puget Sound contains many areas with low levels of dissolved oxygen (DO) as a result of excess nitrogen. More specifically, Puget Sound contains low oxygen in the strata where aquatic life has historically thrived.

¶ 13 What is unknown, at least within Puget Sound, is to what extent excess nitrogen in these strata is due to WWTPs. The Pacific Ocean is the largest source of nitrogen entering Puget Sound. The Pacific is believed to account for about 88 percent of the total nitrogen entering Puget Sound. Just because the Pacific is the largest source of nitrogen does not mean that it is the largest driver of oxygen depletion in the life-sustaining layers of the Sound.

¶ 14 Oceans and seas are complex ecosystems. The tides, water temperature, geography, and other variables impact flow and mixing among bodies of water. Most of the nitrogen that enters Puget Sound via the Pacific also flows back out. But the nitrogen entering Puget Sound from the Pacific is unlikely to have a significant negative impact on oxygen levels because water entering from the Pacific is usually colder, meaning it is denser than the water already in the Sound, causing the water from the Pacific to sink below the water already in the Sound. The negative impacts of excess nitrogen occur closer to the surface, in the euphotic zone, where the sun's light allows for photosynthesis to occur. The euphotic zone is also where most marine life is found.

¶ 15 WWTPs emit significant amounts of nitrogen. Yet it is unknown to what extent this nitrogen causes DO impairment in Puget Sound. Nitrogen at the point of discharge can be measured, but one cannot determine where this nitrogen goes once the wastewater gets carried away on the currents and mixes with the rest of the Sound. Without this information, it is not possible to reasonably regulate nitrogen discharges from WWTPs. This is because anthropogenic pollutant discharges only violate Washington's clean water standard if it can be shown that human actions "cause the D.O. of that water body to decrease more than 0.2 mg/L." WAC 173-201A-210(1)(d)(1).

Development of the Salish Sea Model

¶ 16 To fill this knowledge gap, Ecology and the Pacific Northwest National Laboratory (PNNL) spent years developing the Salish Sea Model (SSM). The SSM is a predictive computer model that lets Ecology isolate and test water quality variables based on actual water quality data and predict water quality in areas where we do not currently have actual water quality measurements. It takes months to prepare the data to run a single scenario, days to run it through the SSM on one of PNNL's high powered computers, and additional time to interpret and report the data.

¶ 17 Some of the questions the SSM helps to answer are:

- "Are human sources of nutrients in and around the Salish Sea significantly impacting water quality now? How bad might it get in the future?"
- "Where are the areas that are most sensitive to human impacts? When are those effects the most harmful?"
- "How much do we need to reduce human sources of nutrients to protect water quality in the Salish Sea?"

Administrative Record (AR) at 104. The model also allows Ecology to predict where and by how much DO levels would improve based on hypothetical nitrogen reductions. The model also allows Ecology to test and quantify its hypothesis that DO levels are most impaired in Puget Sound's remote inlets and basins due to poor circulation resulting in pollutants accumulating and spending more time in those areas.

¶ 18 Despite its immense power, the SSM does have limits. While the SSM can account for human-caused sources of pollution, the model cannot isolate the effect of individual WWTPs. However, Ecology hopes to further refine the SSM "to define discharger-specific nutrient loading limits based on localized and far-field impacts." Clerk's Papers (CP) at 127.

¶ 19 Professors Gordon Holtgrieve and Mark Scheuerell from the University of Washington, scientists working with the regulated stakeholders, have also expressed concern that Ecology is overconfident in the SSM's predictive power. Every predictive model has levels of uncertainty, often reported as confidence intervals. In lay terms, these scientists worry that the SSM is not yet ready for prime time because it appears to lack sufficient sensitivity to confidently determine which segments of Puget Sound violate the DO standard in WAC 173-201A-210 as a result of human-caused pollution. The SSM's predictive accuracy is particularly important because many areas of Puget Sound are on the edge of the state's DO water quality standard. These scientists are also concerned that Ecology has not publicly shared sufficient information for others to independently verify Ecology's interpretation of the results.

¶ 20 To be clear, this appeal is not about whether Ecology should be using the SSM to inform regulation or whether it is accurate and reliable. This appeal is about whether Ecology violated the APA by adopting rules without allowing for public comment during its efforts to investigate and respond to human causes of DO depletion in Puget Sound.

¶ 21 In January 2019, Ecology published the results of its first three scenarios using the SSM. The report, referred to as the Bounding Scenarios Report (BSR), modeled "a range of climate and ocean conditions" from 2006, 2008, and 2014. CP at 34. The report looked at current levels of pollution during those years and what would happen if nitrogen and carbon discharges were reduced at all WWTPs, only midsize and large WWTPs, and only large WWTPs. There are 79 WWTPs in the United States' portion of the Salish Sea.

¶ 22 The report's authors found that approximately 20 percent of Puget Sound did not meet Washington's DO water quality standards during each of the reference years. The modeling used in the BSR suggested that reducing nitrogen and carbon discharges from WWTPs using "seasonal biological nitrogen removal (BNR) technology" would improve DO compliance by approximately 50 percent, meaning only about 10 percent of Puget Sound would continue to not meet DO standards. CP at 37. The report's authors also found DO noncompliant areas within all of Puget Sound's basins, except Admiralty Inlet. The authors also found "[a]ll areas not meeting the water quality standard have depleted levels of DO in the water column as a result of human loadings from Washington State." CP at 36. While the SSM cannot yet quantify the effects of individual WWTPs, the model confirmed that discharges have both a near- and a far-field effect, meaning that discharges into one part of Puget Sound contribute to DO depletion in other parts of the Sound as the discharged water mixes and travels along the currents.

Northwest Environmental Advocates (NWEA) Rulemaking Petition

¶ 23 For years, Ecology has kept stakeholders updated on the development of the SSM and other water quality efforts through the Puget Sound Nutrient Forum. The forum also presented stakeholders with preliminary results from the SSM. Shortly before the official publication of the BSR, NWEA—an active participant in the Nutrient Forum—filed a petition with Ecology "to propose and adopt a rule establishing technology-based effluent limits for the discharge of nutrients and toxics from municipal wastewater treatment facilities that discharge to Puget Sound and its tributaries." AR at 231. Specifically, NWEA wanted a rule designating tertiary treatment of wastewater as "AKART." AR at 231.

¶ 24 AKART stands for "All Known, Available, and Reasonable Treatment." WAC 173-201A-020. AKART represents "the most current methodology that can be reasonably required for preventing, controlling, or abating the pollutants associated with a discharge." *Id.* Under RCW 90.52.040, Ecology is required to adopt rules requiring "wastes to be provided with all known, available, and reasonable methods of treatment prior to their discharge or entry into waters of the state." Such treatment is required regardless of whether the water quality is pristine, impaired, or anywhere in between. RCW 90.52.040. In addition to implementing state law, AKART standards also mirror parallel provisions of the Clean Water Act requiring NPDES permittees to adopt the best available technology economically achievable for eliminating the discharge of pollutants. *See* 33 U.S.C. §§ 1311, 1314. Thus, if tertiary treatment meets the definition of AKART, Ecology is obligated by statute to make tertiary treatment a precondition to issuance/reissuance of NPDES permits.

¶ 25 On January 11, 2019, Ecology sent NWEA a concise letter denying the rulemaking petition. Under the APA, Ecology had 60 days to either initiate rulemaking or issue a denial explaining the reasons for denial and "where appropriate" the alternative means Ecology would use to address NWEA's concerns. RCW 34.05.330(1). Ecology denied rulemaking because AKART technologies must be economically feasible and Ecology believed that tertiary treatment was cost prohibitive. While it may be economically feasible for some WWTPs, NWEA's petition wanted tertiary treatment mandated for all 79 Puget Sound WWTPs, regardless of any one plant's size and impact on Puget Sound. Ecology also denied rulemaking because the SSM needed further refinements before Ecology had sufficient data to craft discharger-specific limits for individual NPDES permittees.

¶ 26 Although Ecology denied rulemaking, Ecology shares NWEA's concerns and ultimate goals. It is the policy of this state

> to maintain the highest possible standards to insure the purity of all waters of the state consistent with public health and public enjoyment thereof, the propagation and protection of wild life, birds, game, fish and other aquatic life, and the industrial development of the state, and to that end require the use of all known available and reasonable methods by industries and others to prevent and control the pollution of the waters of the state of Washington.

RCW 90.48.010. In the denial letter, Ecology announced the alternative actions it would take:

> Ecology remains committed to [working with stakeholders to solve the DO problem in Puget Sound]. While this work is progressing, Ecology *will* through the individual permitting process:
>
> 1. Set nutrient loading limits at current levels from all permitted dischargers in Puget Sound and its key tributaries to prevent increases in loading that would continue to contribute to Puget Sound's impaired status.
> 2. Require permittees to initiate planning efforts to evaluate different effluent nutrient reduction targets.
> 3. For treatment plants that already use a nutrient removal process, require reissued discharge permits to reflect the treatment efficiency of the existing plant by implementing numeric effluent limits used as design parameters in facility specific engineering reports.

CP at 127 (emphasis added). Ecology also stated that it would explore development of a general permit to regulate "nutrient loading" (i.e., nitrogen discharges) into Puget Sound. CP at 127. A general permit that covers multiple discharging entities is an alternative to issuing individual NPDES permits. WAC 173-226-020, -050.

¶ 27 Unhappy with the denial of its rulemaking petition, NWEA sought judicial review. Division Two of this court affirmed Ecology's denial of the rulemaking petition. *See generally Nw. Env't Advocs. v. Dep't of Ecology*, No. 54810-1-II, 18 Wash.App.2d 1005, 2021 WL 2556573 (Wash. Ct. App. June 22, 2021) (unpublished), http://www/courts.wa.gov/opinions/pdf/548101_unp.pdf).

NPDES Permits and the Puget Sound Nutrient General Permit

¶ 28 Ecology started adding new terms to individual NPDES permits as those permits came up for renewal, requiring nitrogen discharge limits and nitrogen reduction planning. Ecology also worked to develop a general permit. The final version of the general permit went into effect January 1, 2022. It placed a limit on how many pounds of nitrogen each large and midsize WWTP could discharge per year and required all WWTPs to create nitrogen reduction plans. Any WWTP that exceeds its annual limit must spend the next year studying what caused it to exceed its limit and what corrective action it can take to not exceed its limit. If a WWTP exceeds its limit two years in a row, it must begin taking that corrective action. The validity of the general permit is currently in litigation at the Pollution Control Hearings Board. That litigation is stayed pending the resolution of this appeal.

Concerns Raised by the Regulated Community

¶ 29 The findings of the BSR, the rulemaking denial letter, and the prospect of a general permit all happened within a fairly short time frame. The commitments made in the denial letter especially alarmed the regulated community.

¶ 30 In the denial letter, Ecology promised that as each NPDES came up for renewal, it would "[s]et nutrient loading limits at current levels ... to prevent increases in loading that would continue to contribute to Puget Sound's impaired status." CP at 127. The short-term effect of freezing nutrient loading limits impairs development because development increases demand on WWTPs. But, it is not possible to significantly reduce nitrogen in the short term. Significant nitrogen reduction requires long-term capital improvements. Immediately, the city of Tacoma (City) started putting caveats in building permits allowing the City to "rescind the permit" in the event Ecology limited the City's treatment capacity by capping nitrogen discharges. CP at 991. This put several major projects in limbo, including multifamily housing developments, a behavioral health hospital, and an expansion at Bates Technical College Medical School.

¶ 31 An internal legal memo authored by counsel for the City concisely lays out its concerns:

> The costs of such full-scale improvements are estimated to range from $250 million to over $750 million and would likely take at least six years or longer to fund, plan for and implement. In the interim, implementation of the TIN [total inorganic nitrogen] load cap would have the unintended consequence of halting development, in effect a de facto moratorium. Projects could not be approved because sewer capacity would not be available. The City will be exposed to substantial risk if it does not qualify all sewer availability notices with the right to rescind the assurance of sewer availability in the event Ecology's permit caps sewer capacity. Adding this condition will impair lending and effectively halt most development, including affordable housing, shelters, and accessory dwelling units. Further, funding of capital improvements needed to meet the new permit requirements has the potential to more than double or triple sewer rates, disproportionately affecting low-income populations.

AR at 620.

¶ 32 There were also concerns that capping nitrogen discharges at current levels, without allowing leeway for development to continue, would unintentionally force growth into rural areas. This would be in areas where septic is allowed due to a lack of sewer service. The unintended consequence of this could make matters worse, causing leaky and untreated septic waste to enter the Puget Sound.

Petition for Judicial Review

¶ 33 To prevent Ecology from limiting WWTP discharges, the City and the other respondents filed a joint petition for judicial review under RCW 34.05.570. The City alleged Ecology violated the APA by adopting three "rules" outside of the APA's rulemaking process. Two of the purported rules were in the BSR and the third purported rule was in the denial letter. The City refers to the first purported rule as the DO standard rule, the second as the DO impairment rule, and the third as the TIN cap rule.[2]

¶ 34 The City alleged the DO standard rule appeared on page 20 of the BSR, that the DO impairment rule could be found on pages 12, 60, 61, and 62 of the BSR when read together, and that the TIN cap rule could be found in the three commitments Ecology made in the denial letter.

¶ 35 With respect to the DO standard rule, the City alleged the BSR effectively amended WAC 173-201A-210(1)(d)(iii), which covers DO testing and sampling procedures. With respect to the DO impairment rule, the City alleged the BSR effectively amended the state's 303(d) list[3] of impaired water segments when the BSR reported the SSM's findings of areas not meeting Washington's DO water quality standard. With respect to the TIN cap rule, the City alleged that Ecology placed new limits in NPDES permits.

2. The phrase "total inorganic nitrogen" does not appear in the denial letter. The reason the City refers to it as the TIN cap rule is because TIN is the parameter that Ecology settled on for implementing the commitments in its letter.

3. The 303(d) list is a reference to the list states are required to periodically submit to the Environmental Protection Agency under 33 U.S.C. § 1313(d). Entities that discharge into waterways on the 303(d) list are subject to more stringent requirements in their NPDES permits.

¶ 36 In addition to arguing that the three alleged rules violated RCW 34.05.570 by not going through the rulemaking process, the City also alleged that they were arbitrary and capricious and exceeded Ecology's statutory authority.

¶ 37 The trial court agreed with the City on all grounds and remanded the matter "to Ecology for consideration of the immediate adoption of temporary emergency rules while regular rule-making proceeds." CP at 1483. Ecology appeals.

ANALYSIS

¶ 38 In its briefing to this court, the City abandoned its prior claims that Ecology's purported rules are arbitrary and capricious and exceeded Ecology's statutory authority. Accordingly, the only substantive issue is whether the three purported rules are "rules" as defined by RCW 34.05.010(16) and were therefore required to be adopted through formal rulemaking.

A. Standard of Review

[1] ¶ 39 Whether any of the three purported rules adopted by Ecology are "rules" as defined by Washington's APA are questions of statutory interpretation, the court reviews de novo. *Nw. Pulp & Paper Ass'n v. Dep't of Ecology*, 200 Wash.2d 666, 672, 520 P.3d 985 (2022).

[2, 3] ¶ 40 Ecology argues that because it is the agency designated to regulate water pollution, we should defer to its interpretation of the laws it administers. *See City of Redmond v. Cent. Puget Sound Growth Mgmt. Hr'gs Bd.*, 136 Wash.2d 38, 46, 959 P.2d 1091 (1998) (this court defers to an agency's interpretation of the law it administers). We agree with the legal principle cited by Ecology, but disagree it applies here. We are tasked here with determining the scope of Ecology's *authority* to promulgate purported rules. " '[W]e do not defer to an agency the power to determine the scope of its own authority.' " *Ass'n of Wash. Bus. v. Dep't of Ecology*, 195 Wash.2d 1, 10, 455 P.3d 1126 (2020) (internal quotation marks omitted) (quoting *Lenander v. Dep't of Ret. Sys.*, 186 Wash.2d 393, 409, 377 P.3d 199 (2016)).

B. The Purported Rules

¶ 41 The APA defines "rule" as

> any agency order, directive, or regulation of general applicability (a) the violation of which subjects a person to a penalty or administrative sanction; (b) which establishes, alters, or revokes any procedure, practice, or requirement relating to agency hearings; (c) which establishes, alters, or revokes any qualification or requirement relating to the enjoyment of benefits or privileges conferred by law; (d) which establishes, alters, or revokes any qualifications or standards for the issuance, suspension, or revocation of licenses to pursue any commercial activity, trade, or profession; or (e) which establishes, alters, or revokes any mandatory standards for any product or material which must be met before distribution or sale.

RCW 34.05.010(16).

[4] ¶ 42 No agency subject to Washington's APA may adopt a rule outside of the rulemaking process established in chapter 34.05 RCW, §§ .310-.395. RCW 34.05.570(2)(c). The label that an agency assigns to its activities does not determine whether those activities constitute rulemaking under the APA. *McGee Guest Home, Inc. v. Dep't of Soc. & Health Servs.*, 142 Wash.2d 316, 322, 12 P.3d 144 (2000).

[5] ¶ 43 The APA definition of "rule" implies a two-step inquiry. First, the court determines whether the purported rule is an " 'order, directive, or regulation of general applicability.' " *Nw. Pulp*, 200 Wash.2d at 672, 520 P.3d 985 (quoting RCW 34.05.010(16)). Second, the court determines whether the purported rule "fall[s] into one of the five enumerated categories" in RCW 34.05.010(16). *Id.* at 672-73, 520 P.3d 985. If the purported rule fails the first part of the inquiry, "we need not address whether [it] falls within one of the enumerated categories in satisfaction of the second element." *Id.* at 676, 520 P.3d 985.

¶ 44 For the first inquiry, the City argues that each of Ecology's purported rules are directives of general applicability. For the second inquiry, the City argues that each of the purported rules fit within RCW 34.05.010(16) categories (a) and (c).[4]

1. *The DO standard described on page 20 of the BSR is not a rule*

[6] ¶ 45 This court's first step is to determine whether page 20 of the BSR states a directive of general applicability. The APA does not define "directive" or "general applicability." However, the Supreme Court has previously defined the latter term: "[W]here the challenge is to a policy applicable to all participants in a program, not its implementation under a single contract or assessment of individual benefits, the action is of general applicability within the definition of a rule." *Failor's Pharm. v. Dep't of Soc. & Health Servs.*, 125 Wash.2d 488, 495, 886 P.2d 147 (1994) (citing *Simpson Tacoma Kraft Co. v. Dep't of Ecology*, 119 Wash.2d 640, 648, 835 P.2d 1030 (1992)).[5]

[7] ¶ 46 While the Supreme Court has defined "general applicability," it has not defined the term "directive" as used in the APA. Undefined terms in statutes are given their ordinary dictionary definition. *Am. Legion Post No. 32 v. City of Walla Walla*, 116 Wash.2d 1, 8, 802 P.2d 784 (1991). Webster's defines "directive" in its noun form as "something that serves to direct, guide, and usu. impel toward an action, attainment, or goal." WEBSTER'S THIRD NEW INTERNATIONAL DICTIONARY 641 (1993).

[8] ¶ 47 Applying this definition, page 20 of the BSR does not contain a directive of general applicability. Page 20 of the BSR states, in relevant part:

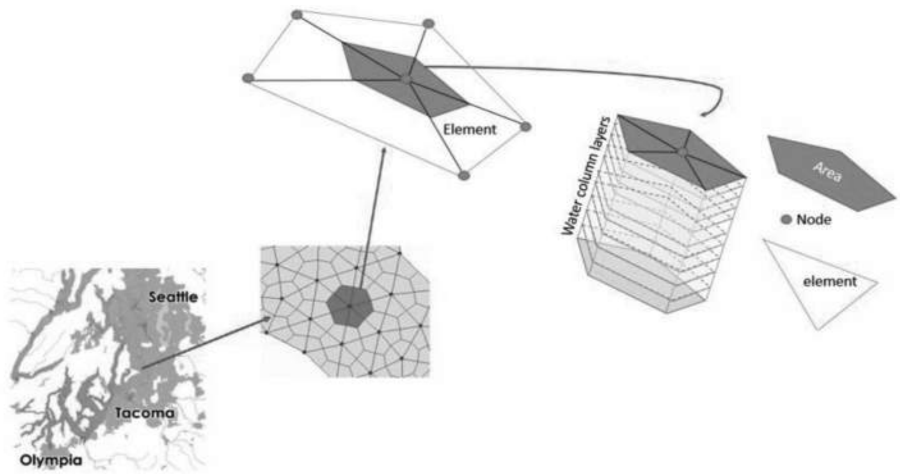
> Regions of Puget Sound that do not meet the DO standard are expressed in terms of area (e.g., acres or km2). Since the model is three dimensional, each vertical column of water is represented by ten layered grid cells. Area, in this context, refers to the surface area of the vertical column (which is equivalent to the area represented by the grid cell in Figure 4). If DO levels in one or more layers in the water column does not meet the DO standard, the surface area of that water column is counted towards the total noncompliant area.

CP at 44. Following is a graphic from the BSR depicting the SSM's water column layering.

4. In its first amended petition for judicial review, the City alleged categories (c) and (d), but not (a). Ecology argues that the City's failure to plead RCW 34.05.010(16)(a) in its petition for judicial review precludes consideration of that category. To support its argument, Ecology cites RCW 34.05.546(7). That subsection requires the petitioner to set forth in its petition for review its "reasons for believing that relief should be granted."

RCW 34.05.546(7) does not describe the required level of specificity. On its face, it might require citation only to RCW 34.05.010(16) or it might require citation to one or more of subsection 16's five categories. Because Ecology does not cite any authority to support its argument or attempt to show what level of specificity the legislature intended, we decline to consider the argument. *Holland v. City of Tacoma*, 90 Wash. App. 533, 537-38, 954 P.2d 290 (1998) (passing treatment of an issue or lack of reasoned argument is insufficient to merit judicial consideration).

5. Various cases additionally state, "[a]n action is of general applicability if applied uniformly to all members of a class." *See, e.g., Failor's Pharm.*, 125 Wash.2d at 495, 886 P.2d 147. Trial courts should not commit the logical fallacy of implying the converse; that is, by implying that an action is *not* of general applicability if *not* applied uniformly to all members of a class. Implying this logical fallacy would make it easy for an agency to skirt the rulemaking requirements of the APA simply by imposing incremental standards on permittees rather than a single standard.



CP at 45 (Fig. 4).

¶ 48 This portion of the BSR simply explains how the BSR's authors reported their results. As defined above, a directive is something that impels toward an action. Because the DO standard does not impel anyone to act, it is not a "directive" and it therefore is not a "rule" under the APA.

¶ 49 Yet the BSR report promises to "supply information [to Ecology to] design management strategies for anthropogenic nutrient inputs affecting DO" and "will be used to inform and develop the nutrient management strategy for Puget Sound." CP at 45-46. The City argues that these and other comments within the report show that the BSR approach for measuring DO will be used for determining whether they are in violation of applicable DO standards. We are unpersuaded.

¶ 50 The BSR is a tool that Ecology will use to better measure and control DO levels. There is no indication from the report or elsewhere that Ecology plans to use anything other than the existing rule, WAC 173-201A-210(1), for measuring DO levels for deciding whether any WWTP is in violation of its individual permit or a general permit.

¶ 51 Because the first purported rule does not state a "directive," this court does not address whether it meets either categories (a) or (c) of the second element.

2. *The description of DO impairment on pages 12 and 60-62 of the BSR is not a rule*

¶ 52 Page 12 of the BSR states in relevant part:

> We found the following when applying [Washington's DO] standards to the model results:
>
> - The total area of greater Puget Sound waters not meeting the marine DO standard was estimated to be around 151,000 acres (612 km2) in 2006, 132,000 acres (536 km2) in 2008, and 126,000 acres (511 km2) in 2014. These areas correspond roughly to about 23%, 20%, and 19% of greater Puget Sound in each year, respectively, excluding the intertidal zone.
> - Noncompliant areas are located within all Puget Sound basins except Admiralty Inlet. All areas not meeting the water quality standard have depleted levels of DO in the water column as a result of human loadings from Washington State. Model computations take into account multiple oceanographic, hydrographic, and climatological drivers, so that depletions due to human activity alone can be computed by excluding other influences, such as that of the Pacific Ocean.

CP at 36.

¶ 53 The above comments show that the modeling scenarios run using the SSM projected that every single basin in Puget Sound, except Admiralty, had at least one water column layer that failed to meet DO standards. As argued by Professors Holtgrieve and Scheuerell, many of these noncompliant layers might actually be compliant due to limitations in the SSM's sensitivity. For purposes of the BSR, the report's authors classified these areas as DO-impaired.

¶ 54 BSR pages 60-62 discuss the SSM's results concerning DO depletion due to human causes. Page 60 states, in relevant part:

> The cumulative impact of all human activities causes DO concentrations to decrease by more than 0.2 mg/L at multiple locations in Puget Sound. Figure 25 shows the spatial distribution of minimum water column DO for both existing and reference conditions, along with the difference between the two, for 2006, 2008, and 2014. Spatial patterns in minimum DO under the reference scenario closely resemble the existing condition patterns. The difference plot shows that maximum DO depletions (depletions below the reference condition DO levels) are predicted to occur in inlets where flushing is relatively poor compared to the main channel ....

CP at 84.

¶ 55 Page 61 (right) is Figure 25, a graphic representation of Puget Sound's DO levels at reference levels without human influence, at existing levels, and the difference between the two, as predicted by the SSM.

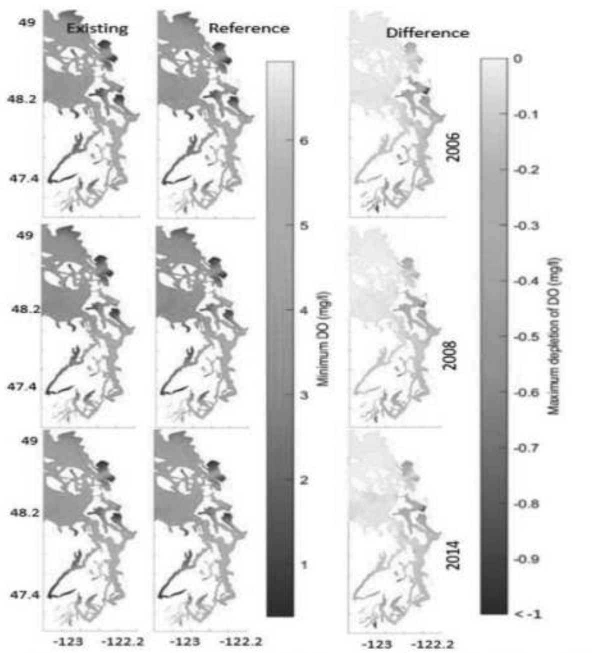


Figure 25. Comparison of the spatial distribution of predicted 2006, 2008, and 2014 minimum dissolved oxygen (DO) concentrations, corresponding reference condition scenarios, and the difference between them.
Areas that are green to blue are most sensitive to DO depletion from all human sources in Washington.

¶ 56 Page 62 reiterates the findings summarized in the abstract from page 12, but with more detail on duration and degree of DO noncompliance.

¶ 57 The City argued that when read together, the pages conclude "that all municipal WWTPs discharging to Puget Sound are causing or contributing to the alleged impairment, effectively expanding the existing list of 'impaired' or CWA 303(d) water bodies in Washington to include all of Puget Sound." CP at 1204.

[9] ¶ 58 During oral argument, the City withdrew this assignment of error.[6] We accept this concession. Similar to our conclu-

6. Wash. Court of Appeals oral argument, *City of Tacoma v. Dep't of Ecology*, No. 39494-8-III (June 7, 2023), at 40 min., 40 sec., *video recording by* TVW, Washington State's Public Affairs Network, https://tvw.org/video/division-3-court-of-appeals-2023061095/?eventID=2023061095.

sion in the previous section, BSR pages 12, 60, 61, and 62 do not state a directive. That is, they do not impel one to act. Rather, these pages state the authors' conclusions.

3. *Ecology's commitments in the denial letter and subsequent actions show it has adopted rules in violation of the APA*

¶ 59 In the abstract, it is difficult to discern whether Ecology's commitments to NWEA in the denial letter constitute a rule under the APA. It therefore is necessary to consider how Ecology has implemented its commitments.

¶ 60 We previously outlined how Ecology began implementing some of its commitments through the issuance of renewed individual permits while in the process of formulating a general permit. We now provide greater detail on this process.

The new general permit

¶ 61 Beginning in April 2018, Ecology convened meetings of the Puget Sound Nutrient Forum for the purpose of developing a nutrient reduction plan for Puget Sound. At the first meeting, Ecology outlined to stakeholders some options to address nutrient sources and some nutrient reduction strategies being used in other parts of the country. At the March 2019 meeting, representatives from around the country discussed their use of general permits to regulate nutrient pollution in their respective areas. Following these presentations, stakeholders expressed interest in a general permit that would address Puget Sound nutrient pollution. Pursuant to WAC 173-226-060, in August 2019, Ecology issued a preliminary determination to develop a general permit, and provided a 60-day comment period.

¶ 62 Ecology convened a Puget Sound Nutrient General Permit advisory committee to advise it in drafting permit requirements to reduce nutrient loads discharged into Puget Sound by WWTPs. The advisory committee represented diverse stakeholders, including WWTPs, environmental organizations, and state and federal agencies. The City was a member of the committee.

¶ 63 After several monthly meetings, Ecology developed a preliminary draft general permit and solicited public comment from January 27, 2021 through March 15, 2021. Ecology used the comments it received to develop a formal draft general permit, which it released for another round of public comment on June 16, 2021. Ecology issued the general permit on December 1, 2021.

¶ 64 The general permit categorizes permittees as dominant, moderate, or small—based on the amount of TIN they annually discharge into Puget Sound. Dominant and moderate loaders have TIN action levels that Ecology calculated to reflect the pounds of TIN each facility discharges each year. Dominant and moderate loaders are required to implement a nutrient optimization plan to maximize nitrogen removal by their existing treatment facility and submit a nutrient reduction evaluation to Ecology by December 31, 2025.

¶ 65 If a dominant loader exceeds its action level, it must submit a report with a proposed approach to reduce its annual TIN load by 10 percent but it does not need to implement the proposed approach unless it exceeds its action level two years in a row or three years during the five-year permit term.

¶ 66 If a moderate loader exceeds its action level, it must submit a report with a proposed approach to reduce its annual TIN load below its action level but does not need to implement the proposed approach unless it exceeds its action level two years in a row or three years during the five-year permit term.

¶ 67 Small loaders do not have any caps on nutrient discharges but must implement a nutrient optimization plan to maximize nitrogen removal by their existing treatment facility and submit an AKART analysis to Ecology by December 31, 2025.

¶ 68 The impact of these changes goes further than requiring the WWTPs to comply with existing water quality standards. As noted previously, these changes actually freeze existing nutrient loading limits because the action level is based on each permittee's prior year TIN load rather than existing water quality standards.

Renewal of individual permits

¶ 69 While Ecology was in the process of formulating the general permit, it imposed restrictions similar to those described in the individual permits for Birch Bay and the Big Lake WWTPs. Those individual permits became effective March 1, 2021, and do not expire until 2026.

The practical effect of the denial letter creates rules

¶ 70 Ecology argues that the denial letter cannot be a rule within the meaning of the APA because it does not direct, order, or require anything. We disagree. As explained below, it directs its own staff to impose new restrictions within NPDES permits.

First inquiry: Directive of general applicability

[10, 11] ¶ 71 The first inquiry is whether the purported rule is an order, directive, or regulation of general applicability. *Nw. Pulp*, 200 Wash.2d at 672, 520 P.3d 985. "[W]here the challenge is to a policy applicable to all participants in a program, not its implementation under a single contract or assessment of individual benefits, the action is of general applicability within the definition of a rule." *Failor's Pharm.*, 125 Wash.2d at 495, 886 P.2d 147 (citing *Simpson*, 119 Wash.2d at 648, 835 P.2d 1030). Here, Ecology's commitments in the denial letter are of general applicability because they apply to all WWTPs.

[12] ¶ 72 The parties, however, dispute whether the action is a "directive." As previously defined, a directive is something that impels action. The precise issue presented in this appeal is whether a directive can be an internal directive, e.g., a commitment by Ecology that its own staff will impose new requirements on permittees.

[13] ¶ 73 Ecology argues that including an internal directive within the APA definition of directive is inconsistent with *Sudar v. Department of Fish and Wildlife Commission*, 187 Wash. App. 22, 31-33, 347 P.3d 1090 (2015). We question some of the broad language used by the *Sudar* court.

¶ 74 We begin first by discussing *Simpson*. In *Simpson*, Ecology determined that the state's existing water quality standard required all NPDES permits issued to pulp and paper mills to limit dioxin discharges to no more than 0.13 parts per quadrillion because that was the level at which dioxin " 'may . . . adversely affect public health.' " 119 Wash.2d at 643, 835 P.2d 1030. "Ecology arrived at this numeric standard by using federal guidance and federal data, but without going through rule-making procedures." *Id.* at 643-44, 835 P.2d 1030. Ecology's staff included the new standard in all pulp and paper mills' NPDES permits. *Id.* at 644, 835 P.2d 1030.

¶ 75 The pulp and paper mills sued. They argued that this new numeric standard that Ecology's staff required in all renewed permits needed to be adopted through the rule-making process. The Supreme Court agreed. It noted that the nature of a rule is " 'it [must] apply to individuals only as members of a class.' " *Id.* at 648, 835 P.2d 1030 (quoting William R. Andersen, *The 1988 Washington Administrative Procedure Act—An Introduction*, 64 WASH. L. REV. 781, 790 (1989)). The high court concluded that the numeric standard was a directive of general applicability because it applied "uniformly to the entire class of entities which discharges dioxin into the state's waters . . . ." *Id.* It also concluded that the violation would subject the respondents to punishment if they did not comply with the new standard. *Id.* at 647, 835 P.2d 1030. Because the two inquiries for what constitute a rule were satisfied, the court concluded that the rule was invalid because Ecology failed to satisfy the APA requirements for rulemaking. *Id.* at 648-49, 835 P.2d 1030. *Simpson* stands for the proposition that "directive" includes an agency's internal directive to its staff for issuing permits.

¶ 76 In *Sudar*, the Fish and Wildlife Commission adopted Policy C-3620. The policy set "guiding principles and a series of actions it may follow to improve the management of salmon in the Columbia River Basin." 187 Wash. App. at 27, 347 P.3d 1090. The policy "outline[d] a number of objectives, including phasing out the use of nonselective gill nets in nontribal commercial fisheries . . . and the transition of gill net use to off-channel areas." *Id.* The *Sudar* court held that the policy was not a rule under the APA and distinguished *Simpson* on the basis that the policy was "unenforceable until and unless the Department promulgates rules that can be enforced on violators." *Id.* at 32, 347 P.3d 1090. This is not an apt distinction. In *Simpson*, the directive to the agency employees was not a promulgated rule. Rather, the agency's employees were directed to include a new standard in all renewed permits and, by doing so, the permitees were subject to punishment if they violated the new standard.

¶ 77 Ecology argues that construing directive as including an internal directive is inconsistent with *Northwest Pulp*. We conclude that the language relied on by Ecology is nonbinding dicta.

¶ 78 In *Northwest Pulp*, our Supreme Court reviewed a challenge to Ecology's adoption, in its manual, of two new methods for identifying the source of polychlorinated biphenyls (PCBs) in water, Methods 1668C and 8082A. 200 Wash.2d at 670, 520 P.3d 985. There, permit writers were required to use Method 608.3 to determine compliance with PCB limits but had discretion whether to use data collected by Methods 1668C and 8082A when evaluating the source of PCBs. *Id.* at 670-71, 520 P.3d 985. There, the court agreed with the lower appellate court's distillation of what characterizes a rule of general applicability: an agency action is not a rule when it " '(1) allows staff to exercise discretion, (2) provides for case-by-case analysis of variables rather than uniform application of a standard, and (3) is not binding on the regulated community ....' " *Id.* at 673, 520 P.3d 985 (quoting *Nw. Pulp & Paper Ass'n v. Dep't of Ecology*, 20 Wash. App. 2d 533, 500 P.3d 231 (2021), *aff'd*, 200 Wash.2d 666, 520 P.3d 985). Applying those standards, the court concluded that the challenged methods were not rules because permit writers had discretion to choose the best method for measuring PCB sources on a case-by-case basis. *Id.* at 674, 520 P.3d 985.

[14] ¶ 79 Admittedly, later in the opinion, the court noted that Ecology's internal manual had no independent regulatory effect. *Id.* at 676, 520 P.3d 985. This is the comment Ecology relies on for implying that only regulations can be a rule. We disagree for two reasons. First, there is no functional difference between a promulgated rule that adds new terms for renewing a permit and a directive to staff to add new terms for reissuing a permit. Second, the *Northwest Pulp* court's comment was surplusage and, taken literally, would have overruled *Simpson*. It is well established that statements in a case that do not relate to an issue before the court and are unnecessary to decide the case constitute obiter dictum and need not be followed. *Malted Mousse, Inc. v. Steinmetz*, 150 Wash.2d 518, 531, 79 P.3d 1154 (2003). If the court's passing comment was intended to change precedent, agencies could adopt rules internally without the rulemaking process simply by directing staff to include the new rules in every renewed permit. This would render the APA's requirement for rulemaking meaningless.

¶ 80 Here, unlike *Northwest Pulp*, Ecology directed its staff to include new requirements in both the individual permits and the general permit. The record indicates these requirements were nondiscretionary and were part and parcel of the commitments Ecology made to NWEA.

<u>Second inquiry:</u> *The action establishes, alters, or revokes any qualification or requirement relating to the enjoyment of benefits or privileges conferred by law*

¶ 81 To prove that the denial letter established a "rule" under RCW 34.05.010(16)(c), the City relies heavily on *Failor's Pharmacy* and *Hillis v. Department of Ecology*, 131 Wash.2d 373, 932 P.2d 139 (1997).

¶ 82 In *Failor's Pharmacy*, the Department of Social and Health Services (DSHS) issued policy memoranda changing the way DSHS calculated Medicaid pharmacy reimbursement rates. 125 Wash.2d at 491-92, 886 P.2d 147.[7] The policy memoranda established

7. *Failor's Pharmacy* was decided under a prior version of the APA when it was codified under chapter 34.04 RCW; however, the definition of "rule" and its five categories were the same then as today.

reimbursement tiers based on a pharmacy's business volume. *Id.* After several years operating under these new rate calculations, multiple pharmacies sued. *Id.* at 492, 886 P.2d 147.[8]

¶ 83 The pharmacies argued that the policy memoranda instituted invalid rules because they were orders/directives/regulations of general applicability that established, altered, or revoked a qualification or requirement relating to the enjoyment of benefits or privileges conferred by law. *Id.* at 494, 886 P.2d 147. DSHS responded that the policy memoranda did not " 'relat[e] to the enjoyment of benefits or privileges conferred by law' " under former RCW 34.04.010(2)(c) (1988) because pharmacies have "neither statutory nor contractual rights to payment until performance and can withdraw from the program at any time ...." *Id.* at 496, 886 P.2d 147. DSHS additionally responded that Medicaid participation was voluntary and the pharmacies were free to accept or reject Medicaid clients. *Id.*

¶ 84 The Supreme Court disagreed with DSHS by focusing on Medicaid patients. While federal case law suggested that Medicaid participation was not a benefit or a privilege conferred by law to Medicaid providers, Medicaid was a benefit conferred to Medicaid patients. *Id.* at 496-97, 886 P.2d 147. In holding that the policy memoranda instituted invalid rules, the court stated:

> [T]he inclusion of the reimbursement schedules in a unilateral contract does not preclude their status as a rule. ... The benefit of the Medicaid program runs to the Medicaid patient, RCW 74.09.200, and its enjoyment is altered by the change in reimbursement rates. By insulating reimbursement schedule changes from rulemaking requirements Defendant denied notice and comment to those intended beneficiaries of the program.

Id. at 497, 886 P.2d 147 (citations omitted).

[15] ¶ 85 *Failor's Pharmacy* directly supports the City's argument. The challenged portion of the denial letter promised that Ecology's permit writers would alter the qualifications and requirements for NPDES permits. A letter mandating that new performative language be included in all NPDES permits is indistinguishable from the memoranda in *Failor's Pharmacy* mandating new price terms in Medicaid reimbursement contracts. Furthermore, issuance of an NPDES permit is a privilege conferred by law because without an NPDES permit, no person or entity may discharge any substance into Puget Sound. RCW 90.48.160, .162.

¶ 86 Ecology attempts to distinguish *Failor's Pharmacy* by arguing that the new requirements in the permits are mandated by WAC 173-201A-510, which prohibits WWTPs from violating existing water quality standards. We disagree that the new permit requirements merely require the WWTPs to comply with existing water quality standards. Existing water quality standards set numeric levels for DO in Puget Sound but do not regulate or set numeric levels for nitrogen discharges. While nitrogen is one of several causes of DO impairment, it has never been subject to direct regulation until now.

¶ 87 We conclude that the City has satisfied both parts of the two-part inquiry and that the commitments in the denial letter are "rules," as defined by the APA. We further conclude that the new requirements in the individual permits and the general permit are unlawful. If Ecology desires to keep its commitments to NWEA, it must do so through the rulemaking procedures of the APA.

[16] ¶ 88 Affirm in part; reverse in part.[9]

8. Similar to this case, the pharmacies were affected by the agency's policy memorandum only indirectly, by the agency requiring its staff to include the new terms in its Medicaid reimbursement contracts. An additional similarity is the presence of a tiered system based on volume rather than a uniform requirement.

9. Amici raise the question of whether the City had standing to file suit in superior court. Ecology did not raise standing as an issue before this court. We generally decline to address issues raised solely by amici. *State v. J.W.M.*, 1 Wash.3d 58, 74 n.4, 524 P.3d 596 (2023); *State v. Hirschfelder*, 170 Wash.2d 536,552, 242 P.3d 876 (2010); *Teamsters Local 839* v. *Benton County*, 15 Wash. App. 2d 335, 352, 475 P.3d 984 (2020). For this reason, we decline to address the issue of standing.

WE CONCUR:

Fearing, C.J.

Pennell, J.

WASHINGTON STATE NURSES ASSOCIATION, UFCW 3000 and SEIU Healthcare 1199NW on behalf of certain of the employees they represent, Respondent,

v.

MULTICARE HEALTH SYSTEM, Appellant.

No. 84660-4-I

Court of Appeals of Washington, Division 1.

Filed September 18, 2023

Background: Unions representing employees sued employer that unilaterally recouped overpayments to employees, alleging that employer violated regulation allowing it to unilaterally recoup "inadvertent" and "infrequent" overpayments, and sought injunctive and declaratory relief. Employer removed the action, asserting that the claims were preempted by federal law. The United States District Court for the Western District of Washington, Lauren King, J., 2022 WL 3042013, disagreed and granted union's request to remand on question of whether adjustments complied with regulation. On remand, the Superior Court, King County, Douglass A. North, J., granted summary judgment in favor of unions. Employer appealed.

Holdings: In a case of first impression, the Court of Appeals, Diaz, J., held that:

(1) genuine issue of material fact existed as to whether employer's overpayments were "rare," so as to be "infrequent";

(2) genuine issue of material fact existed as to whether overpayments were "unintentional," so as to be "inadvertent";

(3) genuine issue of material fact existed as to whether overpayments were not deliberately done, so as to be "inadvertent";

(4) unions were not judicially estopped from raising claim that employer violated regulation; and

(5) unions' claims were not preempted by the National Labor Relations Act (NLRA).

Reversed and remanded.

1. Summary Judgment ⇨78

If the moving party does not satisfy its initial burden of proof to show by uncontroverted facts that there is no genuine issue of material fact, summary judgment should not be granted, regardless of whether the nonmoving party has submitted affidavits or other evidence in opposition to the motion.

2. Summary Judgment ⇨50

Summary judgment should be granted only if, from all the evidence, a reasonable person could reach only one conclusion.

3. Administrative Law and Procedure ⇨1241

Regulations are interpreted similarly to statutes.

4. Administrative Law and Procedure ⇨1245

In interpreting a regulation, the court construes the act as a whole, giving effect to all of the language used.

5. Administrative Law and Procedure ⇨1243

If a regulation is unambiguous, intent can be determined from the language alone, and the court will not look beyond the plain meaning of the words of the regulation.

6. Labor and Employment ⇨62, 2191

Under the Industrial Insurance Act, the State Department of Labor and Industries (L&I) has the authority to supervise, administer, and enforce all laws pertaining to em-

Elements of a Comprehensive Puget Sound Nutrients Program

Michael Connor, Ph.D., [1] and William Stelle[2]

A. Introduction

Continuing and projected human population growth and development in western Washington is generating a variety of water quality problems that threaten the health and aquatic productivity of Puget Sound, undercutting our efforts to recover salmon, the orca, and other aquatic life. These include the "conventional" pollutants like excess water temperatures in certain rivers and estuarine areas, low levels of dissolved oxygen in certain shallow embayments, and an array of "toxics" from runoff, spills and a variety of other sources. The Department of Ecology (DOE) has worked diligently over the last decade to examine whether excess nutrients are choking the system, and last fall proposed a new "general permit" to address an important component of the problem – increasing amounts of nutrients and other related pollutants from sewage treatment plants discharging directly into the Sound. DOE has invited public comments on its proposed permit, which as a general matter provides a good and creative framework from which to work. Below we offer both organizational and technical refinements to advance an approach that is designed to bolster the financial capability and a decision-making and science apparatus to do it effectively and efficiently. We also offer in part D a set of technical observations which dive deeper into the science and modeling issues which underscore the design and execution of an effective nutrients strategy. We see this as a generational opportunity to help rebuild the productivity of Puget Sound if we can get the details right. The most important ingredient for success will be the active leadership of both the regulatory community -- led by DOE and EPA -- and the water utilities which will shoulder a significant share of its funding and implementation.

B. Objectives

We write to recommend modernizing the conventional water quality regulatory machinery that builds upon the innovations which have occurred in several of the major estuaries around the coastal United States over the last two decades, including Chesapeake Bay, San Francisco Bay, the Gulf of Mexico and Massachusetts Bay. The approach embraces several objectives:

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[1] Mike Connor has worked for 45 years on coastal eutrophication issues as an academic (WHOI/MIT Ph.D. and Harvard School of Public Health post-doc), POTW manager (Boston Harbor Clean-up chief scientist for MWRA and GM of East Bay Dischargers Authority), NGO environmental manager (San Francisco Estuary Institute General Manager and New England Aquarium VP), and government regulator (founding EPA staffer for three New England National Estuary Programs and EPA consultant to John Armstrong when he started the Puget Sound Estuary Program at EPA10). He is a frequent Olympic Peninsula tourist and a recent retiree hoping to relocate there.

[2] Will Stelle has been deeply involved with salmon recovery in the Pacific northwest and California for years. He is currently the President of the Washington Water Trust Board and is a former two-term Regional Administrator of NOAA Fisheries during the Clinton and Obama administrations, where he managed the listings of multiple salmon populations in the Pacific northwest and California and implemented the first stages of ESA salmon recovery efforts, emphasizing reforms in the four "H's" of harvest, hatcheries, hydropower and habitat. He has also been heavily involved with Puget Sound conservation, serving as co-chair of its Federal Caucus during his second tour of NOAA duty. The views expressed here are personal and do not reflect the Washington Water Trust or other organizations with whom he is affiliated.

1. Adopting a comprehensive approach that addresses the major sources of nutrients into the watershed, both from pipeline discharges[3] *and other sources*;

2. Embracing multiple geographic scales that gets at the big picture by designing local strategies tailored to the local ecology;

3. Designing a phased implementation approach that starts immediately on those actions which can be taken with current capabilities while planning and building the needed improvements which will take years;

4. Providing the financial capacity to do the job effectively and efficiently, funding the necessary planning, implementation, compliance and effectiveness monitoring and continuing to invest in new science to steer the effort; and

5. Embracing other necessary imperatives including the use of "green infrastructure" where possible, reducing greenhouse gas emissions and accounting for other climate change adaptations; reflecting social equity and fairness imperatives, and honoring Tribal Treaty rights and obligations.

C. Key Elements

Our approach recognizes that the challenges in tackling nutrients and DO problems successfully go far beyond the normal permit-by-permit, pipeline-by-pipeline approach, which is how the permitting machinery typically works. It presents a wonderful opportunity to strengthen the way that regional water quality improvements are planned, permitted, and implemented, and potentially tied into other riverine/estuarine habitat objectives that are vital to salmon recovery. Because Puget Sound is not nearly as impacted as the other major national estuaries, we've got time to develop a new framework for managing these challenges under the umbrella of a new general permit, which should include the following:

1. A new, invigorated collaboration for developing and implementing the strategy which includes the Department of Ecology, other government regulators, Tribal sovereigns, the local entities representing the major sources of nutrients, and other essential stakeholders. The recent engagements around nutrients have unfortunately been far too polarized, with the various "camps" seemingly talking past one another rather than addressing the significant unresolved issues. We need to change the dynamic and spend less time arguing positions and more time resolving issues successfully, steered by clear-eyed science about what we know and don't know about how things work. DOE has provided in its proposal a good platform from which to advance which opens the door to creative solutions, but we seem to be defaulting into hardened "positions" as we advance;

2. A new consortium of municipal sewage agencies to serve as the permit holder and shoulder the responsibility for coordinated planning, implementation, monitoring, information-sharing and adaptation on a collective basis;

3. An expert science institution to provide independent analysis, modeling, monitoring, information sharing, and performance tracking capabilities to verify if we are achieving the desired outcomes and enable us to adjust as needed;

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[3] We encourage including under the general permit both pipeline discharges into marine waters and also discharges into the rivers upstream which flow into the Salish Sea.

4. Increased funding for modeling and monitoring provided by new nutrient discharge permit fees tied to nutrient loading levels and coupled with state matching grant support to help fund the institutional capacity to do the work and provide immediate and direct financial incentives to reduce loadings;

5. Consistent planning for potential nutrient discharge upgrades across large and small dischargers to ensure shared access to good information, local ownership and timely implementation; and

6. Updating science-based water quality goals that are based on now-outdated decades-old framing of oxygen standards to be reflective of the hypoxia area-time framework used by Long Island Sound, the Gulf of Mexico, and the Chesapeake Bay.

D. More Specific Comments on the Draft Nutrients General Permit

We include below more technical background and specifics for the general ideas expressed above.

1. **Puget Sound's eutrophication problem is slowly progressing.** Puget Sound's oxygen status has been measurably declining for more than 60 years. The declines have proceeded slowly, and the specific actions to most cost-effectively solve the problems are not yet clear. DOE and the region overall has time to get the science and policy right. In the interim, DOE's plans for freezing loads and encouraging optimization as an important first step are well-supported.

   DOE emphasizes the comparison to other estuaries around the US that have faced the same issue. While comparisons are difficult since different agencies use slightly different assumptions, a rough comparison of the nitrogen loading to the Sound to other major US estuaries[4] with active nutrient management programs suggests that Puget Sound has a number of qualities in its favor. These characteristics have mitigated the impact of its discharges and need to be better understood so as to gauge the effectiveness of any particular regulatory strategy. The ratio of Puget Sound's population to its water area suggests it is in slightly better shape than the other estuaries, and Puget Sound has two other advantages that allow the region and DOE time to respond:

   a. Its average depth is much deeper than the other urban coastal areas giving it a significantly reduced load of nitrogen per volume of water. Because the load is diluted

[4] This comparison builds on an approach by Kelly (2008) https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1046&context=usepapapers and adds some data from Puget Sound (https://apps.ecology.wa.gov/publications/SummaryPages/1203049.html) and SF Bay (loadings only include POTW discharges, not rivers like the SSM). The Boston Harbor data are from before the Boston Harbor Project that moved the outfall offshore. The data should be considered illustrative of the overall points being made. They are very rough estimates with variability of at least 30-40% even including such parameters as area and volume. The comparison does point out the importance of understanding the zone of impact of deep discharges of nutrients and the exchange with surface waters that would allow light to reach enriched waters and grow phytoplankton.

over a much larger volume, the overall nitrogen concentration contributed by POTWs is reduced.

b. Puget Sound also differs significantly from these estuaries in that the import of nitrogen from deep offshore coastal waters dominates its nutrient loads.[5] As a result, reducing loadings from pipeline discharges across-the-board are less certain to achieve results than locally-tailored strategies.[6]

Estuary	Population	Area	Volume	Depth	Residence Time	Annual N load	Load per volume	Concentration
Units	Millions	sq.mi	Tr gal	(avg ft)	months	million lbs	uM/m3-yr	uM Nitrogen
N. Gulf of Mexico	18	7700	158	100	6	4004	217	108
Chesapeake	16	4480	18	21	7.6	250	156	99
Long Island Sound	15	1320	22	78	6	186	1770	37
SF Bay	8	550	3	14	0.8	40	317	21
Puget Sound	4	1020	44	450	2	104	49	12
old Boston Harbor	2.5	50	0.2	17	0.27	31	3927	87

2. **An integrated nutrient strategy needs to include all POTWs discharging into or upstream of Puget Sound, and needs to be based upon an overall nitrogen budget which encompasses all sources of nutrients -- both pipeline discharges and other "non-point" sources.** The proposed permit's focus on POTWs directly discharging into Puget Sound fails to recognize the importance of other "direct dischargers" of nitrogen upstream of Puget Sound. Moreover, an overall nitrogen budget for Puget Sound is crucial to making a convincing argument that the actions proposed by DOE will have measurable impacts and result in the intended outcomes..

The draft permit indicates that the nutrient loads that POTWs are discharging into the rivers upstream are only 15-20% less than those being discharging directly into Puget Sound, yet riverine POTW discharges are not proposed to be covered by the general permit. DOE states that only deep water, POTW-derived, summertime nitrogen loads need consideration. Some of the assumptions about the interaction and seasonality of POTW and riverine discharges are illustrated by virtual dye models, but the assumptions would be much more compelling if they were documented by the Salish Sea Model (SSM) outputs for eutrophication. A detailed look at this issue by Banas et., 2015[7] concluded that biological parameters such as bacteria and nutrients have much less long-distance transport than standard salinity measures. Besides just tracking the movement of dye particles, the SSM should use its capacity to determine what the percentage contribution of distant sources to local sources for the areas of concern. Since the problems in the Sound are correlated with long residence times of 100-200 days, this assumption needs validation by a model—consider the counter example of the agricultural runoff to the Mississippi River causing the Gulf of Mexico dead zone.

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[5] Mackas and Harrison (1997) estimate the nutrient loads exchanging through the Juan de Fuca and Admiralty Straits to be about 6-8 times greater than the wastewater load (https://apps.ecology.wa.gov/publications/documents/1103057.pdf).

[6] Even zeroing out all anthropogenic loads from the rivers and the POTWs is predicted by DOD to have a small cumulative effect on algal biomass (~5.4%) and Sediment Oxygen Demand (~17%) (https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2017JC013650).

[7] https://www.jstor.org/stable/44851502?seq=1

Finally, back to the big picture, much of the human-derived load input originates from Canada from their POTWs and Frasier River discharges. These are obviously not under DOE's jurisdiction, but they suggest that a parallel effort to secure a bilateral commitment from our northern neighbors to stabilize and reduce these loads will be important for success..

3. **Name a regional consortium as the permit lead.** The permit recognizes that regulating nutrients requires an estuary-wide approach. Rather than having 50+ individual agencies providing contrasting information using different assumptions, it should allow compliance through a new consortium of the POTWs, and commit to using more than half of the $9 million provided by the legislature to fund this organization's start-up. The consortium would be charged with providing annual reports that summarize agency data collection, integration of those data to become regional information, development of consistent agency optimization plans, tracking implementation and effectiveness of those optimization activities, and an evaluation of the costs of implementing further nutrient reduction.[8] Charging the consortium to develop the framework of optimization plans for its agencies would allow more rapid development of a consistent set of the most cost-efficient solutions possible. While optimization plans need to be tailored to individual facilities, there are a standard set of tools that agencies can use.

4. **Long-term wastewater planning is not effective dealing with single issues**. A strict limit on one item (3 ppm of total nitrogen) may not be effective for maximizing the productivity of Puget Sound. Other wastewater treatment issues--e.g. control of Combined Sewer Overflows or Sanitary System Overflows, maximizing the use of recycled water, maximizing freshwater stream flow, treating first-flush stormwater, minimizing toxics discharges-- may be more cost-effective. . A 3-ppm nitrogen goal is certainly not consistent with minimizing the carbon footprint.[9] The permit should encourage the integration of long-term nutrient reductions into overall, long-term wastewater plans for the wastewater utilities. These plans should be updated every permit cycle and reflected in each utility's individual capital plans. Finally, the permit should encourage these long-term plans to consider "green engineering" designs such as increased recycling, wetlands discharges, or sea level rise protections, etc. These "green" solutions would be things the wastewater utilities and the broader Puget Sound community would embrace. POTW capital plans are multi-decade commitments. A "trade" that allows flat nitrogen loads for XX years with implementation of a "green" engineering solution would encourage action.

5. **Charge the POTW consortium with developing a plan to reduce hypoxic zones in the Sound**. Besides nutrient loads, there are several other early actions that may be quicker to implement and more cost-effective (e.g., summertime nitrification; receiving water aeration; effluent aeration; effluent diversion for irrigation; integrating stormwater first flush treatment; wet

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[8] A pertinent example is the San Francisco Bay Area nutrient general permit (https://www.waterboards.ca.gov/sanfranciscobay/board_decisions/adopted_orders/2019/R2-2019-0017.pdf) which uses the Bay Area Clean Water Agency (BACWA), a joint powers agency that represents the 40+ wastewater agencies to compile monitoring data, funding for monitoring and modeling of the Bay for eutrophication, development of regional strategies for the area's POTWs to reach different nutrient load targets, and summarizing regional implementation of load reduction efforts.

[9] The higher carbon footprint required by a 3-ppm goal (due to the required addition of methanol or other carbon sources and much higher energy usage for pumping and aeration) was documented in DOE's November 13, 2020 forum.

weather controls for minimizing DO impacts). Some of these actions could be tested in the early stages of permit implementation.

6. **Use incentives to increase early adoption.** Given the newness of the nutrient general permit, the permit "sticks" for exceeding action limits should be delayed until the next cycle and replaced by "carrots" of assuring agencies that meet the action limits for these five years (or even better performance) shall have the same action levels in the next permit cycle. The major challenge in the SF Bay nutrient permit has been how to encourage early implementation. What we've found is that given the challenges of capital accumulation, spending, and permitting, the major thing the agencies need is time**.** Two permit terms would give them the planning certainty to incorporate into their capital planning. For example, the costs of "sidestream" treatment would be easier to absorb if they allowed compliance with the nutrient permit for 20 years.

7. **Consider nutrient fees**. Nutrient discharge fees have been used successfully in Long Island Sound and the North Sea to develop the most cost-effective solutions for nutrient removal. Both regions have found that ~$6 per pound of nitrogen becomes an efficient trace-off for maximizing nutrient reduction. Charging a nutrient discharge fee (similar to carbon pricing) is probably the most cost-efficient method for providing regional equity. Adopting a small fee (e.g. $.05-.10 per pound of nitrogen discharged) early would enable funding of the consortium's regional planning study, an independent model evaluation group, or cost-sharing for implementing any nitrogen optimization plans proposed by member POTWs. Such fees also provide a structure for additional Clean Water funding provided by the state by showing serious POTW agency intent.

8. **One Sound, One Science.**[10] The multi-billion capital costs that may result from the permit requires an open Puget Sound science community that works together to build a common body of scientific knowledge. Puget Sound has many different agencies providing information about the Sound that needs to be summarized regularly to ensure the regulatory and conservation agenda is driven by a process that tries to reach consensus on the science of the Sound. This open science community will have the capacity to adapt and inform future water, societal, and environmental decisions across multiple organizations and programs. "One Sound, One Science" will accelerate the discovery of facts and innovation within the open science community by exploring genuine differences in scientific opinion and addressing them in a transparent manner. Ver significant costs of managing nutrient discharges to the Sound will be (and should be) borne by public wastewater utilities, who will then pass those costs along to all of us. They deserve a role in the governance of how to ensure collaboration and communication among Sound scientists, agencies, and stakeholders that may have independent scientific missions to fulfill. An open science community that is well-connected with the policy and management community and other users of science has the capacity to inform decisions, adapt to change, and improve the existing science infrastructure.

Of most importance to this "One Sound, One Science" principle is independent peer review of the Salish Sea Model (SSM), as undertaken for the Chesapeake Bay, Long Island Sound, Great Lakes, and Massachusetts Bay models. While the model results have passed a limited peer

[10] This concept appears in many regions of the country, The slogan is borrowed from the Sacramento delta.

review appropriate for scientific publication[11], its multi-billion dollar impact on the nutrient management strategy selection requires a more extensive review by an independent Model Evaluation Group (MEG). The review needs to extend to estimate the model's uncertainty in its prediction of management scenarios. As good as the model is, it is significantly limited by a paucity of data for biological transformation processes that are crucial to its conclusions -- as is very well recognized by its authors. It is quite simplistic in its handling of primary production, sediment diagenesis, zooplankton grazing, light penetration, and it uses settling velocities of carbon five times higher than normal to reproduce the hypoxic zone in Hood Canal and the southern Sound to match with one year of data. Eutrophication models are extraordinarily sensitive to light-limitation and grazing-limitation , which can overwhelm the benefits of nutrient control measures. The existing model outputs make it hard to evaluate this issue.

9. **Make DOE's DO Standard more relevant to estuarine eutrophication.** Before capital planning by the POTWs is finalized, DOE needs to develop a much more sophisticated approach to its DO standards to ensure that money spent on improving Puget Sound's productivity is more intelligently spent. The driver for reducing nitrogen loading is to comply with the state standard of preventing a decline of 0.2 ppm from baseline when water quality standards are violated. As a driver, this standard has two limitations: 1. It is not tied to a specific biological impact; and 2. It is beyond the predicted confidence level of even very sophisticated models. EPA's water quality standards are based on data from exposing organisms to different concentrations of parameters of concern, determining the actual level of impact, and incorporating a safety factor. Estuarine scientists in the Chesapeake, Long Island Sound, or Gulf of Mexico have developed a more advanced approach to consider the time and volume of water that is within certain ranges of percent saturation or absolute concentrations based on effects to local species. The general permit also presents hypoxic zones in the Sound, and it would be easy to adapt the new nutrient goals to address the size and timing of hypoxic zones. This characteristic is much more amenable to monitoring and modeling. Most scientists would argue that large scale estuarine DO models are hard-pressed to characterize DO to 0.5 ppm.[12] Often diurnal changes can vary DO by several parts per million and seasonal changes by twice that. The most obvious alternative to the DOE approach would be to use the same TMDL approach it uses for every other contaminant and use the SSM to calculate what nitrogen loads will allow Puget Sound to meet its DO standard. Such an approach would also give the POTW community clear guidance for their future capital plans.

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[11] https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2017JC013650

[12] See DOE's model's Table 2 in https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2017JC013650)

Final Treatment Plant
Financial Capability Assessment Guidance
Puget Sound Nutrient General Permit

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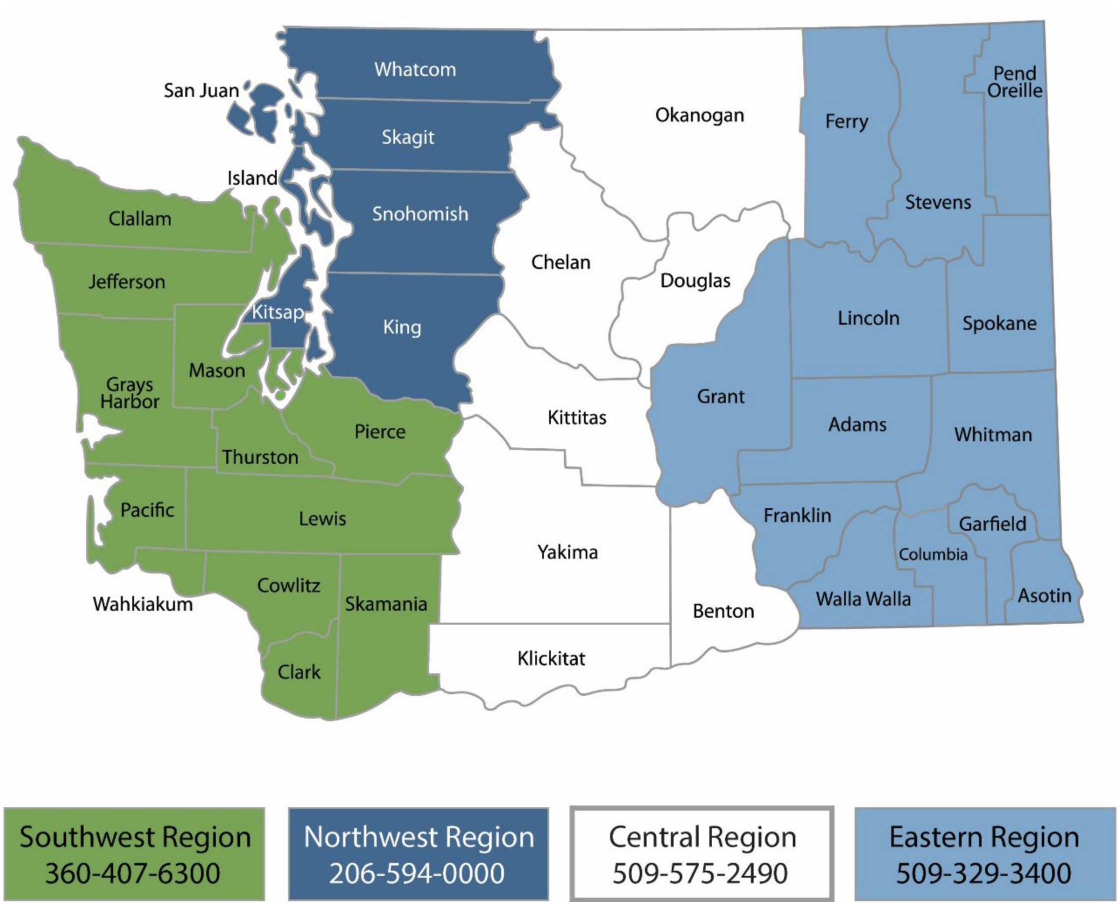

Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	P.O. Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	P.O. Box 330316 Shoreline,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

Final Financial Capability Assessment Guidance

Puget Sound Nutrient General Permit

Updated 10/2024

Water Quality Program
Washington State Department of Ecology
Olympia, WA

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DEPARTMENT OF
ECOLOGY
State of Washington

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Abbreviations and Acronyms

ACS	American Community Survey
AWC	Association of Washington Cities
AKART	All Known, Available, and Reasonable Methods of Prevention, Control, and Treatment
BLS	Bureau of Labor Statistics
CAP	Consumer Assistance Program
CDP	Census Designated Place
CPH	Pollution Control Cost per Household
CWA	Clean Water Act
CWSRF	Clean Water State Revolving Fund
EPA	US Environmental Protection Agency
FAA	Financial Alternatives Analysis
FCA	Financial Capability Assessment
FPL	Federal Poverty Level
LQI	Lowest Quintile of Income
LQPI	Lowest Quintile Poverty Indicator
MHI	Median Household Income
PSNGP	Puget Sound Nutrient General Permit
RCW	Revised Code of Washington
TIN	Total Inorganic Nitrogen
WWTP	Waste Water Treatment Plants
WQS	Water Quality Standards

1. The Purpose of Ecology's Guidance

The Washington State Department of Ecology (Ecology) issued the Puget Sound Nutrient General Permit (Nutrient Permit) on December 1, 2021. The Nutrient Permit requires 58 publicly owned domestic wastewater treatment plants (WWTPs) that discharge wastewater into Puget Sound, to prepare and submit a report to Ecology that identifies reasonable treatment alternatives as part of a required AKART (all known, available, and reasonable methods of prevention control and treatment) analysis for reducing nutrient discharges. The Puget Sound Nutrient General Permit has assigned a category of small, moderate, or dominant to each WWTP based on their percentage of the total inorganic nitrogen (TIN) load currently discharged to Puget Sound.

Wastewater Treatment Plants with Dominant or Moderate TIN loads are required to prepare a Nutrient Reduction Evaluation, which includes an AKART analysis and an Economic Evaluation of reasonable treatment alternatives. For WWTPs with Dominant or Moderate TIN loads, permittees must develop reasonable treatment alternatives for achieving two different levels of treatment: (1.) AKART for nitrogen removal (annual basis) and (2.) 3 mg/L TIN (or equivalent load), as a seasonal average (April through October).

Wastewater Treatment Plants with Small TIN loads are required to prepare an AKART analysis and an Economic Evaluation of reasonable treatment alternatives to maintain an annual TIN average of < 10 mg/L.

For all the WWTPs regulated by the Nutrient Permit, an Economic Evaluation of reasonable treatment alternatives includes completion of an affordability assessment to help identify an economically reasonable level of treatment in the context of AKART.

As referenced on Ecology's website and in the 2022 Fact Sheet, Ecology has used the US Environmental Protection Agency's (EPA) Financial Capability Assessment (FCA) guidance when looking at options for assessing financial capabilities of municipal WWTPs to implement requirements under the Clean Water Act.[2] Specifically, the EPA assessment helps identify the feasibility of permittees to take on the financial costs of an upgrade or municipal wastewater capital improvement reducing nutrients in wastewater effluent by considering factors such as debt capacity of a community, affordability of wastewater utility rate increases to impacted households, and disproportionate impacts to low income and impoverished populations.

Background

In February 2023, the EPA updated its Clean Water Act Financial Capability Assessment Guidance (2023 EPA guidance) to supplement and describe the following: 1995 Interim Economic Guidance for Water Quality Standards (1995 EPA guidance from here on) and 1997 Combined Sewer overflows Guidance for Financial Capability Assessment and Schedule

2 https://ecology.wa.gov/regulations-permits/permits-certifications/nutrient-permit#:~:text=The%20Nutrient%20General%20Permit%20applies,the%20WWTPs'%20existing%20individual%20permits.

Development (1997 EPA guidance from here on).[3,4,5] The largest additions to otherwise similar calculations across both historical guidance approaches is the Lowest Quintile Poverty Indicator (LQPI) that defines disadvantaged households within a community, and the "Expanded Economic Impacts Matrix" that combines the LPQI with previous measures of financial health.

Refining calculations: While Ecology recommends continued use of EPA's FCA guidance, the release of the February 2023 version (revised March 2024) and an updated EPA spreadsheet tool created an opportunity to review and improve its usefulness for evaluating public project impacts in the context of state-specific data.

For example, at the time of this writing, EPA's FCA spreadsheet tool provides calculations necessary to evaluate wastewater treatment projects under "Alternative 1" in the 2023 EPA guidance. However, Alternative 1 (based on 1997 FCA guidance) is intended for schedule development and negotiation, and Section 3 (based on 1995 Water Quality Standards (WQS) guidance) is intended to guide states in evaluating the economic impact of water quality decisions (2023 EPA guidance pg. 34). Despite the former approach garnishing an outsized level of detail and support in EPA's 2023 guidance document and spreadsheet tool, the context of the latter is more applicable to requirements of the Nutrient Permit. In addition, the EPA's LQPI leverages national baselines in its calculation and reports impacts in total (i.e. existing and project impact together) that could limit fair and robust evaluation in the Washington state context. [6]

To be consistent with EPA's 2023 guidance and available tools, whilst better assisting Washington public sector wastewater entities, Ecology developed an amended EPA FCA spreadsheet tool (hereafter referenced as Ecology's spreadsheet tool, located on Ecology's Puget Sound Nutrient General Permit web page). Ecology's spreadsheet tool aligns calculations with Section 3 of EPA's 2023 guidance "economic impact analysis for WQS decisions for the public sector." To this, Ecology's spreadsheet tool also reports total impacts and non-project baselines, state-regional level baselines, and alternative measures like costs as a percent of lowest quintile of income (LQI).

No new data inputs are needed to complete Ecology's spreadsheet tool beyond what was already required in EPA's configuration. Ecology's spreadsheet tool also fully maintains EPA's original Alternative 1 results and overall layout to the degree that they are useful for other federal or state consultation.

The purpose of this guidance document is to:

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[3] https://www.epa.gov/system/files/documents/2023-01/cwa-financial-capability-assessment-guidance.pdf
[4] https://www.epa.gov/system/files/documents/2024-01/interim-economic-guidance-water-quality-standards-workbook-1995.pdf
[5] https://www3.epa.gov/npdes/pubs/csofc.pdf
[6] Note that other versions and vintages, reflecting adjustments to the EPA's FCA calculator may be in use elsewhere throughout state government, including Ecology. If completing an FCA for a use outside of Nutrient Permit purposes, be sure to consult with appropriate contacts.

- Provide tips for completing Ecology's spreadsheet and steps for submitting materials to Ecology (Section 2),
- Describe Ecology's motivation in amending EPA guidance (Section3), and
- Give updated information on funding opportunities for public wastewater treatment plants in Washington state (Section 4).

Environmental justice considerations

> Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations, and policies (**RCW 70A.02.005**).

Ecology supports state and local government evaluation of environmental justice impacts of permitted actions on rate payers and vulnerable populations and corresponding efforts to mitigate negative impacts for communities that have the greatest environmental and health burdens.

This FCA guidance and the assessment results are not intended to be an absolute or comprehensive picture of the environmental justice impacts from municipal wastewater management, including any nutrient reduction actions to comply with the Nutrient Permit. Permittees are required to assess environmental justice broadly and identify strategies to mitigate harms and amplify benefits for people experiencing the greatest environmental and health burdens in the Nutrient Permit (page 18).[7]

In this FCA guidance, Ecology provides tools to understand the *financial* impacts of anticipated permitted actions. These financial impacts include economic justice considerations such as, income inequality, poverty, and income-based food assistance among other measures. Permittees should incorporate the recommended justice considerations within their FCA, particularly the lowest quintile of income (LQPI), with the broader environmental justice review in the Nutrient Permit to develop a fuller understanding of the equity considerations of each permitted project.

2. Analytical Steps and Deliverables

Governments have the authority to levy taxes and distribute pollution control costs among households and businesses according to the tax base. Similarly, sewage authorities charge for services, and thus can recover pollution control costs through user fees. Whether or not the community faces substantial impacts from the Nutrient Permit depend on existing pollution control burdens, the cost of new pollution control projects, the financial health of the community, and its socioeconomic vulnerability, among other factors.

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[7] https://apps.ecology.wa.gov/paris/DownloadDocument.aspx?Id=390719

To provide a standardized categorization of these impacts, **we recommend the following steps outlined in Ecology's FCA spreadsheet tool (tab references in red below), and related analytical sections of the 2023 EPA FCA guidance**.[8] This multistep approach includes:

1. Identifying your affected community (**Instructions_Demographic, Inputs_Demographic**),
2. Calculating pollution control cost per household as a percent of median household income (%MHI) and upper limit of the lowest quintile income (%LQI) (**Instructions_RI, Inputs_RI**),
3. Determining initial financial capability through a combination of %MHI and an index of six socioeconomic, debt, and financial indicators (**Instructions_FCI, Inputs_FCI**),
4. Calculating the Lowest Quintile Poverty Indicator (LQPI) score (**Instructions_Results_LQPI, Results_LQPI**),
5. Combining the results of the Initial Economic Impact and the LQPI score to determine the Expanded Economic Impact (**Results_FCA_ECY**),
6. Performing a Financial Alternatives Analysis (FAA) (**Instructions_Checklist_FAAs , Checklist_FAA**),
7. Iterating step 1-6 as needed with any updates resulting from the financial alternative analysis and related research.

Upon completion, we recommend permittees submit, at a minimum, the following materials to Ecology's Water Quality Permitting Portal (WQWebPortal):

1. The Ecology FCA spreadsheet tool, filled out with required information. This includes providing links or citations for non-automatically generated data inputs (in comments and sources columns, where applicable). Please attach documentation if an internal source is used. The WWTP should provide this information for chosen treatment alternatives. Permittees may also include in materials for context additional instances of the tool, related to the consideration of other options (please clearly mark as non-chosen alternatives).
2. A document discussing results of the Expanded Financial Capability Assessment (Results_FCA_ECY). This should include, but is not limited to:
    - Screenshot(s) of the expanded FCA matrix with and without project(s), along with intermediate statistics such as %MHI and %LQI.

[8] Caveats and additions to note when comparing EPA's current online FCA spreadsheet tool and Ecology's spreadsheet tool are discussed in greater detail in Section 2.2.

- Project and community details that may drive (or attenuate) impacts.
- Other key inputs and unique characteristics of the affected community that the permittee feels are not fully captured by the analysis (an example could include a community that imposes restrictions on property taxes).
- Summaries of similar relevant analysis performed by, or known to, the permittee. This could include data, presentations, local rate studies, surveys, or interviews.

3. A completed FAA. This can be printed from the completed Ecology FCA spreadsheet tool (Checklist_FAA), or a word document if room for additional discussion and formatting is desired.[9, 10]
4. Supplemental material as needed.

When preparing materials, keep in mind that break points between categories in the FCA analysis are not, nor are intended to be, an absolute or comprehensive demarcation of financial capability.

Identifying overburdened communities and barriers to affordability do not relieve jurisdictions from meeting Water Quality Standards. On one hand, low-income households may pay a higher percentage of their total income for basic services and clean water, but on the other, if water quality standards of a community remain lower, overburdened and/or low-income neighborhoods will likely continue to suffer impacts to human health and use of the state's waters for activities such as swimming, and fishing. In short, if one of the intended goals of the permit is to address impacts to residents, allowing lower water quality may have the opposite effect by increasing pollution in the neighborhoods where they live, recreate, or consume local fish and shellfish.

While the Financial Alternatives Analysis (FAA) provides permittees, Ecology, and the public, information about mitigating efforts, where high impacts are found, it is especially critical that communities develop a solution that accommodates the need to protect the receiving water while also providing a level of service to all residents within their community. In these instances, Ecology encourages permittees to evaluate, or re-evaluate, tiered or other alternative rate structures to offset adverse effects to the lowest income populations within the sewer service area or other innovative measures (e.g., fixed vs. variable charges, efficiency-

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[9] We highly recommend first reviewing Chapter 4 of this guidance for funding and rate assistance options, and Appendix C of EPA's 2023 FCA Guidance for additional details and resources associated with FAA question.

[10] See EPA compendium of Drinking Water and Wastewater Customer Assistance Programs that describes the benefits, implementation, and examples of customer assistance programs (CAPs) throughout the country (https://www.epa.gov/waterfinancecenter/compendium-drinking-water-and-wastewater-customer-assistance-programs). EPA's financial leadership guidance offers additional discussion on several themes found in the FAA (https://www.epa.gov/waterfinancecenter/water-infrastructure-financial-leadership).

oriented rate design, or usage based rates) that ensure affordability when adopting a new rate structure to support treatment upgrades.

The Association of Washington Cities (AWC) 2018 Utility Rate Survey is an excellent resource for sewer rates and examples.[11] These data allow permittees to compare utility rates, rate structures, number of connections, and other characteristics for up to three cities at a time (note there are no counties or special purpose districts included in the AWC data). Out of 295 communities Ecology surveyed in 2016, 116 offered a discounted rate based on criteria determined by the billing entity or city ordinance.[12]

2.1 Notes on Identifying the Affected Community

It is important to first define the affected community prior to completing other steps in the FCA. This is to ensure that fiscal and socioeconomic data is appropriately described throughout the analysis. For the purposes of the FCA, the "affected community" is typically made up of households at the city, town, or Census designated place (CDP) level, in a utility or water-sewer district service area responsible for paying the compliance costs of water treatment (see 57 RCW for water-sewer district definitions). We reference "city" hereafter for simplicity.

In the simple case (Case A), water-sewer districts generally line up with the jurisdictional boundaries of a single city, while in more complex cases, others may serve just portions of a city, multiple cities, or some combination of cities and portions of cities.

- **Case A (Simple):** When all households in a single city pay compliance costs of water treatment, the city is the affected community.

  Case B. When all households in two or more cities pay compliance costs of water treatment, multiple cities make up the affected community.

- **Case C**. One or more cities with partial service can make up the affected community if a predominant share of households within each are responsible for paying the compliance costs of water treatment.

  What constitutes a "predominant share" should be dependent on several factors. Generally, at least 75% of all households in the city should be responsible for paying the compliance costs of water treatment. More importantly, households that are not in the service area but included by way of city level reporting should not skew fiscal and social information in a material way. Permittees should provide, to the extent possible, quantitative or qualitative information about the balance of these households including but not limited to income, average assessed property value, and unemployment rates. Documented plans to connect

[11] https://datadatadata-awcnet.opendata.arcgis.com/pages/utrs2018
[12] Summary report: https://apps.ecology.wa.gov/publications/documents/1710024.pdf . Data available at: https://data.wa.gov/Natural-Resources-Environment/2016-Residential-Sewer-Rate-Survey/sibs-5k6j/data

the balance of households to services in the foreseeable future may be another justification for including otherwise partially served cities as the affected community.[13]

- Any combination of **Case B** and **Case C** can make up the affected community
- **Case D**. If only a portion of a single city is served (e.g., less than 75% of households served in a small special district), and limited in reporting standard fiscal and socioeconomic data, you may consider the city as the affected community. As with **Case C** above, permittees should take efforts to consider whether socioeconomic information at the city level would misrepresent the subset of households responsible for compliance cost. If so, describe to the best of your ability how, or contact Ecology for additional guidance.

A Note on Tribal Service Agreements

Permittees may have agreements with Tribes to provide wastewater services on Tribal reservation lands. Therefore, we encourage permittees to consider the following questions for each Tribe impacted by this permit:

1. Do you have a wastewater service agreement with neighboring Tribe(s)?
2. What is your relationship with the Tribal government?
3. Is the Tribe (Tribal government) aware that you will report social and economic data to Ecology for this permit?

Before collecting any Tribal information, permittees should discuss the data required by the FCA with the Tribes included in their wastewater service agreements. These discussions should describe the purpose of the PSNGP and the FCA and whether publicly available data accurately describes the portion of the Tribe affected by the service agreement.

Ecology recommends breaking these communications into two categories:

1) Household level data from the US Census Bureau,

The FCA requires collection of household demographic data. Census data at the city, town, or CDP level, may not accurately represent data for households on the Tribal reservation. One way to incorporate this Tribal data into Residential indicators (RI) and Lowest Quintile

[13] For complex service areas, electronic Geographic Information System (GIS) shapefiles can be analyzed with census electronic shapefiles, allowing a more precise characterization. This includes but is not limited to intersecting parcel maps with permittee service areas. Ultimately, it is the applicant's responsibility to describe these data, and their limitations. We recommend including any service maps, Census data, and files/code used in this step with materials submitted to Ecology.

Poverty Indicator (LQPI) scores, is to rely on data from the US Census at the “American Indian Area” level.[14, 15]

However, if a Tribe or permittee feels that the “American Indian Area” level misrepresent households within the service area, the Tribe or permittee may provide alternative data. An example is if service agreements do not extend to an entire “American Indian Area” level but Census data is not available below the reservation level. In this instance, the Tribe could provide more localized data, or a Tribe could confirm that alternate publicly available data is a good proxy for the portion of the reservation receiving services.

2) Government level finances

Financial obligations of a Tribe that are shared with the local government responsible for running the permittee’s facility should be reflected in the permittee’s certified annual financial reports, local governments assessor’s office records, or other standard budgeting and accounting materials. This is similar to overlapping debt with non-Tribal local governments with service agreements (see Instructions_FCI tab in Ecology’s spreadsheet tool for additional details) and might include debt held by a Tribe for public services that are partially chargeable to the permittee’s non-Tribal government annually for their use, such as a local park or law enforcement.

We encourage permittees and Tribes to discuss and coordinate on how to report shared financial agreements. If using Ecology’s spreadsheet tool, overlapping debt shares can be itemized on the “Inputs_FCI” tab.

2.2 Notes on Project Costs

Permittees shall provide project costs at the Class 5 level of estimates as established by the Association for the Advancement of Cost Engineering International (**Inputs_RI**).

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[14] To find data on Tribal geographies, navigate to https://data.census.gov/, select “All Geographies” on the left hand side pane, and then “American Indian Areas”. After selecting relevant Tribal areas, data tables can be searched for in the Census website’s search bar. See the “Census Bureau Data” table on the “Inputs Demographic” tab of Ecology’s spreadsheet tool for exact table numbers. Permittees will need to paste (hardcode) these data into Ecology’s spreadsheet because only CDPs, towns, or cities are currently available as an auto-populate features in the Census Bureau Demographic Data Generator (see Inputs_Demographic tab).

[15] If unemployment rates are not available from the BLS in Tribal areas, consider 5-year ACS data on unemployment rate for populations 16 years and over, in the civilian labor force on table DP03 for American Indian Area geographies.

3. Ecology Additions and Motivation

The following subsections describe Ecology's amendments to EPA's 2023 guidance and online FCA spreadsheet tool (as of 09/2024) in more detail. Note that these amendments are automatically incorporated into the results of Ecology's FCA spreadsheet tool in tab "Results_FCA_ECY" and require no new input or calculation on the permittee's part beyond what is already required by the EPA's original tool.

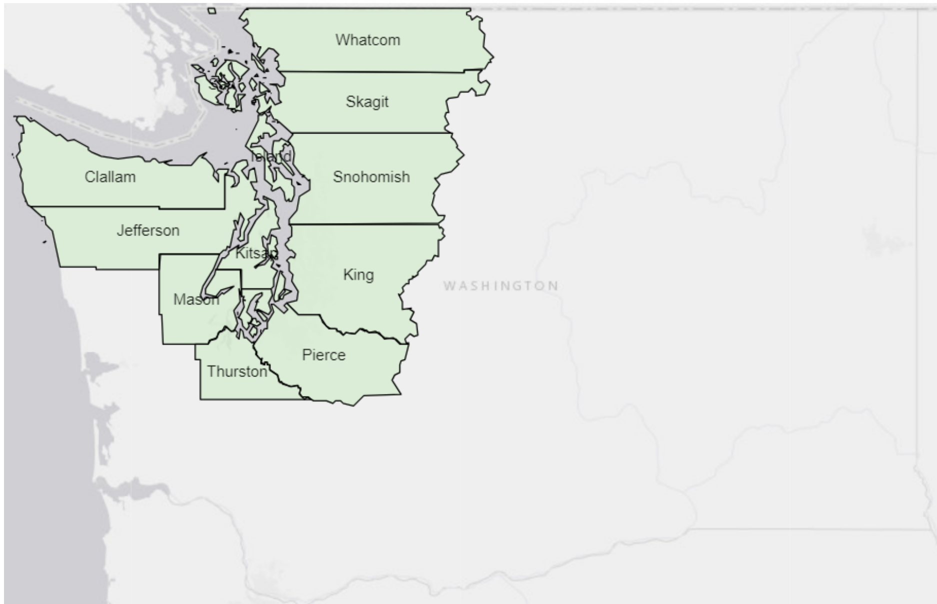
3.1 Puget Sound Regional Baselines

State level baselines for some calculations are recommended by EPA's 2023 guidance when calculating public sector impacts, as opposed to national baselines (see Section 3). It is also the only substantive statistical difference between "Alternative 1" and "Section 3" results in EPA's guidance beyond naming conventions and terminology.[16]

Ecology's guidance and spreadsheet tool makes an additional baseline distinction within the state between the Puget Sound, and other regions such as western Washington non-Puget sound, and eastern Washington. For the purposes of Ecology's FCA spreadsheet tool, the Puget Sound baseline is made up of counties defined by the University of Washington's Puget Sound Institute and the United States Geologic Survey (USGS), excluding Lewis County.[17, 18] Other state-regional baselines, such as Western Washington non-Puget Sound and Eastern Washington are available in Ecology's spreadsheet tool and may be considered for non-PSNGP applications.

[16] See Section 1(3)(b) of EPA's 2023 guidance for additional discussion.
[17] https://www.eopugetsound.org/terms/85
18 Lewis County is hydrologically linked to the Puget Sound through drainages and therefor in the watershed, however it does not contain PSNGPs which are defined as direct dischargers into the Sound. It is also absent of some economic features that characterize counties directly adjacent to the Puget sound such as ports, water views, and direct recreational access.

Figure 1. Counties in the Puget Sound Regional Baseline



Ecology's spreadsheet tool retains Alternative 1 labeling and references throughout the calculator for consistency with other helpful portions of EPA's guidance, such as robust technical appendices describing Alternative 1 calculations and data sources. Ecology's spreadsheet tool also provides a separate section producing all results using national baselines.

3.1.1 Household Income Baseline

Comparing service area income to broader conditions in the Puget Sound region is a practically important feature. Considering that median household income in the Puget Sound region was $102,551 in 2022 (Figure 2), or over 30% higher than the broader US ($75,149).[19] In this way, Puget Sound communities would appear arbitrarily strong against national or statewide baselines when calculating components of the FCI. But because of unique regional characteristics—chief among them a higher cost of living—results would not accurately capture local hardship.

In consultation with the EPA, and response to feedback from stakeholders during public comment, Ecology's amended spreadsheet tool calculates relevant FCI results from the Puget Sound regional baseline (with alternative options for Western Washington Non-Puget Sound, and Eastern Washington baselines, if relevant). [20]

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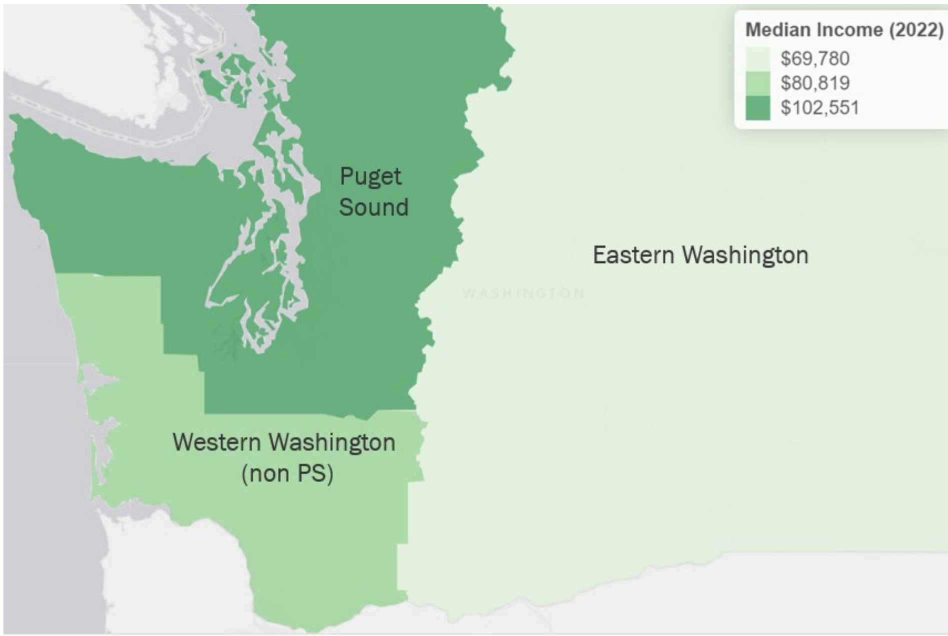
[19] Using 2022 ACS 5-year estimates https://data.census.gov/table?q=b19013.

[20] Regional baseline statistics are summarized from county level ACS 5-year estimates, weighted by the proportion of households each county represents in the region.

Figure 2. Median Household Income by Region



3.1.2 Lowest Quintile Poverty Indicator Baselines

The Lowest Quintile Poverty Indicator (LQPI) aids in assessing the severity and prevalence of poverty in the affected community. In EPA's original formulation, the weighted index is made up of 6 measures, which take on a 1, 2, or 3 to describe poverty conditions, mid-range, or strong (good) conditions respectively after comparing the affected community with national averages. Inputs into the LQPI (other than "Trend in Household Growth") are evaluated using a ±25% benchmark to national figures.[21] This bracketing methodology is commonly used to characterize outliers on either end of the data distribution. Using a ±25% benchmark closely aligns with the middle quintile of data for the parameter, which can characterize the "middle class."

As with concerns over household income in FCI calculation above, comparing LQPI measures in Washington to a national baseline may misrepresent local hardship. For example, the Percentage of Population with Income Below 200% of the Federal Poverty Level (FPL) in the US is 28.8% (2022 ACS 5-year estimates), while in parts of Washington State, such as the Puget Sound region, is only 20%.[22] Again, this differential does not necessarily suggest households in

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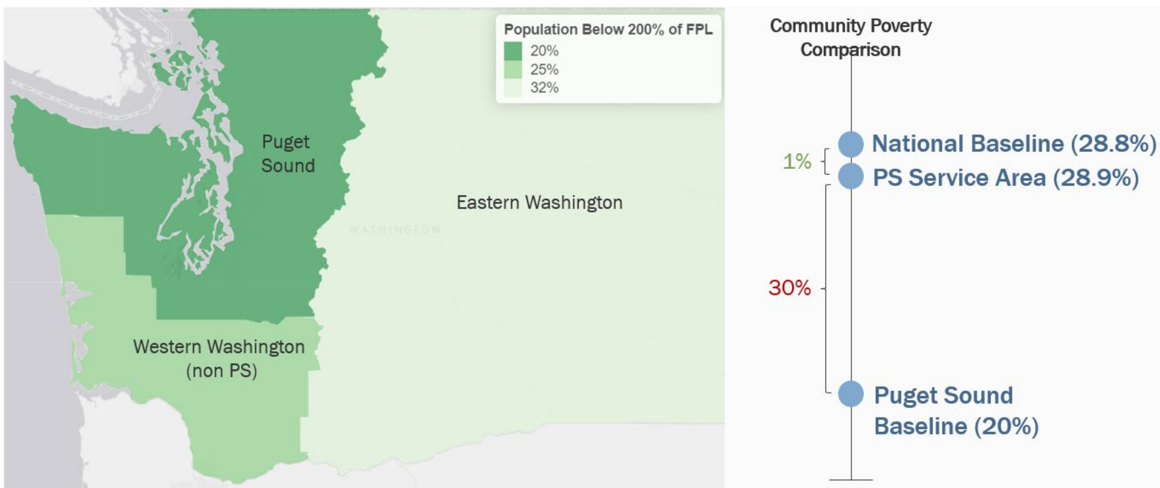
[21] Note that "Trend in Household Growth," the fifth indicator, is based on 5-year Geometric Average Growth Rates instead of quintiles. $5\ Year\ Geometric\ Growth\ Rate = (1 + (HH_n - HH_{n-5}) / HH_{n-5})^{1/5} - 1$; where HH is the number of occupied housing units, and n is most recent Census data year. For example, if a community had 15,500 occupied housing units in the most recent census data year and had 15,000 occupied units five census data years prior, the 5-year average geometric growth rate would be 0.66% = $(1 + (15{,}500 - 15{,}000) / 15{,}000)^{1/5} - 1$.

[22] Table S1701 (https://data.census.gov/table/ACSST5Y2022.S1701?q=S1701&g=040XX00US53). Note that outside of Alaska and Hawaii, the threshold establishing federal poverty is the same for all states.

the Puget Sound are better off financially than other parts of the state or country. Rather, it partially reflects the cost of living in the region, the income necessary to support basic needs, and the fact the federal poverty levels are fixed for all contiguous states.

Consider a single Puget Sound community as a service area. Here, the Census reported that 28.9% of its population fell below 200% of FPL in 2022 (ACS 5-year estimate). Since that statistic is almost identical to the national average (1% lower), the service area would fall into the LQPI's "mid-range" using the standard EPA formula (Figure 3). Conversely, when compared to its state-regional peers, poverty in this community is shown to be 30% higher, and therefore would fall into the LQPI's "weak" (high poverty) category.

Figure 3. Percent of Population Below 200% of FPL and Baseline Comparison



In consultation with the EPA, and response to feedback from stakeholders during public comment, Ecology's amended spreadsheet tool calculates relevant LQPI results from the Puget Sound regional baseline (with alternative options for Western Washington Non-Puget Sound, and Eastern Washington baselines, if relevant). [23]

3.2 Impacts of Wastewater Treatment With and without Project

Capturing baseline impacts of wastewater treatment in a community is critical when comparing to the same community with the proposed project(s). Ecology's spreadsheet tool presents a side-by-side comparison simultaneously which aids permittees and Ecology in understanding the impacts of permit requirements, and their potential contribution to cumulative burden on ratepayers.

[23] Regional baseline statistics are summarized from county level ACS 5-year estimates, weighted by the proportion of households each county represents in the region.

3.3 Costs in Terms of Percent of Upper Limit of Lowest Quintile Income

While the upper limit of the lowest quintile of income (LQI) is incorporated into results through baseline comparisons in the LQPI, we calculate and report existing and new treatment costs as a percentage of LQI as a standalone statistic. This isolates additional information about impacts beyond median income households, impact disparities, and changes in disparity across treatment alternatives when compared with %MHI.

4. Assistance and Funding Sources to Consider

Ecology's water quality financial management section (FMS) provides technical assistance, in coordination with the EPA, Rural Community Assistance Corporation (RCAC), Evergreen Rural Water of Washington (ERWoW), and the Washington State Department of Commerce's Small Communities Initiative (SCI). With a single application to Water Quality Combined Fund, Ecology can identify water quality-related opportunities, that best match the financial needs of project applicants.[24] This coordinated effort offers a wide variety of resources for supporting communities in accessing funds, and identifying support for managing and implementing infrastructure improvements.[25] Particularly relevant loans and grants administered through the Combined Fund:

- Puget Sound nutrient reduction grants program. In the 2021-23 biennial budget, the state Legislature appropriated $9 million for the to help municipalities prepare and plan for future treatment facility upgrades and implement operational modifications necessary to maximize nutrient removal from existing treatment processes. Ecology is currently working on the next phase of funds in the form of a budget request for the next biennium (beginning August 2025). If funds are approved, eligible applicants are the 42 municipalities that operate the 58 wastewater treatment plants that discharge to Puget Sound and are covered by the permit.[26]
- The Clean Water State Revolving Fund (CWSRF) which provides low-interest and forgivable principal loan funding for wastewater treatment construction projects, eligible nonpoint source pollution control projects, and eligible "green" projects. Established by the federal Clean Water Act (CWA), the CWSRF is funded through an annual EPA capitalization grant, state matching funds, and principal and interest repayments on past program loans.
- Income and need based programs, including the Centennial Clean Water Program, that provides wastewater treatment construction projects for financially distressed communities.

[24] https://ecology.wa.gov/water-shorelines/water-quality/water-quality-grants-and-loans
[25] For this permit, technical assistance can be requested by contacting Stephanie Allen (sall461@ecy.wa.gov).
[26] https://ecology.wa.gov/About-us/Payments-contracts-grants/Grants-loans/Find-a-grant-or-loan/Puget-Sound-Nutrient-Reduction[27] Active and available at the time of this writing.

In addition to State, federal technical assistance is also available, largely from the EPA.[27] These include, but are not limited to:

- EPA's Environmental Finance Centers, which deliver targeted technical assistance to local governments, states, tribes, and non-governmental organizations to protect public health, safeguard the environment, and mitigate environmental justice concerns.[28] The EFCs serve an important role in helping to ensure that communities that have difficulty in securing public funding receive the help they need to access resources to support infrastructure improvements. Requests for technical assistance can be made through EPA's Water Technical Assistance Program or by emailing WaterTA@epa.gov
- EPA's Training and Technical Assistance for Small Systems Funding provides technical assistance through national providers via grant funding to support small drinking water and wastewater systems that serve small and rural communities.[29] EPA is committed to helping communities across America upgrade and maintain water infrastructure that is essential to public health and environmental protection.
- EPA's Environmental Justice Small Grants Program, which supports and empowers communities working on solutions to local environmental and public health issues.[30] The program is designed to help communities understand and address exposure to multiple environmental harms and risks.
- EPA resources associated with the Bipartisan Infrastructure Law (BIL), including Closing America's Wastewater Access Gap Community Initiative.[31,32]

Federal and private water infrastructure funding, active and available at the time of this writing including but not limited to:

- Water Infrastructure Finance and Innovation Act (WIFIA): https://www.epa.gov/wifia
- The Environmental Justice Collaborative Problem-Solving (CPS) Cooperative Agreement Program: https://www.epa.gov/environmental-justice/environmental-justice-collaborative-problem-solving-cooperative-agreement
- Source Reduction Assistance (SRA) Grant Program: https://www.epa.gov/p2/source-reduction-assistance-grants
- CoBank's Rural Water and Wastewater Lending: https://www.cobank.com/corporate/industry/water

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[27] Active and available at the time of this writing.
[28] https://www.epa.gov/waterfinancecenter/efcn
[29] https://www.epa.gov/dwcapacity/training-and-technical-assistance-small-systems-funding
[30]https://www.epa.gov/environmentaljustice/environmental-justice-small-grants-program[31] https://www.epa.gov/infrastructure
[31] https://www.epa.gov/infrastructure
[32] https://www.epa.gov/water-infrastructure/closing-americas-wastewater-access-gap

- National Rural Water Association (NRWA)'s Rural Water Loan Fund: https://nrwa.org/members/products-services-portfolio/rural-water-loan-fund/
- U.S. Department of Agriculture (USDA)'s Water and Waste Disposal Guaranteed Loan Program: https://www.rd.usda.gov/programs-services/water-waste-disposal-loan-guarantees
- USDA's Water & Environmental Programs (WEP): https://www.rd.usda.gov/programs-services/all-programs/water-environmental-programs
- USDA's Water & Wastewater Projects Revolving Fund Program: https://www.rd.usda.gov/programs-services/revolving-funds-for-financing-water-and-wastewater-projects
- USDA's Water & Waste Disposal Loan & Grant Program: https://www.rd.usda.gov/programs-services/water-waste-disposal-loan-grant-program
- USDA's Water & Waste Disposal Predevelopment Planning Grants: https://www.rd.usda.gov/programs-services/water-waste-disposal-predevelopment-planning-grants
- U.S. Department of Commerce – Economic Development Administration (EDA)'s funding and technical assistance: https://www.eda.gov/funding/programs
- U.S. Department of Health and Human Services – Indian Health Service (IHS)'s Sanitation Facilities Construction (SFC) Program: https://www.ihs.gov/dsfc/
- U.S. Department of Housing and Urban Development (HUD)'s Community Development Block Grant (CDBG) Program: https://www.hud.gov/program_offices/comm_planning/communitydevelopment
- HUD's Section 108 Loan Guarantee Program: https://www.hudexchange.info/programs/section-108/
- Others, including private funding, can be

Bipartisan Infrastructure Law (BIL) Resources

- Overview BIL: https://www.epa.gov/infrastructure
- Closing America's Wastewater Access Gap Community Initiative: https://www.epa.gov/water-infrastructure/closing-americas-wastewater-access-gap-community-initiative
- Bipartisan Infrastructure Law SRF Memorandum: https://www.epa.gov/dwsrf/bipartisan-infrastructure-law-srf-memorandum

- Frequent Questions about BIL State Revolving Funds: https://www.epa.gov/system/files/documents/2024-10/bil-srf-qs-and-as-10-01-2024_1.pdf

SEPA[1] Environmental Checklist

Purpose of checklist

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

Instructions for applicants

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

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

Instructions for lead agencies

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

Use of checklist for nonproject proposals

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

[1] https://ecology.wa.gov/Regulations-Permits/SEPA/Environmental-review/SEPA-guidance/Checklist-guidance

A.Background

Find help answering background questions[2]

1. **Name of proposed project, if applicable:**

   Rulemaking – Chapter 173-201A WAC, Water Quality Standards for Surface Waters of the State of Washington (Natural Conditions)

2. **Name of applicant:**

   Washington State Department of Ecology (Ecology), Water Quality Program

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

   Vince McGowan, Water Quality Program Manager

   Department of Ecology

   PO Box 47600

   Olympia, WA 98504-7600

   Marla Koberstein, Rulemaking Lead

   swqs@ecy.wa.gov

   360-628-6376

4. **Date checklist prepared:**

   March 28, 2024

5. **Agency requesting checklist:**

   N/A – Nonproject SEPA for rulemaking

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

September 27, 2022	Announce start of rulemaking (file CR-101)
May 9, 2024	Propose formal draft rule (file CR-102)
July 12, 2024	End public comment period
Fall 2024	Make decision on rule adoption (file CR-103)

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

   No.

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

[2] https://ecology.wa.gov/Regulations-Permits/SEPA/Environmental-review/SEPA-guidance/SEPA-checklist-guidance/SEPA-Checklist-Section-A-Background

Supporting documents for the proposed rule can be found on the rulemaking webpage[3] and includes:

- Draft Technical Support Document
- Preliminary Regulatory Analysis
- Draft Rule Implementation Plan
- Citation List

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

No.

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

The U.S. Environmental Protection Agency must approve any state water quality standards that have been adopted before they can be used for Clean Water Act purposes.

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

Ecology is proposing revisions to chapter 173-201A WAC, Water Quality Standards for Surface Waters of the State of Washington. We are proposing the following revisions in this rulemaking:

- WAC 173-201A-020, Definitions: adding a definition for a performance-based approach method and adding a definition for local and regional sources of human-caused pollution.
- WAC 173-201A-200(1)(c), Aquatic life temperature criteria, subsection (i): updating the allowable insignificant changes to freshwater temperature criteria when natural conditions are the applicable criteria.
- WAC 173-201A-200(1)(d), Aquatic life dissolved oxygen (D.O.) criteria, subsection (i): updating the allowable insignificant changes to freshwater dissolved oxygen criteria when natural conditions are the applicable criteria.
- WAC 173-201A-210(1)(c), Aquatic life temperature criteria, subsection (i) updating the allowable insignificant changes to marine water temperature when natural conditions are the applicable criteria.
- WAC 173-201A-210(1)(d), Aquatic life dissolved oxygen (D.O.), subsection (i): updating the allowable insignificant changes to marine water dissolved oxygen when natural conditions are the applicable criteria.

[3] https://ecology.wa.gov/regulations-permits/laws-rules-rulemaking/rulemaking/wac-173-201a-natural-conditions

- WAC 173-201A-260(1), Natural and irreversible human conditions: updating the natural conditions criteria language and describing methods for determining natural conditions criteria values.
- WAC 173-201A-430(2), Site-specific criteria: updating how analyses must be conducted.
- WAC 173-201A-470, Performance-based approach: adding this new section to describe and reference the methodology to determine natural conditions criteria values.
- Ecology publication 24-10-017, A Performance-Based Approach for Developing Site-Specific Natural Conditions Criteria for Aquatic Life in Washington, a separate rule document that provides the methodology to determine natural conditions criteria values.
- Minor non-substantive edits to rule language in WAC 173-201A-430(2) to reflect the latest version of referenced documents.

We are proposing revisions to natural conditions provisions in our surface water quality standards to provide water quality protection for aquatic life organisms and to establish possible methods for deriving those protective values. As part of this rule proposal, we:

- Evaluated the latest scientific data, methods, modeling tools, and approaches to update the natural conditions provisions necessary for refining aquatic life protection.
- Considered the U.S. Environmental Protection Agency's recommend approaches for natural conditions in water quality standards, including a performance-based approach for determining protective natural conditions criteria.
- Considered the U.S. Environmental Protection Agency's draft, deliberative, and Washington-specific recommendations for the performance-based approach methodology.

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

The proposed revisions to the water quality standards will apply to all waterbodies in the state of Washington. In addition, some of the proposed revisions can be applied on a site-by-site basis when the underlying requirements are met.

B.Environmental Elements

This is a nonproject SEPA that involves a rulemaking for the Washington State surface water quality standards. The rulemaking, if concluded, will revise natural conditions provisions for the protection of aquatic species. The environmental elements are not applicable because the rulemaking action being considered will not result in any physical changes to any waters of the state where the new rules will apply.

C.Signature

Find help about who should sign[4]

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

5/1/2024

X Kalman Bugica

Signed by: Bugica, Kalman (ECY)

Type name of signee: Kalman Bugica

Position and agency/organization: Water Quality Standards, Washington State Department of Ecology.

Date submitted: May 10, 2024

D.Supplemental sheet for nonproject actions

Find help for the nonproject actions worksheet[5]

Do not use this section for project actions.

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

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

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

   The proposal will not increase any of the above-mentioned environmental impacts. The rulemaking proposal will not cause or result in any physical changes to any water of the state where the new rules will apply.

[4] https://ecology.wa.gov/Regulations-Permits/SEPA/Environmental-review/SEPA-guidance/SEPA-checklist-guidance/SEPA-Checklist-Section-C-Signature

[5] https://ecology.wa.gov/regulations-permits/sepa/environmental-review/sepa-guidance/sepa-checklist-guidance/sepa-checklist-section-d-non-project-actions

- **Proposed measures to avoid or reduce such increases are:**

Not applicable.

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

The proposal will not adversely affect plants, animals, fish, or marine life. The proposal is intended to provide water quality and habitat protection for all aquatic life.

The protection is reflected by revising natural conditions provisions, which recognize that conditions in some surface waters during some seasons and in some areas naturally do not meet biologically based numeric criteria. For example, a naturally low-flowing stream in a natural prairie without any human alteration or human-caused pollution may have seasonally higher temperatures than the limit set to protect fish. These inconsistencies may be due to natural processes or seasonal conditions that prevent a waterbody from meeting the applicable aquatic life criteria. Our proposed revisions refine the natural conditions provisions to protect characteristics inherent and unique to a specific water.

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

No additional measures are needed as a result of this rulemaking. The proposed rule revisions are designed to provide protection for endangered species and their populations. These protections align with EPA policy for protecting aquatic life using the natural condition of a water.

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

The proposal will not deplete energy or natural resources.

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

Not applicable.

4. How would the proposal be likely to use or affect environmentally sensitive areas or areas designated (or eligible or under study) for governmental protection, such as parks, wilderness, wild and scenic rivers, threatened or endangered species habitat, historic or cultural sites, wetlands, floodplains, or prime farmlands?

Not applicable.

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

Not applicable.

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

Not applicable.

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

Not applicable.

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

The proposal will not result in increased demands on transportation or public services and utilities.

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

Not applicable.

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

The proposal will not conflict with local, state, or federal laws or requirements since the Washington State Department of Ecology is the sole agency responsible for developing water quality standards under the Federal Clean Water Act. The final rule, once adopted, will need to receive federal approval from the U.S. Environmental Protection Agency before it can be used for Clean Water Act purposes.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
1200 Sixth Avenue, Suite 155
Seattle, WA 98101

WATER
DIVISION

November 19, 2021

Mr. Vince McGowan
Water Quality Program Manager
Washington State Department of Ecology
PO Box 47600
Olympia, Washington 98504-7600

Re: EPA's Action on Revisions to the Washington State Department of Ecology's Surface Water Quality Standards for Natural Conditions Provisions

Dear Mr. McGowan:

The U.S. Environmental Protection Agency (EPA) has completed the review and reconsideration of Washington's natural conditions provisions (WAC 173-201A-200(1)(c)(i), 173-201A-210(1)(c)(i), 173-201A-200(1)(c)(v), 173-201A-200(1)(d)(i), 173-201A-210(1)(d)(i), 173-201A-200(1)(d)(ii), and 173-201A-260(1)(a)), which were submitted to EPA by the Washington Department of Ecology in 2003 and 2006. Under section 303(c) of the Clean Water Act (CWA), 33 U.S.C. § 1313(c), states must submit new and revised water quality standards to EPA for review and action, and EPA approves those water quality standards if they meet the requirements of the CWA and EPA's implementing regulations. EPA's review and reconsideration is outlined below and further described in the enclosed Technical Support Document.

As you are aware, on February 10, 2014, the Northwest Environmental Advocates filed a complaint in U.S. District Court for the Western District of Washington (Case No. 2:14-cv-0196-RSM) challenging, in part, EPA's February 11, 2008 CWA section 303(c) approval of the natural conditions provisions identified above. On October 17, 2018, the Court issued an Order Granting a Stay (Dkt. 95) pending EPA's reconsideration of its prior determinations. The Court subsequently granted an extension for EPA to complete its reconsideration by November 19, 2021 (Dkt. 118).

EPA's CWA section 303(c) action applies only to waters in the State of Washington and does not apply to waters that are within Indian Country, as defined in 18 U.S.C. § 1151. Nothing in the enclosed decision document shall constitute an approval or disapproval of a water quality standard that applies to waters within Indian Country. EPA, or authorized Indian Tribes, as appropriate, will retain responsibilities for water quality standards for waters within Indian Country.

Summary of EPA's Action

EPA has completed its reconsideration, as contemplated by the Court's Order, and is not changing its February 11, 2008 approval of the revisions to the following sections of WAC Chapter 173-201A.

- WAC 173-201A-200(1)(c)(v): Natural condition narrative aquatic life temperature criteria for lakes

- WAC 173-201A-200(1)(d)(ii): Natural condition narrative aquatic life dissolved oxygen criteria for lakes

Because EPA is not changing its earlier approval, it is taking no new action with respect to those provisions.

EPA has completed its reconsideration, as contemplated by the Court's Order, and is disapproving revisions to the following sections of WAC Chapter 173-201A pursuant to its authority under section 303(c)(3) of the CWA, 33 U.S.C. § 1313(c)(3), and 40 CFR Part 131:

- WAC 173-201A-260(1)(a): Natural and irreversible human conditions
- WAC 173-201A-200(1)(c)(i) and WAC 173-201A-210(1)(c)(i): Allowable human contribution to natural conditions provisions for aquatic life temperature (fresh water and marine water, respectively)
- WAC 173-201A-200(1)(d)(i) and WAC 173-201A-210(1)(d)(i): Allowable human contribution to natural conditions provisions for aquatic life dissolved oxygen (fresh water and marine water, respectively)

EPA appreciates Ecology's commitment and ongoing work to update Washington's water quality standards. We also appreciate the collaboration by your staff to address the complexities associated with criteria revisions. If you have any questions regarding this letter, please contact me at (206) 553-1855 or Lindsay Guzzo, EPA staff lead, at (206) 553-0268 or Guzzo.Lindsay@epa.gov.

Sincerely,

DANIEL OPALSKI

Digitally signed by DANIEL OPALSKI
Date: 2021.11.19 09:38:35 -08'00'

Daniel D. Opalski
Director

Enclosure: Technical Support Document

cc (e-Copy): Ms. Melissa Gildersleeve, Water Quality Management Section Manager, Ecology
Mr. Chad Brown, Water Quality Management Unit Supervisor, Ecology

Technical Support Document

EPA's Clean Water Act Action on Revisions to the Washington State Department of Ecology's Surface Water Quality Standards for Natural Conditions Provisions

November 19, 2021

I. Clean Water Act Requirements for Water Quality Standards

The objective of the Clean Water Act (CWA) is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters with an interim goal, where attainable, to achieve water quality that provides for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water. Under section 303(c) of the CWA and federal implementing regulations at 40 CFR § 131.4, states (and authorized tribes) have the primary responsibility for reviewing, establishing, and revising water quality standards (WQS). These standards include the designated uses of a waterbody or waterbody segment, the water quality criteria that protect those designated uses, and an antidegradation policy. This statutory and regulatory framework allows states to work with local communities to adopt appropriate designated uses (as required at 40 CFR § 131.10(a)) and to adopt criteria to protect those designated uses (as required at 40 CFR § 131.11(a)).

States are required to hold public hearings for the purpose of reviewing applicable WQS periodically but at least once every three years and, as appropriate, modify and adopt these standards (40 CFR § 131.20). Each state must follow applicable legal procedures for revising or adopting such standards (40 CFR § 131.5(a)(6)) and submit certification by the state's attorney general, or other appropriate legal authority within the state, that the WQS were duly adopted pursuant to state law (40 CFR §131.6(e)). The U.S. Environmental Protection Agency's (EPA) review authority and the minimum requirements for state WQS submittals are described at 40 CFR § 131.5 and 131.6, respectively.

States are required by 40 CFR § 131.11(a) to adopt water quality criteria that protect their designated uses. In adopting such criteria, states should establish numeric values based on one of the following:

(1) CWA section 304(a) guidance;
(2) CWA section 304(a) guidance modified to reflect site-specific conditions; or,
(3) Other scientifically defensible methods (40 CFR § 131.11(b)(1)).

In addition, states should establish narrative criteria where numeric criteria cannot be established or to supplement numeric criteria (see 40 CFR § 131.11(b)(2)).

Section 303(c) of the CWA requires states to submit new or revised WQS to EPA for review and action. EPA reviews these changes and approves the WQS if they meet the requirements of the CWA and EPA's implementing regulations.

EPA considers four questions (described below) when evaluating whether a particular provision is a new or revised WQS. If all four questions are answered "yes" then the provision would likely constitute a new or revised WQS that EPA has the authority and duty to approve or disapprove under CWA § 303(c)(3).[1]

1. Is it a legally binding provision adopted or established pursuant to state or tribal law?
2. Does the provision address designated uses, water quality criteria (narrative or numeric) to protect designated uses, and/or antidegradation requirements for waters of the United States?

[1] *What is a New or Revised Water Quality Standard under 303(c)(3)? Frequently Asked Questions*, EPA No. 820F12017 (Oct. 2012). Available at https://www.epa.gov/sites/production/files/2014-11/documents/cwa303faq.pdf

3. Does the provision express or establish the desired condition (e.g., uses, criteria) or instream level of protection (e.g., antidegradation requirements) for waters of the United States immediately or mandate how it will be expressed or established for such waters in the future?
4. Does the provision establish a new WQS or revise an existing WQS?

If EPA approves a state's WQS submission, such standard(s) shall thereafter be the applicable standard for CWA purposes. When EPA disapproves a state's WQS, EPA shall notify the state and specify why the WQS is not in compliance with the requirements of the CWA and federal WQS regulations and specify any changes that are needed to meet such requirements (33 U.S.C. § 1313(c)(3); 40 CFR § 131.21).

Finally, EPA considers non-substantive edits to existing WQS to constitute new or revised WQS that EPA has the authority to approve or disapprove under § 303(c)(3). While such edits and changes do not substantively change the meaning or intent of the existing WQS, EPA believes it is reasonable to treat such edits and changes in this manner to ensure public transparency as to which provisions are applicable for purposes of the CWA. EPA notes that the scope of its review and action on non-substantive edits or editorial changes extends only to the edits or changes themselves. EPA does not re-open or reconsider the underlying WQS that are the subject of the non-substantive edits or editorial changes.

II. Background

On February 10, 2014, the Northwest Environmental Advocates filed a complaint in U.S. District Court for the Western District of Washington (Case No. 2:14-cv-0196-RSM) challenging, in part, EPA's February 11, 2008 CWA section 303(c) approval of the natural conditions provisions. On October 17, 2018, the Court issued an Order Granting a Stay (Dkt. 95) pending EPA's reconsideration of its prior determinations. The Order noted that EPA may complete its reconsideration by October 17, 2021, by making approval or disapproval decisions, or a final determination that such provisions are not water quality standards. The Court subsequently granted an extension for EPA to complete its reconsideration by November 19, 2021 (Dkt. 118).

This Technical Support Document constitutes EPA's reconsideration of the remaining provisions subject to the Court Order. EPA previously completed its review and reconsideration of the other provisions in actions dated April 30, 2019, October 13, 2020, and September 30, 2021.

III. Results of EPA's Reconsideration

In its February 11, 2008 action, EPA approved the revised natural conditions provisions at:

- WAC 173-201A-200(1)(c)(i) and WAC 173-201A-210(1)(c)(i): Allowable human contribution to natural conditions provisions for aquatic life temperature (fresh water and marine water, respectively);
- WAC 173-201A-200(1)(c)(v): Natural condition narrative aquatic life temperature criteria for lakes;
- WAC 173-201A-200(1)(d)(i) and WAC 173-201A-210(1)(d)(i): Allowable human contribution to natural conditions provisions for aquatic life dissolved oxygen (for fresh water and marine water, respectively);

- WAC 173-201A-200(1)(d)(ii): Natural condition narrative aquatic life dissolved oxygen criteria for lakes; and
- WAC 173-201A-260(1)(a): Natural and Irreversible Human Conditions.

Upon reconsideration, EPA is not changing and taking no action with respect to the February 11, 2008 approval of the provisions at WAC 173-201A-200(1)(c)(v) and WAC 173-201A-200(1)(d)(ii). EPA is disapproving the provisions at WAC 173-201A-200(1)(c)(i), WAC 173-201A-210(1)(c)(i), WAC 173-201A-200(1)(d)(i), WAC 173-201A-210(1)(d)(i), and WAC 173-201A-260(1)(a).

EPA's CWA section 303(c) action and the associated rationales are provided below. Today's action applies only to waters within the jurisdiction of the State of Washington and does not apply to waters that are within Indian Country, as defined in 18 U.S.C. § 1151. Nothing in this decision document shall constitute an approval or disapproval of a WQS that applies to waters within Indian Country. EPA, or authorized Indian Tribes, as appropriate, retain the authority to establish WQS for waters within Indian Country.

1. Natural Conditions Narrative Criteria For Lakes

In its February 11, 2008 action, EPA approved the revised temperature and dissolved oxygen natural conditions narrative criteria for lakes at WAC 173-201A-200(1)(c)(v) and WAC 173-201A-200(1)(d)(ii), respectively. More detail and information regarding EPA's action can be found in the 2008 decision document.[2]

The underlined text indicates the new and/or revised language from Ecology's 2006 WQS submittal, and strikeout text indicates Ecology's previous text, which had been replaced by the new or revised text.

Aquatic life temperature criteria for lakes

> **WAC 173-201A-200(1)(c)(v):** For lakes, human actions considered cumulatively may not increase the 7-DADMax temperature more than 0.3°C (0.54°F) above natural conditions. ~~Temperature - no measurable change from natural conditions.~~

Aquatic life dissolved oxygen criteria for lakes

> **WAC 173- 201A-200(1)(d)(ii):** For lakes, human actions considered cumulatively may not decrease the dissolved oxygen concentration more than 0.2 mg/L below natural conditions. ~~Dissolved oxygen - no measurable decrease from natural conditions.~~

EPA's Reconsideration: EPA has completed its reconsideration and is taking no action with respect to its February 11, 2008 approval of the revisions at WAC 173-201A-200(1)(c)(v) and WAC 173-201A-200(1)(d)(ii).

EPA Rationale for the 2008 approval:
In 2006, Ecology submitted revisions to the temperature and dissolved oxygen aquatic life criteria for lakes. The revisions clarified and quantified the previous criteria of "no measurable change from natural

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[2] February 11, 2008. Letter from Michael F. Gearheard, Director, Office of Water & Watersheds, EPA Region 10, to David C. Peeler, Program Manager, Department of Ecology, re: EPA Approval of the 2003/2006 Revisions to the Washington Water Quality Standards Regulations. Available at: https://www.epa.gov/sites/production/files/2017-10/documents/wawqs-letter-02112008.pdf

conditions" (for temperature) and "no measurable decrease from natural conditions" (for dissolved oxygen) by identifying a 0.3ºC increase in temperature and a 0.2 mg/L decrease in dissolved oxygen as what would constitute a "measurable" departure from natural conditions. For temperature, the revision also added a 7-DADMax metric to the criterion.

In the February 11, 2008, Technical Support Document, EPA concluded that a 0.3ºC increase in temperature from natural conditions was insignificant and well within the range of uncertainty of the thermal requirements for salmon, which is approximately +/- 0.5ºC. EPA also noted that 0.3ºC was consistent with reliable field detection levels for temperature and is therefore considered within the error band associated with typical temperature monitors (pp. 27-28). The revised temperature criterion also added the 7-DADMax metric recommended for temperature standards by the *Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* (EPA910-B-03-002, April 2003, hereinafter referred to as "Temperature Guidance") and that EPA determined to be scientifically defensible (p.4). EPA's 2008 approval, therefore, concluded that Washington's revisions to the aquatic life temperature criterion for lakes were protective of designated uses and scientifically defensible.

In assessing Washington's revisions to the dissolved oxygen criterion for lakes, EPA similarly concluded that a 0.2 mg/L decrease from natural conditions was insignificant. The 2008 approval rationale explained that an allowable decrease of 0.2 mg/L is within the monitoring measurement error for recording instruments typically used to monitor dissolved oxygen. EPA also explained that numerous factors impact oxygen levels in lakes and without at least some allowance for insignificant decreases a natural conditions criterion for dissolved oxygen in lakes would be unnecessarily restrictive for the protection of designated uses (p. 32). EPA's 2008 approval, therefore, concluded that Washington's revisions to the aquatic life dissolved oxygen criterion for lakes was protective of designated uses and scientifically defensible.

The narrative criteria are the applicable temperature and dissolved oxygen criteria for lakes in Washington, and leaving in place EPA's 2008 approval of these criteria ensures that aquatic life criteria for temperature and dissolved oxygen in lakes remain in effect for CWA purposes.

2. Natural and Irreversible Human Conditions

In its February 11, 2008 action, EPA approved the new narrative natural conditions provision at WAC 173-201A-260(1)(a) and took no action on the irreversible human conditions provision at WAC 173-201A-260(1)(b) after concluding the provision is not a WQS that EPA has the authority to approve or disapprove under section 303(c) of the CWA. More detail and information regarding EPA's action can be found in the 2008 decision document.[3]

With respect to WAC 173-201A-260(1)(a), EPA's 2008 decision stated that it is acceptable, under certain circumstances, for water quality criteria to reflect the natural condition of a water body as an alternative to the generally applicable numeric criteria. The rationale for this was that Washington's designated uses were supported by the water in its natural condition, prior to any human effects on water quality.

[3] February 11, 2008. Letter from Michael F. Gearheard, Director, Office of Water & Watersheds, EPA Region 10, to David C. Peeler, Program Manager, Department of Ecology, re: EPA Approval of the 2003/2006 Revisions to the Washington Water Quality Standards Regulations. Available at: https://www.epa.gov/sites/production/files/2017-10/documents/wawqs-letter-02112008.pdf

The text of the provision first appeared in a 2003 water quality standards submittal to EPA and again in a 2006 submittal and is excerpted below.

> **WAC 173-201A-260(1):** Natural and irreversible human conditions.
> (a) It is recognized that portions of many water bodies cannot meet the assigned criteria due to the natural conditions of the water body. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the natural conditions constitute the water quality criteria.

EPA's Reconsideration: EPA has completed its reconsideration and in accordance with its CWA authority, 33 U.S.C. § 1313(c)(3) and 40 CFR Part 131, disapproves the provision at WAC 173-201A-260(1)(a).

EPA Rationale: The natural conditions narrative provision at WAC 173-201A-260(1)(a) is broadly drafted and does not specify the types of criteria or pollutants to which it applies. On reconsideration, EPA concludes that as written this provision could be applied to a wide range of naturally occuring pollutants, including toxic pollutants, and could even allow an exception from otherwise applicable numeric human health criteria. Therefore, it is not consistent with EPA's interpretation of the relationship between natural conditions and the protection of designated human health uses, which is articulated in EPA's November 5, 1997 policy guidance entitled ''Establishing Site Specific Aquatic Life Criteria Equal to Natural Background.''[4] EPA's 2008 decision document cited to the 1997 policy guidance, as well as to language in an Advance Notice of Proposed Rulemaking for the Water Quality Standards program (*see* 63 Fed. Reg. 36,724, 36761 (Jul. 7, 1998)), as setting forth the relevant policy considerations for establishing water quality criteria based on natural conditions. However, what EPA failed to appropriately consider in its 2008 decision is that these documents only addressed the establishment of aquatic life criteria for pollutants at levels equal to the natural background condition, and expressly did not apply to human health uses, whereas the provision at WAC 173-201A-260(1)(a) is not similarly limited in scope to aquatic life uses or to specific pollutants.

In contrast with aquatic life uses, a naturally occurring level of a pollutant does not necessarily protect designated human health uses. Naturally occurring levels of a pollutant are assumed to protect aquatic life species that have naturally developed in the affected waters. However, humans generally do not adapt to higher ambient pollutant levels, even if they are naturally caused. Consequently, the same assumptions of protectiveness cannot be made with regard to designated uses that affect human health (*e.g.,* people eating fish or shellfish from Washington waters, and recreating in Washington waters). For this reason, EPA's 1997 guidance also states that where the natural background concentration exceeds the state-adopted human health criterion, at a minimum, states should re-evaluate the human health use designation.[5]

No Changes Necessary to Address the Disapproval: The effect of EPA's disapproval is that, as of the date of this action, the provision at WAC 173-210A-260(1)(a) is no longer an applicable WQS for CWA purposes. Because Washington's WQS currently include applicable numeric criteria that EPA determined to be protective of designated uses, no changes to Washington's WQS are necessary to meet the requirements of the CWA. Therefore, EPA is not specifying any changes that Washington must

[4] Davies, Tudor T., *Establishing Site Specific Aquatic Life Criteria Equal to Natural Background,* EPA Memorandum to Water Management Division Directors, Regions 1–10, State and Tribal Water Quality Management Program Directors, posted at: *https://www.epa.gov/sites/default/files/2014-08/documents/naturalbackground-memo.pdf*
[5] *Id.* at p. 2.

adopt to meet CWA requirements. EPA provides the following discretionary recommendations for the State's consideration.

EPA understands that WAC 173-201A-260(1)(a) was developed in parallel with numeric aquatic life criteria for marine and fresh waters, and that Washington intended to rely on the natural condition narrative to address circumstances where waterbody conditions are naturally less stringent than the adopted biologically-based numeric aquatic life criteria. In this respect the availability of a criterion that accounts for less stringent natural conditions was an important consideration in the establishment of numeric criteria for aquatic life. EPA continues to believe that appropriately drafted natural condition provisions can serve an important role in state WQS by reflecting a naturally occuring spatial and temporal variability in water quality that is protective of uses. A new general natural condition provision that is narrowly tailored to aquatic life uses could be adopted as a narrative criterion where numerical criteria cannot be established or to supplement numerical criteria (40 C.F.R. § 131.11(b)(2)). Alternatively, the adoption of a performance-based approach could be used to establish aquatic life criteria reflecting a natural condition for specific pollutants (see discussion for temperature and dissolved oxygen below).

EPA recommends removing the current WAC 173-201A-260(1)(a) from the State's WQS regulations to avoid confusion and provide greater clarity as to what is in effect for CWA purposes.

3. Allowable Human Contribution to Natural Conditions Provisions for Aquatic Life Temperature and Dissolved Oxygen Criteria For Fresh and Marine Waters

In its February 11, 2008 action, EPA approved the new and revised natural conditions provisions for temperature in fresh and marine waters at WAC 173-201A-200(1)(c)(i) and WAC 173-201A-210(1)(c)(i), respectively; and for dissolved oxygen in fresh and marine waters at WAC 173-201A-200(1)(d)(i) and WAC 173-201A-210(1)(d)(i), respectively. More detail and information regarding EPA's action can be found in the 2008 decision document.[6]

In the 2008 approval, EPA determined that insignificant temperature increases or insignificant decreases of dissolved oxygen concentrations above or below the natural condition were protective of the applicable designated uses because such insignificant departures from the natural condition were within the range of scientific uncertainty of effects on designated uses and/or within the error band associated with typical monitoring equipment. Specific to temperature, these "de minimis" allowable human-caused increases above natural conditions are consistent with the Temperature Guidance.[7]

The texts of each of the provisions are excerpted below.

Allowable human contribution to natural conditions provisions for aquatic life temperature:

> **Freshwater, WAC 173-201A-200(1)(c)(i):** When a water body's temperature is warmer than the criteria in Table 200 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to

[6] February 11, 2008. Letter from Michael F. Gearheard, Director, Office of Water & Watersheds, EPA Region 10, to David C. Peeler, Program Manager, Department of Ecology, re: EPA Approval of the 2003/2006 Revisions to the Washington Water Quality Standards Regulations. Available at: https://www.epa.gov/sites/production/files/2017-10/documents/wawqs-letter-02112008.pdf

[7] EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA-910-B-03-002. April 2003. Available at https://nepis.epa.gov/Exe/ZyPDF.cgi/P1004IUI.PDF?Dockey=P1004IUI.PDF

natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F).

Marine water, WAC 173-201A-210(1)(c)(i): When a water body's temperature is warmer than the criteria in Table 210 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F).

Allowable human contribution to natural conditions provisions for aquatic life dissolved oxygen:

Freshwater, WAC 173- 201A-200(1)(d)(i): When a water body's D.O. is lower than the criteria in Table 200 (1)(d) (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the D.O. of that water body to decrease more than 0.2 mg/L.

Marine water, WAC 173-201A-210(1)(d)(i): When a water body's D.O. is lower than the criteria in Table 210 (1)(d) (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the D.O. of that water body to decrease more than 0.2 mg/L.

EPA's Reconsideration: EPA has completed its reconsideration and in accordance with its CWA authority, 33 U.S.C. § 1313(c)(3) and 40 CFR Part 131, disapproves the provisions at WAC 173-201A-200(1)(c)(i), WAC 173-201A-210(1)(c)(i), WAC 173-201A-200(1)(d)(i) and WAC 173-201A-210(1)(d)(i).

EPA Rationale:
The allowable human contribution to natural condition provisions for temperature (WAC 173-201A-200(1)(c)(i) and 210(1)(c)(i)) and disolved oxygen (WAC 173-201A-200(1)(d)(i) and 210(1)(d)(i)) allow for human actions considered cumulatively to cause insignificant increases in temperature (0.3°C) or decreases in dissolved oxygen (0.2mg/L) from the natural condition of the waterbody. As discussed above, EPA is disapproving the provision at WAC 173-201A-260(1)(a) that allows for the natural condition of a waterbody to constitute the applicable criteria when the natural condition is less stringent than otherwise applicable numeric criteria.[8] Absent an approved WQS that allows for the natural condition to constitute the applicable water quality criteria, the applicable criteria for temperature and dissolved oxygen in Washington waters are the numeric criteria in Tables 200(1)(c) and (1)(d) and 210(1)(c) and (1)(d). However, the temperature and dissolved oxygen natural condition provisions are based on the natural condition of the waterbody; the provisions do not authorize human actions to cause insignificant exceedances to the applicable numeric criteria. EPA is therefore disapproving the temperature and dissolved oxygen provisions that allow insignificant human impacts to the natural condition because such impacts are not tied to approved criteria that are in effect under the CWA.

No Changes Necessary to Address the Disapproval: The effect of EPA's disapproval is that, as of the date of this action, the provisions at WAC 173-201A-200(1)(c)(i), WAC 173-201A-210(1)(c)(i), WAC 173-201A-200(1)(d)(i), and WAC 173-201A-210(1)(d)(i) are no longer applicable WQS for CWA purposes. Because Washington's WQS currently include applicable biologically-based numeric criteria

[8] EPA's interpretation of WAC 173-201A-260(1)(a) is consistent with Ecology's January 29, 2016 letter in which it stated "[t]he rule makes it clear that where Ecology identifies a natural condition that is less stringent than the numeric criteria in the state's water quality standards, the natural condition supersedes the numeric criteria." Letter from David C. Peeler, Water Quality Program Manager, Ecology, to Michael Gearheard, EPA Region 10, Re: Ecology Responses to USEPA Region 10 Questions Regarding Washington's 2003 Adopted Water Quality Standards, p. 2.

for temperature and dissolved oxygen that EPA determined to be protective of designated uses, no changes to Washington's WQS are necessary to meet the requirements of the CWA. Therefore, EPA is not specifying any changes that Washington must adopt to meet CWA requirements. EPA provides the following discretionary recommendations for the State's consideration.

Washington, at its discretion, could adopt new natural conditions criteria specific to temperature and/or dissolved oxygen. One possibility would be for Washington to adopt into its WQS a performance-based approach for establishing temperature and/or dissolved oxygen criteria representative of the natural condition of a waterbody. A performance-based approach is a binding methodology that provides a transparent, predictable, repeatable, and scientifically defensible procedure to derive numeric criteria or to translate a narrative criterion into quantifiable measures that are protective of designated uses. The performance-based approach relies on the adoption of a systematic process (i.e., a criterion derivation methodology) rather than a specific outcome (i.e., concentration limit for a pollutant) consistent with 40 CFR Sections 131.11 and 131.13. When such a performance-based approach is sufficiently detailed and has suitable safeguards to ensure predictable, repeatable outcomes, EPA approval of such an approach also serves as approval of the outcomes as well. *See EPA Review and Approval of State Water Quality Standards*, 65 FR 24,641, 24,649 (Apr. 27, 2000).

A second possibility would be for Washington to adopt numeric temperature and dissolved oxygen criteria that account for natural conditions using the best available relevant data. EPA encourages Washington to consider magnitude, frequency, and duration components in setting water quality criteria to protect against acute and chronic effects.[9] This may include establishing protective site-specific criteria accounting for specific characteristics, such as unique temperature and/or dissolved oxygen regimes in different waterbodies (see EPA's Temperature Guidance).[10] Site-specific criteria established in this manner would be subject to CWA section 303(c) review.

Washington, at its discretion, could also choose to adopt new WQS provisions that allow for human actions, considered cumulatively, to cause insignificant exceedances in temperature and dissolved oxygen. As articulated in the 2008 Technical Support Document, EPA believes insignificant or de minimis exceedances to applicable temperature and/or dissolved oxygen criteria caused by human actions, considered cumulatively, may still be protective of designated uses.[11] Any such human use allowance provision must be scientifically defensible and tied to approved criteria that are protective of designated uses, which could include criteria based on the natural condition of the waterbody.

EPA recommends removing the disapproved provisions from the State's WQS regulations to avoid confusion and provide greater clarity to what is in effect for CWA purposes.

[9] EPA Water Quality Standards Handbook – Chapter 3: Water Quality Criteria. EPA-823—B-17-001; 2017. Available at https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter3.pdf

[10] EPA Issue Paper 3: Spatial and Temporal Patterns of Stream Temperature (Revised), October 2001. EPA-910-D-01-003, pages 2-9. Available at https://www.epa.gov/sites/production/files/2018-01/documents/r10-water-quality-temperature-issue-paper3-2001.pdf

[11] 2008 TSD at pp. 20-21, 32.

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Opinion on Puget Sound Nutrient Source Reduction Project Dissolved Oxygen Modeling and Bounding Scenarios (Ahmed et al. 2019)

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The Salish Sea Model is being used by Washington Department of Ecology to predict dissolved oxygen (DO) throughout the Salish Sea at multiple depths to assess whether any areas are out of compliance with the Washington Water Quality Standard of 0.2 mg/L decrease in dissolved oxygen due to human activities. Results of initial bounding scenarios are presented in Ahmed et al. 2019[i], where existing dissolved oxygen concentration (with human influence) were modeled for 2006, 2008, and 2014. Assumed "reference" conditions (conditions without human impact) for each year were also modeled where watershed and marine source nitrogen and carbon loads were set to an estimated natural level. The report concludes that regional nutrient contributions from humans exacerbate low DO causing approximately 20% (19%–23%) of the greater Puget Sound (by surface area) to fall below the dissolved oxygen standards (pg. 62). The opinions expressed below are based on our reading of this report and two subsequent conversations between Holtgrieve and Washington Department of Ecology staff about the modeling process (hereafter, Ecology).

Our overall concern is that the inappropriate treatment of uncertainty in the analysis, and the minimal effort to communicate that uncertainty, leads to a general overconfidence that nutrients are in fact a meaningful problem in the Puget Sound. A proper uncertainty assessment will decrease the surface area of Puget Sound considered out of compliance substantially (visually estimated to be a more than 80% reduction). Washington Department of Ecology, in essence, assumes their model is a perfect understanding of dissolved oxygen in Puget Sound. In fact, we know the model does not represent *in situ* dissolved oxygen conditions well enough to determine if a particular point on the map is not in compliance at the level of certainty expressed in the report (0.030–0.049 mg/L, page 59). All models have uncertainty, including uncertainty about the model itself, uncertainty in the parameters, and uncertainty in the data used to calibrate the model. This fundamental fact dictates that environmental modeling in support of decision-making must accurately and transparently incorporate uncertainty into analyses and policy documents.[ii] To make effective decisions, you must know not only the best scientific estimate of what is happening but also the chance of being wrong, which in this case is quite high. The information provided by Ahmed et al. 2019 falls well short of what can be considered appropriate treatment of uncertainty in environmental decision-making.[iii]

In establishing whether or not a location in Puget Sound at a given time is in compliance, there are two tests, conducted in series, and the site is considered out of compliance if both answers are affirmative:

1) Is the reference condition model prediction of dissolved oxygen below a threshold? The threshold is from 4 to 7 mg/L, varying by location.[iv]
2) Is the difference of existing and reference dissolved oxygen ≥ 0.2 mg/L? This is a comparison of two model runs, one for existing condition and a second for reference conditions.

There is uncertainty associated with both tests that must be considered. Currently the process only considers uncertainty for the second question and treats the first as being completely without error. This is incorrect. Furthermore, the calculation of the uncertainty of the difference between existing and reference conditions (i.e., question 2) as defined on page 59 of Ahmed et al. 2019 is incorrect. Ahmed et al. 2019 incorrectly treat the models' root mean squared error (RMSE) as equivalent to the standard deviation (SD) of the predictions. Third, in estimating the covariance of model runs, Ahmed et al. 2019 greatly inflate their sample size by treating all individual predictions for each cell and depth layer as independent. This artificially raises the covariance between model runs, which in-turn artificially shrinks their estimated standard deviation. Ahmed et al. 2019 also does not formally consider that predictions of unobservable conditions (i.e., the reference conditions) are inherently more uncertain than prediction of observed data – that is, they do not include predication intervals as would be standard for any regression model used to estimate a value that is unobservable.

The document appended below — written by my co-author Mark Scheuerell — details the specifics of why the Ahmed et al. 2019 uncertainty estimates are incorrect; it shows that using RMSE will substantially underestimate the uncertainty and why predictions of unobserved states are inherently more uncertain than comparing model outputs to data. ***Our initial reanalysis demonstrates the true standard deviation of the difference between model predictions is 0.32 mg/L, about 8 times greater than 0.041 mg/L reported in Ahmed et al. 2019 for 2014.*** Note this reanalysis addresses only one of at least four statistical problems.

With a standard deviation of 0.32 mg/L, the 95% prediction interval for the mean is conservatively on the order of ± 0.9 mg/L (assuming a very large sample size; see page 6 in the appendix). Put another way, if the model predicts a value of 6 mg/L for some place and time, we can say the true value is somewhere between 5.1 and 6.9 mg/L with only a 5% chance of being wrong about that. If we want only a 1% chance of being wrong, then we have to expand the possible range to between 4.7 and 7.3 mg/L. If we want to limit the range to being between 5.8 and 6.2 mg/L, then there is roughly a 72% chance of the true value being *outside* that range. This example is highly conservative and is an underestimate of the true uncertainty. ***Nonetheless, the uncertainty of a single prediction is <u>at least</u> 4.5-times higher than the 0.2 mg/L threshold criteria*** when using a 5% acceptable error rate.

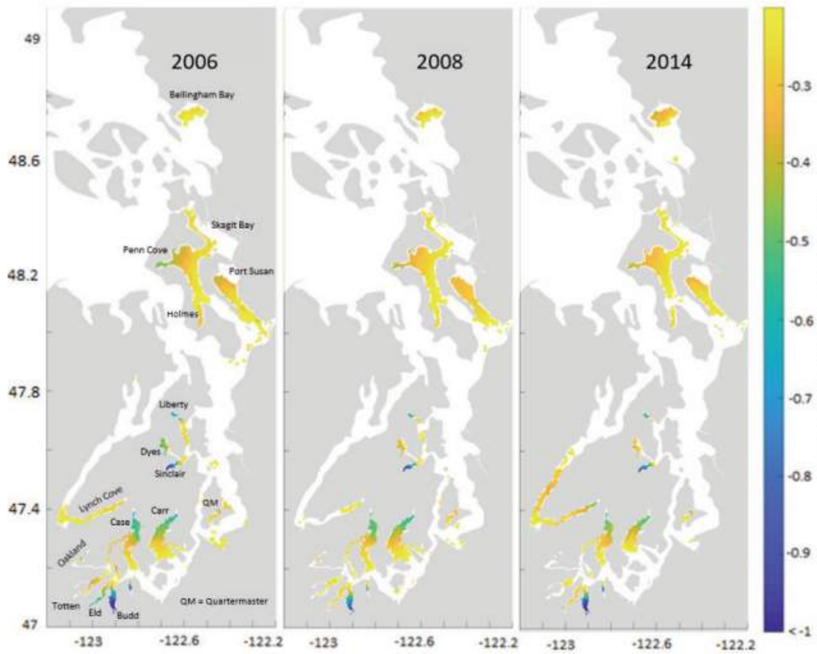

Figure 26 from Ahmed et al. 2019: Maximum dissolved oxygen (DO) depletions from anthropogenic sources in 2006, 2008, and 2014, leading to noncompliance with the water quality standards (WQS).

Given the above and to the extent the information in Ahmed et al. 2019 is true and meaningful, we can say that in order to be 95% confident that a given area of Puget Sound is in fact out of compliance, the model must predict a ≥ 0.9 mg/L depletion of dissolved oxygen. Figure 26 from Ahmed et al. 2019 above shows areas in Puget Sound with >0.2 mg/L depletion (darker areas are more depleted in DO). Only the darkest blue colors are ≥ 0.9 mg/L. ***Therefore, a very small fraction of the areas previously deemed out of compliance meet this 0.9 mg/L threshold for conclusively determining a human effect.*** In fact, most areas in Puget Sound that are currently considered out of compliance are very near the 0.2 mg/L criteria, which means there has been no measurable change in dissolved oxygen given uncertainty in the modeling process.

The four statistical errors described above and in the appended document — 1) not considering errors in prediction of reference dissolved oxygen, 2) use of RMSE in the variance calculations, 3) inflation of sample size, and 4) using confidence estimates rather than prediction estimates — are significant, and we demonstrate that these substantially change the assessment of compliance to the dissolved oxygen standard. In all cases, these statistical errors result in an underestimate of uncertainty that is meaningful for decision-making. We also note that the report does not include a full description of the modeling process, so it is very possible other statistical errors have occurred.

We recommend to Ecology the following:

1. Correct mistakes in calculating model uncertainty. Specifically, specify the standard deviation of the model fits to data rather than using RMSE, remove inflation of covariance by appropriately specifying the sample size, provide prediction intervals for forecasts, and consider uncertainty in both steps of compliance assessment process. We also recommend that validation procedures be employed, were parts of the observed data are held back, the

model parameters are fit, then the predicted results compared to the reserved data using RMSE or, preferably, formal cross-validation.
2. Allow an independent review of the uncertainty analysis related to compliance standards and incorporate all relevant suggestions into a new presentation of results.
3. Present the model uncertainties in a more transparent way that acknowledges that the model has large errors in predicting both absolute concentration and change in dissolved oxygen. Thus, the question about compliance is not really yes or no, but yes or no with a specified chance of being wrong. Policymakers must be presented an analysis with a correctly specified errors that accurately portray current scientific understanding.
4. Present the areas predicted to be out of compliance with an associated type I error probability. That is, make a map of areas that are predicted out of compliance at a 95% level of certainty, also maybe at the 90% and 80% levels. This will let policymakers judge for themselves how willing they are to be wrong, given the inherent communicated uncertainty in the modeling process. ***Acceptable error rate is an important policy decision.***

It is critically important that uncertainty in the model predictions be adequately considered and transparently reported to policymakers, as it will dramatically change the definition of the problem we aim to solve. Ahmed et al. 2019 fails to accomplish this critical task and thus is inconsistent with what is currently considered best practices. ***Mistakes in Ahmed et al. 2019 lead to <u>at least</u> an eight-fold underestimate of uncertainty and overconfidence in the model results, which leads to a systematic overestimate of the area expected to be out of compliance.*** A complete error analysis will undoubtedly increase the error level even more. If/when uncertainty is properly considered, the areas and times deemed out of compliance with the dissolved oxygen standard will decrease dramatically, fundamentally redefining the problem we aim to solve. It is therefore absolutely critical this part of the analysis be done correctly before any decisions are made.

We stand ready to assist Ecology in their analysis if requested.

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[i] Ahmed, A., C. Figueroa-Kaminsky, J. Gala, T. Mohamedali, G. Pelletier, S. McCarthy. 2019. Puget Sound Nutrient Source Reduction Project, Volume 1: Model Updates and Bounding Scenarios. Washington Department of Ecology, Publication No. 19-03-001.
[ii] Clark et al. (2001) Science 293(5530): 657-660.
[iii] Regan et al. (2005) Ecological Applications 15(4): 1471–1477
[iv] This part of the criteria remains a point of confusion and emphasizes the need for greater transparency in compliance assessment. We originally thought that the comparison was with respect to current conditions, as this seems most relevant to the issue at hand. However, on 3 June 2019, Christiana Figueroa-Kaminsky (Ecology) wrote in an email “Please note that to determine compliance with the standard—the first step is to compare natural or reference condition (not existing) with the 5 or 6 mg/L in most inlets. There are no observations for reference condition, so we have no statistics to present there. If the reference condition is below 5 or 6 mg/L for the inlets, we have to use the difference of the model runs (existing minus reference). This is by far the most common type of DO noncompliance found in our region. So, the difference of model runs method is the only way to compute compliance or not in more than about 95% of the instances.” Regardless, considering uncertainty in predictions of absolute concentration (step 1) is necessary but has thus far been ignored.

Critique of model evaluation by the Washington Department of Ecology

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Comparison of existing and reference scenarios

The focus of the modeling analysis is a comparison of results obtained with two scenarios: a "reference" case that represents a system without anthropogenic inputs, and an "existing" case that represents contemporary conditions. Specifically, Ecology is interested in the difference between the modeled concentration of dissolved oxygen estimated via the two models. In addition, Ecology would like to know the estimated uncertainty in that difference.

Variance of predictions

In the section titled "Uncertainty in Dissolved Oxygen Depletion Estimates" (p59), it states,

> The RMSE of differences is calculated to understand the uncertainty associated with the result of subtracting one model scenario from another model scenario (i.e., the difference between two model scenarios). In this case, we calculated the error associated with the DO depletions computed from the difference between the existing and reference model scenarios.

The section then goes on to describe how the calculations were made using the estimated root mean squared error (RMSE) between the predictions and observations, but there is a mistake in the assumed relationship between the standard deviation of the predictions and the RMSE.

Variance of predictions

To demonstrate this, consider this simple equation that relates individual observations (o_i) and predictions (p_i):

$$o_i = p_i + e_i,$$

where e_i are the model prediction errors (i.e., the difference between the observed and predicted values). From this relationship we know that the variance of the observations is a function of the variances of both the predictions and errors, and their covariance, such that

$$\text{Var}(o) = \text{Var}(p) + \text{Var}(e) + 2\ \text{Cov}(p, e)$$

We can rewrite the above equation to show that the variance of the predictions is

$$\text{Var}(p) = \text{Var}(o) - \text{Var}(e) + 2\ \text{Cov}(p, e).$$

Variance in the difference of predictions

In this case Ecology is interested in the uncertainty (variance) in the difference between the predictions from the two models representing existing and reference conditions, which we write as p_{ex} and p_{ref}, respectively. We then define the difference δ as

$$\delta = p_{ex} - p_{ref}$$

and hence

$$\begin{aligned}\text{Var}(\delta) &= \text{Var}(p_{ex}) + \text{Var}(p_{ref}) - 2\ \text{Cov}(p_{ex}, p_{ref}) \\ &= \text{Var}(p_{ex}) + \text{Var}(p_{ref}) - 2\ \text{Cor}(p_{ex}, p_{ref})\ \text{SD}(p_{ex})\ \text{SD}(p_{ref})\end{aligned}$$

This is where Ecology gets their calculations wrong. In a forecasting context, the hope is that the predictions match the observations very closely and hence the errors are small. One measure of forecast skill is the root mean-squared error (RMSE), which equals the standard deviation of the errors. More specifically,

$$\text{RMSE}_{o,p} = \text{SD}(e) = \sqrt{\text{Var}(e)} = \sqrt{\frac{\sum(p_i - o_i)^2}{N}}.$$

Importantly, however, the $\text{RMSE}_{o,p}$ is not equal to the variance of the predictions, $\text{Var}(p)$, which is required for the calculations of the error in differences.

Re-analysis

The Ecology report does not provide estimates of the variance in the model predictions, but we can generate approximations from the information provided and a simple assumption. For most of the DO models, $\text{RMSE}_{ex} \approx 1$ (Table 7) and the correlation between the predicted and observed values is about 0.85 (Table 8). Recognizing that

$$\text{RMSE}_{ex} = \sqrt{(1 - R^2)}\ \text{SD}(o),$$

we can estimate the SD of the observations as

$$\mathrm{SD}(o) = \frac{\mathrm{RMSE}_{ex}}{\sqrt{(1-R^2)}} \approx \frac{1}{\sqrt{(1-0.85^2)}} \approx 1.9$$

and hence the variance of the observations is

$$\mathrm{Var}(o) = \mathrm{SD}(o)^2 \approx 1.9^2 = 3.61.$$

Now we can estimate the variance of the predictions for the model with existing conditions as above, with

$$\begin{aligned}\mathrm{Var}(p_{ex}) &= \mathrm{Var}(o) - \mathrm{Var}(e) + 2\ \mathrm{Cov}(p_{ex}, e)\\ &= \mathrm{Var}(o) - \mathrm{RMSE}_{ex}^2 + 2\ \mathrm{Cov}(p_{ex}, e)\\ &\approx 3.6 - 1^2 + 2\ \mathrm{Cov}(p_{ex}, e).\end{aligned}$$

Absent information on the covariance between the predicted values and the model errors, we will assume that the model is well behaved and $\mathrm{Cov}(p_{ex}, e) \approx 0$, such that

$$\mathrm{Var}(p_{ex}) \approx 3.6 - 1^2 + 2(0) = 2.6$$

To the extent that $\mathrm{Cov}(p_{ex}, e)$ is positive (negative), $\mathrm{Var}(p_{ex})$ will be larger (smaller) than this estimate.

If we also assume, as Ecology did, that $\mathrm{Var}(p_{ex}) = \mathrm{Var}(p_{ref})$, then we can estimate the variance in the difference (δ) between the predictions from the two models as above, such that

$$\begin{aligned}\mathrm{Var}(\delta) &= \mathrm{Var}(p_{ex}) + \mathrm{Var}(p_{ref}) - 2\ \mathrm{Cor}(p_{ex}, p_{ref})\ \mathrm{SD}(p_{ex})\ \mathrm{SD}(p_{ref})\\ &= \mathrm{Var}(p_{ex}) + \mathrm{Var}(p_{ex}) - 2\ \mathrm{Cor}(p_{ex}, p_{ref})\ \mathrm{SD}(p_{ex})\ \mathrm{SD}(p_{ex})\\ &= 2\ \mathrm{Var}(p_{ex}) - 2\ \mathrm{Cor}(p_{ex}, p_{ref})\ \mathrm{Var}(p_{ex})\\ &= 2\ \mathrm{Var}(p_{ex})\,(1 - \mathrm{Cor}(p_{ex}, p_{ref}))\\ &= 2(2.6)\,(1 - \mathrm{Cor}(p_{ex}, p_{ref}))\,.\end{aligned}$$

Thus, if $\mathrm{Cor}(p_{ex}, p_{ref}) = 0$, then $\mathrm{Var}(\delta) = 5.2 \Rightarrow \mathrm{SD}(\delta) \approx 2.3$; conversely, as $\mathrm{Cor}(p_{ex}, p_{ref}) \to 1$ then $\mathrm{Var}(\delta) \to 0$.

Although Ecology's report did not say what $\mathrm{Cor}(p_{ex}, p_{ref})$ was, but we can estimate it from the calculations on p59. For example, if we assume that $\mathrm{Var}(\delta) = 0.041$ as for Ecology's model in 2014, then analogous to above we have

$$\mathrm{Var}(\delta) = \mathrm{Var}(p_{ex}) + \mathrm{Var}(p_{ref}) - 2\ \mathrm{Cor}(p_{ex}, p_{ref})\ \mathrm{SD}(p_{ex})\ \mathrm{SD}(p_{ref})$$
$$\Downarrow$$
$$\mathrm{Cor}(p_{ex}, p_{ref}) = \frac{(\mathrm{Var}(\delta) - \mathrm{Var}(p_{ex}) - \mathrm{Var}(p_{ref}))}{-2\ \mathrm{SD}(p_{ex})\ \mathrm{SD}(p_{ref})}$$
$$\approx \frac{(0.041 - 1^2 - 1^2)}{-2(1)(1)}$$
$$\approx 0.98$$

This correlation is remarkably high, indicating that the two models produce nearly identical predictions of DO. Inserting this correlation coefficient into the equation for $\mathrm{Var}(\delta)$ gives $\mathrm{Var}(\delta) = 2(2.6)(1 - 0.98) = 0.104$, and hence $\mathrm{SD}(\delta) \approx 0.32$. This value is about eight times greater than those reported in Ecology's document. Thus, if the treshhold concentration for DO depletion is 0.2 mg/L, then the estimated coefficient of variation (CV) around it is 160%.

Example of SD versus RMSE

Here is a simple example that shows how $\mathrm{SD}(\hat{y})$ and $\mathrm{RMSE}(\hat{y})$ are different. Consider a case where we had reason to believe that a variable y was a function of another variable x. In effort to undercover the nature of their relationship, we collected 20 samples of both y and x (Figure 1).

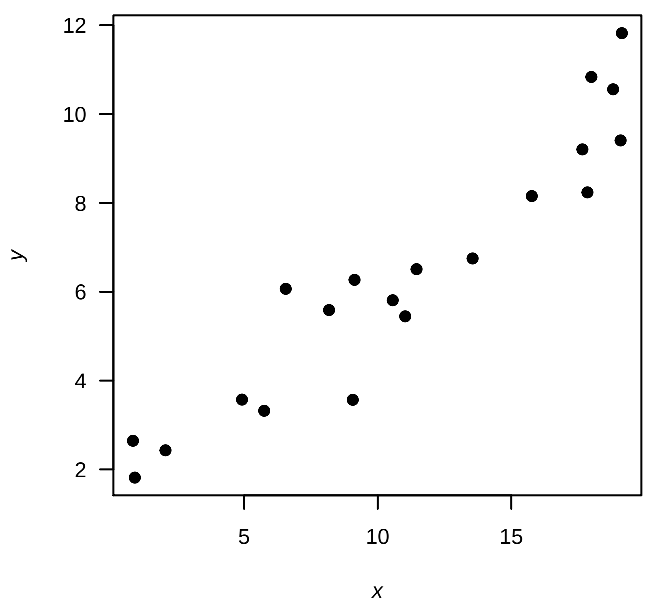

Figure 1. Plot of some hypothetical data.

Based on the apparent relationship between x and y, we might assume that each of the observed values y_i is a linear combination of an intercept β_0, the effect β_1 of a covariate x_i, and some random observation error ϵ_i, such that

$$y_i = \beta_0 + \beta_1 x_i + \epsilon_i,$$

and $\epsilon_i \sim \text{N}(0, \sigma)$. We could easily estimate the unknown parameters in this model (β_0, β_1, σ), and then use the deterministic portion of the model to make predictions to compare with each of the observed values. Specifically, the predictions ($\hat{y}_i$) would be given by a straight line, such that

$$\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i.$$

We could then estimate the SD of these predictions and the model's RMSE (Figure 2). It turns out that the SD of $\hat{y}$ is ~2.82, but the RMSE is only ~0.94, which is about 3 times less.

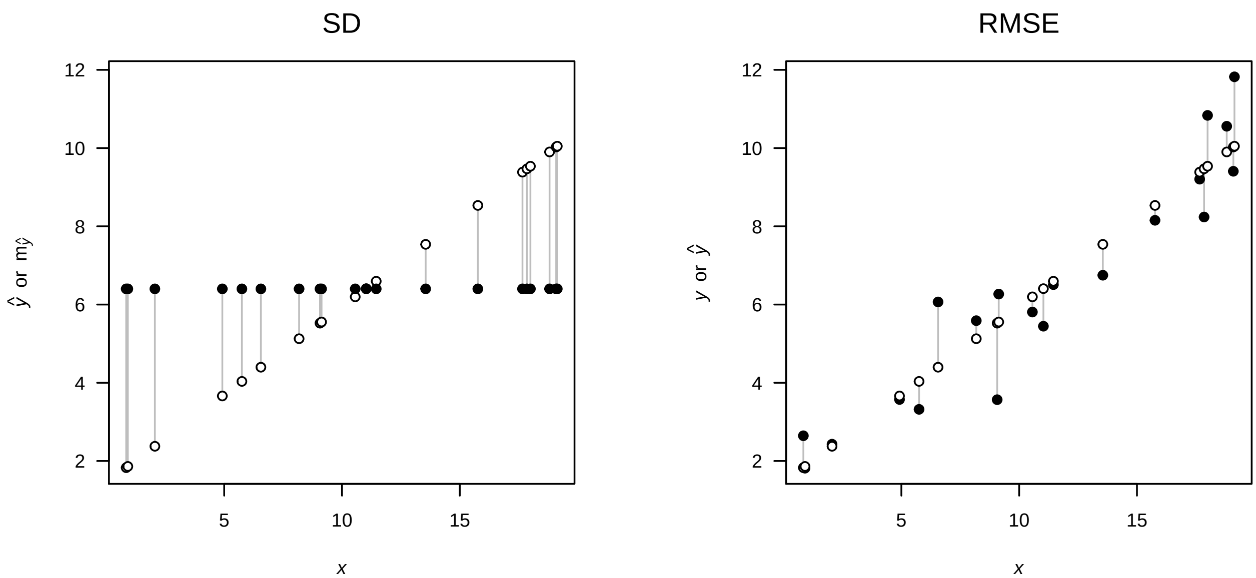

Figure 2. Graphical examples of the difference between the SD of the predictions (left) and the RMSE of the predictions (right). For the SD, the comparison is based upon the differences between the predictions (open circles) and their mean (filled circles). For the RMSE, the comparison is based upon differences between the predictions (open circles) and the observed data (filled circles). In both cases, one would square the length of each of the vertical gray lines, sum them up, and divide by the number of them before finally taking the square root.

Prediction errors

The above example dismisses an important aspect of RMSE: it should be used to compare "out of sample" predictions. Furthermore, RMSE give us an indication as to the predictive error, *on average*, rather than the uncertainty in a specific prediction.

Returning to our example above, we could estimate our uncertainty around the fitted relationship between x and y with a confidence interval (CI), which would give us an indication of the range of where the "true" fitted values would lie had we repeated our sampling exercise many times.

Specifically, a $(1-\alpha)100\%$ CI on the expected relationship between x and y at some value x_k is given by

$$\hat{y}_i \pm t_{\alpha/2,n-2}\sqrt{\sigma\left(\frac{1}{n}+\frac{(x_k-\bar{x})^2}{\sum(x_i-\bar{x})^2}\right)}.$$

The interval increases as the distance between x_k and $\bar{x}$ increases (Figure 3).

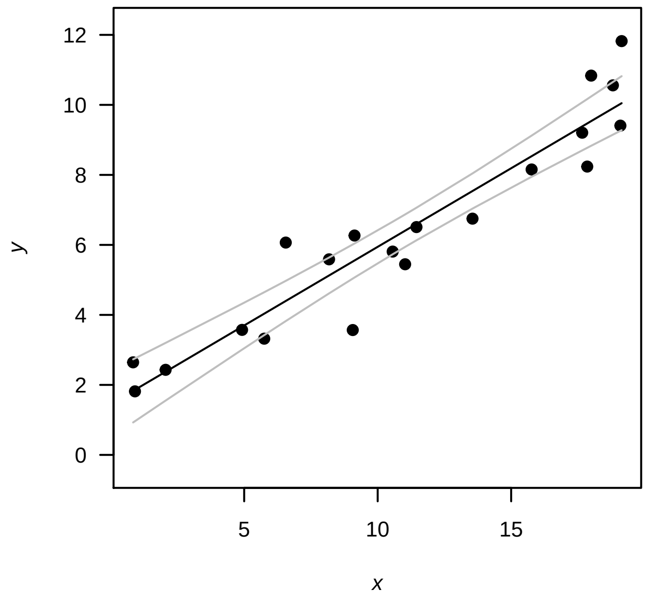

Figure 3. Example of a 95% confidence interval (gray lines) around the expected relationship between x and y (black line).

In a case like this, however, where we wish to make out-of-sample predictions about some new state of nature, our uncertainty around any single prediction will be necessarily greater. Specifically, a $(1-\alpha)100\%$ prediction interval (PI) around $\hat{y}$ at some value x_k is given by

$$\hat{y} \pm t_{\alpha/2,n-2}\sqrt{\sigma\left(1+\frac{1}{n}+\frac{(x_k-\bar{x})^2}{\sum(x_i-\bar{x})^2}\right)}.$$

Here the paranthetic multiplier on the residual variance σ has increased by 1, which means the prediction interval is wider (less certain) than the confidence interval (Figure 4). This is because the CI only needs to account for uncertainty in estimating the expected value of y whereas the PI needs to account for a random future value of y that tend to fall away from the mean.

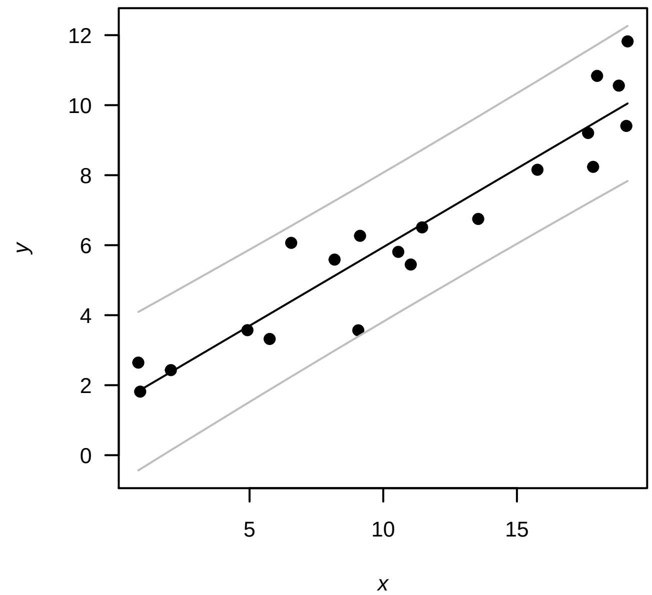

Figure 4. Example of a 95% prediction interval (gray lines) for future unobserved values of y.

So, for example, if we wanted to predict, with 95% certainty, what we would observe for y if $x = 10$, we would get 5.94 ± 2.13 (Figure 5). The relatively wide prediction interval suggests that it might be difficult to discern the prediction for y when $x = 10$ to the expected values for y if x were as low as 5 or as high as 15.

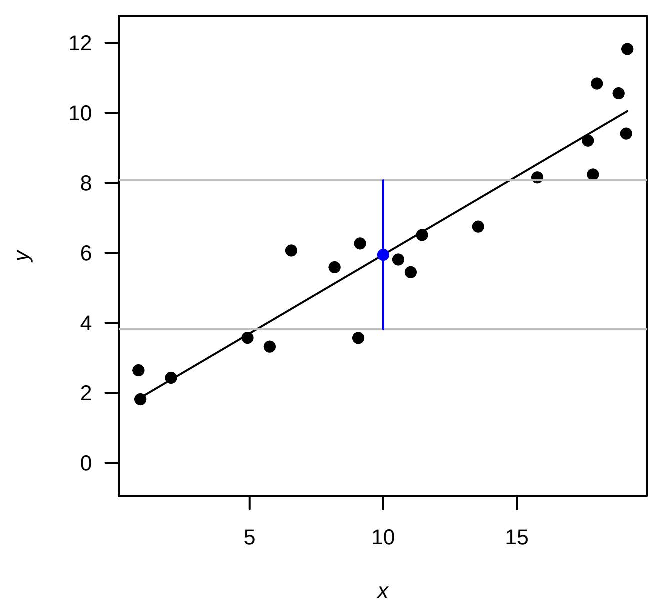

Figure 5. Example of the uncertainty around a new prediction for y when $x = 10$.

Memo

From: Lincoln Loehr
To: Scott Redman
Date: February 29, 2020 (minor corrections April 3, 2020)
Subject: Scientific perspective re dissolved oxygen criteria

It is virtually certain that the dissolved oxygen criteria are not biologically based, and have no documented scientific foundation. The dissolved oxygen criteria are the driver in the modeling efforts to date, and in the Department of Ecology's assertions of reasonable potential for all the dischargers to be contributing to violations of the criteria.

Ecology admits that the criteria were adopted in 1967 by a predecessor agency, and that the archives provide no documentation of the basis for the criteria other than a comment letter stating the need to allow some human degradation beyond natural levels in marine waters during periods of upwelling (which the criteria did accommodate). (Letter from Ecology's water quality standards coordinator Mark Hicks to Lincoln Loehr, July 8, 1998.)

Ecology asserts that the criteria were based on a 19**6**8 Department of the Interior criteria document. (Nutrient Forum presentation on May 30, 2018). However, the adopted dissolved oxygen criteria for both marine and freshwater bear no resemblance to the DOI document and it is virtually certain that the predecessor agency did not rely on that document.

Ecology acknowledges that the 0.2 mg/L difference from human causes component of the criteria is not biologically based. (Nutrient Forum presentation on May 30, 2018.)

The predecessor agency made no effort to understand actual dissolved oxygen levels throughout our inland marine waters before adopting the criteria (Eugene E. Collias, personal communication in the 1970s). Hence, the classifications applied to our inland marine waters (Extraordinary, Excellent, Good, and Fair) and their associated dissolved oxygen criteria had no relationship to what the waters actually exhibited.

The states bordering Chesapeake Bay, confronting the need for nutrient reductions, realized that the dissolved oxygen criteria they had could not work and with EPA's help, developed new dissolved oxygen criteria that recognized 5 different types of water, incorporated averaging considerations, as well as differences in depth and seasons and complied with endangered species consultation requirements with NMFS and USFWS. In developing new recommended dissolved oxygen criteria for Chesapeake Bay, EPA emphasized that 40 CFR 131.11 requires that states must adopt water quality criteria that protect the designated uses, that such criteria must be based on sound scientific rationale, and that such criteria must be based on scientifically defensible methods.

Washington's criteria were adopted before there was an EPA, before there was a Clean Water Act, and before EPA had developed the implementing regulations, which includes 40 CFR 131.11. Washington's criteria are 5**3** years old, are not biologically based, are without scientific rationale, and do not match well with what the real world looks like. The State Agency is negligent in its failure to develop new dissolved oxygen criteria meeting the requirements of 40 CFR 131.11. 303(d) listings of impaired waters for dissolved oxygen are based on the criteria, and the modeling to date is driven by the criteria. The flawed and non-biologically based dissolved oxygen criteria, make the necessity of the General Permit for nutrient reduction questionable.

I look forward to discussions about this concern at the mid-May meeting.

Lincoln Loehr
Oceanographer, water quality/permitting consultant

Attachments:
July 8, 1998 letter from Mark Hicks to Lincoln Loehr
40 CFR 131.11

Volume 17/Number 11/November 1986

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VIEWPOINT

Viewpoint is a column which allows authors to express their own opinions about current events.

The Exclusion of Science from Major Water Quality Decisions

LINCOLN C. LOEHR

Mr Loehr is an oceanographer who has participated in many oceanographic cruises in Puget Sound, Washington. He has become active in the political process seeking to change the state's law requiring secondary treatment of all municipal wastes discharged to marine waters.

A recent interpretation of the State law has determined that the state could not consider water quality as a factor when evaluating whether municipal sewage treatment plants discharging to Puget Sound or adjacent marine waters could be permitted to discharge at less than full secondary treatment level. The Federal law requires secondary treatment but has a waiver provision by which a discharger may present information that may permit a case-by-case decision on the level of treatment necessary. The information required by the Federal law to make this case-by-case decision is essentially scientific. Scientific information is irrelevant to the State law. To receive a waiver it is necessary for both the State Department of Ecology and the Federal Environmental Protection Agency to concur. Since the State Department of Ecology could not consider water quality, they denied virtually all waiver applicants. Given this State denial, the Environmental Protection Agency did not have to review the scientific information and issued denials. Thus we are launched on a program that ultimately will cost between $1 000 000 000 and $2 000 000 000. The scientific community is in general agreement that it will do little or nothing towards solving any of the real pollution problems that exist in Puget Sound. The public, however, rightfully expects that this should result in major improvements to the environment. Politics, environmental groups and press sensationalism have played a major role in shaping public opinion.

In 1982, 32 municipal sewage treatment plants (STPs) discharging to marine waters in the state of Washington applied for waivers of the Federal secondary treatment requirement under guidelines developed by the Environmental Protection Agency (EPA). Waivers are permitted under Section 301(h) of the Federal Clean Water Act.

Law Governing Issuance of a Section 301(h) Modified Permit

Section 301(h) of the Clean Water Act provides that:

The Administrator, with the concurrence of the State, may issue a permit under section 402 which modifies the requirements of subsection (b) (1) (B) of this section with respect to the discharge of any pollutant from a publicly owned treatment works into marine waters, if the applicant demonstrates to the satisfaction of the Administrator that:

1. there is an applicable water quality standard specific to the pollutant for which the modification is requested, which has been identified under section 304(a) (6) of this Act:
2. such modified requirement will not interfere with the attainment or maintenance of that water quality which assures protection of public water supplies and the protection and propogation of a balanced, indigenous population of shellfish, fish and wildlife, and allows recreational activities in and on the water.
3. the applicant has established a system for monitoring the impact of such discharge on a representative sample of aquatic biota, to the extent practicable;
4. such modified requirements will not result in any additional requirements on any other point or nonpoint source;
5. all applicable pretreatment requirements for sources introducing waste into such treatment works will be enforced;
6. to the extent practicable, the applicant has established a schedule of activities designed to eliminate the entrance of toxic pollutants from non-industrial sources into such treatment works;
7. there will be no new or substantially increased discharges from the point source of the pollutant to which

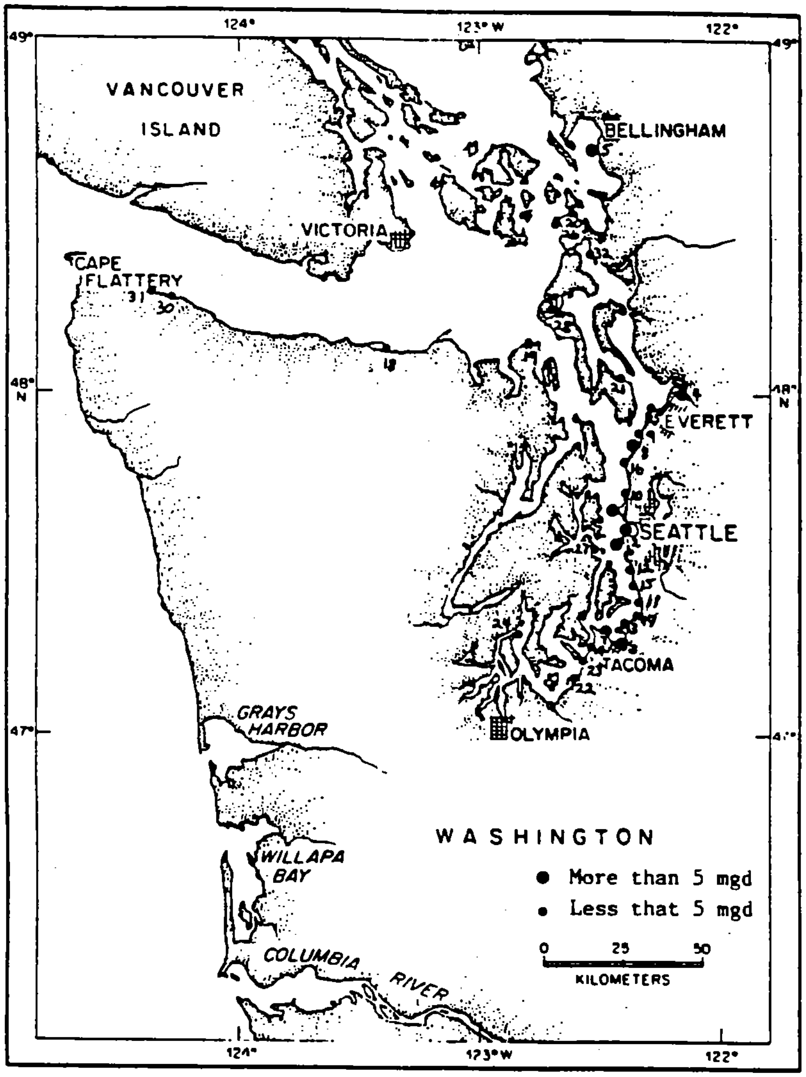

Fig. 1 Sewer discharges in the State of Washington that applied for waivers of the secondary treatment requirement.

the modification applies above that volume of discharge specified in the permit.

For the purposes of this subsection the phrase 'the discharge of any pollutant into marine waters' refers to a discharge into deep waters of the territorial sea or the waters of the contiguous zone, or into saline estuarine waters where there is strong tidal movement and other hydrological and geological characteristics which the Administrator determines necessary to allow compliance with paragraph (2) of this subsection, and section 110(a) (2) of this Act. A municipality which applies secondary treatment shall be eligible to receive a permit pursuant to this subsection which modifies the requirements of subsection (b) (1) (B) of this section with respect to the discharge of any pollutant from any treatment works owned by such municipality into marine waters. No permit issued under this subsection shall authorize the discharge of sewage sludge into marine waters. (Source: *Fed. Reg.*, Vol. 47, No. 228, 26 November, 1982.)

The 32 waiver applicants for the state of Washington are listed in Table 1 and their locations are shown in Fig. 1. All knew that applying did not assure them of a waiver, but they had definite reason to expect a thorough, case-by-case review of the environmental information that EPA required, and that approval or denial would be based on that review. EPA had even encouraged many of the smaller dischargers to apply for the waiver even though the information requirements were costly and EPA had originally imposed unrealistic time frames for the collection of this information.

There are other sewage treatment facilities discharging to Puget Sound that are at secondary treatment. Generally these were built to discharge secondary-treated effluent in recognition of site-specific environmental constraints (usually depth, mixing and flushing characteristics drove this decision). In some cases, environmental degredation from secondary treated effluent occurs because the volume of flow exceeds what the area in the vicinity of the discharge can handle. Proper outfall siting is critical and should also avoid commercially significant shellfish beds as well as seeking optimum physical parameters.

The time-line showing significant events in the development and implementation of the waiver process pertains to these dischargers, is as follows:

1972 Federal Water Pollution Control Act passed (later called the Clean Water Act).

1974 Municipality of Metropolitan Seattle (METRO) commenced detailed evaluation of impacts from its primary and secondary treatment facilities.

1976 METRO lobbied Congress to change the law to allow consideration of waivers on case-by-case basis. Los Angeles STPs joined in this effort.

1977 US Congress passes Section 301(h) amendments to the Clean Water Act. EPA tasked with developing the rules and regulations to implement this section.

1979 EPA promulgates 301(h) rules and regulations in June. Deadline for completed applications was September. In August, Region X EPA administrator sent letters to small dischargers urging them to apply for the waivers. Regulations stated that EPA would review, and that if they approved, the States would then review. Concurrence by both EPA and State necessary for granting of waiver.

1981 US General Accounting Office investigates EPA on subject of the 301(h) rules and determines that 'Billions could be saved' if EPA would make the rules more reasonable, especially for the smaller dischargers.

1982 US Congressional Investigations and Oversight Committee issues report blasting EPA for not carrying out the intent of Congress with regards to Section 301(h). Report was subtitled, 'A Case Study of Lawmaking by Rulemakers'.

1982 EPA tentatively decides to approve some Puget Sound waivers, including METRO's biggest facility at West Point. Decision now passed to State.

1982 EPA issues new 301(h) rules and regulations as well as detailed guidelines for answering the applicant questionnaire. Relaxed rules for small discharges (less than 5 mgd). Shifted review requirements to the State first, after which EPA would review if the State tentatively approved an application. All State dischargers who applied under the 1979 rules chose to reapply under the new rules.

1983 32 applications submitted, State Department of Ecology commences review. Some doubt raised about whether State law permitted them to consider water quality in this review.

1983 State Attorney General's office issues an opinion on the State law. 'All known, available, reasonable technology' must be used, *regardless of water quality*. Wording goes back to 1944.

1983 Effort to change State law. Bill passed in the House, died in Senate Park's and Ecology Committee.

1983 Puget Sound Water Quality Authority created by law, appointed by Governor, 21 members, *no marine scientists appointed.*

1983 Department of Ecology determines secondary treatment is reasonable, meaning (1) affordable, and (2) subject to environmental site-specific constraints but, (3) *without consideration of water quality*. Review of applications continues but all scientific information presented is now ignored in the review as it is irrelevant to the State law.

1984 Six grey whales die in Puget Sound. Considerable press interest in pollution stories. Election year and both Governor candidates make Puget Sound clean-up a political priority. A veterinarian autopsies one whale and proclaims Puget Sound pollution killed it. Greenpeace also blames pollution. National Marine Fisheries Service concludes pollution not the cause of death, and deaths viewed as from natural causes.

1984 Department of Ecology denies virtually all waivers except two of the smallest and the largest. These were considered unreasonable for secondary treatment on the basis of cost or environmental site-specific constraints. The two smallest (Sneehosh Beach and Manchester) would have had very high treatment costs of $75 to $98 per month per house, and the West Point facility would have had to fill in 20 acres of intertidal land to expand to secondary treatment.

1984 Puget Sound Alliance (a coalition of environmental groups) forms. They are strong on environmental activism and lobbying, but they are lacking in marine science participation in defining their goals.

1984 Washington Environmental Council and Friends of the Earth file a lawsuit with METRO for discharging less than secondary treated effluent.

TABLE 1

Waiver Applicants in Washington State (see Fig. 1 for locations)

		Flow (mgd)
1	Seattle (West Point)	125.000
2	Seattle (Duwamish)	43.300
3	Tacoma (Central)	28.000
4	Everett	20.390
5	Bellingham	10.400
6	Seattle (Alki)	10.000
7	Tacoma (North End)	10.000
8	Edmonds	5.700
9	Lynnwood	4.000
10	Seattle (Carkeek)	3.400
11	Des Moines	3.380
12	SWSSD (Salmon Creek)	3.200
13	Lakehaven (Lakota)	3.040
14	Tacoma (Western Slopes)	3.000
15	SWSSD (Miller Creek)	2.850
16	Seattle (Richmond Beach)	2.500
17	Lakehaven (Redondo)	2.200
18	Port Angeles	1.830
19	Port Townsend	1.030
20	Anacortes (Main Plant)	0.890
21	Langley	0.500
22	Steilacoom	0.500
23	Westside S.D.	0.500
24	Mason County (Hartstene Point)	0.353
25	Mukilteo	0.250
26	Anacortes (Skyline)	0.230
27	Kitsap County (Manchester)	0.140
28	Coupeville	0.125
29	Penn Cove	0.060
30	Clallam County (Clallam Bay)	0.040
31	Clallam County (Seiku)	0.030
32	Skagit County (Snee-oosh Beach)	0.010

Source: Region X EPA

(The Clean Water Act does permit virtually anyone to sue a discharger, the State and the EPA on water quality issues such as secondary treatment).

1984 The Puget Sound Water Quality Authority endorses secondary treatment for all Puget Sound dischargers after debating the resolution for 20 minutes.

1984 The EPA commenced review and the new Regional Administrator decides to deny the waiver for the West Point facility.

1984 Five small dischargers decide to appeal through the State Pollution Control Hearings Board. The other dischargers do not appeal or even withdraw their applications.

1985 Select House Panel on Puget Sound Clean-Up formed in State Capitol and holds hearings twice a week for several months. Puget Sound Alliance actively lobbying. Informal group of marine scientists testify, questioning the wholesale conversion to secondary treatment and asking for the law to be changed to allow case-by-case decisions.

1985 Effort again made to change State law. Bill again passed in the House but dies in Senate Park's and Ecology Committee. One State Senator (Phil Talmadge) considered to be the individual who stopped the bill from going to the full Senate for voting in each case. He is identified here because of the pivotal role he has played in this very expensive undertaking. Depending upon one's point of view, he either deserves full credit or full blame.

1985 Appeals heard. During one appeal the Department of Ecology argued that the Pollution Control Hearings Board should not permit any testimony regarding Puget Sound, circulation, toxicants, water quality or the biota as it was irrelevant and prejudicial to the Department of Ecology's case. During another appeal, the Department of Ecology admitted that their departmental review of the application determined secondary treatment was not needed for water quality purposes. The decisions on the first three appeals have been made and the Hearings Board determined that State law did indeed prohibit them from considering water quality and the first three waiver appeals were denied.

While the above time-line effectively tells much of the story, there are some additional points to elaborate on. The Chairman of the Pollution Control Hearings Board did not sign the orders in which the board turned down the waiver denial appeals of Bellingham, Port Angeles and Lynnwood. Rather, he wrote a 6 page concurring statement. In it he repeated the Federal law (Section 301(h)) and the State law, and clearly identified that the requirement for secondary treatment here lay with the State law, not the Federal law. He clearly stated that the evidence supported the position that these communities' primary-treated effluents were not having significant impacts on the marine environment, and that there were significant impacts related to economic costs and the added requirements of disposing of additional sludge which outweighed the undefined benefits of secondary treatment. He stated several times that the State had to change the law to prevent this wasteful situation which, 'violates any standard of fairness'.

The main problems in Puget Sound are toxi spots in the sediments and shellfish bed closures bacteria. The toxic hot spots are site-specific and are related to past, or possibly present discharges from industries, industrial runoff, and urban storm sewer/combined sewer overflows to intertidal areas. The problems are not related to the majority of the sewer outfalls in Puget Sound. Because of the active circulation within Puget Sound and the tremendous volume of deep water which acts as a nutrient and dissolved oxygen buffer, there is not a problem associated with nutrient enhancement or dissolved oxygen depletion associated with most of the sewage treatment plants. A glacial fjord with good tidal circulation is considerably different from a shallow drowned river valley type of estuary.

During the recent debate on secondary treatment, I have been especially concerned with the position taken by the EPA. The regional administrator, Ms. Ernesta Barnes, has emphasized how the Federal law requires secondary treatment. She has downplayed the waiver provision. In testifying before the Select House Panel on Puget Sound on 25 March 1985 she emphasized how Congress intended secondary treatment and that the waiver provision only contemplated discharges to the open ocean. She emphasized that Puget Sound is not an open ocean. Note that the Federal Law itself (presented in this article) defines a discharge into marine wate including 'saline estuarine waters where there is st tidal movement and other hydrological and geological characteristics which the Administrator determines necessary to allow compliance . . .' The following paragraphs are quoted from the Congressional Investigation titled 'Implementation of the Clean Water Act concerning Ocean Discharge Waivers (A Case Study of Lawmaking by Rulemakers)' which was prepared in 1982.

> The 1977 ocean discharge waiver provision was controversial from the outset, due primarily to the fact that it represented the first breach in the new national approach to water pollution abatement adopted in 1972: the basing of cleanup requirements on the performance capability of treatment technologies. While communities discharging to fresh waters would still be required to meet the statute's minimum, 'technology based', secondary treatment requirement, qualified coastal communities would now have an opportunity to temper this mandate, based on assessment of the ocean's 'assimilative capacity', that is, the extent to which it could absorb pollution without harm.
>
> There were two basic reasons underlying Congress' willingness to make this limited exception: first, Congress recognized that the physical and chemical characteristics of the marine environment are significantly different from those of inland fresh waters

that full secondary treatment was not necessary in all cases to achieve national water quality goals.

Second, Congress wanted to avoid treatment for treatment's sake, particularly given the multi-million dollar cost of the additional margin of wastewater treatment capability that would otherwise be required by many coastal communities. For those able to comply with the law's several strict prerequisites to a waiver, this expense could be avoided.

Subsequent investigation by the Subcommittee, and an additional day of hearings, on 18 February 1982, disclosed that the attitude of those EPA officials involved was one of at least reluctant acceptance of this amendment to the law, if not outright defiance. The record clearly shows that the regulations that the EPA proposed, and the regulations as finally adopted, along with other statements and actions of agency officials had the effect of preventing communities from obtaining waivers from the law's full municipal secondary treatment requirement.

The answers to the questions of how and why this happened can be seen in the collective set of attitudes, actions, and statements and written records of those EPA officials involved. Key, was the ability of the EPA rulemakers to transform their negative attitudes about the waiver amendment into both procedural and substantive constraints to its application. And underlying all of these actions was a functional, if not formal policy adhered to by the agency rulemakers; to avoid regulatory concessions that 'might weaken our no-retreat-from-secondary position'.

The subcommittee's oversight of the EPA's implementation of the 1977 ocean discharge waiver provision was not intended to review the 'environmental' merits of that amendment. Rather, it was initially concerned with why there had been so much delay in carrying out that amendment, and, later, *with the role and influence, respectively, that administrative agencies and their officials play in shaping or altering the intent and ultimate results of laws enacted by Congress.*

The record of what has transpired under the ocean discharge waiver provision of the Clean Water Act underscores the need for Congress to maintain close oversight of Executive departments and agencies. And to the extent that Congress continues to delegate rulemaking authority to the Executive, it must also be cognizant of the actions and comments of the rulemakers themselves.

It is essential that the State legislature change the State law so that the tremendous investment of secondary treatment is only spent where it is truly needed. This will make it easier then to fund clean-up actions that are necessary (e.g. site-specific toxic sediments and bacterial contamination of commercial shellfish beds). If the State law is changed, we can anticipate problems with EPA refusing to reopen the files of applicants who decided against appealing or who withdrew their applications. Those actions were taken in recognition of the futility of waivers under the State law, the public attitudes as formulated by the press and, the rhetoric of politicians. Congressional assistance may then be needed to grant an exception to EPA's time requirements for review of the waiver applications.

In view of the position taken by EPA in influencing this state's legislature regarding waivers, I believe it is time that the Congress again opens its investigations into EPA's role in implementing the Clean Water Act. We still are plagued by lawmaking by rulemakers!

Author's address: 12215 9th NW, Seattle, WA 98177, USA.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
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1200 Sixth Avenue, Suite 155
Seattle, WA 98101

WATER
DIVISION

November 19, 2021

Mr. Vince McGowan
Water Quality Program Manager
Washington State Department of Ecology
PO Box 47600
Olympia, Washington 98504-7600

Re: EPA's Action on Revisions to the Washington State Department of Ecology's Surface Water Quality Standards for Natural Conditions Provisions

Dear Mr. McGowan:

The U.S. Environmental Protection Agency (EPA) has completed the review and reconsideration of Washington's natural conditions provisions (WAC 173-201A-200(1)(c)(i), 173-201A-210(1)(c)(i), 173-201A-200(1)(c)(v), 173-201A-200(1)(d)(i), 173-201A-210(1)(d)(i), 173-201A-200(1)(d)(ii), and 173-201A-260(1)(a)), which were submitted to EPA by the Washington Department of Ecology in 2003 and 2006. Under section 303(c) of the Clean Water Act (CWA), 33 U.S.C. § 1313(c), states must submit new and revised water quality standards to EPA for review and action, and EPA approves those water quality standards if they meet the requirements of the CWA and EPA's implementing regulations. EPA's review and reconsideration is outlined below and further described in the enclosed Technical Support Document.

As you are aware, on February 10, 2014, the Northwest Environmental Advocates filed a complaint in U.S. District Court for the Western District of Washington (Case No. 2:14-cv-0196-RSM) challenging, in part, EPA's February 11, 2008 CWA section 303(c) approval of the natural conditions provisions identified above. On October 17, 2018, the Court issued an Order Granting a Stay (Dkt. 95) pending EPA's reconsideration of its prior determinations. The Court subsequently granted an extension for EPA to complete its reconsideration by November 19, 2021 (Dkt. 118).

EPA's CWA section 303(c) action applies only to waters in the State of Washington and does not apply to waters that are within Indian Country, as defined in 18 U.S.C. § 1151. Nothing in the enclosed decision document shall constitute an approval or disapproval of a water quality standard that applies to waters within Indian Country. EPA, or authorized Indian Tribes, as appropriate, will retain responsibilities for water quality standards for waters within Indian Country.

Summary of EPA's Action

EPA has completed its reconsideration, as contemplated by the Court's Order, and is not changing its February 11, 2008 approval of the revisions to the following sections of WAC Chapter 173-201A.

- WAC 173-201A-200(1)(c)(v): Natural condition narrative aquatic life temperature criteria for lakes

- WAC 173-201A-200(1)(d)(ii): Natural condition narrative aquatic life dissolved oxygen criteria for lakes

Because EPA is not changing its earlier approval, it is taking no new action with respect to those provisions.

EPA has completed its reconsideration, as contemplated by the Court's Order, and is disapproving revisions to the following sections of WAC Chapter 173-201A pursuant to its authority under section 303(c)(3) of the CWA, 33 U.S.C. § 1313(c)(3), and 40 CFR Part 131:

- WAC 173-201A-260(1)(a): Natural and irreversible human conditions
- WAC 173-201A-200(1)(c)(i) and WAC 173-201A-210(1)(c)(i): Allowable human contribution to natural conditions provisions for aquatic life temperature (fresh water and marine water, respectively)
- WAC 173-201A-200(1)(d)(i) and WAC 173-201A-210(1)(d)(i): Allowable human contribution to natural conditions provisions for aquatic life dissolved oxygen (fresh water and marine water, respectively)

EPA appreciates Ecology's commitment and ongoing work to update Washington's water quality standards. We also appreciate the collaboration by your staff to address the complexities associated with criteria revisions. If you have any questions regarding this letter, please contact me at (206) 553-1855 or Lindsay Guzzo, EPA staff lead, at (206) 553-0268 or Guzzo.Lindsay@epa.gov.

Sincerely,

DANIEL OPALSKI

Digitally signed by DANIEL OPALSKI
Date: 2021.11.19 09:38:35 -08'00'

Daniel D. Opalski
Director

Enclosure: Technical Support Document

cc (e-Copy): Ms. Melissa Gildersleeve, Water Quality Management Section Manager, Ecology
Mr. Chad Brown, Water Quality Management Unit Supervisor, Ecology

Technical Support Document

EPA's Clean Water Act Action on Revisions to the Washington State Department of Ecology's Surface Water Quality Standards for Natural Conditions Provisions

November 19, 2021

I. Clean Water Act Requirements for Water Quality Standards

The objective of the Clean Water Act (CWA) is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters with an interim goal, where attainable, to achieve water quality that provides for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water. Under section 303(c) of the CWA and federal implementing regulations at 40 CFR § 131.4, states (and authorized tribes) have the primary responsibility for reviewing, establishing, and revising water quality standards (WQS). These standards include the designated uses of a waterbody or waterbody segment, the water quality criteria that protect those designated uses, and an antidegradation policy. This statutory and regulatory framework allows states to work with local communities to adopt appropriate designated uses (as required at 40 CFR § 131.10(a)) and to adopt criteria to protect those designated uses (as required at 40 CFR § 131.11(a)).

States are required to hold public hearings for the purpose of reviewing applicable WQS periodically but at least once every three years and, as appropriate, modify and adopt these standards (40 CFR § 131.20). Each state must follow applicable legal procedures for revising or adopting such standards (40 CFR § 131.5(a)(6)) and submit certification by the state's attorney general, or other appropriate legal authority within the state, that the WQS were duly adopted pursuant to state law (40 CFR §131.6(e)). The U.S. Environmental Protection Agency's (EPA) review authority and the minimum requirements for state WQS submittals are described at 40 CFR § 131.5 and 131.6, respectively.

States are required by 40 CFR § 131.11(a) to adopt water quality criteria that protect their designated uses. In adopting such criteria, states should establish numeric values based on one of the following:

(1) CWA section 304(a) guidance;
(2) CWA section 304(a) guidance modified to reflect site-specific conditions; or,
(3) Other scientifically defensible methods (40 CFR § 131.11(b)(1)).

In addition, states should establish narrative criteria where numeric criteria cannot be established or to supplement numeric criteria (see 40 CFR § 131.11(b)(2)).

Section 303(c) of the CWA requires states to submit new or revised WQS to EPA for review and action. EPA reviews these changes and approves the WQS if they meet the requirements of the CWA and EPA's implementing regulations.

EPA considers four questions (described below) when evaluating whether a particular provision is a new or revised WQS. If all four questions are answered "yes" then the provision would likely constitute a new or revised WQS that EPA has the authority and duty to approve or disapprove under CWA § 303(c)(3).[1]

1. Is it a legally binding provision adopted or established pursuant to state or tribal law?
2. Does the provision address designated uses, water quality criteria (narrative or numeric) to protect designated uses, and/or antidegradation requirements for waters of the United States?

[1] *What is a New or Revised Water Quality Standard under 303(c)(3)? Frequently Asked Questions*, EPA No. 820F12017 (Oct. 2012). Available at https://www.epa.gov/sites/production/files/2014-11/documents/cwa303faq.pdf

3. Does the provision express or establish the desired condition (e.g., uses, criteria) or instream level of protection (e.g., antidegradation requirements) for waters of the United States immediately or mandate how it will be expressed or established for such waters in the future?
4. Does the provision establish a new WQS or revise an existing WQS?

If EPA approves a state's WQS submission, such standard(s) shall thereafter be the applicable standard for CWA purposes. When EPA disapproves a state's WQS, EPA shall notify the state and specify why the WQS is not in compliance with the requirements of the CWA and federal WQS regulations and specify any changes that are needed to meet such requirements (33 U.S.C. § 1313(c)(3); 40 CFR § 131.21).

Finally, EPA considers non-substantive edits to existing WQS to constitute new or revised WQS that EPA has the authority to approve or disapprove under § 303(c)(3). While such edits and changes do not substantively change the meaning or intent of the existing WQS, EPA believes it is reasonable to treat such edits and changes in this manner to ensure public transparency as to which provisions are applicable for purposes of the CWA. EPA notes that the scope of its review and action on non-substantive edits or editorial changes extends only to the edits or changes themselves. EPA does not re-open or reconsider the underlying WQS that are the subject of the non-substantive edits or editorial changes.

II. Background

On February 10, 2014, the Northwest Environmental Advocates filed a complaint in U.S. District Court for the Western District of Washington (Case No. 2:14-cv-0196-RSM) challenging, in part, EPA's February 11, 2008 CWA section 303(c) approval of the natural conditions provisions. On October 17, 2018, the Court issued an Order Granting a Stay (Dkt. 95) pending EPA's reconsideration of its prior determinations. The Order noted that EPA may complete its reconsideration by October 17, 2021, by making approval or disapproval decisions, or a final determination that such provisions are not water quality standards. The Court subsequently granted an extension for EPA to complete its reconsideration by November 19, 2021 (Dkt. 118).

This Technical Support Document constitutes EPA's reconsideration of the remaining provisions subject to the Court Order. EPA previously completed its review and reconsideration of the other provisions in actions dated April 30, 2019, October 13, 2020, and September 30, 2021.

III. Results of EPA's Reconsideration

In its February 11, 2008 action, EPA approved the revised natural conditions provisions at:

- WAC 173-201A-200(1)(c)(i) and WAC 173-201A-210(1)(c)(i): Allowable human contribution to natural conditions provisions for aquatic life temperature (fresh water and marine water, respectively);
- WAC 173-201A-200(1)(c)(v): Natural condition narrative aquatic life temperature criteria for lakes;
- WAC 173-201A-200(1)(d)(i) and WAC 173-201A-210(1)(d)(i): Allowable human contribution to natural conditions provisions for aquatic life dissolved oxygen (for fresh water and marine water, respectively);

- WAC 173-201A-200(1)(d)(ii): Natural condition narrative aquatic life dissolved oxygen criteria for lakes; and
- WAC 173-201A-260(1)(a): Natural and Irreversible Human Conditions.

Upon reconsideration, EPA is not changing and taking no action with respect to the February 11, 2008 approval of the provisions at WAC 173-201A-200(1)(c)(v) and WAC 173-201A-200(1)(d)(ii). EPA is disapproving the provisions at WAC 173-201A-200(1)(c)(i), WAC 173-201A-210(1)(c)(i), WAC 173-201A-200(1)(d)(i), WAC 173-201A-210(1)(d)(i), and WAC 173-201A-260(1)(a).

EPA's CWA section 303(c) action and the associated rationales are provided below. Today's action applies only to waters within the jurisdiction of the State of Washington and does not apply to waters that are within Indian Country, as defined in 18 U.S.C. § 1151. Nothing in this decision document shall constitute an approval or disapproval of a WQS that applies to waters within Indian Country. EPA, or authorized Indian Tribes, as appropriate, retain the authority to establish WQS for waters within Indian Country.

1. Natural Conditions Narrative Criteria For Lakes

In its February 11, 2008 action, EPA approved the revised temperature and dissolved oxygen natural conditions narrative criteria for lakes at WAC 173-201A-200(1)(c)(v) and WAC 173-201A-200(1)(d)(ii), respectively. More detail and information regarding EPA's action can be found in the 2008 decision document.[2]

The underlined text indicates the new and/or revised language from Ecology's 2006 WQS submittal, and strikeout text indicates Ecology's previous text, which had been replaced by the new or revised text.

Aquatic life temperature criteria for lakes

> **WAC 173-201A-200(1)(c)(v):** For lakes, human actions considered cumulatively may not increase the 7-DADMax temperature more than 0.3°C (0.54°F) above natural conditions. ~~Temperature - no measurable change from natural conditions.~~

Aquatic life dissolved oxygen criteria for lakes

> **WAC 173- 201A-200(1)(d)(ii):** For lakes, human actions considered cumulatively may not decrease the dissolved oxygen concentration more than 0.2 mg/L below natural conditions. ~~Dissolved oxygen - no measurable decrease from natural conditions.~~

EPA's Reconsideration: EPA has completed its reconsideration and is taking no action with respect to its February 11, 2008 approval of the revisions at WAC 173-201A-200(1)(c)(v) and WAC 173-201A-200(1)(d)(ii).

EPA Rationale for the 2008 approval:
In 2006, Ecology submitted revisions to the temperature and dissolved oxygen aquatic life criteria for lakes. The revisions clarified and quantified the previous criteria of "no measurable change from natural

[2] February 11, 2008. Letter from Michael F. Gearheard, Director, Office of Water & Watersheds, EPA Region 10, to David C. Peeler, Program Manager, Department of Ecology, re: EPA Approval of the 2003/2006 Revisions to the Washington Water Quality Standards Regulations. Available at: https://www.epa.gov/sites/production/files/2017-10/documents/wawqs-letter-02112008.pdf

conditions" (for temperature) and "no measurable decrease from natural conditions" (for dissolved oxygen) by identifying a 0.3ºC increase in temperature and a 0.2 mg/L decrease in dissolved oxygen as what would constitute a "measurable" departure from natural conditions. For temperature, the revision also added a 7-DADMax metric to the criterion.

In the February 11, 2008, Technical Support Document, EPA concluded that a 0.3ºC increase in temperature from natural conditions was insignificant and well within the range of uncertainty of the thermal requirements for salmon, which is approximately +/- 0.5ºC. EPA also noted that 0.3ºC was consistent with reliable field detection levels for temperature and is therefore considered within the error band associated with typical temperature monitors (pp. 27-28). The revised temperature criterion also added the 7-DADMax metric recommended for temperature standards by the *Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* (EPA910-B-03-002, April 2003, hereinafter referred to as "Temperature Guidance") and that EPA determined to be scientifically defensible (p.4). EPA's 2008 approval, therefore, concluded that Washington's revisions to the aquatic life temperature criterion for lakes were protective of designated uses and scientifically defensible.

In assessing Washington's revisions to the dissolved oxygen criterion for lakes, EPA similarly concluded that a 0.2 mg/L decrease from natural conditions was insignificant. The 2008 approval rationale explained that an allowable decrease of 0.2 mg/L is within the monitoring measurement error for recording instruments typically used to monitor dissolved oxygen. EPA also explained that numerous factors impact oxygen levels in lakes and without at least some allowance for insignificant decreases a natural conditions criterion for dissolved oxygen in lakes would be unnecessarily restrictive for the protection of designated uses (p. 32). EPA's 2008 approval, therefore, concluded that Washington's revisions to the aquatic life dissolved oxygen criterion for lakes was protective of designated uses and scientifically defensible.

The narrative criteria are the applicable temperature and dissolved oxygen criteria for lakes in Washington, and leaving in place EPA's 2008 approval of these criteria ensures that aquatic life criteria for temperature and dissolved oxygen in lakes remain in effect for CWA purposes.

2. Natural and Irreversible Human Conditions

In its February 11, 2008 action, EPA approved the new narrative natural conditions provision at WAC 173-201A-260(1)(a) and took no action on the irreversible human conditions provision at WAC 173-201A-260(1)(b) after concluding the provision is not a WQS that EPA has the authority to approve or disapprove under section 303(c) of the CWA. More detail and information regarding EPA's action can be found in the 2008 decision document.[3]

With respect to WAC 173-201A-260(1)(a), EPA's 2008 decision stated that it is acceptable, under certain circumstances, for water quality criteria to reflect the natural condition of a water body as an alternative to the generally applicable numeric criteria. The rationale for this was that Washington's designated uses were supported by the water in its natural condition, prior to any human effects on water quality.

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[3] February 11, 2008. Letter from Michael F. Gearheard, Director, Office of Water & Watersheds, EPA Region 10, to David C. Peeler, Program Manager, Department of Ecology, re: EPA Approval of the 2003/2006 Revisions to the Washington Water Quality Standards Regulations. Available at: https://www.epa.gov/sites/production/files/2017-10/documents/wawqs-letter-02112008.pdf

The text of the provision first appeared in a 2003 water quality standards submittal to EPA and again in a 2006 submittal and is excerpted below.

> **WAC 173-201A-260(1):** Natural and irreversible human conditions.
> (a) It is recognized that portions of many water bodies cannot meet the assigned criteria due to the natural conditions of the water body. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the natural conditions constitute the water quality criteria.

EPA's Reconsideration: EPA has completed its reconsideration and in accordance with its CWA authority, 33 U.S.C. § 1313(c)(3) and 40 CFR Part 131, disapproves the provision at WAC 173-201A-260(1)(a).

EPA Rationale: The natural conditions narrative provision at WAC 173-201A-260(1)(a) is broadly drafted and does not specify the types of criteria or pollutants to which it applies. On reconsideration, EPA concludes that as written this provision could be applied to a wide range of naturally occuring pollutants, including toxic pollutants, and could even allow an exception from otherwise applicable numeric human health criteria. Therefore, it is not consistent with EPA's interpretation of the relationship between natural conditions and the protection of designated human health uses, which is articulated in EPA's November 5, 1997 policy guidance entitled ''Establishing Site Specific Aquatic Life Criteria Equal to Natural Background.''[4] EPA's 2008 decision document cited to the 1997 policy guidance, as well as to language in an Advance Notice of Proposed Rulemaking for the Water Quality Standards program (*see* 63 Fed. Reg. 36,724, 36761 (Jul. 7, 1998)), as setting forth the relevant policy considerations for establishing water quality criteria based on natural conditions. However, what EPA failed to appropriately consider in its 2008 decision is that these documents only addressed the establishment of aquatic life criteria for pollutants at levels equal to the natural background condition, and expressly did not apply to human health uses, whereas the provision at WAC 173-201A-260(1)(a) is not similarly limited in scope to aquatic life uses or to specific pollutants.

In contrast with aquatic life uses, a naturally occurring level of a pollutant does not necessarily protect designated human health uses. Naturally occurring levels of a pollutant are assumed to protect aquatic life species that have naturally developed in the affected waters. However, humans generally do not adapt to higher ambient pollutant levels, even if they are naturally caused. Consequently, the same assumptions of protectiveness cannot be made with regard to designated uses that affect human health (*e.g.,* people eating fish or shellfish from Washington waters, and recreating in Washington waters). For this reason, EPA's 1997 guidance also states that where the natural background concentration exceeds the state-adopted human health criterion, at a minimum, states should re-evaluate the human health use designation.[5]

No Changes Necessary to Address the Disapproval: The effect of EPA's disapproval is that, as of the date of this action, the provision at WAC 173-210A-260(1)(a) is no longer an applicable WQS for CWA purposes. Because Washington's WQS currently include applicable numeric criteria that EPA determined to be protective of designated uses, no changes to Washington's WQS are necessary to meet the requirements of the CWA. Therefore, EPA is not specifying any changes that Washington must

[4] Davies, Tudor T., *Establishing Site Specific Aquatic Life Criteria Equal to Natural Background,* EPA Memorandum to Water Management Division Directors, Regions 1–10, State and Tribal Water Quality Management Program Directors, posted at: *https://www.epa.gov/sites/default/files/2014-08/documents/naturalbackground-memo.pdf*
[5] *Id.* at p. 2.

adopt to meet CWA requirements. EPA provides the following discretionary recommendations for the State's consideration.

EPA understands that WAC 173-201A-260(1)(a) was developed in parallel with numeric aquatic life criteria for marine and fresh waters, and that Washington intended to rely on the natural condition narrative to address circumstances where waterbody conditions are naturally less stringent than the adopted biologically-based numeric aquatic life criteria. In this respect the availability of a criterion that accounts for less stringent natural conditions was an important consideration in the establishment of numeric criteria for aquatic life. EPA continues to believe that appropriately drafted natural condition provisions can serve an important role in state WQS by reflecting a naturally occuring spatial and temporal variability in water quality that is protective of uses. A new general natural condition provision that is narrowly tailored to aquatic life uses could be adopted as a narrative criterion where numerical criteria cannot be established or to supplement numerical criteria (40 C.F.R. § 131.11(b)(2)). Alternatively, the adoption of a performance-based approach could be used to establish aquatic life criteria reflecting a natural condition for specific pollutants (see discussion for temperature and dissolved oxygen below).

EPA recommends removing the current WAC 173-201A-260(1)(a) from the State's WQS regulations to avoid confusion and provide greater clarity as to what is in effect for CWA purposes.

3. Allowable Human Contribution to Natural Conditions Provisions for Aquatic Life Temperature and Dissolved Oxygen Criteria For Fresh and Marine Waters

In its February 11, 2008 action, EPA approved the new and revised natural conditions provisions for temperature in fresh and marine waters at WAC 173-201A-200(1)(c)(i) and WAC 173-201A-210(1)(c)(i), respectively; and for dissolved oxygen in fresh and marine waters at WAC 173-201A-200(1)(d)(i) and WAC 173-201A-210(1)(d)(i), respectively. More detail and information regarding EPA's action can be found in the 2008 decision document.[6]

In the 2008 approval, EPA determined that insignificant temperature increases or insignificant decreases of dissolved oxygen concentrations above or below the natural condition were protective of the applicable designated uses because such insignificant departures from the natural condition were within the range of scientific uncertainty of effects on designated uses and/or within the error band associated with typical monitoring equipment. Specific to temperature, these "de minimis" allowable human-caused increases above natural conditions are consistent with the Temperature Guidance.[7]

The texts of each of the provisions are excerpted below.

Allowable human contribution to natural conditions provisions for aquatic life temperature:

> **Freshwater, WAC 173-201A-200(1)(c)(i):** When a water body's temperature is warmer than the criteria in Table 200 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to

[6] February 11, 2008. Letter from Michael F. Gearheard, Director, Office of Water & Watersheds, EPA Region 10, to David C. Peeler, Program Manager, Department of Ecology, re: EPA Approval of the 2003/2006 Revisions to the Washington Water Quality Standards Regulations. Available at: https://www.epa.gov/sites/production/files/2017-10/documents/wawqs-letter-02112008.pdf
[7] EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA-910-B-03-002. April 2003. Available at https://nepis.epa.gov/Exe/ZyPDF.cgi/P1004IUI.PDF?Dockey=P1004IUI.PDF

natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F).

Marine water, WAC 173-201A-210(1)(c)(i): When a water body's temperature is warmer than the criteria in Table 210 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F).

Allowable human contribution to natural conditions provisions for aquatic life dissolved oxygen:

Freshwater, WAC 173- 201A-200(1)(d)(i): When a water body's D.O. is lower than the criteria in Table 200 (1)(d) (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the D.O. of that water body to decrease more than 0.2 mg/L.

Marine water, WAC 173-201A-210(1)(d)(i): When a water body's D.O. is lower than the criteria in Table 210 (1)(d) (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the D.O. of that water body to decrease more than 0.2 mg/L.

EPA's Reconsideration: EPA has completed its reconsideration and in accordance with its CWA authority, 33 U.S.C. § 1313(c)(3) and 40 CFR Part 131, disapproves the provisions at WAC 173-201A-200(1)(c)(i), WAC 173-201A-210(1)(c)(i), WAC 173-201A-200(1)(d)(i) and WAC 173-201A-210(1)(d)(i).

EPA Rationale:
The allowable human contribution to natural condition provisions for temperature (WAC 173-201A-200(1)(c)(i) and 210(1)(c)(i)) and disolved oxygen (WAC 173-201A-200(1)(d)(i) and 210(1)(d)(i)) allow for human actions considered cumulatively to cause insignificant increases in temperature (0.3ºC) or decreases in dissolved oxygen (0.2mg/L) from the natural condition of the waterbody. As discussed above, EPA is disapproving the provision at WAC 173-201A-260(1)(a) that allows for the natural condition of a waterbody to constitute the applicable criteria when the natural condition is less stringent than otherwise applicable numeric criteria.[8] Absent an approved WQS that allows for the natural condition to constitute the applicable water quality criteria, the applicable criteria for temperature and dissolved oxygen in Washington waters are the numeric criteria in Tables 200(1)(c) and (1)(d) and 210(1)(c) and (1)(d). However, the temperature and dissolved oxygen natural condition provisions are based on the natural condition of the waterbody; the provisions do not authorize human actions to cause insignificant exceedances to the applicable numeric criteria. EPA is therefore disapproving the temperature and dissolved oxygen provisions that allow insignificant human impacts to the natural condition because such impacts are not tied to approved criteria that are in effect under the CWA.

No Changes Necessary to Address the Disapproval: The effect of EPA's disapproval is that, as of the date of this action, the provisions at WAC 173-201A-200(1)(c)(i), WAC 173-201A-210(1)(c)(i), WAC 173-201A-200(1)(d)(i), and WAC 173-201A-210(1)(d)(i) are no longer applicable WQS for CWA purposes. Because Washington's WQS currently include applicable biologically-based numeric criteria

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[8] EPA's interpretation of WAC 173-201A-260(1)(a) is consistent with Ecology's January 29, 2016 letter in which it stated "[t]he rule makes it clear that where Ecology identifies a natural condition that is less stringent than the numeric criteria in the state's water quality standards, the natural condition supersedes the numeric criteria." Letter from David C. Peeler, Water Quality Program Manager, Ecology, to Michael Gearheard, EPA Region 10, Re: Ecology Responses to USEPA Region 10 Questions Regarding Washington's 2003 Adopted Water Quality Standards, p. 2.

for temperature and dissolved oxygen that EPA determined to be protective of designated uses, no changes to Washington's WQS are necessary to meet the requirements of the CWA. Therefore, EPA is not specifying any changes that Washington must adopt to meet CWA requirements. EPA provides the following discretionary recommendations for the State's consideration.

Washington, at its discretion, could adopt new natural conditions criteria specific to temperature and/or dissolved oxygen. One possibility would be for Washington to adopt into its WQS a performance-based approach for establishing temperature and/or dissolved oxygen criteria representative of the natural condition of a waterbody. A performance-based approach is a binding methodology that provides a transparent, predictable, repeatable, and scientifically defensible procedure to derive numeric criteria or to translate a narrative criterion into quantifiable measures that are protective of designated uses. The performance-based approach relies on the adoption of a systematic process (i.e., a criterion derivation methodology) rather than a specific outcome (i.e., concentration limit for a pollutant) consistent with 40 CFR Sections 131.11 and 131.13. When such a performance-based approach is sufficiently detailed and has suitable safeguards to ensure predictable, repeatable outcomes, EPA approval of such an approach also serves as approval of the outcomes as well. *See EPA Review and Approval of State Water Quality Standards*, 65 FR 24,641, 24,649 (Apr. 27, 2000).

A second possibility would be for Washington to adopt numeric temperature and dissolved oxygen criteria that account for natural conditions using the best available relevant data. EPA encourages Washington to consider magnitude, frequency, and duration components in setting water quality criteria to protect against acute and chronic effects.[9] This may include establishing protective site-specific criteria accounting for specific characteristics, such as unique temperature and/or dissolved oxygen regimes in different waterbodies (see EPA's Temperature Guidance).[10] Site-specific criteria established in this manner would be subject to CWA section 303(c) review.

Washington, at its discretion, could also choose to adopt new WQS provisions that allow for human actions, considered cumulatively, to cause insignificant exceedances in temperature and dissolved oxygen. As articulated in the 2008 Technical Support Document, EPA believes insignificant or de minimis exceedances to applicable temperature and/or dissolved oxygen criteria caused by human actions, considered cumulatively, may still be protective of designated uses.[11] Any such human use allowance provision must be scientifically defensible and tied to approved criteria that are protective of designated uses, which could include criteria based on the natural condition of the waterbody.

EPA recommends removing the disapproved provisions from the State's WQS regulations to avoid confusion and provide greater clarity to what is in effect for CWA purposes.

[9] EPA Water Quality Standards Handbook – Chapter 3: Water Quality Criteria. EPA-823—B-17-001; 2017. Available at https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter3.pdf
[10] EPA Issue Paper 3: Spatial and Temporal Patterns of Stream Temperature (Revised), October 2001. EPA-910-D-01-003, pages 2-9. Available at https://www.epa.gov/sites/production/files/2018-01/documents/r10-water-quality-temperature-issue-paper3-2001.pdf
[11] 2008 TSD at pp. 20-21, 32.

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'Natural conditions' are at the center of disputes over dissolved oxygen standards

Questions over water quality standards have centered around nutrients that can lead to algal blooms and low oxygen levels. (Above) An algal bloom in Liberty Bay, WA in 2016. Photo: Ecology

KEYWORDS: EUTROPHICATION, HYPOXIA, SALISH SEA CURRENTS MAGAZINE, WATER QUALITY

By Christopher Dunagan

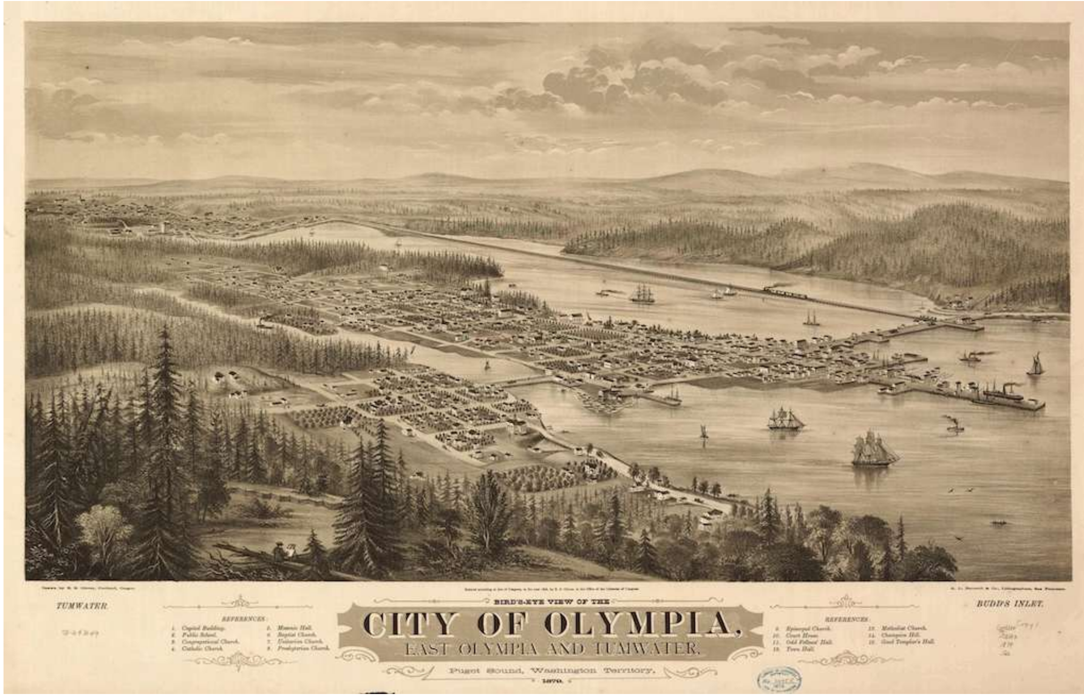
Published March 25, 2025

Oxygen is indisputably essential to aquatic life, but conflicts are brewing over water quality standards mandated in state regulations. This article is part of a series of reports funded by King County about the quest to define healthy oxygen levels in Puget Sound. By some estimates, those definitions could affect billions of dollars in state and local spending. [Editor's note: King County is currently in litigation with the Washington State Department of Ecology over the issue of dissolved oxygen water quality standards.]

Before early settlers built the region's first sawmill at Tumwater in 1848, before Arthur Denny and his party settled the future city of Seattle in 1851, and before the federal government created Washington Territory in 1853, the waters of Puget Sound and its freshwater streams were as clean as nature could provide. Fish and wildlife were abundant, having adapted to local conditions alongside native people of the area.

Needless to say, things have changed since those days. In the parlance of today's water-quality regulations, the clean waters of yesteryear are known as "natural conditions." Nobody believes that we will ever see those conditions again, but the term "natural conditions" has taken on a profound meaning as a point of reference. How far do we humans want to go in restoring polluted waters and limiting unhealthy discharges of wastewater into Puget Sound?

Washington Department of Ecology is currently struggling to establish a regulatory system involving natural conditions, based on the idea that it makes no sense to set cleanup goals beyond the best that nature has ever provided. The federal Environmental Protection Agency, which maintains ultimate authority over the nation's waterways, overturned



Illustrated view of the city of Olympia, East Olympia and Tumwater, Puget Sound, Washington Territory, 1879. Image: Illustrated perspective map: [Library of Congress, Geography and Map Division]

Ecology's existing natural conditions rule in 2021. Since then, Ecology has been working on a revision, particularly addressing water-quality goals for temperature and dissolved oxygen.

The agency recently completed [limited rules] for setting cleanup standards in defined locations. The ongoing effort is to create an enduring "performance-based" program that would empower experts to identify natural conditions anywhere in Puget Sound, along with an approved allowance for human degradation. The first draft received rather harsh comments from the EPA. A revised proposal that addresses only dissolved oxygen for marine waters [was released for public comment this week.]

In a letter to Ecology about the first draft, Rebecca Garnett, manager of standards and assessment for EPA's Region 10, said any new water quality criteria must meet scientific standards, be spelled out in sufficient detail, and fully protect aquatic creatures. "As currently proposed," she wrote, "the EPA is concerned that Ecology's performance-based approach for developing site-specific natural conditions criteria is not sufficiently 'binding, clear, predictable, and transparent.'"

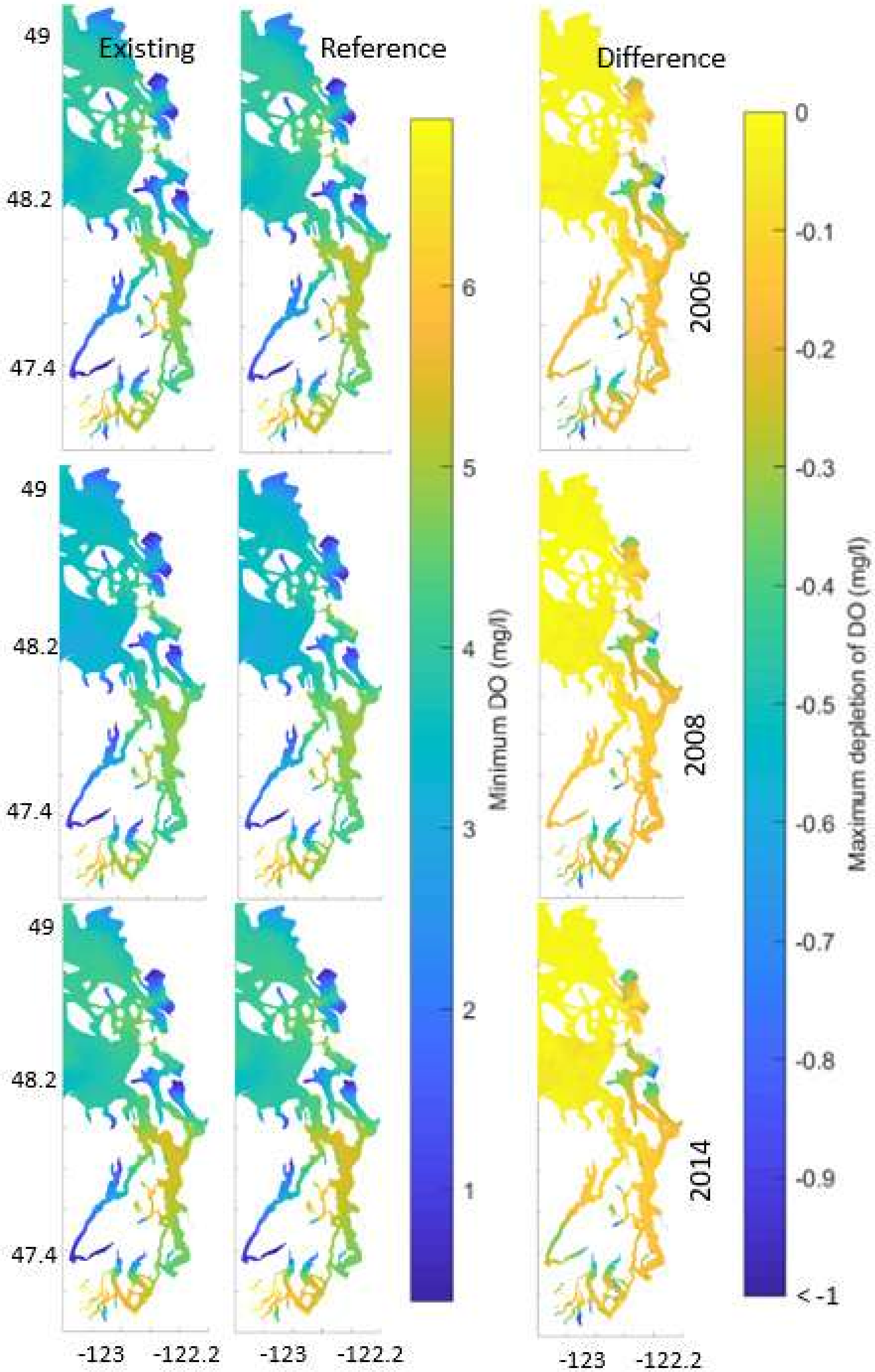
In a legal sense, water quality standards are essential, because they determine how much money is spent by government and industry to clean up our troubled waterways and improve survival for fish, crabs and other animals. According to some estimates, billions of dollars may be needed to bring major sewage-treatment plants into compliance.

> Documentation used to justify dissolved oxygen standards, developed more than 50 years ago, appear to be lost, according to Ecology's Water Quality Program, but agency officials maintain that available studies still support those numeric limits as protective of aquatic creatures.

Developing these new water-quality standards is complicated and intriguing, involving computer models to describe water-quality conditions that existed long before people changed the environment. A typical method of estimating natural conditions is to go out and measure current conditions in specific areas and then subtract all known causes of human degradation, often with the help of computers.

Natural conditions criteria may come into play when a body of water fails to meet established "numeric criteria." Numeric criteria are levels of oxygen and temperature that scientists say will meet the biological needs of aquatic creatures. Exceptions to numeric criteria are allowed for areas that have naturally lower levels of oxygen or naturally higher temperatures than the numeric criteria. For oxygen, the numeric criteria for most of Puget Sound is no less than 6 or 7 milligrams per liter, depending on the location. Based on studies, it appears that most of Puget Sound has never met those standards — not even in prehistoric times. This means that we could eliminate all human causes of low oxygen and still come up short of the approved numeric criteria.

This dilemma raises the stakes for choosing the correct natural conditions criteria. It also raises questions about whether Puget Sound is using the correct numeric standards, originally developed in 1967. Some officials in local government and industry as well as some scientists are calling for Ecology to overhaul the numeric criteria for oxygen throughout Puget Sound. The nonprofit advocacy group Association of Washington Cities, among others, would like the Legislature to fund a study to determine the actual needs of aquatic creatures in Puget Sound. For now, Ecology has placed a higher priority on developing natural conditions criteria.



The minimum dissolved oxygen level for most of Puget Sound is 7 mg/l, and 6 mg/l for areas to the west of Whidbey Island and into Bellingham Bay. The natural or "reference" condition map (center) shows that few areas of Puget Sound meet these minimum numeric standards. Areas in the difference map (right) that are green to blue are most sensitive to depletion of dissolved oxygen from human sources. Map: Ecology

"This matters," states a news release from the agency, "because Ecology and all organizations working on clean water efforts need to focus the state's pollution-reduction efforts on waterbodies where humans are causing pollution, not on waterbodies that are naturally different."

FITTING NATURE INTO A REGULATORY FRAMEWORK

Arguments over how far to go in cleaning up the streams, bays and open waterways of Puget Sound have their regulatory foundation within the federal Clean Water Act of 1972. The law establishes a national policy to “restore and maintain the chemical, physical and biological integrity of the nation’s waters.” The law asserts a goal of eliminating all water pollution and directs the Environmental Protection Agency to follow a specific process, in concert with the various states.

The Department of Ecology, authorized by the EPA to administer the Clean Water Act in Washington state, has its hands full in issuing permits for pollutant discharges, developing cleanup plans for polluted waterways, enforcing regulations to protect marine and fresh waters, and safeguarding the health of humans and animals.

Water quality standards have been developed and formally approved to protect aquatic species, human health, human activities and even esthetics, such as odor and appearance. For aquatic species, the numeric limits for physical and chemical conditions are based on the goal of protecting the most sensitive species in designated areas.

Oxygen is considered an essential element for sea life in marine waters. Numeric criteria for oxygen in Puget Sound, ranging from 4 to 7 milligrams per liter, date back to 1967 under the Federal Water Pollution Control Act, the predecessor to the Clean Water Act. Documentation used to justify those standards, developed more than 50 years ago, appear to be lost, according to Ecology’s Water Quality Program, but agency officials maintain that available studies still support those numeric limits as protective of aquatic creatures.

Most of Puget Sound is designated for a minimum of 7 mg/l. Areas to the west of Whidbey Island and into Bellingham Bay are designated for no less than 6 mg/l. The innermost portions of Tacoma’s Commencement Bay, Olympia’s Budd Inlet and Shelton’s Oakland Bay are designated for 5 mg/l, down to 4 mg/l in a few relatively tiny areas of those waterways.

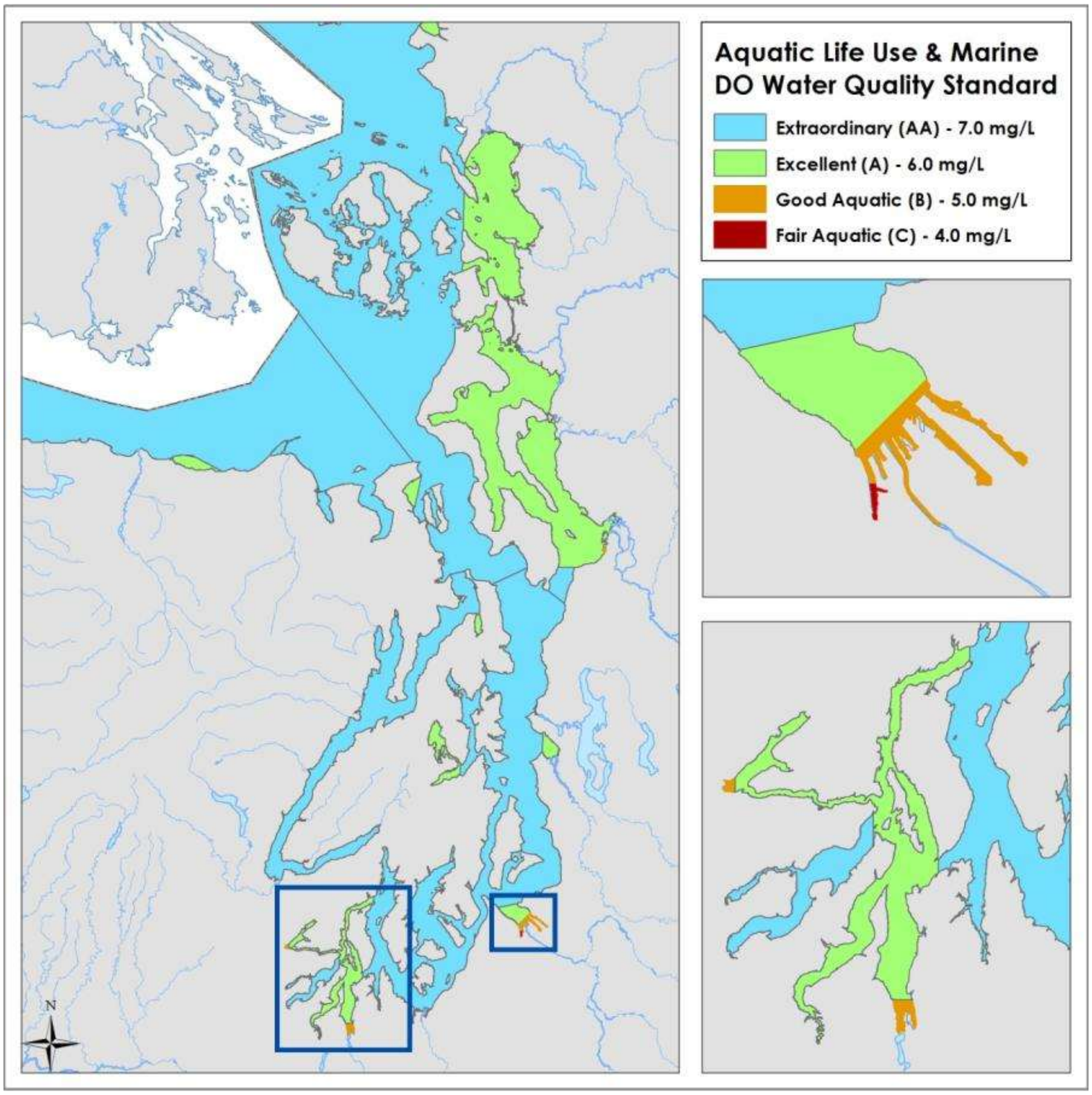
Critics argue that 6 or 7 mg/l is generally overly protective of water quality, since most areas of Puget Sound apparently never met those standards, not even in prehistoric times when marine species were abundant. Some say the criteria should be updated with more recent science, perhaps considering the depth of channels and other factors that affect natural oxygen levels. Chesapeake Bay on the East Coast has taken this approach. As things stand, the numeric criteria for Puget

Sound are destined to be largely displaced by natural conditions criteria based on computer models.

BIOLOGICAL NEEDS OF SPECIES

The concept of using a numeric standard for water quality is rather simple, perhaps too simple, some people say. For example, one can estimate, based on laboratory studies, the biological needs of salmon, including healthy levels of temperature and oxygen. These biological requirements may vary, depending on the activity of the fish, its body condition and other factors.

The biological needs may be complex and dynamic, yet Washington’s numeric water quality criteria are reduced to single numbers. Much of Puget Sound has been designated as “extraordinary” water quality, a category that calls for a minimum oxygen level of 7 mg/l and a maximum temperature of 13 degrees C (55.4 F). Other criteria establish limits for turbidity, acidity and bacteria. Besides “extraordinary,” various areas of Puget Sound have been designated as “excellent,” “good” or “fair,” each with their own criteria to protect named species residing there.



According to water quality standards for Puget Sound, as shown on the map, most of the waterway should contain at least 7 milligrams per liter of dissolved oxygen to meet numeric criteria. Where natural levels of oxygen are believed to be lower than these numeric criteria, the Washington Department of Ecology would allow for "natural conditions criteria." The agency is currently revising its process for determining natural conditions. Map: Ecology

Oxygen and temperatures can vary by location and depth in Puget Sound. State regulations call for taking measurements at depths that represent the "dominant aquatic habitat" at each monitoring site. Such monitoring helps to determine whether a water body complies with established criteria or is "impaired" for certain water quality parameters. Because conditions change over time, particularly with seasonal cycles, some areas may comply at one time but not another.

Since few areas of Puget Sound can meet the numeric criteria for dissolved oxygen at all times, even under natural conditions, some individuals and groups are calling for revisions to the criteria. They contend that limits of 6 or 7 mg/l are considerably higher than needed to protect marine life in Puget Sound. Rather than resorting to computer models to determine natural conditions criteria, scientific studies could help establish new numeric criteria based on biological needs.

"Ecology has acknowledged that it has no documentation as to the scientific basis for the marine DO standards that were adopted by a predecessor agency in 1967," said Carl Schroeder of the Association of Washington Cities, commenting on the proposed natural conditions criteria.

Schroeder noted that cities are responsible for many of the sewage-treatment plants in Puget Sound, including those facing costly upgrades to improve oxygen conditions. Since costs must be passed on to customers via higher sewer rates, local governments must be able to explain the rationale for Ecology's water quality standards, he said.

After 56 years without a clear scientific foundation, he continued, "it is startling that Ecology continues to move forward without seeking or incorporating information on the dissolved oxygen needs of the organisms present in Puget Sound."

During last year's legislative session, Schroeder and others attempted to get Washington lawmakers to appropriate $500,000 for a scientific review of the biological needs of Puget Sound species in connection with the state's cleanup standards. The proposed study would have involved the Washington Academy of Sciences. Funding for the study was approved by the House but failed to survive final negotiations in the Senate. This year, Schroeder continues to push for legislative funding, despite tight budget conditions.

Lincoln Loehr, a retired oceanographer and environmental consultant, has been on a crusade of sorts to get Ecology to review the numeric criteria for oxygen. He first petitioned the agency to review the oxygen criteria in 1998, before most people were aware that natural conditions criteria would become such a key factor in setting cleanup targets. Loehr shared his views with many technical groups working on the low-oxygen problems of Puget Sound, and in 2017 he petitioned Ecology again to review the numeric criteria.

"Washington's marine DO water quality criteria, adopted in 1967, have no discoverable scientific basis," Loehr wrote in a report reviewing the history of numeric criteria and recommending that the EPA step in and develop new criteria. "While the state can identify waters as not meeting these criteria, that determination does not demonstrate that the waters are impaired, as the comparison is made with baseless criteria. Similarly, computer modeling to compare to a 0.2 mg/l decrease in DO from human causes (part of the state's criteria) is not a basis for demonstrating impairment, as it has no biological basis."

Responses from EPA officials have offered no support for revising the state's numeric criteria, which federal law says can be more restrictive than federal requirements. Ecology officials defend the existing criteria as being protective of marine species, but critics contend they are overly protective. Loehr argues in favor of changes to the numeric criteria, saying the Clean Water Act calls for standards that accurately reflect the "latest scientific knowledge."

Sara Thitipraserth, director of natural resources for the Stillaguamish Tribe, expressed similar concerns in letters to Ecology and the EPA.

"It is the view of the Stillaguamish Tribe that the Marine Dissolved Oxygen Water Quality Criteria of Washington state are in need of thoughtful, science-based revision," she wrote. "They are outdated, simplistic, and fail to consider the geography and hydrology of Puget Sound. Neither are they based on or referenced with scientific research…

"Once appropriate standards are established," she added, "it is likely that many so-called water quality exceedances will cease to exist. Currently, marine waters with 5 mg/l dissolved oxygen in many deep-water basins are considered noncompliant, when in fact the oxygen level poses no threat to organisms that might be using it. Scientists in the region commonly acknowledge that the harm to a deep-water marine biological community does not occur until the water becomes hypoxic, that is, when oxygen levels drop below 2 mg/l."

MEASURING THE NEEDS FOR OXYGEN

Tim Essington, a fisheries ecologist at the University of Washington, has studied the effects of oxygen depletion on many species in Puget Sound. Although not directly involved in regulatory issues, Essington's research involves studying biological thresholds. For example, declining oxygen levels eventually reach a point when fish must respond with physiological or behavioral changes if they are to survive. This level of oxygen is called the “critical threshold” for a given species, and it varies by temperature.

A key issue is whether the laboratory environment accurately represents conditions faced by aquatic animals in the real world. Fish in a lab, for example, are held under precise conditions of oxygen and temperature to see how they respond, whereas fish in the wild are likely to swim away and seek better conditions when faced with low oxygen levels. Activity and stress can affect their metabolism and their need for oxygen. Temperature is another factor.

“In the lab, you are measuring routine behavior; the fish is not trying to chase down food,” Essington said. “But in terms of ecological relevance, animals do need to eat. The process of finding food costs oxygen, and there is also the need to avoid predators.”

Animals can acclimate to low-oxygen conditions, such as what occurs when a human athlete trains at high altitude, he continued. The oxygen capacity of the blood can change, and fish can even increase the surface area of their gills. Meanwhile, over generations, localized populations within a species may adapt to low-oxygen conditions and pass on those traits to their offspring.

Studying the presence or absence of species under various oxygen conditions can provide clues to their needs in the wild, Essington said, but one needs to understand that the most sensitive species may already be gone. Such observations of wild behavior can be compared to observations in a lab to better understand the oxygen needs of Puget Sound species.

In Chesapeake Bay on the East Coast, the EPA faced the challenge of low-oxygen conditions by dividing the bay into five habitat types, including considerations for the depth of the water. Since deeper water typically contains less oxygen, dominant species are more tolerant of those conditions. The resulting guidelines (PDF) were completed in 2003 with numeric criteria for oxygen, water clarity and chlorophyll. They were subsequently adopted into regulations by the four governmental jurisdictions around the bay: Washington, D.C. and the states of Maryland, Virginia and Delaware.

Proponents of changing Washington state’s numeric criteria for oxygen often point to Chesapeake Bay as an example of how to fit biological needs into a regulatory framework.

EPA identified and described five habitats to ensure the protection of the living resources of the Chesapeake Bay and its tidal tributaries. Some say a similar approach would be appropriate for Puget Sound.

An alternative approach

In establishing numeric criteria for Chesapeake Bay, the Environmental Protection Agency divided the bay into five habitat types to protect species in each location. Each has its own standards for dissolved oxygen:

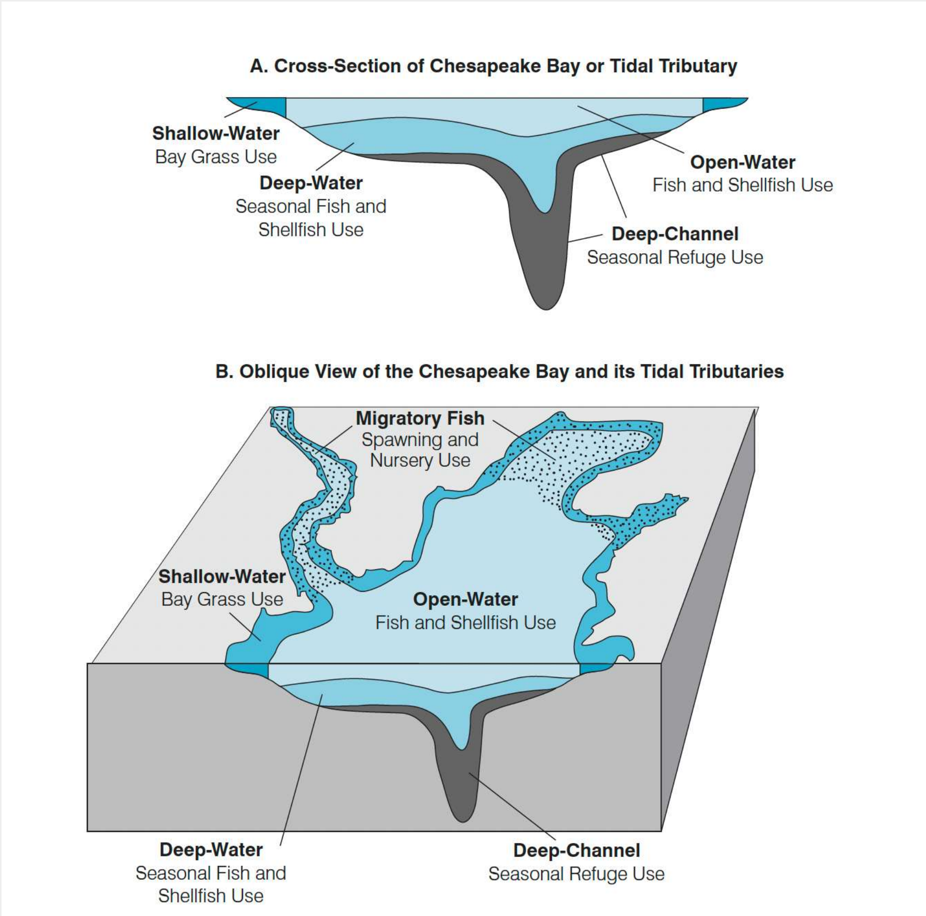
Migratory fish spawning and nursery. Largely freshwater streams and tidally influenced locations where freshwater comes into saltwater. Oxygen levels must generally be above a seven-day average of 6 mg/l from Feb. 1 to May 31, when young fish are migrating. Levels are allowed to drop to 5.0 or 5.5 mg/l, depending on salinity, from June 1 to Jan. 31.

Shallow water bay grass. Mostly underwater areas near the shore where fish and crab find food and protection from predators among the vegetation. Oxygen criteria call for a 30-day average no lower than 5.0 or 5.5 mg/l, depending on salinity, although a seven-day average of at least 4 mg/l also meets the standard.

Open-water fish and shellfish. Includes surface waters in streams, embayments and open waters of the bay where diverse populations of fish spend their time. Oxygen criteria call for a 30-day average no lower than 5.0 or 5.5 mg/l, depending on salinity, although a seven-day average of at least 4 mg/l also meets the standard.

Deep-water seasonal fish and shellfish. Representing transitional waters between the well-mixed surface waters and the deep channels of the bay where bottom-feeding fish, crabs, oysters and other species live. Numeric criteria call a 30-day average oxygen concentration of at least 3 mg/l or a one-day average of 2.3 mg/l, except for Oct. 1 to May 31 when the higher “open-water” criteria apply.

Deep-channel seasonal refuge. The home of sediment-dwelling worms and small clams consumed by bottom-feeding fish and crabs, a habitat known for very-low oxygen levels. To meet the criteria, oxygen levels must never get below 1 mg/l.



Five habitats types designated for Chesapeake Bay. Illustration: EPA

Note: These five habitats also include absolute minimums, separate from averages, which must never be exceeded. For some species, temperature is also considered.

NATURAL CONDITIONS APPROACH

From the beginning, Ecology officials realized that some areas of Puget Sound contained naturally low levels of oxygen that could never meet the numeric criteria, even under the best conditions.

"We have long acknowledged that (portions of) Puget Sound is naturally impaired for DO," said Leanne Weiss, unit supervisor in Ecology's Water Quality Management Division, "and that's why these other processes and options are so important."

In fact, when considering all the nation's waterways, EPA recognized as early as 1997 that natural conditions, absent human impacts, might be lower in oxygen or higher in temperature than numeric criteria in some areas. A (1997 EPA memo) establishes a policy allowing for numeric limits to be supplanted by natural levels.

Current revisions to Ecology's natural conditions regulations came about from a lawsuit filed by Northwest Environmental Advocates. In response to the lawsuit, the EPA agreed to reconsider its 2008 approval of Ecology's natural conditions rule. After review, the EPA reversed its approval (EPA document from 2022), leaving Washington without a natural-conditions option for cleanup goals.

One reason for the reversal was the lack of a clear statement that the natural conditions criteria applied only to aquatic life, not to human health standards, according to the EPA. As described in the 1997 EPA memo on natural conditions criteria, aquatic species may adapt over time to waters with naturally low levels of oxygen or high temperature, but that's not the case for humans. People should be protected from harmful natural conditions by changing the "designated use" of a waterway, the memo says. That might mean excluding fishing or other recreational activities or even issuing public-health warnings.

Ecology's revised rule is written to limit its application to aquatic species.

"Having a standard to determine what is normal and natural for a particular waterbody is important information for setting discharge limits and knowing when action is needed to protect or restore water quality," Ecology states on its rule-making webpage. "Nearly every state and many tribal nations have a provision in their EPA-approved water quality standards to protect aquatic life based on natural conditions of the water bodies."

EPA specifically overturned Ecology's natural conditions criteria for both oxygen and temperature in marine waters and freshwater streams. It did not overturn the criteria in lakes, which EPA determined to be adequately protective as written into the rule.

Oxygen is often the driving factor for marine creatures, and it has received much attention from Ecology because low-oxygen conditions are creating serious problems in Puget Sound. While oxygen levels are a concern in some streams, temperature can be a critical factor for fish where logging has removed large trees that help keep the waters cool (Taking the temperature of salmon).

As with oxygen, when studies show that natural conditions are warmer than designated temperatures, streams have been allowed to reach their estimated "natural" temperatures plus 0.3 degrees — the "human use allowance."

EPA did not determine whether the human use allowance of 0.2 mg/l for oxygen and 0.3 degrees C for temperature was or was not close enough to the actual levels expected under natural conditions, but the agency did insist that Ecology provide scientific justification for those allowances. EPA's 1997 memo allowing for natural conditions does not mention any such allowance.

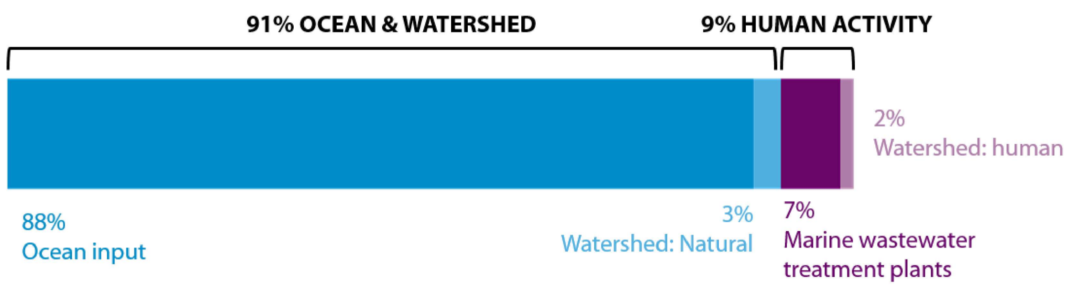
To get natural conditions back into play, Ecology has been working on a performance-based approach — a step-by-step process approved through a formal rule-making procedure. Public comments on the new proposal are being accepted until May 22. Once the process is adopted by Ecology and approved by the EPA, anyone could theoretically follow the process. Ecology would be responsible for establishing allowable limits for temperature or oxygen anywhere in Puget Sound. The resulting natural conditions criteria, based on careful modeling, would be accepted by authorities without further approval.

The first draft maintained 0.2 mg/l and 0.3 degrees C as allowable deviations, consistent with rules adopted years ago and renewed in November. Without these allowances, cleanup standards for oxygen and temperature would need to be set at the natural levels seen in prehistoric times, officials say. Such levels would be unattainable in today's world of human impacts.

Ecology has approved one change to tighten the human use allowance. When natural oxygen conditions are found to be very low — specifically below 2 mg/l — the human use allowance is limited to 10 percent below the natural level. For example, if the natural oxygen level is 1 mg/l, then the allowance can be no more than 0.1 mg/l, setting the cleanup target at 0.9 mg/l.

ENDANGERED SPECIES PROTECTIONS

During the 2008 approval of the natural conditions criteria, federal agencies responsible for protecting listed species under the Endangered Species Act analyzed the effects of Ecology's revised water quality standards for oxygen and temperature, including the relevant human use allowances: 0.2 mg/l for oxygen and 0.3 degrees C for temperature. While the standards may not fully protect listed salmon during all life stages, they are "not likely to jeopardize the continued existence" of the listed species, according to the National Marine Fisheries Service. When the current revisions are complete, the federal agencies are expected to undertake a new analysis of the natural conditions rule, taking into account changing conditions and new research. They must show that the new rule is protective of threatened and endangered species before it can become effective.



Most of the nitrogen in Puget Sound (~91%) comes from natural sources –– mainly the ocean, with a small amount carried in from surrounding watersheds via surface runoff and rivers. Less than 10 percent is attributed to human activity, including wastewater treatment plants (7%) along with agriculture and urban runoff (2%). Levels of dissolved oxygen in Puget Sound are largely determined by how much of this nitrogen reaches the surface layer, where sunlight encourages the rapid growth of plankton. The plankton eventually die and decay, consuming oxygen in the process. Graphic: PSI

Because the performance-based approach relies on computer modeling to identify natural conditions, the process outlined by Ecology prescribes model selection, assumptions, operation and reliability; choice of data; considerations of climate change; interpretation of model outcomes; documentation; peer review; and many other issues. Ecology's proposed revisions have been drafted with guidance from EPA's natural conditions "framework" (PDF).

When the first version of the performance-based approach was released for public comment last May, the document was met with many questions and concerns. Among other things, the EPA called for adding "critical steps" in the process; stronger language to convey that each step is "binding" on the applicant, not voluntary; plus additional detail to "ensure a repeatable and transparent process."

One of the challenges in determining natural conditions is to identify ALL the human sources affecting the waterway. If any human sources are missed, the resulting estimate of natural conditions could lead to cleanup standards that adversely affect species that are still present and preclude the return of missing species.

While an approved performance-based approach would allow Ecology to establish water quality goals without further rulemaking, another approach is to study a particular area and propose water quality criteria that meets the needs of species in that area. Results from this "site-specific approach" would be proposed and adopted as a rule by Ecology with final approval from the EPA.

In the end, whether cleanup goals are based on numeric criteria or on natural conditions, the ultimate goal is to restore water quality for all species in Puget Sound — including, as much as possible, those species that thrived when natural conditions prevailed.

This article was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

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Oxygen for life: The biological impacts of low dissolved oxygen

About the Author

Christopher Dunagan is a senior writer at the Puget Sound Institute.

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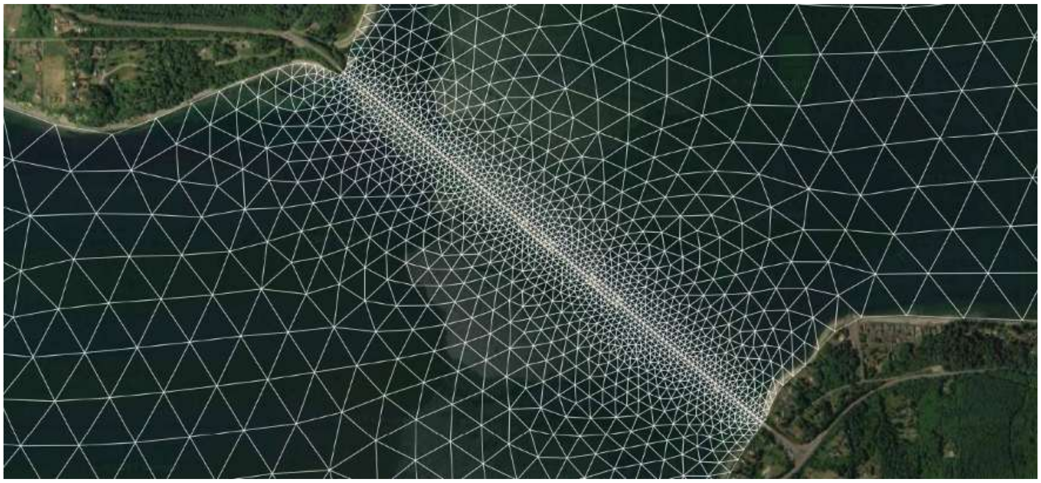

The "unstructured grid" used in the Salish Sea Model allows for greater resolution (smaller triangles) when studying complex water circulation, such as around the Hood Canal bridge. The model is being used to study ocean alkalinity enhancement. Graphic: Tarang Khangaonkar

WATER QUALITY, MODELING

Unpacking uncertainty: How experts recommend improving Puget Sound modeling

By Marielle Kanojia Published April 2, 2025 Comments Closed

An external scientific review by independent experts is a common and valuable practice, particularly when the models have significant management implications. This ethos is why peer review is foundational to science in general. By providing an objective assessment, external reviewers can help ensure the models are robust and appropriate for the management decisions they're being applied to. For example, the Chesapeake Bay Program's suite of modeling tools has undergone several expert reviews over the last 30 years. In 2023, the Southern California Coastal Water Research Project Authority similarly launched an independent expert panel to review their coastal eutrophication numerical modeling.

We are navigating complex decisions

Our region is navigating complex decisions on how best to manage nitrogen to maintain healthy habitats. Excess nitrogen from human activities can potentially increase harmful algal blooms, decrease dissolved oxygen, compound ocean acidification, and cause other changes that may harm marine life. Recent regulations are particularly focused on the impacts of excess nitrogen on low dissolved oxygen in Puget Sound. While low dissolved oxygen occurs naturally, excess nitrogen from human activities may change the timing, location, and size of algae blooms and by extension marine life's exposure to low dissolved oxygen.

Modeling is driving nutrient management in Puget Sound

The Salish Sea Model was developed to help inform these complex decisions. Washington State uses monitoring data and the Salish Sea Model to determine compliance with Washington's dissolved oxygen water quality standard and to establish each 303(d) listing. The state also uses the model to explore the effectiveness of potential nutrient reductions and to establish targets for load reductions at wastewater treatment plants. Regulation using the model may result in billion-dollar wastewater treatment plant upgrades. The nutrient management decisions we make now could shape the future of wastewater treatment, water quality, and our communities for decades to come. Consequently, there is heightened interest in assessing the Salish Sea Model's performance, particularly the regulatory application.

Regulatory Application: Determining Non-Compliance
Since parts of Puget Sound naturally have low dissolved oxygen, it's important to determine the decrease in dissolved oxygen due to excess nutrients from human activities, specifically. The Department of Ecology uses monitoring data and the Salish Sea Model to determine compliance with Washington's dissolved oxygen water quality standard and to

establish each 303(d) listing. The Salish Sea Model simulates both **existing conditions** and **natural conditions** (i.e., an approximation of conditions before western settlement). A location in Puget Sound is predicted to be **non-compliant** if any of the 10 depth-layers:
1. Fall below the numeric criteria (e.g., 7 mg/L) **or** natural conditions at that location, whichever is lower
AND
2. The existing condition is at least 0.2 mg/L or 10% lower than the natural conditions, whichever change is smaller.

If a single layer at any location is non-compliant for at least an hour, the day is considered non-compliant.

**Ecology adopted revisions to the natural conditions provision and shared updated Performance-Based Approach guidance for public comment by May 22, 2025.*

Learning from global experts

When addressing complex environmental challenges, valuable insights can be gained from the extensive experience of scientists in other regions like the Chesapeake Bay and the Baltic, where models have been used to manage nutrients for decades. In 2024, the University of Washington Puget Sound Institute convened global experts to advise on how to improve the application of the Salish Sea Model to inform recovery goals and nutrient management decisions in Puget Sound. We were fortunate to benefit from the expertise of scientists who have led cutting-edge research and advised regional managers on the application of modeling and monitoring in nutrient management programs in other regions. The Model Evaluation Group included:

- **Bill Dennison:** Vice President for Science Application and Professor at University of Maryland Center for Environmental Science
- **Jacob Carstensen:** Professor at Aarhus University, Denmark
- **Jeremy Testa:** Associate Professor at University of Maryland Center for Environmental Science
- **Kevin Farley:** Professor and the Blasland, Bouck and Lee Faculty Chair at Manhattan College
- **Peter Vanrolleghem:** Professor at Université Laval, Canada

Meet the Model Evaluation Group

Expert findings

In analyzing the existing literature and available data on the Salish Sea Model at the time, the experts found:

- On average, Salish Sea-wide model simulations have comparable performance to other models used to set water quality standards and nutrient discharge limits elsewhere in the USA. Evaluating the average model skill for the entire region can miss important local nuances in specific areas where non-compliance is predicted. However, while other states use models to set water quality standards and nutrient discharge limits, to our knowledge, they only use monitoring data to assess compliance with nutrient and dissolved oxygen water quality standards.
- Dissolved oxygen non-compliance in Puget Sound occurs primarily in portions of Hood Canal and 16 shallow embayments. Within these non-compliant areas, the model error is greater. For example, the 2014 modeled results for current conditions ranged from 1.04 – 3.05 mg/L DO RMSE across 22 sites in these embayments. These RMSE results are approximately an order of magnitude greater than the 0.2 mg/L DO human allowance that is used to determine regulatory compliance. This highlights the value of looking at model performance analysis specifically in the places and at the times where model outputs are used in regulatory decision-making.
- The regulatory determination of non-compliance was found to be quite sensitive to the natural conditions threshold defined by the state's water quality standards. For example, in 2014, 58% of the non-compliant area was at most 0.1 mg/L above the 0.2 mg/L human allowance threshold.

Expert recommendations

In 2024, the Model Evaluation Group recommended the following model analysis to increase confidence in the regulatory application and strengthen a process-based approach to understanding water quality drivers of change:

- Focus additional validation studies on shallow embayments and portions of Hood Canal where human activities may further reduce low dissolved oxygen levels. Preliminary analysis suggests there is larger model error in these areas. Long-term, increased monitoring in these areas could also support refined modeling of these shallow embayments.

- Perform validation studies using sub-sets of data above/below the pycnocline to better understand the importance of and model skill related to processes influencing dissolved oxygen, such as vertical mixing, stratification, phytoplankton growth, and water-sediment interactions.
- Analyze model performance for non-calibration years and across multiple years to characterize model skill beyond the three existing, single-year runs. Consider performing additional sensitivity scenarios for model years that are at opposite ends of the spectrum of interannual variability.
- Use new monitoring data to analyze model performance for sediment oxygen demand and to validate related processes like carbon fluxes and denitrification.
- Characterize the potential propagation of error associated with uncertainties in model parametrization, loadings, etc., and how this may influence confidence in the model-to-model comparison used when determining regulatory compliance.

Read the Modeling Recommendations in detail

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A century of warming has reduced dissolved oxygen in Puget Sound

At Carr Inlet, warming temperatures account for about 50 percent of the dissolved oxygen loss over the past century. Photo: Washington Department of Ecology (CC BY-NC 2.0)

KEYWORDS: HYPOXIA, NUTRIENT POLLUTION, SALISH SEA CURRENTS MAGAZINE, WATER QUALITY, MARINE HABITAT

By Sarah DeWeerdt

Published June 10, 2025

A new study outlines the strong link between dissolved oxygen declines and increasing water temperatures, raising questions about the effect of future climate change on Puget Sound.

Warming waters likely contribute to decreasing dissolved oxygen levels in Puget Sound, adding another layer of complexity to efforts to understand the health of the estuary and ensure healthy conditions for aquatic life ranging from zooplankton and crabs to salmon and killer whales.

The finding emerges from a preliminary University of Washington analysis of temperature and dissolved oxygen measurements taken at multiple locations in Puget Sound over the past century. The work, which is available on ESS Open Archive but has not yet been peer-reviewed, suggests that increasing temperatures account for roughly half of the dissolved oxygen decline documented in central Puget Sound over the last 100 years.

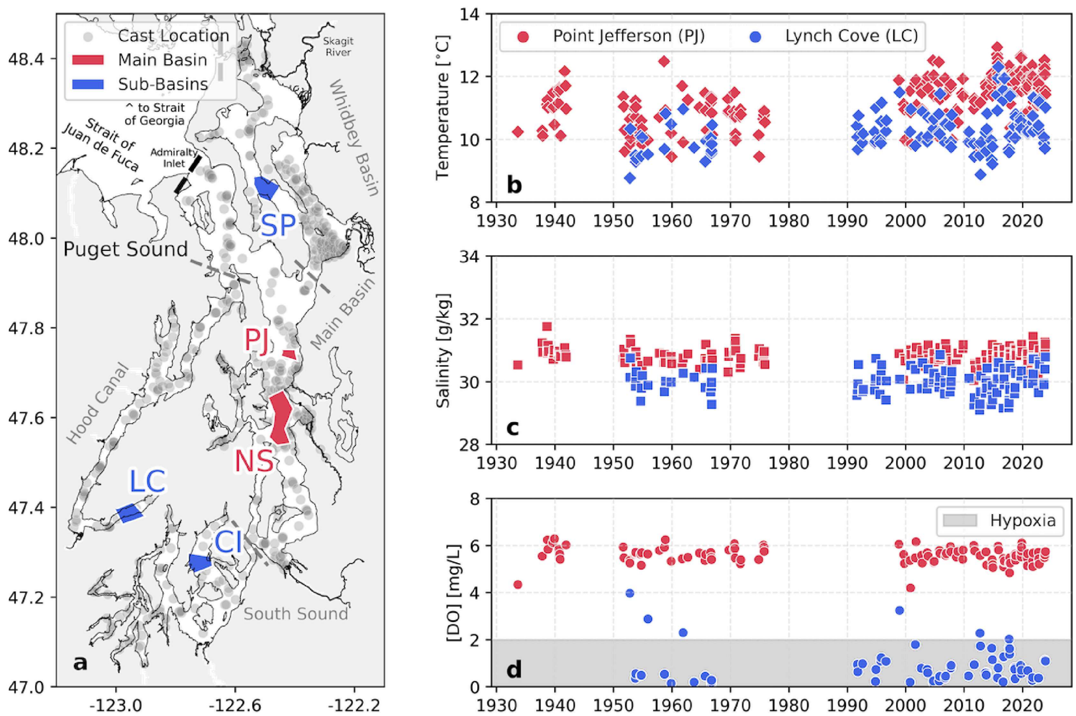
Puget Sound is "a very complex system that has many other things going on," says University of Washington doctoral student Dakota Mascarenas, the study's first author. But, she says, "we've identified a mechanism that, on a century scale, might have about this level of impact." Mascarenas also presented the unpublished data at an online Science of Puget Sound Water Quality workshop in February.

It's well known that warmer water holds less dissolved oxygen and other dissolved gases. As water gets warmer, water molecules move faster and jostle against each other more, making it more likely that oxygen molecules will get pushed out of the surface of the water.

In fact, scientists have documented temperature-related oxygen decreases at a global scale. There's widespread concern that climate change and continued increases in temperature could further reduce oxygen levels in marine ecosystems. And so, the look backwards: "The first step in trying to predict the future is to know what happened in the past," says University of Washington oceanographer Parker MacCready, a senior author of the new study.

The researchers analyzed more than 12,000 measurements of water quality parameters (temperature, salinity, and dissolved oxygen) dating all the way back to 1932. The measurements were taken near the bottom of the water column in late summer and early fall – where and when low-oxygen conditions are most likely to develop in Puget Sound.

They identified five locations with at least 60 years' worth of the requisite data: Saratoga Passage in the Whidbey Basin, Lynch Cove in Hood Canal, Carr Inlet in South Sound, and Point Jefferson and a location near Seattle in the Main Basin of Puget Sound.



Map (a) of five Puget Sound data collection locations with sufficient data for century-scale trend analysis (SP= Saratoga Passage, PJ=Point Jefferson, NS=Near Seattle, LC=Lynch Cove. CI=Carr Inlet) and August-November, bottom values at selected sites for (b) temperature, (c) salinity, and (d) DO between 1930 and 2025. Source: Mascareneas et al. 2025 DOI: 10.22541/essoar.174461801.10035683/v1

The long timeframe was necessary to discern patterns that transcend the variations in ocean conditions that happen seasonally, from year to year, and on longer cycles (such as the Pacific Decadal Oscillation and El Niño-Southern Oscillation) affecting Puget Sound. "There's a lot of different timescales of potential variation," says Mascarenas. "We've done our best to look as long as we can."

The full series of measurements revealed that the five Puget Sound sites have warmed by about 1.4 °C over the past century. This is in line with regional trends in ocean and atmospheric warming.

Meanwhile, dissolved oxygen has decreased at a rate of 0.3-0.9 milligrams per liter per century at the two Main Basin sites. Outside of central Puget Sound, dissolved oxygen trends were more variable: declining at Carr Inlet, stable at Saratoga Passage, and slightly increasing at Lynch Cove.

The researchers then used a well-established equation to calculate the reduction of oxygen in the water, given how much it has warmed. This revealed an expected decrease in dissolved oxygen of 0.31 milligrams per liter per century on average, across all locations.

At Point Jefferson and the near-Seattle location in the Main Basin, this warming-related, expected decline explains 40-100% of the actual decrease in dissolved oxygen observed over the past century. At Carr Inlet, warming accounts for about 50% of the dissolved oxygen loss. Elsewhere, measurements were too variable to draw conclusions.

The marked effect of temperature in explaining oxygen decline was surprising, says MacCready. Although the relationship between temperature and dissolved oxygen is well known, the scientific conversation about dissolved oxygen in Puget Sound has been so focused on nutrient pollution that he hadn't given temperature much thought, he says.

Globally, an estimated 15% of the ocean's oxygen loss between 1960 and 2010 can be attributed to the effects of increasing temperature, according to [a report](#) from the International Union for the Conservation of Nature. Warming may explain roughly half of the oxygen loss in the upper 1,000 meters of the ocean, the report says.

Because Puget Sound's Main Basin is deep, contains about 65% of the total volume of Puget Sound, and supplies water to other sub-basins, the Main Basin findings likely reflect changes affecting Puget Sound as a whole, the researchers argue. "That's probably the closest to the background trend that we're going to be able to see," says Mascarenas.

Similar findings have been documented in the Chesapeake Bay – another large estuary adjacent to urban and agricultural development but with a very different structure compared to Puget Sound. This suggests that temperature-related oxygen declines may be a general phenomenon affecting estuaries around the world.

The new study does not make any predictions about how warming may affect dissolved oxygen in Puget Sound in the future, as climate change intensifies. The relationship may not be a linear one and the system could encounter “tipping points” that magnify the effects, Mascarenas says.

The policy implications of these changes are also uncertain. Will climate change make Puget Sound more sensitive to nutrient loadings and make action to control human-caused nutrient inputs more urgent? Or will warming simply overwhelm any proposed gains from controlling nutrients?

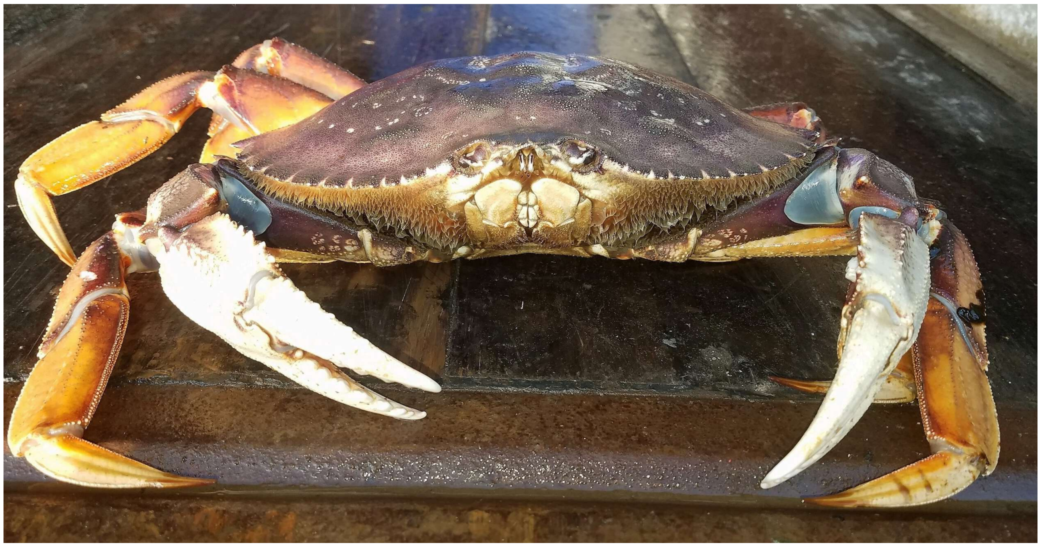
What’s predictable, for now, is further warming, says MacCready. "There's every reason to think that that trend will continue."

This article was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

About the Author

Sarah DeWeerdt is a Seattle-based freelance science writer specializing in biology, medicine, and the environment. Her work has appeared in publications including Nature, Conservation, and Nautilus.

Waters.



Dungeness crabs are one of many Puget Sound species that can be impaired by low-oxygen conditions. Photo: Crabmanners via Wikimedia Commons

WATER QUALITY

Low oxygen challenge, part 1: The debate over oxygen in Puget Sound

By Christopher Dunagan Published June 12, 2025 2 Comments

A new report, Draft Puget Sound Nutrient Reduction Plan, is out today for public review. Experts at the Washington Department of Ecology along with many other researchers have spent years studying and debating the *problem of low oxygen in Puget Sound. Now, many new developments — technical, scientific and legal — are reaching a critical stage and setting up a framework to make some major decisions. This four-part series in Our Water Ways looks back on how we have reached our present condition, including a consideration of possible solutions. Part 3 describes findings in the new report.*

In Puget Sound, low oxygen levels are a proven threat to marine creatures, from fish to shellfish and even tiny organisms. This threat has long been recognized by scientists — particularly within slow-flushing bays and inlets where low levels of dissolved oxygen can impair sea life and occasionally create deadly conditions in late summer and fall.

For decades, government agencies have been studying the low-oxygen problems of Puget Sound, some natural, some man-made. Now, the Washington Department of Ecology has put together a plan to reduce the inflow of nutrients, particularly nitrogen, which can fuel a rapid growth of plankton, setting off a natural process of deoxygenation. A draft plan, released today, will be discussed in parts 3 and 4 of this series. Comments on the plan will be accepted by Ecology until Aug. 27.

Altogether, recent scientific discoveries, advances in computer modeling and a series of legal rulings have established an atmosphere for change. Ecology is pushing forward with plans to control nitrogen coming from sewage-treatment plants and from upstream sources, such as farms and urban areas. Critics on one side say Ecology has overstated the problem and failed to come up with workable solutions. Critics on the other side say actions have been taking way too long.

In this blog post and the next, I hope to describe how we got into our current situation and the factors that will help shape the future health of Puget Sound and ultimately determine which marine species will survive.

Biological effects

Pacific herring spawning in eelgrass, Holms Harbor, Whidbey Island. Photo: Florian Graner, Sealife Productions

Although we rarely see dead fish washing up on shore, marine organisms may succumb to a multitude of unseen stresses caused by low-oxygen waters, stresses that reverberate through the food web, affecting species from plankton to killer whales.

Many aquatic creatures respond to oxygen deficiency with a shift in their physiological makeup, according to Tim Essington, professor of aquatic and fishery sciences at the University of Washington. Without adequate oxygen, they may struggle to find food and avoid predators. They may become susceptible to disease and reproductive failure. Although very real, these and other effects are difficult for researchers to observe in real-world conditions.

"Organisms have a range of responses available to them to try to cope with thresholds of low oxygen," Essington said in a presentation summarized in the Encyclopedia of Puget Sound. "Typically, they can move, acclimate, or in the worst-case scenario, they may die."

Essington has compared low-oxygen conditions for marine organisms to high-altitude effects on humans, an analogy supported by Mindy Roberts, director of the Puget Sound Program for Washington Conservation Action, an environmental group.

"Imagine if you were suddenly transported to the summit of Mount Rainier, where oxygen is 40 percent lower than sea level," said Roberts, a former environmental engineer for Ecology. "In addition to finding it difficult to breathe, your cognitive processes are affected. With my climbing background, I know that this occurs."

Some species are more tolerant of low-oxygen conditions than others. In areas of Puget Sound where oxygen levels are chronically low, some species are no longer present and those that remain are fewer in number. As scientists say, oxygen levels can affect both biodiversity and abundance, causing shifts throughout the entire food web.

Oxygen levels often decline the most at the bottom of Puget Sound, particularly in smaller bays and inlets where the habitat supports a multitude of invertebrates and fish. As oxygen levels decline, sometimes on annual cycles, fish and other mobile species may seek more breathable waters at shallower depths, thus increasing the risk that predators will eat them. Less mobile species may acclimate over time, or they may die out.

While some researchers strive to understand the complex physiological changes at work in low-oxygen conditions, others are using computer models to better understand how nitrogen enters and flows through the waters of Puget Sound, feeding a variety of planktonic species at the base of the food web.

Plankton are an essential food source for many higher-level animals, but excessive nitrogen can produce massive plankton blooms that overwhelm the consumptive capacity of the food web. When that happens, the excess plankton die, sink, and decay, enhancing bacterial growth that consumes the available oxygen (Encyclopedia of Puget Sound).

The latest computer models are designed to replicate the physical and biological conditions throughout Puget Sound, revealing when and where low-oxygen conditions are likely to occur. They also help researchers figure out how to rectify the problem by reducing nitrogen inputs at locations where reductions would have the greatest effect.

A large plankton bloom photographed by Ecology's Eyes Over Puget Sound program in 2023, looking from Seattle to Bainbridge Island. Photo: Washington Department of Ecology.

A major focus of Ecology's strategy is sewage treatment plants, most of which discharge nitrogen directly into Puget Sound. Also important are diffuse sources such as farms and housing developments, where nitrogen from fertilizers and animal wastes get into stormwater and enter rivers and streams that discharge to Puget Sound.

Computer models must also account for complex circulation patterns as well as a massive flows of nitrogen in seawater that move into Puget Sound from the ocean. This oceanic seawater, being saltier and denser than other water in Puget Sound, comes in along the bottom, as lower-density freshwater moves out at the surface. This is typical estuarine flow found in many parts of the world. Because of turbulence, some of the deeper, nitrogen-rich water mixes into the surface layers, where sunlight allows for the growth of plankton and low-oxygen conditions.

The worst conditions can be seen near the bottom in areas with low circulation, where mixing with oxygen-rich water is slow and organic decay draws down oxygen levels. Southern Hood Canal and inlets in South Puget Sound are among the vulnerable areas. These waters can, on occasion, create conditions uninhabitable to most sea life.

Ecology's regulatory efforts to constrain human sources of nitrogen have been on a bumpy course, sometimes challenged by both environmental groups and treatment plant operators.

Most recently, Ecology's plan to control nitrogen from sewage effluent using a new "general permit" has hit a roadblock in a ruling from the state's Pollution Control Hearings Board. The board ruled that Ecology cannot legally require a treatment plant to comply with a general permit if the facility already operates under an individual permit, as most do. As a result, Ecology has shifted its regulatory approach, as will be explained in the final part of this series.

King County is among the local entities participating in studies of low-oxygen conditions and exploring how dissolved oxygen levels affect Puget Sound's varied species and habitats. With billions of dollars needed to upgrade sewage-treatment plants, county officials are asking for a regional strategy focused on the most cost-effective actions.

"King County is committed to protecting Puget Sound, including addressing nutrients," said Akiko Oda, public information officer for the county's Wastewater Treatment Division. "We are continuing the water quality monitoring, technology evaluation and treatment planning that was originally required under the original nutrient general permit."

Roberts, who helped develop early computer models for Ecology, is now a leader in the environmental community. It is past time, she says, to get the major sources of nitrogen under control and begin to restore the health of the waterway.

Natural and unnatural conditions in history

While some areas of Puget Sound are naturally low in oxygen, human activities have been affecting water quality since the first settlers began altering the landscape in the 1800s. References to low-oxygen problems date back to the 1920s, a time when several pulp mills were dumping their industrial wastes into local bays. Cities with one or more mills at that time include Port Angeles, Port Townsend, Shelton and Tacoma, and later Everett (1936) and Bellingham (1938).

A lumber and pulp mill in Shelton, 1947, Ellis Postcard Co. // Photo courtesy of Washington State Historical Society

Effluent from the production of pulp, used to make paper, contains chemicals that can be toxic to fish, shellfish and other organisms. In those early days, another effluent constituent, wood waste, triggered the growth of bacteria that consumed nearly all the oxygen in the vicinity of the mills, upsetting the food web and sometimes creating "dead zones" where nothing could live. Oxygen levels often remained low even after the industrial chemicals dispersed. Chemists at the time debated whether it was toxic compounds or a lack of oxygen causing the most damage to nearby oyster beds.

The Washington Pollution Control Commission, established in 1945, became the first agency authorized to rein in pollution. But early commissioners saw their role as educators more than enforcers, launching a statewide campaign called "Keep Washington Clean," according to a 1967 article by L.A. Powe Jr. in Washington Law Review.

Commercial oyster growers, already fighting to protect their depleted beds, wanted stronger action from the commission. Scientific studies, public hearings and lawsuits became part of the battle by local oystermen, led by the Pacific Coast Oyster Growers Association.

In 1955, the Legislature imposed a permit system to control pollution, giving the commission new authorities. "Instead of waiting for a complaint and then investigating, the commission was placed in a position where industry came to them to request permission to discharge wastes," Powe explained.

Although oyster growers were not satisfied with the pace of progress, stricter limitations on effluent were added to permits over time, and the waters got cleaner. But getting some operations to comply with new requirements remained a concern, according to Dave Nunnallee, who joined the Washington Department of Ecology in 1969 and became an inspector.

"We had laws, but the enforcement was very weak," Nunnallee said in an interview for a "Historically Speaking" (PDF), an Ecology publication celebrating the agency's 35th anniversary in 2005. Nunnallee, who retired in 2006, recently recalled several investigations of untreated wastes, including those from a concrete plant in Renton, a slaughterhouse in Auburn and fish-processing plants on the Seattle's "filthy" waterfront.

In 1973, during a growing environmental movement, the Legislature increased penalties for permit violations from $100 to $5,000 a day, strengthening Ecology's hand with pollution, Nunnallee said.

Effects of sewage

Besides industrial effluent, state pollution officials were aware that sewage treatment plants of the 1970s were releasing organic materials that could deplete oxygen levels — particularly in small, enclosed bays. The Pollution Control Commission, whose name was changed in 1967 to the Water Pollution Control Commission, had long pushed local governments to build "primary" treatment plants to end the practice of discharging raw sewage. But when it came to organic pollutants and dissolved oxygen, the commission was more focused on lakes and rivers than on Puget Sound, Nunnallee recalled.

"Frankly, we weren't too concerned about Puget Sound," he said during the 2005 interview. State officials generally believed that Puget Sound, outside a few small bays, had the capacity to absorb the organic pollution, he said. For example, the costly effort to clean up Lake Washington during the 1960s was declared a tremendous success, but it led to releasing considerably more organic wastes into Puget Sound.

One of the standard tests used to quantify the effects of sewage effluent on water quality involves a calculation of "biochemical oxygen demand," or BOD. The test typically measures the concentration of oxygen in an effluent sample at the beginning and at the end of a five-day period. The result represents the amount of oxygen required for bacteria to break down organic waste in the sample — a rough indicator of the environmental impact. The BOD of raw sewage is typically 300-600 milligrams per liter.

In the midst of an environmental movement that began in the 1960s, Congress took an ambitious leap to clean up the nation's waters by passing the Clean Water Act of 1972. This powerful law has elicited profound changes in regulations by federal, state and local governments — right up to today.

Among its many provisions is a requirement that sewage treatment plants nationwide be upgraded to reduce organic pollutants and improve oxygen conditions. Federal water-quality standards were established based on the capability of existing treatment systems — which could produce effluent with an average BOD less than 45 milligrams per liter. These standards and the processes that could meet them became known as "secondary treatment." Initially, municipalities were given until 1977 to begin construction on the upgrades, although deadlines were extended, and federal waivers were allowed when warranted by water conditions.

At first, Washington state officials refused to push for secondary treatment for facilities discharging into Puget Sound, Nunnallee said. Studies at the time failed to show that major problems resulted from sewage effluent, except in the immediate vicinity of the outfall, he noted. "So, we encouraged the entities to apply for their waivers, not thinking it was that big a water-quality issue."

By 1983, with concerns growing over pollution in Puget Sound, proponents of sewer upgrades argued that state law mandated improvements, specifically because secondary treatment was well-proven technology. They cited the water pollution law of 1945:

"Section 1. It is declared to be the public policy of the State of Washington to maintain the highest possible standards to insure the purity of all waters of the state consistent with public health and public enjoyment thereof … and to that end require the use of *all* *known available and reasonable methods* by industries and others to prevent and control the pollution of the waters of the State of Washington (emphasis added)."

Amendments in 1967 had changed the law slightly to require wastes to undergo "all known, available, and reasonable methods of treatment prior to their discharge," but the intent has remained the same since 1945. This idea of keeping the waters as clean as possible imposed what became known as a "technology-based standard," which Ecology must enforce "regardless of the quality of the water," according to the statute. Many lawsuits would follow, and AKART — "all known, available, and reasonable treatment" — appeared in legal documents again and again right up to recent court rulings, which will be discussed in the next part of this series.

Donald Moos, director of Ecology in 1983, asked for a state attorney general's opinion to determine whether the language of the law would expressly require secondary treatment at all sewage facilities in Washington state.

In his response, Attorney General Ken Eikenberry said "secondary treatment" is not specifically defined in the law. So, while the law clearly calls for modern treatment technology, it must also be "known," "available," and "reasonable." This is an engineering, not a legal question, he said in his legal opinion.

"A review must be conducted by the department of existing engineering technologies in order to enable it to decide which methods of treatment … are suitable with respect to the waste situation involved in the particular case," Eikenberry stated.

After a review by Ecology officials, the agency drafted a policy defining water quality standards that were consistent with secondary treatment. Although some treatment plant operators objected, the standards were generally upheld by the state's Pollution Control Hearings Board. As a result, the issue of feasible technology (AKART) has become a factor in setting effluent limits in permits for all sewage treatment plants.

"The basic problem, however, was that most of us in Ecology didn't feel that secondary treatment was needed, and ultimately we were proved wrong," Nunnallee said in the 2005 interview. Secondary treatment, now the universal standard, has effectively reduced the discharge of organic pollutants into Puget Sound. But the typical secondary-treatment process does little to reduce nitrogen, which can trigger the rapid growth of plankton and produce low-oxygen conditions. The question of what should be done to control nitrogen in Puget Sound has been engaging a host of scientists while prompting legal battles along the way.

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This article was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

The series

Part 1: The debate over oxygen in Puget Sound

Part 2: Water-cleanup plans and the search for 'reasonable' actions

Part 3: Computer models spell out the extent of the water-quality problem.

Part 4: Many actions may be needed to improve Puget Sound waters

Previous: Follow the herring: Why sea lions have been calling Shilshole Marina home

Up Next: Low oxygen challenge, part 2: Water-cleanup plans and the search for 'reasonable' actions

2 Replies to "Low oxygen challenge, part 1: The debate over oxygen in Puget Sound"

JD Ridgley, 1 month ago

I support scientific study and scientific resolution of the problem. I live on the Sound and still do not feel that it is safe enough for swimming, etc.

Jimmie Matei, 1 month ago

After many years of traveling the world on the ocean and much of my research on what happened to the abundance of marine life in my eariler years, has caused me to realize that where ever there is human populations there is ocean floor anoxic conditions or in fresh water creeks, rivers and lakes in some degree of deterioration.
I have been working on a means to convert the anoxic / hypoxic ocean and lake floors to compost and get growing again.
Please contact me if you may wish to learn more as I continue to develop my Ocean Floor Composter.

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Olympia's Budd Inlet Treatment Plant, center, is one of the few nitrogen-removing systems on Puget Sound. Photo: Department of Ecology

WATER QUALITY

Low oxygen challenge, part 2: Water-cleanup plans and the search for 'reasonable' actions

By Christopher Dunagan Published June 12, 2025 Comments Closed

On a clear autumn day, the blue waters of Budd Inlet reflect the distant snow-capped Olympic Mountains. From the water's surface, nobody can tell if low-oxygen conditions might be lurking below, as they often do, creating a stressful or even deadly environment for sea life.

The fact that beauty can disguise the harsh reality of water quality applies to low-oxygen conditions in numerous bays throughout Puget Sound, from Budd Inlet in South Puget Sound to Penn Cove in

Central Puget Sound to Bellingham Bay in North Puget Sound, along with the southern end of a 68-mile-long fjord we call Hood Canal.

Olympia's Capitol Lake // Photo: Gärgollaz via Wikimedia Commons

To address the low-oxygen problems, the Washington Department of Ecology, along with many others, has conducted numerous studies of actual conditions, developed computer models to identify possible solutions, and started the process of regulation. The agency is now nearing completion of an action plan designed to improve the health of Puget Sound. Along the way, we've seen scientific debates and legal battles, as various interests assert wide-ranging opinions about what should be done.

As for Budd Inlet, excess nitrogen, plankton blooms and occasional fish kills are part of the waterway's history. Studies during the 1980s concluded that Budd Inlet's low-oxygen waters were the result of a complex combination of watershed conditions, nitrogen sources and circulation patterns that make Budd Inlet an unusual case study.

Low-oxygen waters were coming into the inlet from freshwater sources — including Olympia's Capitol Lake and nearby streams. Also, before a major system upgrade in 1994, a sewage-treatment plant serving the region was a significant source of nitrogen, known to contribute to oxygen deficits. In addition, according to studies, a significant amount of nitrogen flowed southward into the bay from sewage-treatment plants as far away as Tacoma and Seattle — although the extent of that external nitrogen supply was not known until a modeling effort in 2014. Further complicating the situation throughout Puget Sound is the large, natural supply of nitrogen-rich waters coming in, along the bottom, from the Pacific Ocean.

As described in the previous blog post, federal and state regulations during the 1980s led to upgrades of sewage-treatment plants throughout Puget Sound to meet "secondary treatment" standards for organic wastes. Among them was the regional treatment plant serving Lacey, Olympia, Tumwater and portions of Thurston County, named LOTT. The cooperative venture upgraded the system from primary to secondary in 1982. But even before that, experts realized that much more would be needed to solve the low-oxygen problem.

In 1994, LOTT became the first sewage-treatment system (PDF) on Puget Sound to add nitrogen-removal equipment, known as tertiary treatment, to the treatment process. And, in 2023, LOTT completed construction of a more efficient "second-generation" upgrade to its nitrogen-removal process.

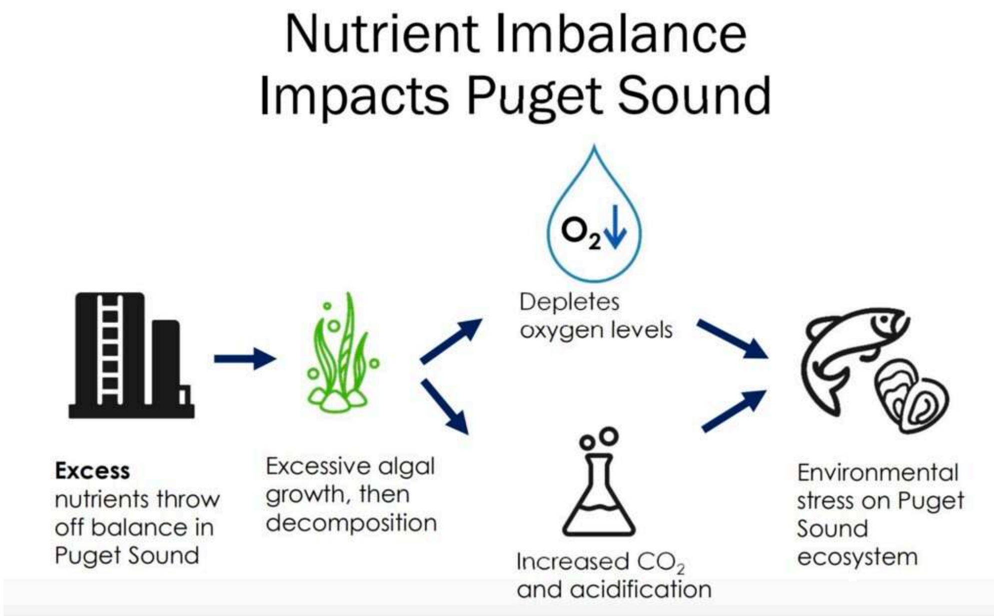
Today, LOTT remains one of the few treatment systems on Puget Sound to institute nitrogen removal, despite ongoing pressure — including lawsuits — from environment groups trying to force upgrades at other treatment plants.

"Known, available, reasonable"

Since 1945, Washington's water pollution laws seem to be calling for the cleanest water possible, within reason. Through the years, in one form or another, the law has maintained language requiring that wastewater dischargers use "all known, available and reasonable technology" to control pollution — the so-called AKART requirement.

In 2018, Northwest Environmental Advocates, an environmental group, petitioned the Department of Ecology to update its AKART standard to tertiary treatment and require all treatment plants to upgrade their systems to reduce nitrogen levels in effluent to no more than 3 milligrams per liter. After all, said NWEA in the petition, this type of treatment has proven successful in many places across the nation and should be a minimum requirement for keeping up with technology.

"Put simply, it's well past time for Ecology to make Puget Sound sewage treatment plants switch from the 100-year-old treatment technology most of them are using," the group said on its website.



Graphic: Washington Department of Ecology

Ecology denied the petition, saying tertiary treatment to remove nitrogen did not meet the definition of "reasonable," as required by law, because such a higher level of treatment is "neither affordable nor necessary for all wastewater treatment plants."

In a 2019 letter of denial (PDF), Ecology Director Maia Bellon acknowledged that nutrient pollution was a significant problem. She said Ecology is committed to limiting nitrogen from sewage treatment plants to current levels and requiring operators to plan for reductions. Ecology's goal, she said, is to develop a plan that limits nitrogen levels in Puget Sound by considering where reductions from various sources would have the greatest effect on improving water quality.

NWEA appealed to Thurston County Superior Court and then to the State Court of Appeals. Both deferred to Ecology's findings that requiring tertiary treatment for all plants in Puget Sound would not be "reasonable." One study cited by Ecology estimated the cost of upgrading all treatment plants at roughly $4.5 billion, or specifically somewhere between $2.24 billion and $8.96 billion.

The appeals court ruled that AKART does not require Ecology to mandate any treatment system across the board or even impose universal water quality standards. "Rather," says the written opinion from June 2021, "the statute mandates that Ecology comply with AKART when issuing permits."

The court concluded that when Ecology applies the required AKART standard to individual permits for each plant, local water conditions — as well as available technology — must be considered.

Another environmental group, Puget Soundkeeper Alliance, brought the AKART issue back to a basic level by appealing a permit issued by Ecology for Seattle's West Point Wastewater Treatment Plant, the largest discharger of sewage effluent in the Puget Sound region. In its appeal to the Pollution Control Hearings Board in May 2024, the group contended that nitrogen and phosphorus are known pollutants and must be controlled with specific effluent limits under both state and federal laws. (Phosphorus is primarily an issue for lakes.)

"State statutes require that permits include and apply 'all known, available, and reasonable technology' or 'AKART' to control pollutants in wastewater or other discharges authorized by … permits," the appeal document (PDF) says.

At the time the appeal was filed, Ecology was working under an approved "nutrient general permit," which prohibited certain treatment plants from increasing current levels of nitrogen in their effluent. Since then, the Pollution Control Hearings Board has invalidated the general permit for facilities that already have an individual permit, such as the West Point plant. Ecology has asked the hearings board to delay proceedings on the West Point appeal until it can issue a new "voluntary" general permit or else place nitrogen restrictions on the facility's individual permit. A decision on the request for delay is expected at any time.

Impaired waters and cleanup plans

One lawsuit currently moving through the courts could force the state Department of Ecology or the federal Environmental Protection Agency to complete a cleanup plan for nitrogen throughout Puget Sound without further delay. That lawsuit, based on requirements of the 1972 Clean Water Act, was first filed by Northwest Environmental Advocates against the EPA in late 2021. Parties went into negotiations but could not reach agreement on how to proceed, so the case became active again last year.

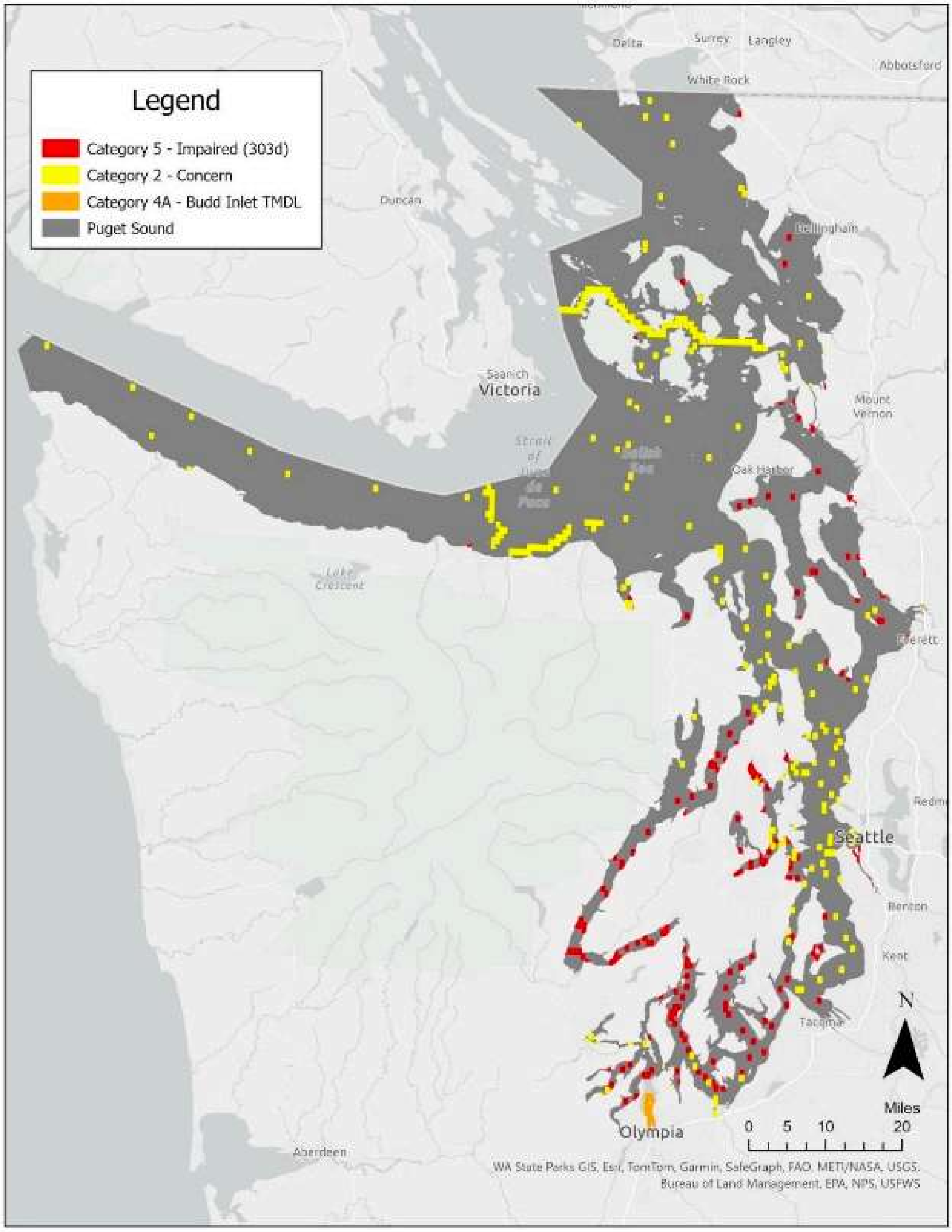
"After years of inaction, it's clear that nothing short of a court order will force EPA and Washington's Department of Ecology to clean up Puget Sound," asserted Nina Bell, NWEA's executive director, in a December 2021 press release about the proposed plan to set nitrogen limits for Puget Sound.

Under the Clean Water Act, states are called on to decide if segments of streams, lakes and marine waters are clean or polluted. The question is: Do the waters meet water-quality standards set by Ecology and approved by the EPA? Standards may include numeric criteria, such as the concentration of dissolved oxygen, or they may be based on natural conditions — theoretical levels that would exist without human influence. (See Encyclopedia of Puget Sound.)

Under the law, water bodies that fail to meet water-quality standards are declared "impaired," and Ecology must undertake a cleanup plan to restore the water body to a healthy condition. The plan involves a determination of the maximum level of pollutants, such as nitrogen, that could be allowed without violating water-quality standards. The document is called a TMDL, for total maximum daily load. The goal of the TMDL process is to reduce various sources of pollution until the total amount is at a safe level, as defined by the calculated TMDL number.

According to Ecology's own estimates at the time, based on modeling, about 20 percent of Puget Sound's marine waters failed to meet water-quality standards for dissolved oxygen, states a legal complaint (PDF) filed by NWEA.

"For over three decades, the marine waters of Puget Sound have been known to be impaired by dangerously low levels of dissolved oxygen, caused by nitrogen pollution…," the document asserts. "Along with oxygen depletion, nitrogen pollution fuels extensive algal



Impaired waters in Puget Sound, including Category 5 (impaired) in red, Category 2 (waters of concern) in yellow, and Category 4A (TMDL) for Budd Inlet in orange. // Map: Ecology’s draft Puget Sound Nutrient Reduction Plan.

blooms in Puget Sound, some toxic to people, some toxic to shellfish, and some that are upending the food chain that supports imperiled Chinook salmon and orca whales.”

Ecology’s approach, sanctioned by the EPA, is to develop a “TMDL alternative” — a nutrient-reduction plan. The effect of that approach has been to avoid regulatory actions required by the Clean Water Act, according to the lawsuit. Citing a 1996 case in Idaho, the complaint says that Congress in 1972 intended that TMDLs be developed “in months and a few years, not decades.” In 2019, the

EPA approved Ecology's idea of creating a nutrient-reduction plan without a TMDL.

According to the lawsuit, failure by Ecology to submit TMDLs to improve water quality in Puget Sound effectively signals a lack of intent to do so and triggers a requirement that EPA take over development of TMDLs to reduce nitrogen and improve oxygen levels.

In response to NWEA's lawsuit, attorneys for the EPA insist that neither Ecology nor the EPA have abandoned their efforts to clean up Puget Sound, including the need to address sources of nitrogen, so NWEA's demands are not justified.

"When this case reaches the summary judgment stage, EPA will argue that Washington has not abandoned efforts to control dissolved oxygen impairments in the Sound; it has made the Sound the center of a robust, multi-pronged monitoring and regulatory effort," states a response brief (PDF) from EPA filed in February. "And while Washington is currently prioritizing direct controls on nutrient pollution through permitting, its cleanup plans also include developing a TMDL to address any remaining dissolved oxygen impairments in Puget Sound."

U.S. District Judge Barbara Rothstein, who is presiding in the case, has asked that legal motions, briefs and documentation be submitted on a schedule starting July 25 and ending Dec. 5 of this year, with her order to follow.

Long-term cleanup schedules

Another lawsuit involving pollution-cleanup plans was first filed by NWEA against the EPA in 1991. Even after 34 years, many issues in the stop-and-go case are still quite alive, because Ecology has been unable to keep pace with an agreed schedule for completing TMDLs. EPA needs to step in as a matter of federal law, according to NWEA.

The 1991 lawsuit was filed when Ecology completed about 20 water-quality-improvement plans over 19 years under the 1972 Clean Water Act, a number that NWEA considered grossly inadequate.

The case was settled out of court in 1992 but reactivated in 1994. In 1998, the parties reached an out-of-court settlement with Ecology agreeing to a long-term aggressive schedule. Under the agreement, Ecology would complete 59 TMDLs statewide the first year and the rest — some 1,566 at the time — over 15 years.

In 2019, some 27 years after the agreement was signed, NWEA reactivated the lawsuit again, saying Ecology had completed less than 900 TMDLs — well short of the 1,566 that were scheduled to be done by 2013. Over the 15 years, Ecology completed an average 58 TMDLs per year but added an annual average of 222 additional "impaired-water" segments that require TMDLs.

"In other words," the complaint (PDF) says, "Washington identifies impaired waters for which TMDLs are needed at a rate four times the pace at which it completes TMDLs for impaired waters."

After the 15-year period was up, the pace of TMDL development by Ecology slowed considerably, according to the lawsuit, adding that the agency also failed to submit a prioritized schedule of future TMDL efforts.

Eventually, the lawsuit led to another settlement in 2023. This time, the parties agreed to allow EPA to hire a consultant to carefully examine the TMDL program and make recommendations for improvement. In response to questions, EPA officials said the consultant's report, expected by the end of this year, will describe Ecology's TMDL program, identify challenges to timely completion and offer recommendations on how to complete TMDLs faster.

"This report will be a neutral analysis of Ecology's program so that they can look at the recommendations and decide which options to pursue," according to a statement from the EPA.

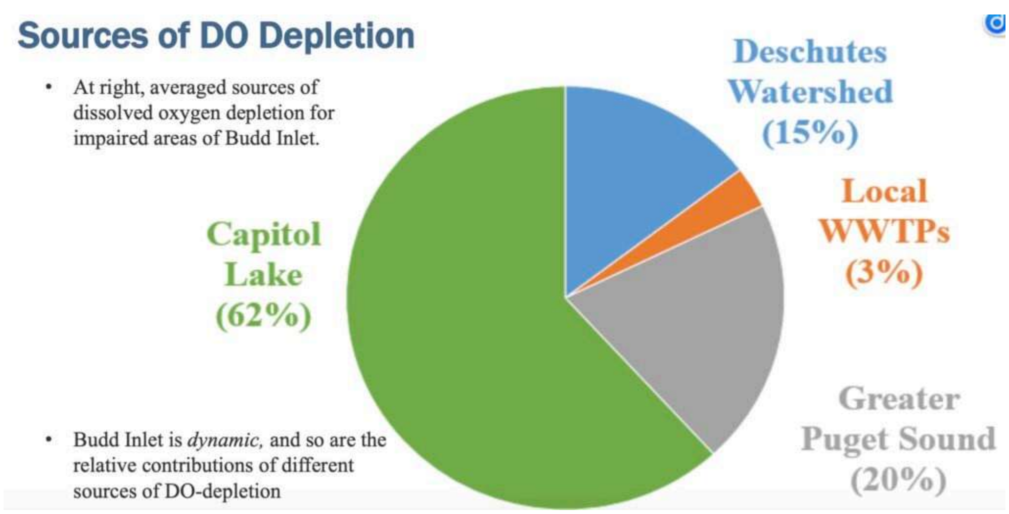
Ecology officials say cleanup plans have become more complex and more comprehensive through the years. Now, a single plan may cover entire watersheds, not just specific segments of streams or marine waters. Newer plans also consider multiple water-quality parameters, not just one, in each TMDL. Officials deny committing any violations of federal law, but say they look forward to the third-party evaluation.

"Though we regularly self-assess to consider opportunities for improvement, this external review is structured to provide new insights and recommendations for ways we can continue to improve while efficiently using our resources for all stages of developing and implementing water quality cleanup plans," Ecology says in a blog post about TMDLs.

"The goal is to reach an agreement on the number of water quality cleanup plans we complete, while ensuring they are effective, support implementation, and clean up Washington's waters."

Budd Inlet TMDL

Efforts to improve oxygen conditions throughout Puget Sound include a special focus on Budd Inlet, where an approved water-quality cleanup plan, or TMDL, uniquely connects to a larger nitrogen-reduction plan for all of Puget Sound. The plan, completed in 2022, identifies the major sources of low oxygen and spells out actions to bring Budd Inlet back into compliance with water quality standards.

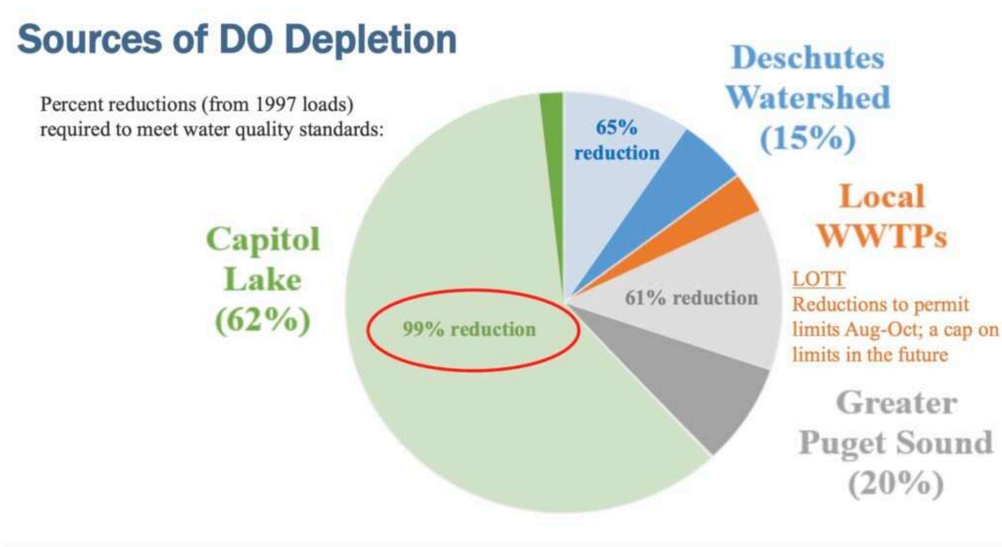


The causes of low oxygen in Budd Inlet and their proportional effects on water quality // Graphic: Ecology's TMDL for Budd Inlet

Based on years of study and computer modeling, with a consideration of water conditions in every portion of Budd Inlet, experts learned that the "critical period" for low oxygen typically begins in August and runs through September. This seasonality became a clear factor in deciding how and where restoration efforts should take place.

It turns out that the greatest factor in oxygen depletion is Capitol Lake, a man-made lake created in 1951 by damming the Deschutes River where it flows into the upper end of Budd Inlet. The lake stimulates the growth of freshwater algae and aquatic plants, which die and wash into Budd Inlet, where their decay consumes available oxygen. Scientists estimate that Capitol Lake accounts for 62 percent of Budd Inlet's oxygen depletion.

An environmental impact statement, completed in 2021, provided alternatives for addressing the environmental problems created by the dam, including the effects of dam removal and estuary restoration. In 2023, the Legislature approved funding to move ahead with planning and designs needed to remove the dam and restore 260 acres of estuarine and salt marsh habitat. If things go smoothly, the restoration project could begin within three years.



The amount of nitrogen reduction from each source required to meet the state's water quality standards // Graphic: Ecology's TMDL for Budd Inlet

The second-greatest source of oxygen depletion, representing 20 percent of the problem, is a flow of nitrogen into Budd Inlet from the rest of Puget Sound. While waters flow both in and out of inlet — and the net flow is outward — the incoming waters, mostly along the bottom, are much higher in nitrogen.

Unlike most TMDLs, which prescribe actions to reduce various sources of pollution in prescribed amounts, the Budd Inlet cleanup plan calls for a 61 percent reduction in oxygen depletion caused by these incoming waters from Puget Sound. How to accomplish this reduction, known as a "bubble allocation," will be determined by the larger planning effort being conducted throughout Puget Sound, called the Puget Sound Nutrient Source Reduction Project. Meeting water quality standards in Budd Inlet will depend on the success of actions outside as well as inside, the waterway.

Other sources of oxygen depletion in Budd Inlet include upstream areas of the Deschutes River watershed (15 percent of the problem) and sewage treatment plants (3 percent). Various actions are proposed for each of these sources to reduce their contributions to the problem.

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This article was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

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Moon jellies seem to do well in warmer, low-oxygen waters, such as those in Sinclair Inlet near Bremerton in August 2022, shown here. Jellyfish may disrupt the food web by consuming large amounts of plankton needed by other species. // Photo by Haila Schultz, University of Washington

WATER QUALITY

Low oxygen challenge, part 3: Computer models spell out the extent of the water-quality problem

By Christopher Dunagan Published June 12, 2025 Comments Closed

After more than eight years of study amid ongoing discussions, the Washington Department of Ecology has made public a far-reaching plan for reducing human sources of nitrogen that contribute to the destructive low-oxygen conditions in Puget Sound. The plan, called the Puget Sound Nutrient Reduction Plan, calls for reductions in nitrogen from sewage-treatment plants, agricultural operations and a variety of other upstream sources.

The plan is based on decades of monitoring to identify the locations of low-oxygen problems, investigations to quantify sources of nitrogen (both natural and human-derived), and computer modeling to reveal how specific source reductions could affect water quality.

By the early 2000s, it had become clear that nitrogen from Central Puget Sound was affecting oxygen levels in South Puget Sound, including Budd Inlet, shown here at Capitol Lake. The State Capitol can be seen right of center. // Photo: Washington Department of Ecology

Nitrogen, an essential ingredient for growth, has been shown to be a problem at times when released into Puget Sound. Excess nitrogen triggers excessive plankton blooms. The plankton eventually die and sink to the bottom, spurring the growth of bacteria, which consume oxygen supplies needed for healthy marine populations.

Besides low-oxygen effects on sea life, some plankton species disrupt the food web, because they cannot be eaten by herring and other small fish that serve as prey for larger fish and marine mammals. Other plankton species excrete dangerous toxins, resulting in "harmful algal blooms" that can kill fish, birds and marine mammals and disrupt commercial shellfish operations. Even beneficial plankton in overabundance can block sunlight and impair eelgrass beds and other essential habitats.

The need for a plan to address the oxygen problems throughout Puget Sound grew out of studies beginning in the 1980s. By the early 2000s, local problems were better understood. It became clear, for example, that low-oxygen levels in Budd Inlet and other South Puget Sound bays were affected by waters coming from the rest of Puget Sound to the north. Since parts of Puget Sound are naturally low in oxygen, an ongoing debate surrounds the extent to which human sources of nitrogen are to blame.

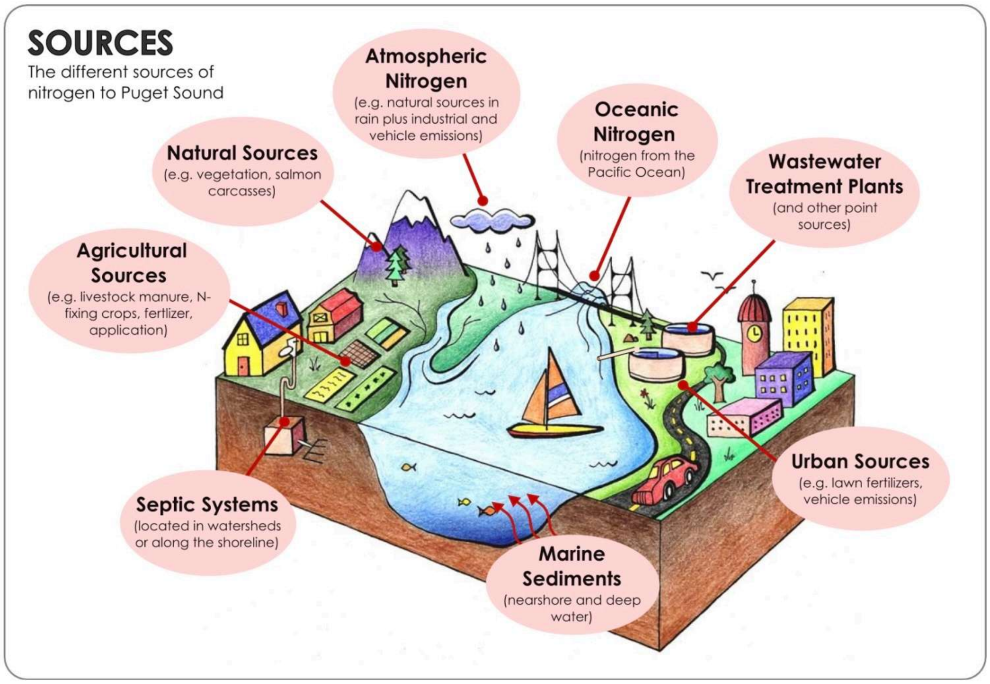
To help pull the information together and develop a plan of action, Ecology launched the Puget Sound Nutrient Source Reduction Project In the spring of 2017. A discussion group, called the Puget Sound Nutrient Forum, started up a year later to hear reports about the latest findings. Participants included researchers, government officials, sewage-treatment plant operators, tribal representatives, environmentalists and others.

Homing in on nutrient sources

By 2019, Ecology staffers were convinced that human sources of nitrogen, including sewage treatment plants, were playing a key role in pushing oxygen concentrations below state water quality standards in some areas. The Salish Sea Model, designed to simulate actual conditions in Puget Sound, accounts for physical processes — currents, tides and nutrient transport — along with chemical and biological processes that transform chemical compounds, including nitrogen. To the surprise of early researchers studying these dynamic changes, models revealed that nitrogen released at one point could move many miles away and trigger the growth of plankton in remote areas.

Model runs reported in 2019 were based on data from the years 2006, 2008 and 2014 and published in the Ecology report "Model Updates and Bounding Scenarios."

"Modeling results show that portions of Puget Sound, primarily South Sound and Whidbey Basin, experience a large number of days when the marine DO (dissolved oxygen) water quality standard is not met," the report states. "In multiple locations within these two regions, the total number of noncompliant days is over three months."



The largest source of nitrogen in Puget Sound is water coming from the Pacific Ocean, but many point and nonpoint sourcces influence the levels of oxygen thoughout the Sound. (Click on image to enlarge.) Graphic: Washington Department of Ecology

Model refinements in 2021 (PDF) began to focus on regions of Puget Sound and to combine scenarios that involved greater or lesser nitrogen discharges from treatment plants versus the upstream watersheds. Further refinements this year provided the foundation for the newly released nutrient reduction plan.

Outcomes of recent model runs have shown that most of the impaired areas are close to meeting the state's natural conditions criteria, which allow dissolved oxygen levels to be as much as 0.2 milligrams per liter above prehistoric levels, as calculated by the model. More than half are within 0.1 mg/l of this standard by some calculations. Nevertheless, significant improvements will be needed to achieve full compliance.

"When it comes to nutrient pollution, there are proven ways to solve the problem, and we will need to use all our tools to get to clean water," said David Giglio, manager of Ecology's Water Quality Program in a news release. "This includes significant investments for wastewater infrastructure. As a region, we need to be as efficient as possible with our resources while we work toward a healthy Puget Sound and restoring salmon runs."

So-called watershed sources include upstream fertilizers used on farms and in urban areas, sewage-treatment plants, septic systems, animal wastes and atmospheric deposition, all washing off the land, eventually entering Puget Sound through 193 rivers and streams in the current model. While nitrogen is a key factor in reducing oxygen levels, the Salish Sea Model also calculates the effects of inflowing organic materials that can reduce oxygen levels through decomposition.

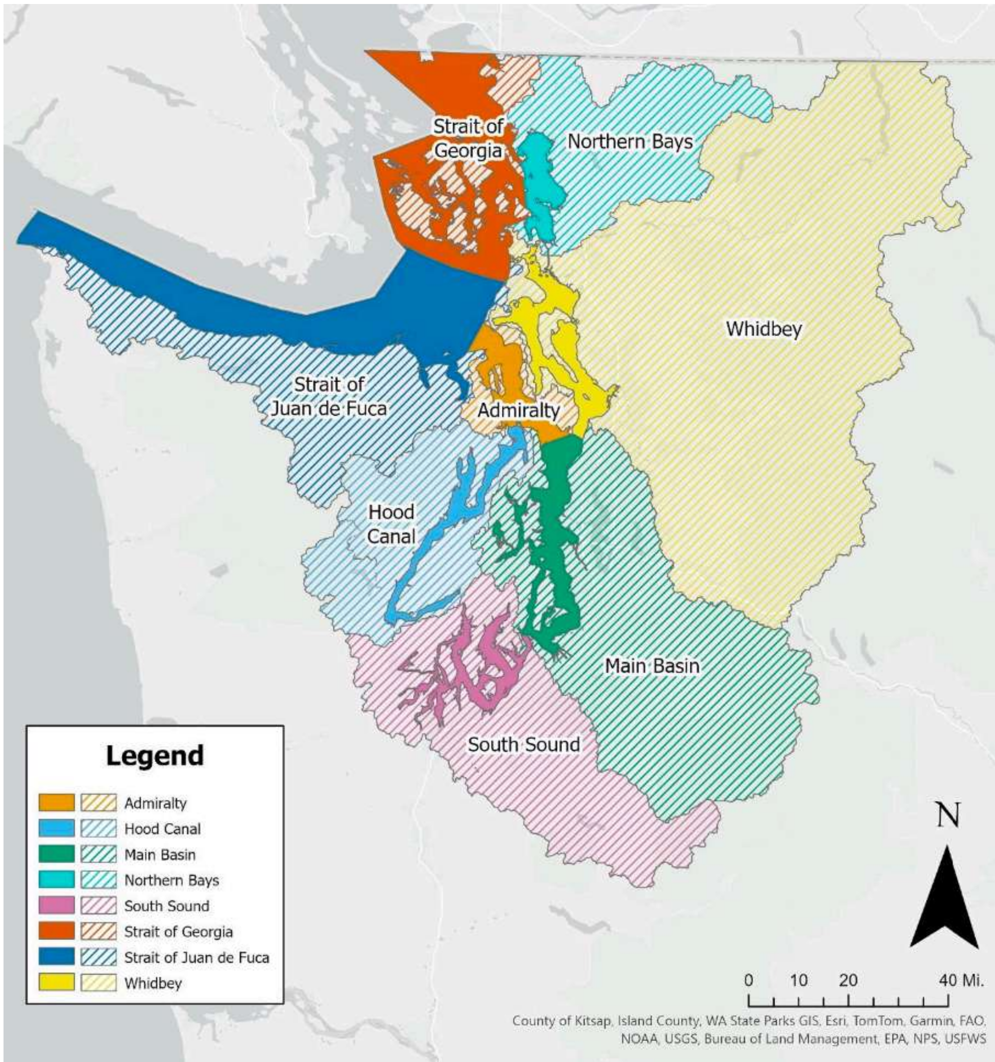
Of all the human sources of nitrogen under consideration, about two-thirds arrives from direct discharges from sewage-treatment plants, with about one-third from upstream sources flowing into rivers and then into the Sound. Natural sources are estimated to contribute about 90 percent of all nitrogen in Puget Sound, but where and when each of these sources arrive in the Sound are key factors in determining oxygen levels at various locations, as accounted for in the model.

Puget Sound currents, driven by tides and incoming freshwater flows, play a major role in oxygen levels at every location in Puget Sound. Most vulnerable to low oxygen levels are small bays as well as the terminal ends of longer inlets, where low circulation and slow flushing rates allow an accumulation of low-oxygen waters on the bottom. Hood Canal, for example, has no major inputs of nitrogen from industry or sewage treatment, yet the southern dead-end portion of the waterway (Lynch Cove) shows persistent low-oxygen conditions, in large part from natural sources of nitrogen.

In some areas, such Central Puget Sound, nitrogen released from treatment plants in Seattle and Tacoma can have far-reaching effects, because the large inputs of nitrogen are carried by strong currents.

Latest model results

In March, the latest refinements in the Salish Sea Model and fresh findings from model runs were revealed in an online meeting of the Puget Sound Nutrient Forum (PDF). More than a dozen model scenarios looked at combinations of various nitrogen levels coming from treatment plants, paired with various nitrogen reductions from watersheds. Improvements were measured by calculating areas of Puget Sound that could meet water quality standards for each combination. Over a full year, for each combination, the model was able to determine minimum oxygen levels as well as the number of days that water-quality violations would occur anywhere in Puget Sound, as described in the report Model Updates and Optimization Scenarios, Phase 2.



The eight basins of Puget Sound used in the Puget Sound Nutrient Reduction Plan. (Click to enlarge.) Map: Washington Department of Ecology

After studying the options based on nutrient reductions at specific locations, Ecology officials selected on option announced today in the draft plan, which establishes regional targets for nitrogen levels in both wastewater and watersheds. Point-source targets will be used to set effluent limits for sewage-treatment plants and industrial facilities.

Watershed targets are aggregated to each of Puget Sound's eight defined basins, including the Strait of Juan de Fuca, Main Basin, South Sound and so on. Watershed targets will be a starting point for a 25-year cleanup effort, including two cleanup plans by 2027.

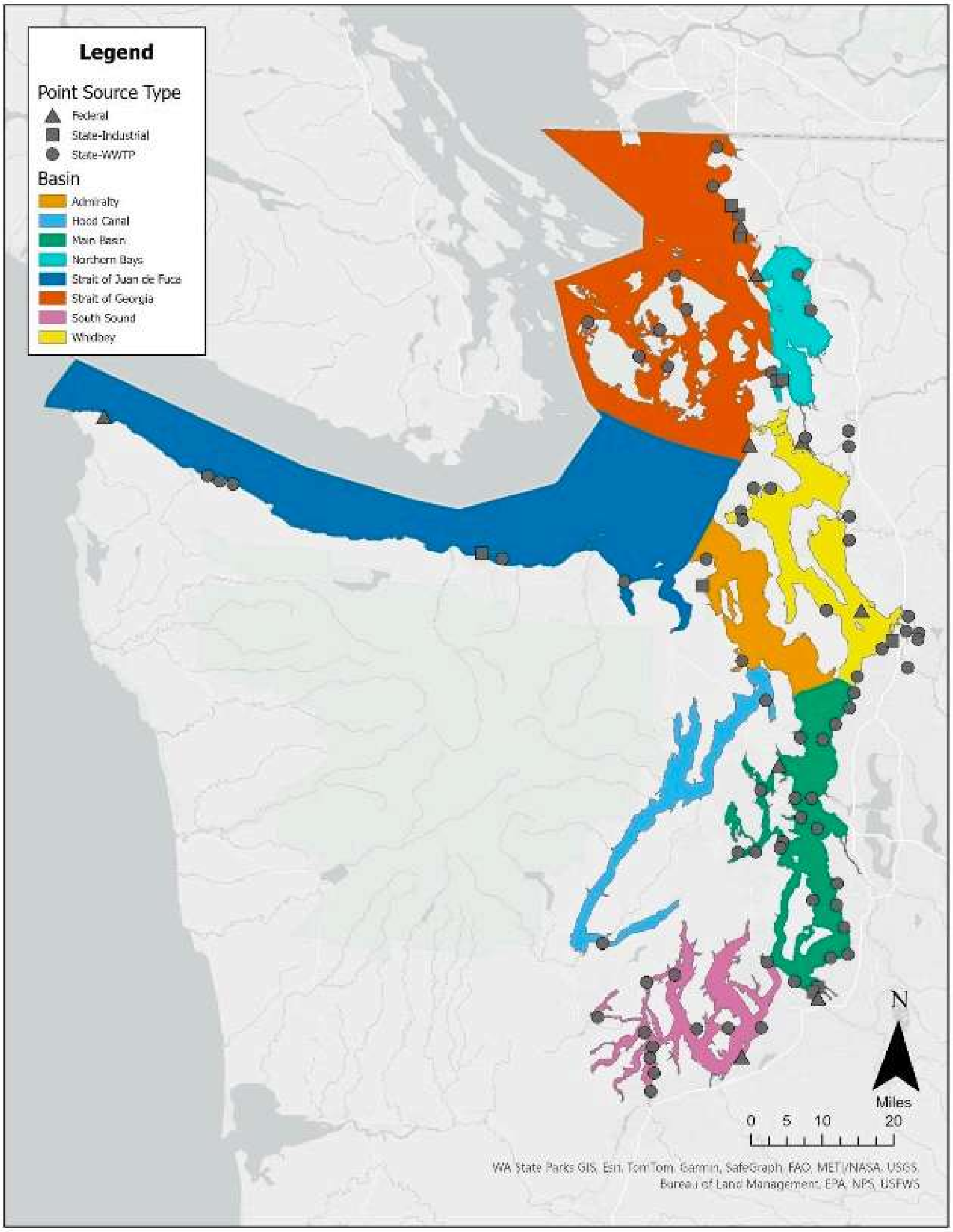
"The watershed targets are represented as a single annual TN (total nitrogen) load for each of the eight Puget Sound basins," the plan says. "Note that these loads represent all upstream nonpoint and point sources of TN in the 163 distinct watersheds draining to Puget Sound."

To meet water-quality standards, the plan calls for a 68 percent reduction in nitrogen coming from human sources in the large watersheds on the east side of Puget Sound, including South Sound. For the small watersheds in that area, the proposed reductions are 61 percent. The reduction goal is 53 percent for Hood Canal and Admiralty Inlet. Watersheds in the Strait of Juan de Fuca and the Strait of Georgia would be capped at existing levels with no further reductions needed.

An important exception is proposed in the "recalcitrant areas" that present major challenges to meeting water quality standards. Specifically, those areas are Lynch Cove in Hood Canal ; Sinclair Inlet and Liberty Bay on the Kitsap Peninsula; and Carr and Henderson inlets in South Sound. To meet water-quality standards, local streams might need to reduce their nutrient loads by 90 percent, according to the plan.

The focus on direct nitrogen inputs to Puget Sound involved 99 "point sources," including 78 sewage treatment plants in Washington, nine sewage treatment plants in British Columbia and 10 industrial facilities.

To gain the best results in water quality with less extensive changes in treatment systems, discharges of nitrogen would be reduced the most during July, August and September — the so-called "hot months" — when sunlight, nutrient buildup and slow mixing triggers plankton blooms, leading to the lowest oxygen levels of the year. The second-highest reductions would be the surrounding months of April, May, June and October, the "warm months" that typically have mixed light levels and water movement. "Cool months," from November through March, are known to have more dynamic changes in weather and mixing and fewer low-oxygen problems.



Marine point sources identified in the Puget Sound Nutrient Reduction Plan. (Click to enlarge.) Map: Washington Department of Ecology

Using this strategy, the plan would propose hot, warm and cool periods for treatment plants discharging more than 22 pounds of total nitrogen and more than 13 pounds of dissolved nitrogen per day in these basins: Northern, with one treatment plant; Whidbey, 11 plants; Main, 14 plants; and South Sound, three plants. Specifically, average nitrogen concentrations were set to 3 milligrams per liter in hot months, 5 mg/l in warm months and 8 mg/l in cool months. For plants on Sinclair Inlet, the limit would be 3 mg/l year-round.

Most large treatment plants discharging into the main basin of Puget Sound, such as Seattle and Tacoma, would be limited to 3 mg/l in both hot and warm months, with 8 mg/l in cool months. West Point in Seattle would use the three limits for hot/warm/cool periods mentioned above. Limits would be set to 2014 nitrogen loads for smaller treatment plants and for those discharging into Hood Canal, Admiralty Inlet, Strait of Juan de Fuca and Straight of Georgia.

Sources of nitrogen in the watersheds

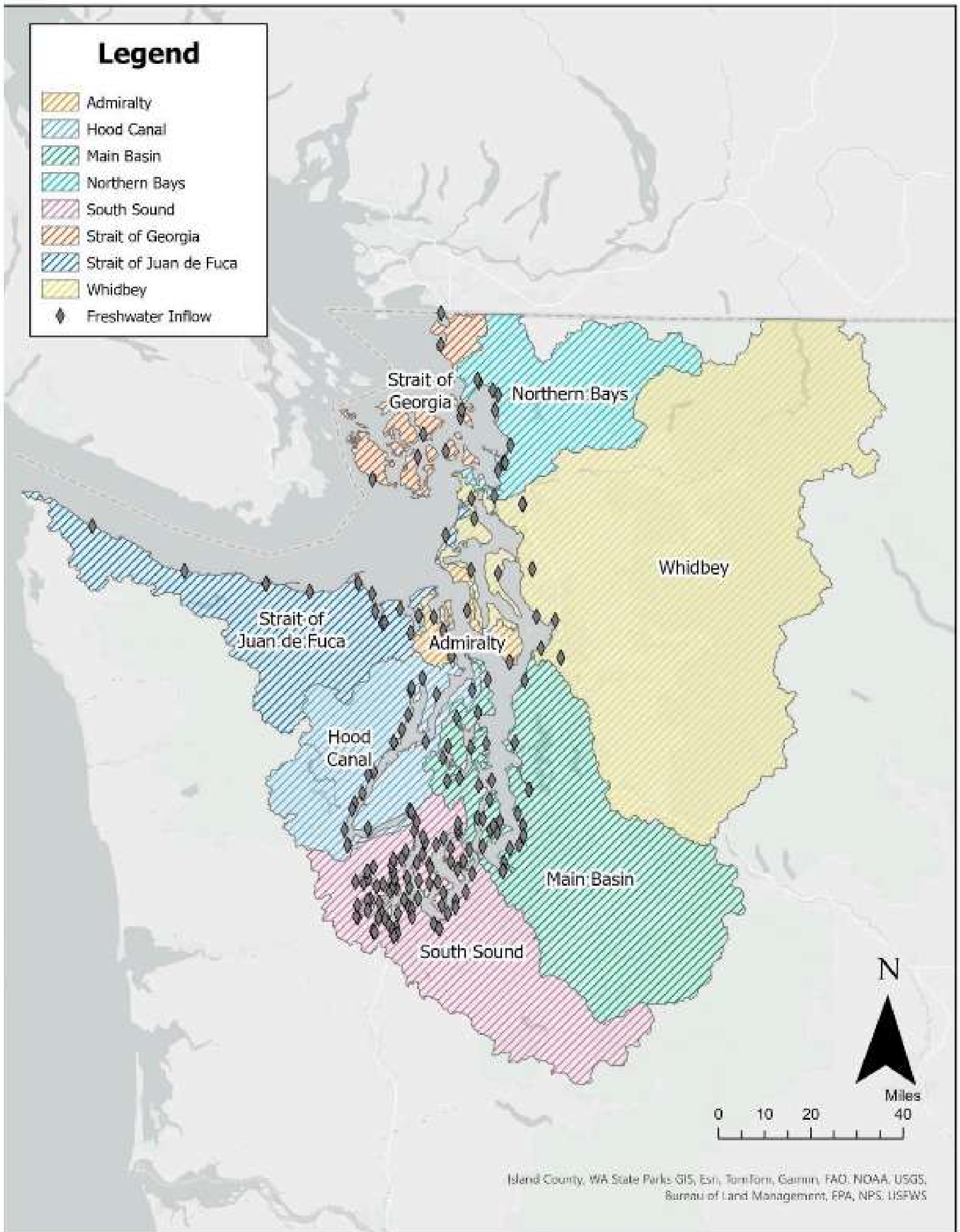
In searching for upstream, land-based sources of nitrogen, scientists have discovered that every river entering Puget Sound contains a unique mix of nitrogen from fertilizers, animal wastes, sewage-treatment plants, alder trees, urban stormwater and septic systems.

The total amount of nitrogen being delivered to Puget Sound varies greatly from river to river and season to season, with the greatest amount of nitrogen arriving during the high river flows of winter, according to a report released this year by the U.S. Geological Survey.

Actual upstream sources of nitrogen in the various rivers are as different as the surrounding land uses — from farm to forest to urban development, according to the study based on a USGS watershed model called SPARROW — SPAtially Referenced Regressions On Watershed attributes. Results of the SPARROW model are under review and yet to be compared with previous models, including Visualizing Ecosystem Land Management Assessments (VELMA) developed by the Environmental Protection Agency and the Hydrological Simulation Program — Fortran (HSPF), a separate USGS model. See also Puget Sound Integrated Modeling Framework.

Of the total nitrogen reaching Puget Sound from 19 major watersheds, more than half came from four river systems: the Nooksack, Snohomish, Cedar-Sammamish and Duwamish-Green. Each of those watersheds contribute about the same amount of nitrogen — around 14 percent of the total — even though the size of the drainage areas is much different. Snohomish is the largest area with 4,836 acres, followed by Nooksack, 3,351; Cedar-Sammamish, 1,688; and Duwamish-Green, 1,361.

Within those four watersheds, the sources of nitrogen are quite different. Nitrogen in the Cedar-Sammamish and Duwamish-Green watersheds, which include urban areas, is dominated by effluent



Watershed inflows identified in the Puget Sound Nutrient Reduction Plan. (Click to enlarge.) Map: Washington Department of Ecology

from upstream sewage treatment plants. The Nooksack, a largely rural area including farms, shows heavy inputs from crop fertilizers, livestock and alder trees. The Snohomish, which includes forested areas, gets its nitrogen largely from alder trees and sewage-treatment plants.

The watershed with the greatest drainage area, the Skagit-Samish with 8,861 acres, comes in fifth in the amount of nitrogen released into Puget Sound. Because of large, forested areas, major nitrogen sources include alder trees and the atmospheric deposition of nitrogen-containing particles.

Nitrogen from alder trees was a major source in most of the 19 watersheds, as alder trees have become more common today than in prehistoric times. Such changes were factored into a "reference scenario" to consider changes from prehistoric times.

"A reference scenario was developed to provide an estimate of the pre-industrial local and regional loads, which indicated that the largest increases in (total nitrogen) yield from historical to present were from the Cedar and Green Rivers as well as Chambers Creek," the report says. Historic modeling could help in developing strategies for reducing nitrogen from various sources.

Septic systems were the largest source of nitrogen coming off the Kitsap Peninsula and the Deschutes and Kennedy-Goldsborough watersheds in South Puget Sound.

The model also calculates phosphorus releases for the various watersheds, because phosphorus tends to stimulate algae growth in freshwater, as nitrogen does in saltwater. Algae coming out of the streams may add to the organic load in the marine waters, contributing to low-oxygen conditions.

Watersheds contributing the greatest phosphorus load to Puget Sound are, in order, the Snohomish, Skagit-Samish, Cedar-Sammamish and Duwamish-Green.

The SPARROW model will be useful in predicting the success of various nitrogen-reduction actions in the watersheds, according to authors of the study. Actions that reduce the amount of nitrogen coming into Puget Sound at certain times of the year, particularly summer and fall, could improve oxygen levels during critical periods.

"The seasonal mass balance representation of streams from headwaters to marine-water discharge points by source is important information to support Ecology's nutrient reduction plan," the report states. "Certainly, there are limitations with process representation and simulation accuracy, but the modeling approach directly provided real, interpretable values… Although model uncertainty can be high when zoomed into unique reaches (mean error 50% nitrogen to 72% phosphorus), an ability to quantify uncertainty in space and time is a strength."

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To reduce the flow of nitrogen into Puget Sound, action will be needed upstream in the watersheds, experts say. Protecting vegetation along streams is a partial solution. Treatment plants, agriculture, urban stormwater and alder trees contribute to the problem. // Photo: Port of Tacoma

WATER QUALITY

Low oxygen challenge, part 4: Many actions may be needed to improve Puget Sound waters

By Christopher Dunagan

Published June 12, 2025

Comments Closed

A grand plan to reduce human sources of nitrogen in Puget Sound started coming into focus in 2019 when the issue of regulations reached a decisive point.

After years of study and advances in computer modeling, experts at the Washington Department of Ecology were beginning to see what it would take to reduce human sources of nitrogen and improve oxygen conditions harming sea life. But key questions remained:

How would the state agency go about getting sewage-treatment plants to reduce their nitrogen releases, and what could anyone do to address the multitude of upstream sources of nitrogen washing off the land?

The answers have come with some resistance, scientific skirmishes and legal entanglements — and many issues remain unresolved today. For example, uncertainty surrounds new permits for sewage-treatment plants because of recent court rulings. Meanwhile, today, Ecology released its long-awaited plan for reducing nitrogen coming into Puget Sound from both point and nonpoint sources.

Nutrient general permit

In January 2020, Ecology announced that it would develop a "nutrient general permit" for all sewage systems discharging directly into Puget Sound. The new permit would address nitrogen and would be in addition to existing individual permits that set limits on other forms of pollution. The general permit would require monitoring of nitrogen discharges, planning efforts to reduce nitrogen releases, and eventually numeric limits for nitrogen in effluent.

The nutrient general permit, now in abeyance, was designed to cover sewage-treatment plants on Puget Sound, including Bremerton's Westside Wastewater Treatment Plant. // Photo: Washington Department of Ecology

Leading up to the decision, Ecology received mixed support for the idea of a general permit. Treatment plant operators — including cities, counties and sewer districts — were generally skeptical and expressed concerns about complying with two major permits. They wanted to make sure that any decisions would be based on solid science and allow time for implementation. Environmental groups and many individuals strongly supported the general permit — or practically any measures that would bring quick action.

After deciding to create a general permit, Ecology called together experts and formed the Nutrient General Permit Advisory Committee to help draft the parameters of the new permit. Individuals affiliated with wastewater facilities, environmental groups, state and federal agencies and a tribal utility were among the members working together through much of 2020. Their recommendations, issued in October that year, were far from unanimous.

While most everyone agreed that planning should take place at the local level, differences of opinion developed between representatives of the environmental community and officials managing sewer utilities. The greatest divide related to placing numeric limits on nitrogen releases and on a schedule for planning, engineering and equipment upgrades to meet stricter standards, whatever they might be.

There was some agreement that "optimization," — making relatively minor changes to current facilities — could help control nitrogen without the expense of full-blown nitrogen-removal systems. But federal and state officials said optimization alone would not be enough to meet Puget Sound's water-quality standards, based on outputs from computer modeling.

On Dec. 1, 2021, following two public comment periods, Ecology approved the general permit, which divides 58 treatment plants into three categories, dominant, moderate and small nitrogen dischargers. Together, the dominant dischargers release more than 99 percent of the total nitrogen from treatment plants, and they would be asked to do the most.

In the beginning, the general permit allows the plants to maintain their current nitrogen releases with careful monitoring as they optimize their existing facilities. The permit also includes "nutrient action levels" that would trigger further reduction efforts when nitrogen releases exceed their current levels by specific amounts.

Legal entanglements

Within a month of permit approval, eight sewage-treatment plant owners filed appeals with the state Pollution Control Hearings Board, which consolidated the appeals into one case. Plaintiffs included King and Pierce counties; the cities of Tacoma, Everett, Bremerton and Edmonds; and the Alderwood and Birch Bay sewer districts. These entities argued that the general permit is unlawful because treatment systems already have individual permits to govern their discharges, and the law does not allow a general permit to override an individual permit.

On the opposite side of the issue, Puget Soundkeeper Alliance, Washington Environmental Council (now Washington Conservation Action) and the Suquamish Tribe also filed appeals, saying the general permit did not go far enough or fast enough in reducing nitrogen going into Puget Sound.

If things weren't complicated enough, another lawsuit filed by the city of Tacoma was making its way through the courts. Tacoma officials argued that Ecology had not followed proper procedures in creating a new rule regarding nutrient limits. This took place at an earlier time, before the general permit came into play, and Ecology insisted that it had not created any new rules at that time.

The Tacoma case, joined by other sewer utilities, focused on a letter issued by Ecology when it turned down a petition from Northwest Environmental Advocates asking Ecology to require nitrogen-removing equipment at all treatment plants in Puget Sound. NWEA cited state law that requires the use of "all known, available and reasonable technology (AKART)." The organization said advance treatment capable of removing nitrogen — so-called tertiary treatment — was "known, available and reasonable" and should be used everywhere. Ecology's letter said that AKART does not apply to the current situation, because tertiary treatment is not reasonable, given the high costs and lack of evidence that high-level treatment is needed everywhere throughout Puget Sound. (This issue was covered in part 2 of this series.)

In turning down the AKART petition, the letter noted that Ecology was taking "alternative measures" to address the low-oxygen problem — including setting nutrient limits at existing levels and requiring treatment plants to plan for further decreases in nitrogen. Tacoma's attorneys argued that such commitments without a public process amounted to unlawful rulemaking. As such, Ecology should be prevented from limiting nitrogen levels until going through proper procedures, according to the lawsuit.

The Suquamish and Squaxin Island tribes filed a brief supporting Ecology and stressing that their treaties with the federal government establish legal rights to harvest fish and shellfish. Such rights, they said, are diminished by poor water quality and delays in addressing the problem. Washington Environmental Council took part in that brief.

The case worked its way up to the State Supreme Court, which eventually ruled last year (PDF) that Ecology's letter was not a formal commitment to limiting nitrogen levels, so it did not amount to rulemaking. Although the parties had agreed that monitoring and planning should move forward under the general permit, the Tacoma lawsuit effectively halted the appeals of the general permit for two years.

Last December, the Pollution Control Hearings Board restarted the appeal process for the general permit. Based on an extensive review and citations of state law, the board ruled (PDF) that Ecology cannot require a general permit if a sewage-treatment facility already has an individual permit for controlling pollution. The general permit could go forward as written, however, provided it becomes voluntary on the part of sewer utilities.

Ecology chose not to appeal the matter to the courts. Instead, the agency decided to keep the general permit for facilities voluntarily choosing to take advantage of the permit's special "flexibility" and "regional approach" to addressing the nitrogen problem. For those entities that choose not to opt in to the general permit, Ecology intends to add new nitrogen-related requirements to existing individual permits, including possible administrative orders to require ongoing monitoring and evaluations, such as those under the general permit. See letter to permittees (PDF).

"We don't know how many people will opt in, but we think it is important to keep the regional approach on the table," said Vince McGowan, manager of Ecology's Water Quality Program at the time.

For one thing, flexibility in the general permit could allow "nutrient trading" — the idea that greater nitrogen reduction at one treatment plant could offset less reduction at another plant, while still meeting water-quality goals, he said. This market-based approach offers a strong incentive to shift costs and save money. This could happen if upgrading an old plant is unreasonable or when a new plant could be efficiently expanded beyond its immediate need.

In its ruling, the Pollution Control Hearings Board said if Ecology truly believes that two permits should be mandated, the Legislature could change the state law. Ecology officials say they have not decided whether they will ask the Legislature for such a change.

Costs and financial challenges

One of the big issues looming over the entire planning effort is the significant costs of adding entirely new treatment processes to already complex facilities designed to remove organic materials from sewage effluent.

Everybody wants to know what nitrogen removal will cost overall and how it will affect sewer bills. Answers about costs vary greatly, depending on the levels of nitrogen removal and the equipment required to meet water-quality goals at a specific location, as predicted by computer models.

In 2023, Susan Burke, an economics professor at Western Washington University, worked with other researchers to examine questions of cost and affordability to Puget Sound sewer customers who will ultimately pay some or all the costs of nitrogen reduction.

"Capital costs associated with adding advanced nutrient removal technologies to all the municipal wastewater treatment plants subject to the Puget Sound Nutrient General Permit are likely to exceed $2 billion, based on a preliminary economic evaluation of potential nutrient limits by Ecology and Tetra Tech (2011) escalated to 2022 dollars," states the "Puget Sound Wastewater Service Affordability Analysis."

The report acknowledges that such estimates are "very low," based on newer information, but they provide a starting point for discussions. In fact, some officials contend the ultimate costs may be many times higher than the range suggested by Tetra Tech in its 2011 report.

The Burke study analyzes the effect of higher sewer rates on 80 utilities around Puget Sound that could be affected by the cost of new nitrogen-removal equipment and ongoing operating costs, including increased electrical consumption.

"Current monthly sewer bills range from $27 to $161," the report states. Changes anticipated under the Puget Sound Nutrient General Permit (PSNGP) could bring monthly sewer bills to between $44 and $196, "depending on the utility and the nutrient-reduction scenario."

Considering a family's ability to pay higher sewer bills, the study concluded that affordability could be an issue for many households in the lowest-income group, which is 20 percent of the population. This is described as the lowest quintile income, or LQI. Future bills could average about 4.4 percent of household income in that group, or just under half of what those families spend on food, based on national statistics.

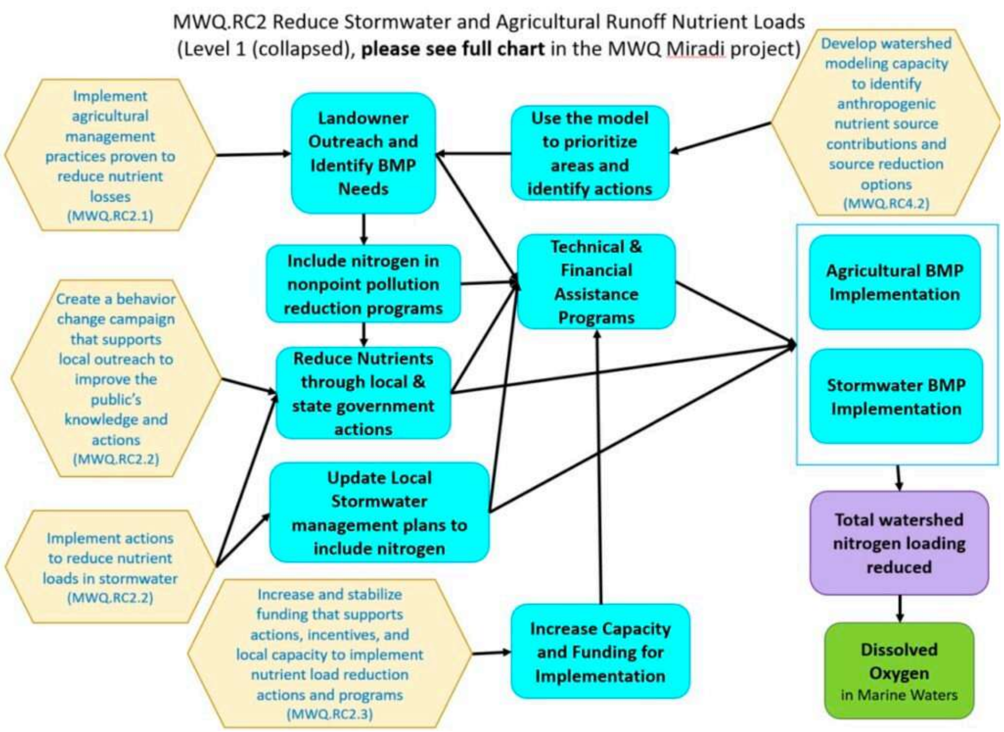
"Our findings suggest that currently only three Puget Sound utilities' sewer rates result in sewer bills less than 2.0 percent of LQI," the report states. "PSNGP-adjusted rates resulted in values ranging between 2.64 percent of LQI and 12.76 percent of LQI. These relatively high values indicate that sewer bills exacerbate the already regressive nature of Washington state's tax structure."

Grants and loans to sewer utilities could help reduce the overall costs borne by ratepayers, the report says, and data about the number of low-income sewer customers in specific areas could help direct those dollars to families with the greatest need. A more-direct effect would be a "low-income assistance program to aid those with the greatest need." Burke is conducting another study looking at a specific type of low-income assistance program, this one under contract with the Washington State Department of Health.

Reducing nitrogen upstream

Computer modeling and ongoing discussions among experts have concluded that, beyond improvements to sewage-treatment plants, major reductions in nitrogen must also occur upstream across the landscape to improve dissolved oxygen conditions in Puget Sound.

As described in part 3 of this series, nitrogen delivered to Puget Sound in major rivers originate from a variety of sources as unique as the surrounding land uses. While computer models help establish nitrogen-reduction goals, they don't offer prescriptions for accomplishing those goals. Reducing such diverse, nonpoint sources will require a wide-ranging strategy that accounts for the diversity of sources, as described in the "Draft Implementation Strategy to Improve and Protect Puget Sound Marine Water Quality and Dissolved Oxygen."



"Results chain" showing actions to reduce nitrogen from urban stormwater and agricultural operations. (Click to enlarge.) Source: Puget Sound Marine Water Quality Implementation Strategy

"Based on the available science and modeling on nitrogen in Puget Sound, human nitrogen source reductions are needed from both point and nonpoint sources in nearly every Puget Sound watershed to improve the DO indicator and meet water quality standards," states the draft implementation strategy released in February under the purview of the Puget Sound Partnership, the state agency leading Puget Sound recovery.

The strategy, developed by specialized teams including more than 40 experts, was designed to help the region reduce nitrogen and thereby improve the health of Puget Sound. The best suggestions to emerge after further planning are expected to be incorporated into the Puget Sound Action Agenda for prioritized funding.

In addition to the implementation strategy, information on reducing upstream sources of nitrogen is provided in Ecology's "Water Quality Management Plan to Control Nonpoint Sources of Pollution." The plan, first adopted in 2015, is currently undergoing revisions, and public comments will be taken until Aug. 29.

Some of the specific ideas for watersheds, covered in these and other documents:

Pollution Identification and Correction (PIC) programs: Long used by some jurisdictions to track down sources of bacterial pollution, PIC programs could be employed to locate the most significant sources of nitrogen in a watershed. Water-quality inspectors typically start at one location in a stream and work their way upstream, taking water samples to identify tributaries delivering the most pollution, then moving farther upstream in search of the source or sources.

Agricultural runoff, primarily crop fertilizers and livestock wastes: The federal Clean Water Act does not address agricultural pollution, but Washington state law prohibits the discharge of any materials that contribute to pollution. "Best management practices," or BMPs, have been designed to help farmers apply appropriate amounts of fertilizer and to reduce runoff from pastures, livestock-confinement areas and manure storage. Local conservation districts often provide advice to farmers, and grants may be available to help with the expenses of carrying out BMPs and other voluntary actions.

Urban stormwater runoff: Nitrogen from lawn fertilizers, pet wastes, wild animals, sewage spills and other sources may wash off the land and into nearby streams, eventually reaching Puget Sound. Methods of containing and infiltrating rainwater into the ground can help keep surface flows from picking up pollution. Commercial stormwater permits may include controls to reduce pollution leaving a property. Municipal stormwater permits, which address runoff from streets and other hard surfaces, may include requirements for source control, water treatment, system maintenance, public education and pollutant limitations. New innovations for onsite nitrogen removal may be required.

Forestry practices: Removal of trees and vegetation along streams can lead to increased water temperatures and greater sedimentation. Warmer waters have less oxygen-carrying capacity, and sedimentation can add nitrogen, phosphorus and organic materials that can reduce oxygen levels. Red alder trees, one of the first species to colonize disturbed areas, can contribute to increased nitrogen, because their roots play host to bacteria that fix nitrogen from the air and release it into the soil. Managed forests may include chemical fertilizers or biosolids from sewage-treatment plants. Maintaining and adding trees to stream buffers have been shown to improve temperatures and reduce nitrogen and other pollutants. Specific strategies for reducing nitrogen from alder trees are under discussion.

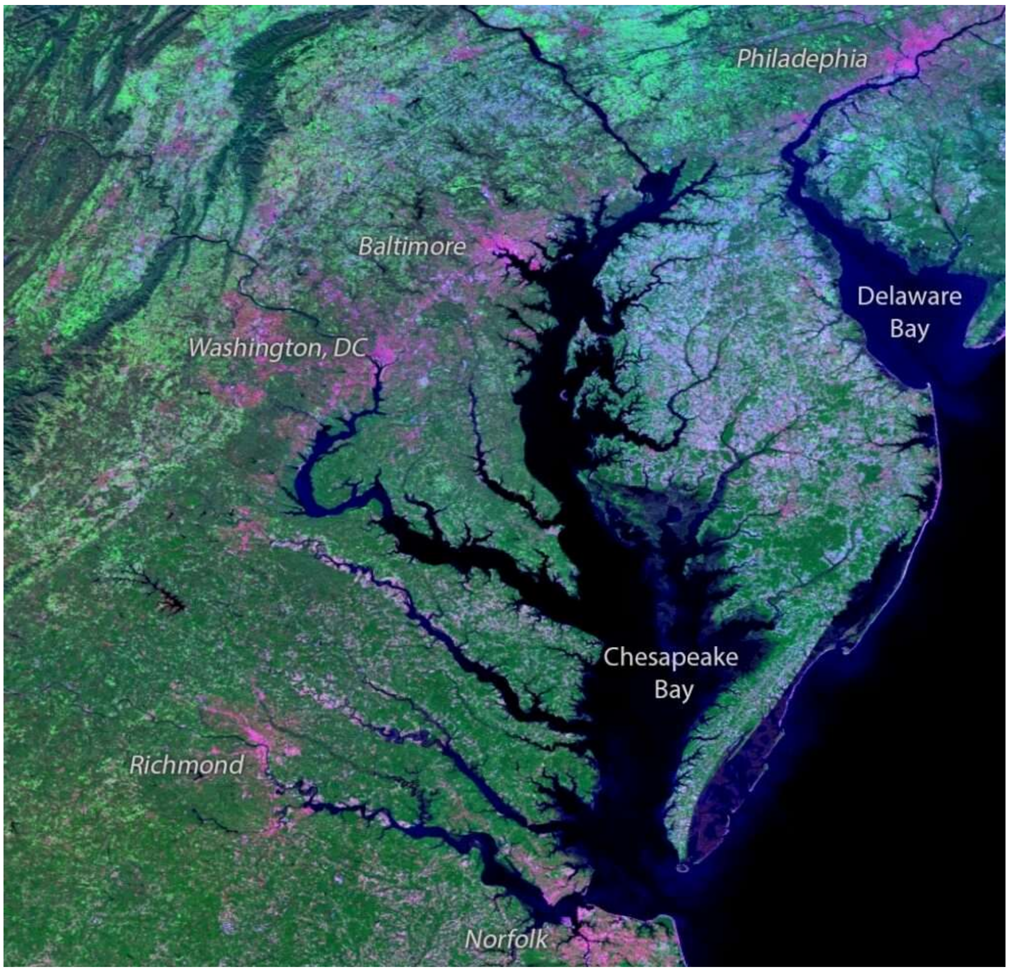
Natural nitrogen attenuation: Nitrogen- or phosphate-laden waters that flow through vegetation can reduce their nutrient loads by effectively fertilizing the plants. The vegetation can be part of a natural area or be incorporated into an artificial stormwater system. Maintaining natural vegetation and wetlands can reduce nutrient loads. Artificial systems often require regular maintenance to remove built-up sediment and excessive plant growth.

Septic systems: In areas without sewers, septic systems are designed to separate solids from liquids and discharge nitrogen-containing effluent into adjoining drainfields. Malfunctioning systems may release excess nitrogen into surface water or groundwater. Although functioning septic systems can theoretically release nitrogen into local waterways, studies have shown that properly maintained systems are not a significant problem. State regulations require regular septic inspections to ensure proper functioning, although enforcement varies among local health jurisdictions.

Challenges to restoration

Controlling upstream sources of nitrogen can be challenging, depending on the source, as we know from experiences elsewhere in the country and across the globe. Overall goals for the east side of Puget Sound may include more than a 60 percent reduction in nitrogen loads, according to recent information from Ecology.

Nitrogen coming into Puget Sound with the rivers consists of a large variety of upstream sources with amounts unique to each river: sewage treatment plants, agricultural operations, urban runoff, alder trees and more. Taken together for all of Puget Sound, sewage treatment plants account for more than a third of the total nitrogen coming into Puget Sound from the watersheds, followed by alder trees with about 15 percent. Farm operations, urban runoff, atmospheric deposition and septic systems are each under 10 percent of the total — although, again, sources in one watershed vary significantly from any other watershed. These numbers were calculated using modeling data reported by Noah Schmadel and colleagues at the U.S. Geological Survey.



While different from Puget Sound in many ways, Chesapeake Bay on the East Coast may offer some lessons in the effort to reduce low-oxygen problems. Satellite photo: NOAA's National Environmental Satellite, Data and Information Service

While conditions are significantly different in Chesapeake Bay on the East Coast, a 40-year struggle to reduce low-oxygen problems in the bay may offer lessons for Puget Sound. Nitrogen inputs to the bay have been reduced since 1985 in the face of a rapidly growing population, yet the region remains far short of its goals to restore the waterway, according to a 2023 study by the Scientific and Technical Advisory Committee (PDF),, made up of 10 experts from five states, one from the District of Columbia, six from the federal government, and 21 at-large members, mostly from universities and research institutions.

The report says nitrogen from nonpoint sources was reduced by 29 million pounds from 1985 to 2022, yet that is just 36 percent of the long-range goal of 80 million pounds.

"Achieving nonpoint source reductions has proven more challenging than anticipated when the first nutrient reductions targets were established in the early 1990s," the report says. "The challenge is twofold. First, voluntary nonpoint source programs struggle to produce the scale of behavioral change and practice adoption necessary to achieve water quality goals — an implementation gap. Second, the nonpoint source programs and practices implemented may not be as effective as expected at reducing nonpoint source pollution —a response gap."

Despite increases in population, nitrogen discharges from sewage-treatment plants were reduced by about 50 percent from 1985 to 2017, thanks mainly to advances in treatment technology, according to a U.S. Geological Survey report titled "Nitrogen in the Chesapeake Bay Watershed: A Century of Change, 1950–2050." While nitrogen reduction will continue, officials say, dramatic reductions from treatment plants and other point sources are unlikely.

"Although implementation of urban management practices to reduce nonpoint sources of nitrogen (such as stormwater) will continue with new development, the potential nutrient reductions of those practices in the future are uncertain," the report says.

For decades, agriculture has played a prominent role in the low-oxygen problem in the Chesapeake, releasing more nitrogen and phosphorus than any other source. State and local governments have invested heavily in programs to reduce nitrogen from farms, but improvements have been slow, officials say.

Much of the agriculture in the Chesapeake watershed lies on the fertile coastal plain on the eastern shore of the bay and in southeastern Pennsylvania, the report notes. “Unfortunately, many of these regions also tend to have geologic settings (for example, sand/gravel, carbonate aquifers) that facilitate nutrient transport to groundwater and eventually streams.”

Reductions in nitrogen were attributed largely to conservation practices, such farmland retirement, animal waste management systems, and conservation tillage, but also bioretention by ponds and wetlands, the report says.

The ecological response to these efforts, such as water quality in the bay, appear to be delayed, as it takes time for existing nitrogen to work its way through the system, according to the report.

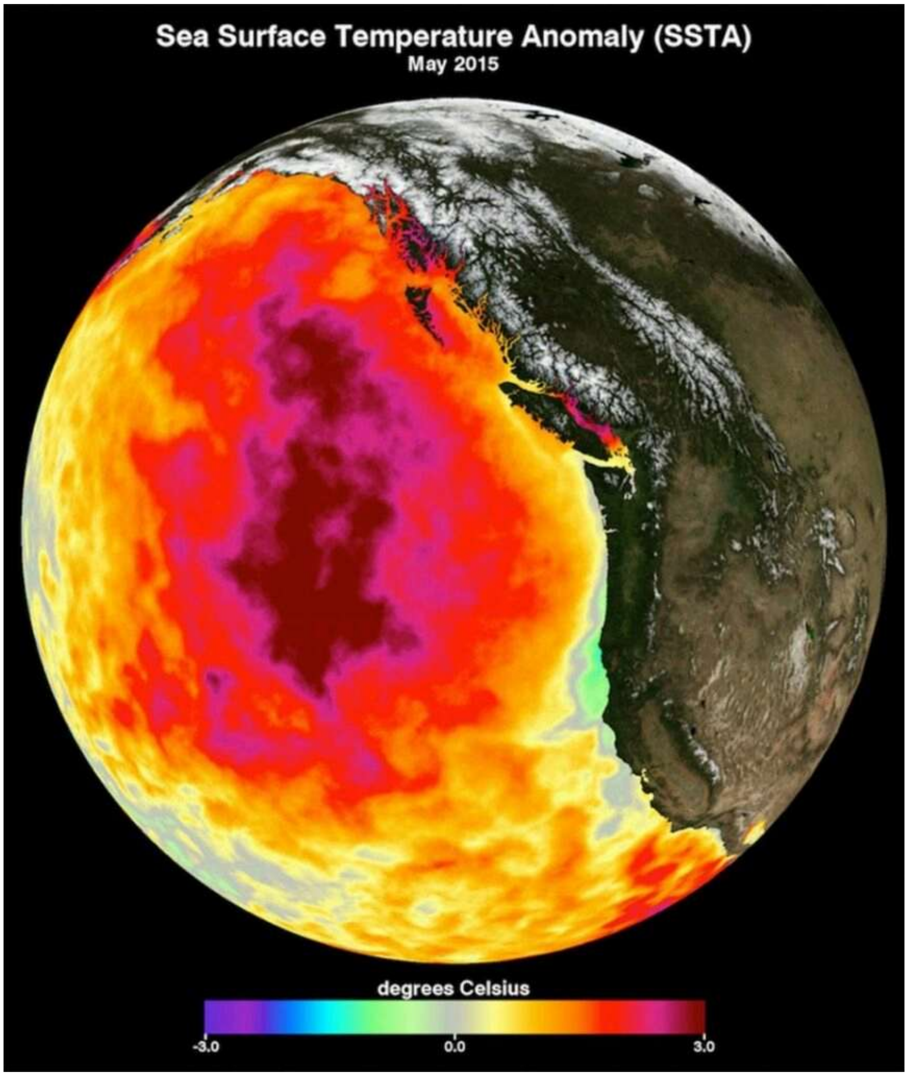
“Can the Chesapeake Bay, and similar estuary communities around the world, find ways to flourish and live sustainably, while at the same time managing nutrients that maintain healthy terrestrial and aquatic ecosystems?” the authors ask. “This” they add, “will be a challenge for the future.”

Climate change and future conditions

Climate change is expected to reduce dissolved oxygen levels in some parts of Puget Sound as a result of multiple factors, including warming waters, alterations in streamflow and potentially greater amounts of nitrogen coming in from the Pacific Ocean, according to experts.

Depending on the location, Puget Sound waters have increased by 0.8 to 1.6 degrees F between 1950 and 2009, according to localized studies, and this trend is likely to continue or even accelerate as a result of climate change. Warmer water cannot hold as much oxygen as cooler water, so this factor alone could increase stresses on marine life.

Puget Sound also is influenced by incoming flows from the Pacific Ocean, where oxygen levels declined roughly 22 percent from 1956 to 2006 at Ocean Station Papa, a weather buoy about 640 miles off the coast of British Columbia. Similar declines have been measured in the Strait of Georgia north of Puget Sound, primarily from coastal



By May 2015, a huge mass of warm water had accumulated off the West Coast of North America, with temperatures up to 3 degrees C (5 degrees F) warmer than average. Such events, which can disrupt the food web, are expected to occur more frequently as global warming drives climate change. // Data image: NASA Earth Data

upwelling of low oxygen water from the deep. Consistent trends have been measured in Washington's Strait of Juan de Fuca, Admiralty Inlet and Hood Canal, suggesting that oceanic conditions could add to future low-oxygen problems in Puget Sound. See "State of Knowledge: Climate Change in Puget Sound."

Climate change is expected to continue an ongoing shift to earlier-in-the-year snowmelt in the mountains, with higher winter streamflows and lower summer streamflows expected over time. These alterations in flow patterns affect both stratification (layering, with freshwater typically on top) and circulation, two major factors that help determine oxygen levels. But neither the precise conditions nor the effects on oxygen levels can be predicted, according to the Climate Impacts Group, a University of Washington program that produced the State of Knowledge report.

"Stratification inhibits mixing of deeper, nutrient-rich water up into the zone where there is enough light for photosynthetic organisms (e.g. algae) to grow and favors the formation of low-oxygen zones at depth," the report states. "In winter, this is not a major limitation, since the main impediment to biological productivity is a lack of sunlight. During the growing season, in contrast, water column stratification can potentially limit the supply of nutrients to phytoplankton and the supply of oxygen to deeper waters."

A 2014 Ecology report, titled "Puget Sound and Straits Dissolved Oxygen Assessment," analyzes impacts of human nitrogen sources along with climate change to the year 2070.

"Stratification overall appears to be strengthening, which could contribute to the downward trend in oxygen," states the report. "The change in stratification from both salinity and temperature changes would also affect circulation. This assessment focuses on changes in DO and nitrogen alone, but additional analyses are needed that also incorporate changes in temperature and salinity at the ocean boundary to assess other potential effects of climate change."

The biggest factors in determining future oxygen levels in Puget Sound are likely to be population growth, land use change and the relative success of strategies to reduce inputs of nitrogen from a variety of human sources, says the report.

"The change in flow regime, coupled with future land-cover-based concentrations, would alter the magnitude and timing of nutrient load delivery from watershed inflows," the report says. "It is possible that future freshwater delivery could partly offset decreases in dissolved oxygen resulting from higher nitrogen loads. Additional investigation is warranted to understand these relationships."

A decade ago, dozens of researchers investigated and reported on an unusual marine heat wave that brought warm waters from the ocean into Puget Sound beginning in 2014 and extending through 2016. The rare water condition nicknamed "the Blob," produced temperatures up to 4 degrees F higher in some places in Puget

Sound. The phenomenon was not good for most sea life, but it offered scientists a fascinating preview of what could happen more frequently in the future, as more heat waves have been reported across the globe.

The warm-water mass, created in the ocean during a period of intense sun and quiet weather conditions, grew large as it moved toward the coast. Scientists reported that plankton blooms started earlier and grew unusually large by the first summer. Plankton were not the typical assortment of species, which helped to distort the food web. Toxic plankton caused the closure of commercial and recreational shellfish beds.

Warm-water fish showed up in large numbers off the coast, and some came into Puget Sound. Anchovy populations seemed to flourish in South Sound. Jellyfish appeared in large numbers and scooped up forage fish, reducing the food supply for other species. Salmon altered their migration patterns. A large number of birds and some marine mammals were sickened or killed by toxic algae.

The warm water decreased oxygen levels in Puget Sound while increasing respiration rates among many species. In Southern Hood Canal, oxygen levels were practically zero in deep water. The Blob began to subside in 2016, and its effects diminished, but repercussions were long-lasting.

Many scientists, caught by surprise by the 2014-16 event, say they are prepared to measure environmental effects from beginning to end when the next big heat wave appears.

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This article was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

The Series

Part 1: The debate over oxygen in Puget Sound

Part 2: Water-cleanup plans and the search for 'reasonable' actions

Part 3: Computer models spell out the extent of the water-quality problem.

Part 4: Many actions may be needed to improve Puget Sound waters

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Previous: Low oxygen challenge, part 3: Computer models spell out the extent of the water-quality problem

Up Next: August 4: Kelp & eelgrass risk assessment results workshop

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An extensive plankton bloom through Central Puget Sound impressed even longtime researchers with the Washington Department of Ecology. This aerial photo of the Noctiluca bloom was taken in June 2013 between Seattle and Bainbridge Island. The photo was featured in the monthly water-quality report from Ecology's Eyes Over Puget Sound program. // Photo: Washington Department of Ecology

WATER QUALITY, MODELING

The quest continues for a nutrient reduction plan

By Puget Sound Institute Published December 20, 2022 Comments Closed

The quest continues for a large-scale plan to reduce human sources of nitrogen and improve the health of Puget Sound. This article is part of the Puget Sound Institute's effort to explore the technical uncertainties related to the science of Puget Sound water quality. The project, jointly funded by King County and PSI, includes online workshops and discussions, along with informational blogs and articles.

By Christopher Dunagan

Human sources of nitrogen in Puget Sound have been blamed for increasing the intensity of algae blooms, lowering oxygen to critical levels, and impairing sea life. In response, officials with the Washington Department of Ecology are developing a Puget Sound Nutrient Reduction Plan to strategically reduce nitrogen in various places.

Ecology experts recognize that the Pacific Ocean is the greatest source of nitrogen to Puget Sound, but how much of that nitrogen contributes to low-oxygen conditions depends on many factors. Because oceanic nitrogen is practically beyond human control, much of the current focus is on the ever-increasing levels of nitrogen from human sources. See Ecology's Oxygen and Nutrients in Puget Sound.

According to Ecology estimates, about two-thirds of the human-induced nitrogen is coming from sewage-treatment plants perched along the shoreline. The rest comes from diverse sources such as septic systems, fertilizers from farms and urban landscapes, animal waste from livestock and pets, and atmospheric deposition from the burning of fossil fuels and organic materials. For planning purposes, these diverse sources of nitrogen are grouped as "watershed" sources, and they enter Puget Sound mostly via streams and stormwater outfalls.

Ecology has begun to address the discharges from sewage-treatment plants with the issuance of a "nutrient general permit" that requires operators to conduct studies, curb nitrogen releases at basically current levels, and eventually cut back on the amount of nitrogen going into Puget Sound.

In response, eight cities, counties, and other sewer operators (listed below) filed appeals to the state's Pollution Control Hearings Board. [Editor's note: King County, which is appealing the permit, is one of the Puget Sound Institute's funders.] A temporary out-of-court agreement has placed some of the permit requirements on hold until the board can decide whether the general permit is legal and necessary.

While stated reasons for the appeals vary among jurisdictions, the sewer operators broadly contend that the new general permit conflicts with federal permits already required of every sewage-treatment plant. Many argue that Ecology has failed to show how their individual operations contribute to the low-oxygen conditions, often mentioning the costs of planning and upgrades to their sewage-treatment plants without clear benefits.

As the eight sewer operators seek to overturn the nutrient general permit, two environmental groups and one tribal government contend that the permit does not go far enough to quickly accomplish corrective actions, considering that many areas of Puget Sound already fail to meet water-quality regulations.

In a joint appeal, the Washington Environmental Council and the Suquamish Tribe argue that loose timelines and other flaws in the permit will allow some treatment plant operators to increase, rather than decrease, nitrogen discharges over the next five years. Similarly, Puget Soundkeeper Alliance is pressing Ecology to establish enforceable limits on nitrogen discharges and to declare that nitrogen reductions can be accomplished with available treatment technology.

Meanwhile, Ecology continues to work on the overall plan to reduce nitrogen loads from all human sources, with a current focus on so-called watershed sources, including stormwater. Solutions involving upland areas may vary for different parts of Puget Sound, according to Dustin Bilhimer, who heads up Ecology's Nutrient Reduction Project. Some areas are more affected by agricultural runoff, while others have extensive discharges of urban stormwater.

Besides improving the ecological health of Puget Sound, the goal is to decrease the number of regulatory water-quality violations, which occur when the level of dissolved oxygen falls below a specific state standard. That standard varies for defined areas of Puget Sound — generally between 4 and 7 milligrams of oxygen per liter in saltwater, depending on the designated use and water-quality classification. Basic concepts are explained further in an Ecology fact sheet (PDF 110 kb) addressing freshwater issues.

Violations of dissolved-oxygen standards have been found so far in 194 designated areas within 46 bays, inlets and open-water sectors in Puget Sound, according to Ecology's Water Quality Assessment, sometimes called the 303(d) list of impaired waters. Another 290 areas in 45 inlets are on the list for low-oxygen problems, but more study is needed to determine regulatory violations.

These lists, prescribed by the Clean Water Act, may include some areas where low-oxygen conditions prevail because of natural conditions — where humans are not primarily to blame for oxygen levels below the numerical standard. Such areas would not be considered a violation and could be removed from the list if they meet so-called natural conditions criteria. At the moment, Ecology is rewriting its natural-conditions criteria for both oxygen and temperature in a formal rule-making process. The rewrite comes at the direction of the Environmental Protection Agency which has temporarily suspended the state's previous natural conditions criteria following a legal challenge.

Excess nitrogen is getting so much attention because nitrogen compounds are a key ingredient — along with sunlight — in the production of excess plankton. Large colonies of plankton eventually die and sink to the bottom, consuming available oxygen as they decay. See related stories: **"**Understanding the causes of low oxygen in Puget Sound" and "Tiny plankton play a mighty role in the health of Puget Sound."

As planning continues, the Puget Sound Nutrient Reduction Project is trying to identify the most significant sources of nitrogen resulting from human activities. The explicit goal is to identify actions that can lead to the highest level of compliance with the state's dissolved-oxygen standards.

Using the Salish Sea Model, experts are studying various scenarios that consider the combined effects of reducing nitrogen from sewage treatment plants and from various watershed sources. Key questions revolve around the locations where nitrogen comes into Puget Sound as well as areas most affected by low-oxygen problems. For example, does it make more sense to reduce smaller inputs of nitrogen close to problem areas or cut back on larger sources farther away?

Considering the multitude of problem areas and nitrogen sources, examining the various options becomes a major challenge, even with the help of computer modeling, according to Ecology's Bilhimer.

From work done so far, it appears that nitrogen-bearing waters readily move from one area of Puget Sound to another, undergoing changes along the way. These enriched waters may contribute to low-oxygen problems a fair distance from the original sources.

Bilhimer says one thing has become abundantly clear from model runs conducted last year: To meet the state's dissolved-oxygen standards in Puget Sound, large reductions of nitrogen are needed from both sewage treatment plants and human watershed sources. Looking to the future, increasing inputs of nitrogen caused by population growth may exacerbate the low-oxygen problems in some areas if actions are not taken, he said.

To improve estimates of nitrogen from watershed sources, new automated monitoring equipment is being installed to gather data on nitrogen levels at 15-minute intervals in eight rivers, rather than the 30-day intervals used for data collected in the past. The result should be better estimates of nitrogen coming from the rivers under various conditions.

This network of monitoring equipment is expected to be in operation by late spring next year. The first device is currently being installed in the Cedar River. Others will go into the Duwamish, Deschutes, Nisqually, Puyallup, Stillaguamish, Nooksack and Skagit rivers.

At the same time, surveys looking upriver in the watersheds will help determine actual sources of nitrogen and their relative contributions to the overall problem, as well as finding ways to address the sources.

To gain a better understanding of upstream sources of nitrogen, Ecology plans to employ a watershed model developed by the U.S. Geological Survey. The model provides a more sophisticated analysis of sources, from urban runoff to agricultural fertilizers to atmospheric deposition. Specifics about the timing and locations of nitrogen flowing into Puget Sound is then incorporated as inputs into the Salish Sea Model. The statistics-based watershed model is called Spatially Referenced Regression On Watershed Attributes, or SPARROW.

An entirely separate modeling project, announced last week, is expected to play a role in the discussion about the effects of nitrogen on the water quality of Puget Sound. In fact, those involved in this new project envision a scope well beyond nitrogen as part of the Puget Sound Integrated Modeling Framework, a new project led by PSI. The work involves coupling together at least five separate models that link data across the watershed. The project will incorporate physical conditions, biological changes and even human interactions within the Puget Sound ecosystem.

In the new project, watershed inputs to Puget Sound will be described using a model developed by the EPA called VELMA, which stands for Visualizing Ecosystem Land Management Assessments. Like SPARROW but with an analytical framework that divides the landscape into discrete segments, VELMA will provide its own estimates of nitrogen going into Puget Sound, estimates that can be used to run the Salish Sea model.

While two or more watershed models might sound like an added complication, being able to compare their outputs will only improve the modeling process and boost confidence in the results, according to Stefano Mazzilli, senior research scientist at PSI. If the separate models produce similar results, it is likely that the modelers are on the right track, he explained. If the results are very different, then modelers will need to figure out what may be wrong with one or more models.

“Having multiple models for estuarine or watershed processes is always beneficial,” Mazzilli said. “Models are built with different purposes, and it is important to recognize that some are better at providing information for particular decisions.”

For example, some models may be better at dealing with rural versus urban areas, or addressing a multitude of environmental stressors, as in studies of toxic chemicals, he noted.

In any case, for a model to be useful to those making decisions about nitrogen, the model must accurately predict the results of actions that could be taken, Mazzilli said. Otherwise, decision-makers won’t know which options will produce the best results. Understanding and reducing uncertainties surrounding the effects of nitrogen and the results of potential actions is the goal a PSI project titled The Science of Puget Sound Water Quality.

As for Ecology's Puget Sound Nutrient Reduction Project, the effort is edging closer to a formal plan after five years of study. The plan will include recommendations for reducing nitrogen to improve the low-oxygen conditions in Puget Sound.

It is worth mentioning, said Bilhimer, that unrelated ecosystem-restoration projects are having their own beneficial effects. For example, efforts to reduce bacterial pollution and reopen shellfish beds — such as in Samish Bay in northern Puget Sound — have also reduced nitrogen levels in the area. Likewise, shoreline restoration projects — such as in Nisqually Estuary in South Puget Sound — have improved natural functions, helping to reduce nitrogen loads, he added.

Further studies of nitrogen sources are planned through next year, according to the latest schedule released Dec. 7 during a meeting of advisers — the so-called Puget Sound Nutrient Forum. Discussions about problem areas and potential solutions will be taken up in 2024, with a special focus on a draft plan to reduce nitrogen from various sources. Formal adoption of the plan could come in 2025.

Parties filing appeals of the Washington Department of Ecology's new nutrient general permit: Puget Soundkeeper Alliance, King County, City of Tacoma, Washington Environmental Council, Suquamish Tribe, City of Everett, City of Bremerton, Birch Bay Water and Sewer District, Alderwood Water and Wastewater District, Pierce County, and City of Edmonds.

Previous: *A network of computer models is predicting the future of Puget Sound*

Up Next: *Remembering Ken Balcomb and his extraordinary life with killer whales*

Other posts in this series about Water quality, Puget Sound, Nitrogen, Low-oxygen problems, Water-quality planning:

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Ecology, EPA now under the gun to adopt new water quality criteria for aquatic creatures

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Review of 2025 Salish Sea Model Updates and Application to Nutrient Management

August 22, 2025

Contributing Authors: Joel Baker, Marielle Kanojia, and Stefano Mazzilli

Funding: This Technical Memorandum was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

Executive Summary

The Puget Sound water quality management community is navigating complex decisions on how best to manage nitrogen to maintain healthy habitats. Too much nitrogen from human activities can potentially increase algal blooms, decrease dissolved oxygen, add to ocean acidification, and cause other changes that may harm marine life. The cumulative effect of multiple stressors - including those resulting from climate change and the presence of toxic contaminants - make it challenging to find the best solution for the range of water quality problems that affect marine life. Regulation is currently focused on the impacts that nitrogen from human sources has on low dissolved oxygen in Puget Sound. In recent years, Washington State has relied on its version of the Salish Sea Model[1]—a coupled hydrodynamic and biogeochemical model—to evaluate regulatory compliance and assess the effectiveness of various nutrient reduction strategies. Model results released in June 2025, underpin the Draft Puget Sound Nutrient Reduction Plan (Reiman, 2025), an advanced restoration plan that establishes watershed and marine point source nitrogen loading targets designed to meet Washington State's marine dissolved oxygen water quality standards throughout Puget Sound. The State ran several scenarios to explore the potential impact of reducing nutrients from marine point sources and watersheds. The targets were ultimately derived from the Opt2_8 modeling scenario described in Figueroa-Kaminsky et al. (2025), which reflects a modified method for predicting non-compliance, updated nutrient loads, and refinements to the model structure and skill assessment relative to Ahmed et al. (2019) and Ahmed et al. (2021).

For the past several years, the University of Washington Puget Sound Institute has played a central role in advancing the science and modeling that underpin nutrient management decisions in the region. This work has included hosting a series of workshops to build consensus and accelerate scientific progress, running the Salish Sea Model to test additional nutrient reduction scenarios, convening an international Model Evaluation Group to assess model performance, and leading cutting-edge research on species-specific risks that integrates temperature-dependent oxygen supply and demand. In 2023-2024, the Puget Sound Institute convened global experts to advise on how to improve the application of the Salish Sea Model to inform recovery goals and nutrient management decisions in Puget Sound. The Model Evaluation Group included scientists who have led pioneering research and advised regional managers on the application of modeling and monitoring in nutrient management programs in other regions, like the Baltic and Chesapeake Bay. These experts – Bill Dennison, Jacob Carstensen, Jeremy Testa, Kevin Farley, and Peter Vanrolleghem – shared several recommendations to improve confidence in applying the Salish Sea Model to support Puget Sound's recovery goals and regulation (Mazzilli et al., 2024). In Figueroa-Kaminsky et al. (2025), the State made significant advances addressing the prior Model Evaluation Group's recommendations.

In this technical memorandum, Puget Sound Institute reviewed Figueroa-Kaminsky et al. (2025) to evaluate how the model updates and analyses influence the proposed nutrient targets. Key takeaways include:

1. **Shift to total nitrogen targets further tightens limits** | The Draft Puget Sound Nutrient Reduction Plan shifted to using total nitrogen (TN) for targets rather than total inorganic nitrogen or dissolved inorganic nitrogen (TIN/DIN). If the DIN-based scenario reductions are applied directly

[1] There are several versions of the Salish Sea Model; see the Salish Sea Modeling Center for additional context. Throughout this technical memorandum, the Salish Sea Model refers to the version used by the State and reflected in Figueroa-Kaminsky et al. (2025) unless otherwise noted.

as TN in permits, the resulting limits would be stricter than the modeled scenarios by capping all nitrogen forms.

2. Proposed watershed reductions face major feasibility challenges | Reducing nutrients from diffuse sources in watersheds is notoriously challenging because actions are often voluntary, require buy-in from thousands of independent landowners, and are frequently undermined by competing agricultural incentives that encourage fertilizer-intensive cropping practices. The proposed reductions range from 53 – 67% in most basins, which exceeds what has been achieved even in the best cases in Denmark and the Chesapeake Bay (Scientific and Technical Advisory Committee (STAC), 2023). Since 1990, Denmark has cut its nitrogen surplus by ~50%, but only through decades of strong political will and strict regulations on livestock, manure, and fertilizer use (Riemann et al., 2016). Implementing the proposed targets will also require a more sophisticated understanding of the watershed sources. Recent modeling by USGS SPARROW, in collaboration with the State, has taken strong initial steps by estimating seasonal loads from both marine point and watershed sources (Schmadel et al., 2025). A helpful next step would be to show watershed sources separately and aligned to the watershed boundaries in the State's Draft Puget Sound Nutrient Reduction Plan. This would allow managers to see how the nutrient sources line up with the watershed-specific targets set in the plan.

3. Model skill vs. regulatory precision is challenging | The State made thorough and thoughtful refinements to the model and analysis of model skill that advanced several of the Model Evaluation Group's recommendations (Mazzilli et al., 2024). While there are some opportunities for refinement, model skill may be reaching the point of diminishing returns. Although overall model performance improved modestly, errors in embayments remain several times higher than the 0.2 mg/L human use allowance. Additionally, the subtraction of two scenarios does not cancel uncertainty—especially since the reference condition cannot be validated. As a result, when compliance is determined by comparing existing and reference scenarios, the true level of uncertainty in the outcome is larger than the model statistics alone suggest and must be explicitly considered in regulatory applications. It seems unlikely that any model could reduce uncertainty to the point that it is lower than the current human use allowance of 0.2 mg/L.

4. Long-term planning depends on realistic future scenarios | In Ahmed et al. (2021), the State took an important first step by modeling 2040 wastewater loads based on population growth but did not account for climate-driven changes to river flows and ocean conditions, land use shifts, or potential management actions. Since nutrient targets will guide decisions for decades, it would be valuable to run a future scenario that incorporates climate change and land use. This would provide a more complete picture of how future conditions may influence Puget Sound's response to nutrient reductions, particularly given the central role of temperature in shaping oxygen availability for marine life.

Modeling informs nutrient management

Modeling informs water quality impairments

Washington uses both Salish Sea Model outputs and measured data to determine 303(d) listings of impaired water bodies. A specific location in Puget Sound is considered non-compliant on a specific date if:

1. **Measured oxygen levels fall below** either the numeric criteria (that ranges from 4 to 7 mg/L) or modeled estimates of natural conditions, whichever is lower

&

2. **Modeling shows that human activities reduce dissolved oxygen** by more than **0.2 mg/L or 10%** below natural conditions, whichever decrease is smaller

Some core model scenarios help assess the effects of human activity and non-compliance:

- **Existing conditions** represent estimated nutrient loads and hydrodynamics in a given year, like 2014.
- **Reference conditions** represent the maximum improvement in dissolved oxygen possible in Puget Sound. In these scenarios, the same hydrodynamics and climate as existing conditions are used, and the river and wastewater treatment plant nutrient loads are replaced with estimated loads before the adoption of modern land-use practices and population growth in Washington State.
- **Natural conditions** aim to reflect what the water quality in Puget Sound was like before substantial human influence, including the global impacts of a changing climate and oceans. Modeling natural conditions would require hindcasting the climate to pre-settlement and removing the influence of all anthropogenic nutrient loads, including those from Canada.

At this time, the Salish Sea Model's *reference condition* scenario only accounts for human impacts from local (i.e., Washington state) sources and does not fully meet the definition for *natural conditions* as outlined in the State's performance-based approach. For example, it does not remove the effects of climate-driven changes in ocean circulation, temperature, or atmospheric conditions. As a result, the model provides a strong foundation for evaluating local nutrient management actions but may not capture the full picture of global or external influences on dissolved oxygen in Puget Sound. Currently, non-local sources like Canada are not assigned targets in the Draft Puget Sound Nutrient Reduction Plan, which focuses specifically on pollution that originates within Washington State.

REFERENCE CONDITIONS

What is changed from existing conditions?

- Natural loads of nitrogen and carbon for Washington's wastewater treatment plants and rivers are estimated from observations in pristine watersheds. These represent a pre-anthropogenic or preindustrial nutrient loading.

What is kept the same?

- Nutrient inputs from:
  - Canadian sources, including the Fraser River
  - Washington's industrial treatment plants and those not under the general permit
  - Climate, hydrology, ocean, and all other boundary and forcing conditions

A unique reference condition is created for each year the model is run.

Modeling informs nutrient targets

The State also ran several scenarios to explore the potential impact of reducing nutrients from marine point sources and watersheds on dissolved oxygen levels and non-compliance. The days, area, and magnitude of non-compliance under existing conditions vary across the 2000, 2006, 2008, and

Explore the Results
Dig into the detailed results on the State's webmap.

2014 runs (Table 1). Due to computational constraints, though, the scenarios exploring the potential impact of reduced nutrient loads were only run for 2014.

Table 1. *Dissolved oxygen noncompliance under existing conditions for the years 2000, 2006, 2008, and 2014 for Washington waters of the Salish Sea. Table 15 from Figueroa-Kaminsky et al. (2025).*

Year	Total days of noncompliance	Total area of noncompliance (km^2)	Maximum magnitude of DO noncompliance (mg/L)
2000	74,156	477	-1.2
2006	136,367	621	-1.4
2008	70,060	465	-0.9
2014	80,279	467	-1.1

[a] Noncompliance excludes masked areas (e.g., Budd Inlet).

Refining watershed scenarios

In Figueroa-Kaminsky et al. (2025), the State simulated several scenarios that combined marine point source and watershed nutrient load reductions. Building on previous studies like Ahmed et al. (2019) and Ahmed et al. (2021), the State started by running several minor variations on watershed reductions in combination with setting wastewater plants' discharge to 3 mg/L, 5 mg/L, and 8 mg/L DIN in hot, warm, and cool months, respectively. All of the scenarios reduced anthropogenic watershed loads by 58-74% (Washington State Department of Ecology, 2025b, Figueroa-Kaminsky et al. 2025). The State selected H1_C as the optimal watershed scenario because "it resulted in similar levels of noncompliance as other initial scenarios without having to reduce anthropogenic loads in watersheds entering the Straits (i.e., with less effort)." Compared to the other watershed scenarios, H1_C had greater reductions in larger watersheds and those entering the Northern Bays, Main Basin, and South Sound. Non-compliance was persistent in small areas of several embayments, including Lynch Cove, Henderson Inlet, Carr Inlet, Sinclair Inlet, and Liberty Bay. Therefore, the State refined the watershed framework to reduce anthropogenic nutrients by 90% in streams near these embayments with persistent non-compliance. Sound-wide, the refined watershed framework reduces TN anthropogenic watershed loads by 61% (Figueroa-Kaminsky et al. 2025).

Refining marine point source scenarios

The State then combined the refined watershed framework with 10 additional alternatives for marine point source reductions. Marine point sources refer to the "NPDES permitted domestic wastewater treatment plants and industrial facilities located in Washington and discharging to Puget Sound" (Washington State Department of Ecology, 2025a). These scenarios represented small variations with anthropogenic marine point reductions ranging from 68 – 74% for TN (Washington State Department of Ecology, 2025b). The difference in outcomes between the scenarios was also minimal; the remaining non-compliant areas ranged from 0.8 to 2.5 km^2 in Sinclair and Henderson Inlet. Across all of these scenarios, the remaining noncompliant areas showed only minor differences from existing conditions, with maximum dissolved oxygen depletions of 0.3 mg/L relative to reference conditions. This is just above the human use allowance, indicating conditions are nearly compliant. Again, these results reflect the combined impact of both the watershed and marine point source reductions, which, in total, ranged from a 65 – 69% reduction in anthropogenic TN loads across the scenarios. These scenarios also found that the following had a negligible, incremental impact on non-compliance (i.e., $\leq$ 1 day):

- Capping very small wastewater treatment plants at 2014 existing loads

- Capping plants discharging to basins that are either well flushed or have small wastewater treatment plant loads at 2014 existing loads – specifically Admiralty Inlet, Hood Canal, the Strait of Juan de Fuca, and the Strait of Georgia.
- Reducing the discharge for dominant plants in the Main Basin from 5 mg/L to 3 mg/L from April – June and October.

Given where non-compliance persisted, another scenario explored the potential impact of increasing treatment at the three plants discharging to Sinclair Inlet (i.e., Bainbridge Kitsap Co 7, Bremerton, and Port Orchard) to a year-round limit of 3 mg/L, instead of the seasonal limits of 3 mg/L in hot months, 5 mg/L in warm months, and 8 mg/L in cool months. The model predicted that this scenario would further reduce the area not meeting dissolved oxygen standards by 1.57 km² and decrease the cumulative number of noncompliant cell-days by 22. In other words, every instance where a model grid cell is out of compliance on a given day, which reflects both how many cells and how many days are affected. Breaking down the 22-cell-day reduction: four different cells each improved by 2, 3, 5, and 9 days of compliance, respectively.

Scenario selected for nutrient reduction targets

The State chose to align the targets in the Draft Nutrient Reduction Strategy with the Opt2_8 modeling scenario (Table 2 and Table 3). The Draft Puget Sound Nutrient Reduction Plan specifically notes, “Scenario Opt2_8 was selected as the basis for the nitrogen targets in this plan because it required a lower amount of nutrient reductions, relative to other scenarios, while achieving DO standards throughout the Sound when the bottom two vertical layers are aggregated. The Phase 2 report did not include results with bottom averaging, but here, we explored that option due to the shallow nature of the assessment units.”

Table 2. Watershed reduction framework applied in the Salish Sea Model scenario Opt2_8. Adapted from Table 4 from the Draft Puget Sound Nutrient Reduction Strategy, Table 2 in Figueroa-Kaminsky et al. (2025), and the June 24, 2025, Nutrient Forum.

Basin(s)	Basin-wide Reduction in Anthropogicn Total Nitrogen Loads	Detailed Reduction in Anthropogenic Total Nitrogen and Organic Carbon Loads
Northern Bays	66%	67.7% in large watersheds* 61.2% in all other watersheds
Whidbey	67%	
Main	68%	90% in watersheds draining to Sinclair Inlet and Liberty Bay 67.7% in large watersheds* 61.2% in all other watersheds
South Sound	63%	90% in watersheds draining to Carr and Henderson Inlets 67.7% in large watersheds* 61.2% in all other
Hood Canal	66%	90% in watersheds draining to Lynch Cove 53.4% in all other watersheds
Admiralty	53%	53.4% in all watersheds
Strait of Juan de Fuca	Capped at 2014 existing levels	
Strait of Georgia		

*Defined as average daily anthropogenic TN load greater than 1,000 kg/day

Table 3. Marine point source reduction framework applied in Salish Sea Model scenario Opt2_8.

Loads*	Facilities
Capped at 2014 loads	• Industrial facilities • Small wastewater treatment plants discharging less than 22 lbs. TN/day or less than 13 lbs. DIN/day • Wastewater treatment plants discharging to Admiralty Inlet, Hood Canal, the Strait of Juan de Fuca, or the Strait of Georgia
3 mg/L DIN Year-Round	• Three domestic wastewater treatment plants discharging to Sinclair Inlet: ▪ Bainbridge Kitsap Co 7 ▪ Bremerton ▪ Port Orchard
8 mg/L DIN – Cool 3 mg/L DIN – Warm & Hot	• Dominant wastewater treatment plants dischargers (> 2000 lbs. TN/day) in the Main Basin ▪ Except for West Point, which is set at 8 cool, 5 warm, and 3 hot targets because it treats combined sewage
8 mg/L DIN – Cool 5 mg/L DIN – Warm 3 mg/L DIN – Hot	• Remaining wastewater treatment plants in the Northern Bays, Whidbey, Main, and South Sound Basins

*The seasons are defined as: cool (November – March), warm (April – June, and October), and hot (July – September). Flows are maintained at 2014 levels.

Table 4 compares the predicted noncompliance in 2014 for existing conditions and the Opt2_8 scenario, which was used to establish the draft nutrient targets. Under existing conditions, 50% of the non-compliant areas in 2014 had changes of 0.3 mg/L, just over the 0.2 mg/L human use allowance. Under Scenario Opt2_8, all the remaining non-compliance is within 0.2 mg/L of the human use allowance.

Table 4. Dissolved oxygen noncompliance predicted for 2014 existing conditions and the Opt2_8 scenario. Adapted from Table 17 from Figueroa-Kaminsky et al. (2025).

Noncompliance Metric	Basin	Total Possible	Existing (2014)	Opt2_8 (2014)
Total days of Noncompliance	Northern Bays	92,345	800	0
	Whidbey Basin	190,530	18,918	0
	Main Basin	324,850	911	34
	South Sound	174,835	8,220	2
	Hood Canal	157,680	51,340	0
	Admiralty	172,645	0	0
	US Strait of Georgia	792,780	0	0
	US Strait of Juan de Fuca	1,096,095	0	0
	Washington waters of the Salish Sea	3,001,760	80,279	36
Total area of Noncompliance (km^2)	Northern Bays	188 km^2	40	0
	Whidbey Basin	371 km^2	185	0
	Main Basin	617 km^2	13	0.83
	South Sound	291 km^2	81	0.11
	Hood Canal	275 km^2	148	0
	Admiralty	350 km^2	0	0

	US Strait of Georgia	1,588 km^2	0	0
	US Strait of Juan de Fuca	2,319 km^2	0	0
	Washington waters of the Salish Sea	5,997 km^2	467	0.93
Maximum Magnitude of dissolved oxygen Noncompliance (mg/L)	Northern Bays	n/a	-0.2	0
	Whidbey Basin		-0.5	0
	Main Basin		-1.1	-0.1
	South Sound		-0.8	0
	Hood Canal		-0.6	0
	Admiralty		0	0
	US Strait of Georgia		0	0
	US Strait of Juan de Fuca		0	0
	Washington waters of the Salish Sea		-1.1	-0.1

Puget Sound Nutrient Reduction Plan

The Draft Puget Sound Nutrient Reduction Plan, an advanced restoration plan, establishes watershed and marine point source nitrogen loading targets designed to meet Washington State's marine dissolved oxygen water quality standards throughout Puget Sound. The targets were derived from the Opt2_8 scenario modeled in Figueroa-Kaminsky et al. (2025). The draft plan was released in June 2025 for public comment.

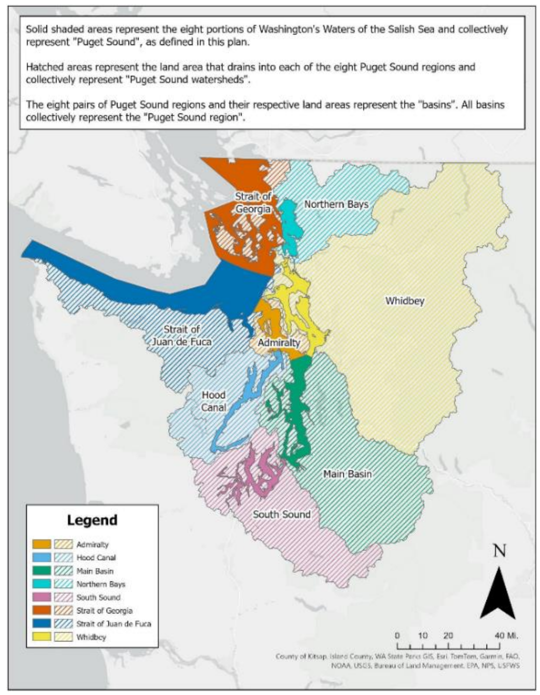

Figure 1. The eight basins the marine point source and watershed targets apply to. Figure 2 from the Draft Puget Sound Nutrient Reduction Plan.

Total nitrogen targets & anthropogenic reductions

The Draft Puget Sound Nutrient Reduction establishes targets for marine point sources and watersheds based on total nitrogen (TN) – the sum of all forms of inorganic and organic nitrogen present in water. The State said its intention in adopting TN was to provide greater implementation flexibility. This represents a notable shift from previous management efforts that primarily focused on total inorganic nitrogen (TIN) or dissolved inorganic nitrogen (DIN), which typically include nitrate, nitrite, and ammonia/um. The inputs to the Salish Sea Model use total nitrogen loads for each river and marine point source, partitioned into DIN and total organic nitrogen (TON). However, within the modeled nutrient scenarios, only the DIN portion of loads is reduced. In addition, the Puget Sound Nutrient General Permit—both the original (2022) and the updated draft (2025) – established action levels using TIN, not TN. Under the General Permit, dominant and moderate dischargers are required to complete a Nutrient Reduction Evaluation that explores treatment options capable of achieving "a final effluent concentration of 3 mg/L TIN (or equivalent load reduction) on a seasonal average (April – October) basis" (Washington State Department of Ecology, 2022 and Washington State Department of Ecology, 2025a). If the State applies the Opt2_8 scenario DIN reduction targets directly as TN when setting Water Quality Based Effluent Limits (WQBELs) for wastewater treatment plants, the resulting permit limits would in effect be more stringent than the scenario itself, since they would cap all forms of nitrogen rather than just dissolved inorganic nitrogen.

The nutrient targets in the plan are aligned with modeled reductions in anthropogenic total nitrogen loads, calculated as the difference between existing and reference loads for the modeled year. These anthropogenic loads reflect only contributions from local and regional U.S. sources, excluding Canadian sources, which remain fixed in both the existing and reference model runs. The State's decision to focus the analysis on U.S. sources is tied to jurisdictional authority, as Canadian discharges fall outside the scope of state regulation. While Canadian point and nonpoint source contributions are represented in the model, they are not targeted for reduction in the draft plan.

Marine point source targets

The Draft Nutrient Reduction Plan sets the following basin-wide targets for marine point sources – NPDES wastewater treatment plants and industrial facilities in Washington state that discharge to Puget Sound – in each region (Table 5). This mirrors how the Salish Sea Model defines marine point sources. Based on these targets, the State will eventually develop total nitrogen Water Quality Based Effluent Limits for Puget Sound dischargers that will be implemented either through the voluntary Nutrient General Permit or plants' individual NPDES permits. *See Appendix E of the Draft Puget Sound Nutrient Reduction Plan for the facility-specific model input loads used to calculate the basin-wide targets.*

While the Draft Puget Sound Nutrient Reduction Plan does not explicitly assign targets for carbonaceous biochemical oxygen (CBOD), the modeling used to inform the targets assumed an annual average of 8 mg/L year-round at marine point sources. This assumption was converted into facility-specific dissolved organic carbon (DOC) loads (McCarthy et al., 2018). For some plants, concurrently reducing CBOD to 8 mg/L limits the feasibility of potential nutrient reduction treatment options. The scenarios also mirrored the watershed nitrogen reductions by applying the same percentage to total organic carbon reductions.

Table 5. *Marine point source targets. From the June 4, 2025, Nutrient Forum presentation.*

Basin	Total Annual Target (lbs. Total Nitrogen/year)	Reduction in Anthropogenic Total Nitrogen*
Northern Bays	449,000	58%
Whidbey	1,130,000	63%
Main	6,300,000	72%
South Sound	898,000	66%
Hood Canal	823	0%
Admiralty	54,400	0%
Strait of Juan de Fuca	233,000	0%
Strait of Georgia	563,000	0%

*Relative to 2014 loads.

Watershed targets

The Draft Puget Sound Nutrient Reduction Plan sets the following watershed targets for point sources and nonpoint sources entering tributaries of Puget Sound (Table 6). These proposed watershed targets will be managed through as yet undeveloped individualized water clean-up plans. The proposed nutrient reduction targets do not consider freshwater dissolved oxygen impairments within the watersheds, so additional load reductions may be necessary in the future. *See Appendix F of the Puget Sound Nutrient Reduction Plan for the detailed watershed load inputs to the model used to collectively determine the basin-wide targets.*

Table 6. Watershed targets. From the June 24, 2025, Nutrient Forum presentation.

Basin	Total Annual Target (lbs. Total Nitrogen/year)	Reduction in Anthropogenic Total Nitrogen*
Northern Bays	3,390,000	66%
Whidbey	11,900,000	67%
Main	4,330,000	68%
South Sound	2,940,000	63%
Hood Canal	1,030,000	66%
Admiralty	50,100	53%
Strait of Juan de Fuca	929,000	0%
Strait of Georgia	1,070,000	0%

*Relative to 2014 loads

Watershed nutrient sources

Recent modeling by USGS SPARROW, in collaboration with the State, has made important progress in understanding nutrient sources and their seasonal patterns. The current pre-print results (Schmadel et al., 2025) report combines contributions from marine point sources and watershed sources as defined in the Draft Puget Sound Nutrient Reduction Plan. A helpful next step would be to segment watershed sources and align them to the watershed boundaries in the State's Draft Nutrient Reduction Plan. Doing so would help managers see how nutrient sources align with watershed-specific targets and support the development of required water clean-up plans.

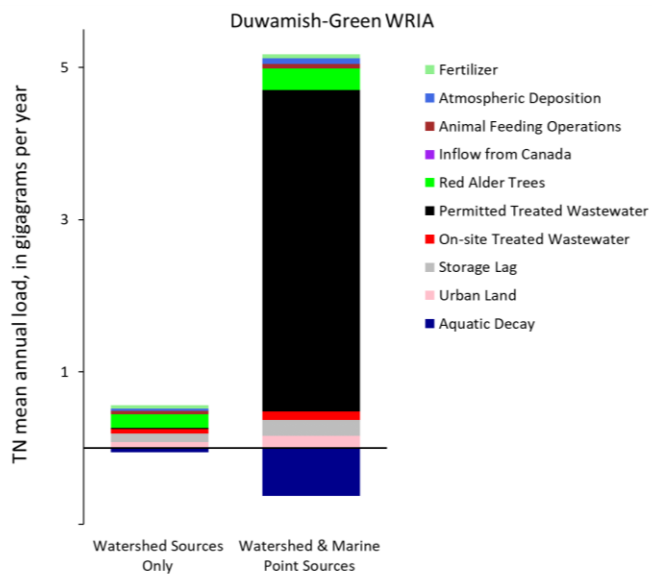

Figure 2. Nutrient sources in the Duwamish-Green WRIA. Watershed sources are based on the accumulated loads at COMID 23977634. The marine point & watershed sources are determined by aggregating the incremental loads within the WRIA.

To assess the feasibility of segmenting SPARROW outputs, we extracted the a) watershed sources and b) marine point & watershed sources for the Duwamish-Green WRIA (Figure 2). Because SPARROW has made its full model outputs publicly available, this type of analysis is relatively straightforward—provided the State identifies the terminal COMIDs that represent watershed inflows to the Salish Sea Model, upstream of marine point sources.

What has changed: methods for predicting non-compliance

In Figueroa-Kaminsky et al., (2025) the State updated its method for assessing dissolved oxygen non-compliance by translating predictions from the Salish Sea Model grid to the 303(d) assessment unit grid. The Salish Sea Model predicts water quality conditions for over 16,000 nodes and associated grid cells. However, Washington's water quality standards are applied to the regulatory 303(d) grid, which does not align with the model grid. To bridge this difference, Ecology developed a translation process that projects

Salish Sea Model outputs onto the 303(d) assessment units. The method calculates an hourly, volume-weighted dissolved oxygen concentration for each of the ten vertical layers within a 303(d) assessment unit. These hourly results are then aggregated into a daily minimum value for each layer, which is evaluated against the water quality standard. If dissolved oxygen in any layer falls below the standard for even a single hour, the entire cell is considered non-compliant for the day. In cases where a 303(d) unit spans multiple polygons with different numeric dissolved oxygen criteria, the more conservative standard is applied. We anticipate that this revised spatial aggregation has a negligible effect on overall estimates of non-compliance.

Additionally, the analysis uses a new metric – **total days of DO noncompliance** – which combines both how widespread the problem is and how long it lasts. It represents the sum of all days across all 303(d) grid cells where dissolved oxygen falls below the standard. In other words, each cell is checked every day of the year; if it is out of compliance on a given day, that counts as one cell-day of noncompliance. Adding these up across all cells gives the total. The maximum possible value in a year is over 3 million.

Updated mask: Previous modeling masked the nearshore because of limitations with the Salish Sea Model. Figueroa-Kaminsky et al., (2025) expanded this to mask:

- Budd Inlet because it is addressed in a separate EPA-approved TMDL and the Salish Sea Model does not currently account for the influence of the Capitol Lake Dam on its hydrodynamics.
- Nodes that represent depths of 4 m or less during ebb tides because the temperature predictions were unreasonably low in the winter during low tides.
- Selected hours in the winter where predicted temperatures at other very shallow subtidal locations were negative in the surface layers.
- 303(d) grid cells where more than 50% of their area is masked.

See Appendix D of Figueroa-Kaminsky et al., (2025) for the step-by-step process for how Salish Sea Model results are masked and re-projected onto the 303(d) grid. See Appendix F of Ahmed et al., (2021) for a detailed description of how non-compliance is evaluated.

What has changed: updated marine point source & watershed loads

In Figueroa-Kaminsky et al., 2025), Appendix C1 and Appendix B1 summarize how the State updated the point source and watershed TN & TOC loads. Appendix C2 and Appendix B3 also plot the flow and water quality for each source.

Marine point sources

As part of the modeling updates that informed the nutrient reduction targets, the State discovered additional data and used monthly averages to fill in gaps and revise nutrient load estimates for seven wastewater treatment plants—Brightwater, Carolyn, Hartstene, McNeil, Tulalip, Sequim, and Rustlewood. While industrial facilities accounted for only 1.7% of the total nitrogen (TN) load from U.S. marine dischargers in 2014, they contributed approximately 25% of the total organic carbon (TOC) load. Updated load estimates for several industrial sources—including aluminum producers, pulp and paper mills, and petroleum refineries—were based on newer permit data and input from The State permit managers.

The State also corrected the location of one Canadian facility, Port Renfrew. This adjustment had a negligible effect on overall Canadian WWTP load estimates, changing the total by less than 0.03% relative to previous assessments in Ahmed et al., (2019).

Overall, updates to existing and anthropogenic TN loads resulted in less than a 5% increase across all U.S. marine point sources. However, certain basins showed more pronounced changes due to improvements in data sources and estimation methods:

- **Strait of Georgia (SOG):** Anthropogenic TN loads increased by 60% in 2014primarily due to revised estimates at oil refineries, which now incorporate plant-specific nitrate/nitrite data – rather than relying on the earlier assumption that all inorganic nitrogen was ammonium.
- **Strait of Juan de Fuca (SJF):** TN loads rose by 16.5% in 2014, largely driven by updated data for McKinley Paper. The State replaced prior surrogate data (from WestRock) with post-2017 plant-specific measurements for nitrogen and carbon species, using these to construct regressions that filled historical gaps.
- **Northern Bays:** TN load estimates increased by 12% in 2014, primarily due to the inclusion of new facility-specific data for the Sequim WWTP.

For other basins, the differences were minimal, generally below 1%.

Table 7 summarizes the differences between the marine point source loads in the Optimization Phase 1 (Ahmed et al., 2021) and Optimization Phase 2 (Figueroa-Kaminsky et al., 2025) reports.

Table 7. Comparison of annual daily average existing, reference, and anthropogenic total nitrogen (TN) point source loads entering different basin in the Salish Sea in Optimization Phase 1 (Ahmed et al. 2021) and Optimization Phase 2 (Figueroa-Kaminsky et al., (2025) during 2006 and 2014. Table C1-1 from Figueroa-Kaminsky et al. (2025).

Total Nitrogen: Existing Loads by Basin	**2006 Opt1 load (kg/day)**	**2006 Opt2 load (kg/day)**	**2006 Diff. in load (kg/day)**	**2006 Diff. in load (%)**	**2014 Opt1 load (kg/day)**	**2014 Opt2 (kg/day)**	**2014 Diff. in load (kg/day)**	**2014 Diff. in load (%)**
South Sound	3,510	3,510	0.00	0.0%	3,260	3,270	10.00	0.3%
Main Basin	29,100	29,100	0.00	0.0%	27,500	27,500	0.00	0.0%
Hood Canal	1.22	1.21	-0.01	-0.8%	1.02	1.02	0.00	0.0%
Whidbey Basin	3,360	3,370	10.00	0.3%	3,810	3,810	0.00	0.0%
Admiralty	75.1	75.1	0.00	0.0%	67.4	67.4	0.00	0.0%
Northern Bays	1,120	1,250	130	11.6%	1,170	1,310	140	12.0%
SOG—US	496	758	262	52.8%	434	697	263	60.6%
SJF—US	278	316	38.0	13.7%	250	290	40.0	16.0%
Salish Sea US Total	**37,940**	**38,380**	**440**	**1.2%**	**36,492**	**36,945**	**453**	**1.2%**
Total Nitrogen: Reference loads by Basin	**2006 Opt1 load (kg/day)**	**2006 Opt2 load (kg/day)**	**2006 Diff. in load (kg/day)**	**2006 Diff. in load (%)**	**2014 Opt1 load (kg/day)**	**2014 Opt2 (kg/day)**	**2014 Diff. in load (kg/day)**	**2014 Diff. in load (%)**
South Sound	29.1	29.1	0.00	0.0%	22.6	22.6	0.00	0.0%
Main Basin	197	197	0.00	0.0%	186	187	1.00	0.5%
Hood Canal	0.006	0.006	0.00	0.0%	0.006	0.006	0.00	0.0%
Whidbey Basin	31.3	31.3	0.00	0.0%	16.9	16.9	0.00	0.0%
Admiralty	1.84	1.84	0.00	0.0%	1.76	1.75	-0.01	-0.6%
Northern Bays	8.04	13.30	5.26	65.4%	8.32	13.7	5.38	64.7%
SOG—US	6.74	11.60	4.86	72.1%	5.79	10.7	4.91	84.8%
SJF—US	1.67	1.54	-0.13	-7.8%	1.64	1.50	-0.14	-8.5%
Salish Sea US Total	**276**	**286**	**10.0**	**3.6%**	**243**	**254**	**11.1**	**4.6%**
Total Nitrogen: Anthropogenic loads by Basin	**2006 Opt1 load (kg/day)**	**2006 Opt2 load (kg/day)**	**2006 Diff. in load (kg/day)**	**2006 Diff. in load (%)**	**2014 Opt1 load (kg/day)**	**2014 Opt2 (kg/day)**	**2014 Diff. in load (kg/day)**	**2014 Diff. in load (%)**
South Sound	3,480	3,480	0.00	0.0%	3,240	3,250	10.00	0.3%
Main Basin	28,900	28,900	0.00	0.0%	27,300	27,300	0.00	0.0%
Hood Canal	1.21	1.20	-0.01	-0.8%	1.01	1.01	0.00	0.0%
Whidbey Basin	3,330	3,340	10.00	0.3%	3,790	3,790	0.00	0.0%
Admiralty	73.3	73.3	0.00	0.0%	65.6	65.7	0.10	0.2%
Northern Bays	1,120	1,240	120	10.7%	1,160	1,300	140	12.1%
SOG—US	489	746	257	52.6%	428	686	258	60.3%
SJF—US	277	314	37.0	13.4%	248	289	41.0	16.5%
Salish Sea US Total	**37,671**	**38,095**	**424**	**1.1%**	**36,233**	**36,682**	**449**	**1.2%**

Watershed loads

As part of the Optimization Phase 2 (Opt2) updates to the Salish Sea Model, the State refined watershed delineations, flow estimates, and nutrient load regressions to improve spatial accuracy and data quality.

Flow inputs

The number of freshwater quality sites used by the State to inform watershed regressions expanded significantly. The State incorporated additional data from its Environmental Information Management system, local governments, Tribes, and federal sources (e.g., USGS, EPA WQX), allowing for site-specific regressions in more basins and reducing reliance on neighboring watershed surrogates. As a result, "the percentage of total watershed area borrowing flow data from neighboring watersheds has dropped from 22% to 8%." (Figueroa-Kaminsky et al., 2025). Ultimately, these had a minimal impact on freshwater flows. The total modeled flow across Washington watersheds decreased by approximately 3% compared to Ahmed et al. (2021). Notably:

- Strait of Georgia: Had the largest relative change, dropping by 38% (equivalent to 6 cubic meters per second (cms), annual daily average) in 2014, due to more realistic WRF-Hydro-based estimates for the San Juan Islands rather than relying on downscaled estimates from the Samish River.
- Whidbey: Had the largest absolute decrease in flow, 78 cms annual daily average (7%) in 2014, largely due to corrected Skagit River data.

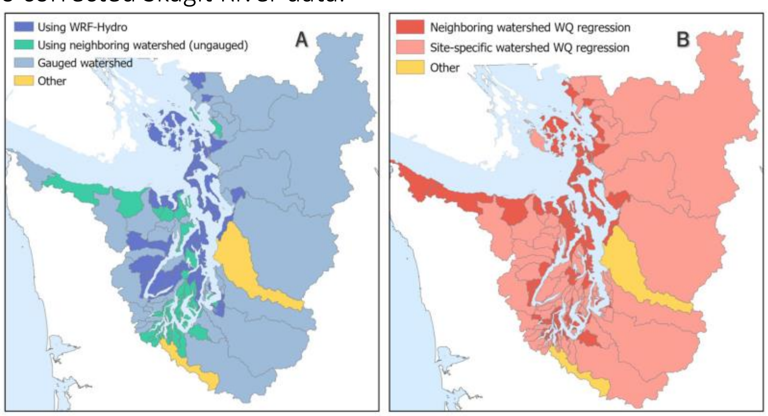

Figure 3. Figure B1-5 from Figueroa-Kaminsky et al. (2025). (A) Current status of flow data availability for Opt2 watersheds. Additional flow data has been acquired since (Ahmed et al. 2021), which includes more gauged watersheds and the use of National Oceanic and Atmospheric Administration (NOAA) Weather Research Forecast (WRF) Hydro data (green). (B) Current status of water quality availability for Opt2 watersheds. The "Other" category refers to flow-controlled watersheds such as Lake Washington and Deschutes/Capitol Lake.

Nitrogen Loads

Additional freshwater nitrogen data allowed the State to develop and refine site-specific regressions between river flow rates and TN concentrations for more watersheds. Estimated existing TN loads from all sources increased modestly by less than 5% overall. However, anthropogenic TN loads increased more significantly—by 20% in 2014— due to expanded spatial and temporal data coverage and improved site-specific regression models. The largest increase in anthropogenic loads occurred in:

- Main Basin: Increased by 1,710 kg/day or 59% in 2014, driven by the incorporation of direct field observations for Dyes Inlet and expanded temporal coverage for the Green River.
- Hood Canal: Increased by 670 kg/day or 152% in 2014; reflecting a shift from surrogate regressions to more site-specific data. The percentage of watersheds with native nitrogen data increased from 25% to 60%, correcting earlier underestimates. Hood Canal's TN load is still about

a third that of South Sound, despite slightly higher annual flows due to much lower development and TN concentrations in the Hood Canal tributaries.

Table 8 summarizes the differences between the watershed loads in the Optimization Phase 1 (Ahmed et al., 2021) and Optimization Phase 2 (Figueroa-Kaminsky et al., 2025) reports.

Table 8. *Comparison of annual daily average existing, reference, and anthropogenic total nitrogen (TN) watershed loads entering different basins in the Salish Sea in Optimization Phase 1 (Ahmed et al., 2021) and Optimization Phase 2 (Figueroa-Kaminsky et al., 2025). Table B2-2 from Figueroa-Kaminsky et al (2025).*

Total Nitrogen: Existing loads by Basin	**2006 Opt1 load (kg/day)**	**2006 Opt2 load (kg/day)**	**2006 Diff. in load (kg/day)**	**2006 Diff. in load (%)**	**2014 Opt1 load (kg/day)**	**2014 Opt2 load (kg/day)**	**2014 Diff. in load (kg/day)**	**2014 Diff. in load (%)**
South Sound	6,800	6,950	150	2.2%	5,710	5,800	90.0	1.6%
Main Basin	7,840	8,970	1,130	14.4%	7,440	8,510	1,070	14.4%
Hood Canal	1,700	2,470	770	45.3%	1,260	2,020	760	60.3%
Whidbey Basin	16,990	16,760	-230	-1.4%	19,690	19,220	-470	-2.4%
Admiralty	169	124	-45.0	-26.6%	216	116	-100	-46.3%
Northern Bays1	6,750	6,020	-730	-10.8%	6,720	6,600	-120	-1.8%
SOG – US	669	1,110	441	65.9%	777	1,320	543	69.9%
SJF – US	774	1,230	456	58.9%	955	1,150	195	20.4%
Salish Sea US Total	**41,692**	**43,634**	**1,942**	**4.7%**	**42,768**	**44,736**	**1,968**	**4.6%**
Total Nitrogen: Reference loads by Basin	**2006 Opt1 load (kg/day)**	**2006 Opt2 load (kg/day)**	**2006 Diff. in load (kg/day)**	**2006 Diff. in load (%)**	**2014 Opt1 load (kg/day)**	**2014 Opt2 load (kg/day)**	**2014 Diff. in load (kg/day)**	**2014 Diff. in load (%)**
South Sound	2,770	2,880	110	3.9%	2,310	2,360	50.0	2.2%
Main Basin	4,440	3,820	-620	-13.9%	4,550	3,910	-640	-14.1%
Hood Canal	1,070	1,070	0.0	0.2%	818	907	89.0	10.9%
Whidbey Basin	11,410	11,000	-410	-3.6%	13,330	12,500	-830	-6.2%
Admiralty	16.3	15.4	-0.90	-5.7%	16.3	14.6	-2.20	-13.1%
Northern Bays1	2,560	2,540	-20.0	-0.8%	3,060	2,960	-100.0	-3.3%
SOG – US	232	136	-96.0	-41.3%	287	178	-109	-38.0%
SJF – US	521	557	36.0	6.9%	491	501	10.0	2.0%
Salish Sea US Total	**23,019**	**22,018**	**-1,001**	**-4.3%**	**24,863**	**23,331**	**-1,532**	**-6.2%**
Total Nitrogen: Anthropogenic loads by Basin	**2006 Opt1 load (kg/day)**	**2006 Opt2 load (kg/day)**	**2006 Diff. in load (kg/day)**	**2006 Diff. in load (%)**	**2014 Opt1 load (kg/day)**	**2014 Opt2 load (kg/day)**	**2014 Diff. in load (kg/day)**	**2014 Diff. in load (%)**
South Sound	4,030	4,070	40.0	1.0%	3,410	3,440	30.0	0.9%
Main Basin	3,400	5,150	1,750	51.4%	2,890	4,600	1,710	59.2%
Hood Canal	628	1,400	772	123%	440	1,110	670	152%
Whidbey Basin	5,580	5,760	180	3.2%	6,360	6,720	360	5.7%
Admiralty	152	108	-44.0	-28.8%	199	102	-97.0	-48.7%
Northern Bays1	4,190	3,480	-710	-16.9%	3,660	3,640	-20.0	-0.5%
SOG – US	438	978	540	123%	490	1,140	650	133%
SJF – US	254	673	419	165%	464	650	186	40.1%
Salish Sea US Total	**18,672**	**21,619**	**2,947**	**15.8%**	**17,913**	**21,402**	**3,489**	**19.5%**

Existing & reference loads

Table 9 summarizes the existing and reference loads following the updates.

Table 9. *Average annual daily flows and average annual daily total nitrogen (TN) and total organic carbon (TOC) marine point source and watershed loads entering Washington waters of Salish Sea for each of the four modeled years. Table 1 from Figueroa-Kaminsky et al. (2025).*

Average annual flow or load	Source	2000	2006	2008	2014
Flows (cms)	Marine point sources	19.1	20.1	17.7	18.1
	Watersheds	1,370	1,810	1,560	1,950
	Total	**1,390**	**1,830**	**1,580**	**1,970**
TN loads (kg/day)	Marine point sources — existing	37,400	38,400	36,200	36,900
	Marine point sources — reference	256	286	244	254
	Marine point — anthro.	37,100	38,100	36,000	36,600
	Watersheds — existing	28,800	43,600	32,400	44,700
	Watersheds — reference	15,000	22,000	16,900	23,300
	Watersheds — anthro.	13,800	21,600	15,500	21,400
	Total — existing	**66,200**	**82,000**	**68,600**	**81,600**
	Total — reference	**15,300**	**22,300**	**17,100**	**23,600**
	Total — anthro.	**50,900**	**59,700**	**51,500**	**58,000**
Anthro. TN load (%)	Marine point sources	73%	64%	70%	63%
	Watersheds	27%	36%	30%	37%
TOC loads (kg/day)	Marine point sources — existing	21,900	17,200	17,200	14,700
	Marine point sources — reference	3,330	3,690	3,020	3,170
	Marine point sources — anthro.	18,600	13,500	14,200	11,500
	Watersheds — existing	174,000	316,000	223,000	322,000
	Watersheds — reference	134,000	198,000	150,000	198,000
	Watersheds — anthro.	40,000	118,000	73,000	124,000
	Total — existing	**196,000**	**333,000**	**240,000**	**337,000**
	Total — reference	**137,000**	**202,000**	**153,000**	**201,000**
	Total — anthro.	**59,000**	**131,000**	**87,000**	**136,000**
Anthro. TOC load (%)	Marine point sources	32%	10%	16%	8.5%
	Watersheds	68%	90%	84%	91%

[a] All values are rounded to three significant figures
cms = cubic meters per second
anthro. = anthropogenic

What has changed: Model structure and skill assessment

The State implemented a series of targeted refinements to the Salish Sea Model to improve dissolved oxygen and nutrient predictions, including:

1. **Updated FVCOM-ICM4 & open boundary tidal constituents:** The model updated the biogeochemical code version, which includes more detailed formulations of both light penetration and hydrodynamic processes. A key enhancement is the corrected photosynthetically active radiation (PAR) scheme, which handles sunlight more realistically. It simulates the lack of sunlight at night and higher, more accurate sunlight levels (i.e., PAR and solar radiation) during daylight hours, instead of spreading light evenly throughout the day. This change helps the model better reflect when and how much sunlight is available for algae to grow. The State also updated the open boundary tidal constituents using the 2015 Eastern North Pacific database (Szpilka et al., 2018), rather than the 2003 version. Additionally, ICM4 supports spatially variable bottom friction, which resulted in similar surface elevation accuracy (average annual RMSE throughout Puget Sound went from 0.43 to 0.41). Variable bottom friction had a larger effect on average water surface elevation in the research version of the model because of its finer-resolution grid (Premathilake & Khangaonkar, 2022).

2. **Refined the reaeration scheme:** The model now uses seasonal formulas to simulate how oxygen from the atmosphere mixes into the water; this modestly improved the annual RMSE for dissolved oxygen from 1.09 to 0.91 Sound-wide.

3. **Recalibrated biogeochemical parameters through sensitivity testing:** A series of parameter adjustments were made based on test runs aimed at improving agreement with observed data:
   - **Water column settling rate parameters** were adjusted and net settling rate parameters were maintained to better match observed sediment oxygen demand. The State found that, "Reducing water column settling velocities WSLAB and WSREF to 2.5 m/d (by a factor of 2) while keeping net sediment velocity in sediments (WSLNET, WSRNET to 1.0 m/d results in SOD fluxes that generally match observations."
   - **Nitrogen mineralization rates** were revised to better simulate ammonium (NH_4^+) dynamics, which are important for oxygen demand and nutrient cycling (Table 10).

Table 10. Updates to kinetic mineralization rates. Table A-6 from Figueroa-Kaminsky et al. (2025).

Mineralization Parameter	Definition	Used by Ahmed et al. (2019)	Used in Current Work
KLDN	Minimum mineralization rate of labile dissolved organic nitrogen (1/day)	0.05	0.075
KLPN	Minimum hydrolysis rate of labile particulate organic nitrogen (1/day)	0.01	0.05
KHNNT	Half saturation concentration of NH_4^+ required for nitrification (g N/m^3)	0.5	0.75

   - **Updated algal rates** to better capture observed chlorophyll concentration — particularly in embayments – the State increased algal growth by updating the maximum photosynthetic rate for the second algal group from 350 to 450 g C/g Chl/day (Cerco & Noel, 2019), while maintaining the original rate for the first group at 350. Additionally, the initial slope of the photosynthesis–irradiance curve (α) was adjusted to reflect longer and earlier seasonal blooms. This change allows algal group 1 to bloom earlier in spring (α = 8) and group 2 to sustain growth later into fall (α = 12), consistent with observations.

4. **Stabilized initial sediment conditions:** To ensure more consistent sediment oxygen demand estimates, the State modified the model's initialization by running a ten-year simulation that loops the same year. Organic material that settles on the seafloor breaks down in different ways over time. This approach allows organic material in sediments to reach a steady state. In particular, it improved the partitioning of particulate organic matter into more reactive (G1) and less reactive (G2) fractions, helping to avoid under- or overestimating long-term oxygen demand near the seafloor. Cumulatively, model refinements have also reduced predicted peak sediment oxygen demand values compared to earlier versions. For example, the highest average sediment oxygen demand predicted across the domain for 2006 is now 0.86 g O_2/m^2/day, down from 1.4 g O_2/m^2/day reported in earlier modeling (Ahmed et al., 2019).

Model skill analysis

Following the model refinements, the State conducted both its standard skill assessments and several targeted evaluations to test model performance across key processes and variables.

The model predicts that embayments – where most non-compliance occurs – are strongly influenced by sediment oxygen demand, microbial respiration, and algal respiration. Sediment oxygen demand accounts for the largest share of dissolved oxygen loss in bottom waters, while microbial respiration is consistently elevated in embayments, especially near their tips. A notable exception is Lynch Cove in Hood Canal, where chronically low oxygen likely constrains respiration year-round. Algal respiration also dominates total microbial oxygen demand in most locations, especially in shallow embayments. For example, at Oakland Bay (OAK004), one of the shallowest sites at 12 meters, it accounts for ~57% of total bottom-water respiration. In deeper locations, such as SAR003 (140.5 m), contributions shift, with algal respiration reduced (~22%) and heterotrophic respiration and nitrification playing larger roles (~38% and 41%, respectively). Given their dominant role in driving oxygen dynamics in embayments, these processes were prioritized in the State's targeted model skill evaluations.

1. **Parameter sensitivity testing**: A modified Monte Carlo analysis was performed using 60 model runs for 2014, varying five biologically important parameters within literature-supported ranges. The sensitivity tests varied the nitrogen uptake, algal settling velocities, maximum photosynthetic rate, minimum respiration rate of labile dissolved organic carbon, and dissolution rate of labile particulate organic carbon. This analysis supported retaining the base calibration established with the model refinements.

2. **Freshwater nitrate-nitrite validation**: Ecology compared its riverine nitrate–nitrite regression models to new high-frequency, continuous monitoring data collected since 2023 at the mouths of four major rivers: the Nooksack, Skagit, Snohomish, and Puyallup. *See Appendix B4 of Figueroa-Kaminsky et al. (2025).*

3. **Sediment oxygen demand and nutrient fluxes**: Model predictions of sediment oxygen demand and nitrogen fluxes were compared to observations at 31 locations, using recent measurements from Shull (2018) and Merritt (2017), and a broader historical dataset compiled by Sheibley and Paulson (2014). *These comparisons are detailed in Appendix I of Figueroa-Kaminsky et al. (2025).*

4. **Microbial respiration in bottom waters**: Total microbial respiration was evaluated at 15 sites against the first region-wide assessment of microbial respiration in the near-bottom waters of the U.S. Salish Sea (Apple and Bjornson, 2019). *Results are presented in Appendix K of Figueroa-Kaminsky et al. (2025).*

5. **Primary productivity and phytoplankton biomass**: To improve alignment with available ^{14}C-based measurements of primary productivity, an additional model run for the year 2000 was completed and compared. Phytoplankton biomass was also evaluated using long-term and seasonal chlorophyll-a monitoring data from the Washington State Department of Ecology, King County, NANOOS, and Western Washington University. *Additional detail in Appendix J of Figueroa-Kaminsky et al. (2025).*

Table 11 summarizes the model skill for the State's different versions of the. Generally, the model improvements from previous versions were modest.

Table 11. Comparison of 2014 model performance for Bounding Scenarios (Ahmed et al. 2019), Optimization Phase 1 (Ahmed et al. 2021), and Optimization Phase 2 (Figueroa-Kaminsky et al. 2025) reports. Table 8 from Figueroa-Kaminsky et al. (2025).

Report	Variable	R	WSS	RMSE	$RMSE_C$	RE	MAE	Bias	Sd_{obs}	N
BSR	Temperature (°C)	0.95	--	0.87	--	--	--	-0.41	--	88,781
Opt1	Temperature (°C)	0.95	0.94	0.78	0.74	0.06	0.62	-0.23	--	97,687
Opt2	Temperature (°C)	0.95	0.95	0.71	0.71	0.06	0.58	0.04	1.87	99,074
BSR	Salinity (psu)	0.75	--	0.88	--	--	--	-0.37	--	88,585
Opt1	Salinity (psu)	0.82	0.87	0.84	0.71	0.02	0.51	-0.44	--	97,487
Opt2	Salinity (psu)	0.83	0.90	0.72	0.72	0.01	0.39	-0.07	1.13	98,884
BSR	DO (mg/L)	0.81	--	0.96	--	--	--	-0.34	--	87,284
Opt1	DO (mg/L)	0.83	0.89	0.98	0.89	0.11	0.74	-0.43	--	96,152
Opt2	DO (mg/L)	0.86	0.93	0.82	0.81	0.08	0.57	-0.08	1.54	97,566
BSR	Chl-a (μg/L)	0.52	--	3.48	--	--	--	-0.13	--	88,895
Opt1	Chl-a (μg/L)	0.52	0.67	3.42	3.42	0.71	1.41	-0.11	--	87,671
Opt2	Chl-a (μg/L)	0.52	0.68	3.27	3.27	0.71	1.35	0.03	3.71	98,932
BSR	NO_3-NO_3 (N-mg/L)	0.84	--	0.07	--	--	--	0	--	1,848
Opt1	NO_3-NO_2 (N-mg/L)	0.84	0.90	0.07	0.07	0.15	0.05	0	--	1,934
Opt2	NO_3-NO_2 (N-mg/L)	0.83	0.9	0.07	0.07	0.15	0.05	-0.01	0.10	1,916
BSR	NH_4^+ (N-mg/L)	0.32	--	0.02	--	--	--	0	--	1,510
Opt1	NH_4^+ (N-mg/L)	0.35	0.56	0.02	0.02	0.58	0.01	0	--	1,595
Opt2	NH_4^+ (N-mg/L)	0.43	0.60	0.02	0.02	0.70	0.02	0.01	0.02	1,572
BSR	PAR (E-m^2/day)	--	--	--	--	--	--	--	--	--
Opt1	PAR (E-m^2/day)	0.61	0.66	6.00	5.94	0.78	1.08	-0.81	--	82,178
Opt2	PAR (E-m^2/day)	0.68	0.79	6.36	6.33	0.76	1.39	-0.60	8.50	63,813

"--" means not calculated or reported.

Model skill in embayments

Model performance was further segmented by depth and sub-region, including embayments, to assess spatial variation in model accuracy. The State's analysis effectively advances the Model Evaluation Group's recommendation to assess model skill at different depths in the water column and in embayments, which are more susceptible to dissolved oxygen non-compliance. Overall, the model performs better in the open estuary than in embayments across all depth layers. It is generally more accurate in predicting dissolved oxygen concentrations in the middle and bottom layers—where oxygen levels are typically lowest.

In embayments, model error (measured as root mean square error, or RMSE) ranges from 0.94 to 1.57 mg/L of dissolved oxygen (Figure 4). Additionally, the model generally underestimates dissolved oxygen in embayments, especially in the bottom layer, where the average bias in 2014 was –0.31 mg/L.

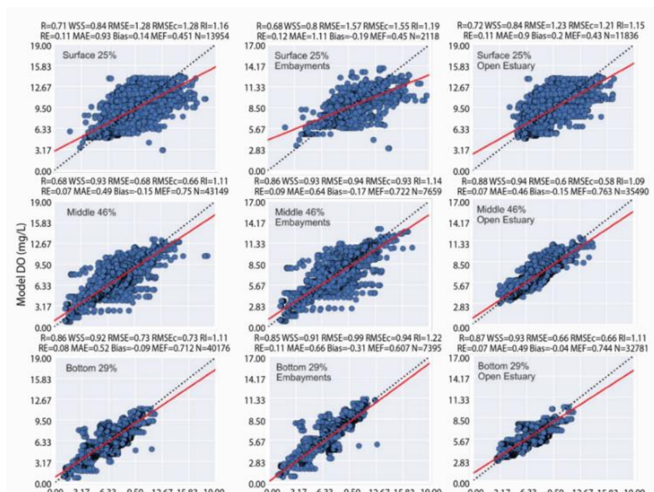

Figure 4. Dissolved oxygen performance segmented by depth, embayments, and open channel. Figure from March 2025 Nutrient Forum.

Table 12. Model skill for different depths in the open estuary vs. embayments.

	RMSE		
	Surface	Middle	Bottom
Open estuary	1.23	0.6	0.66
Embayments*	1.57	0.94	0.99

**Figures D-1, D-2, and D-3 in Figueroa-Kaminsky et al. (2025) show which monitoring locations were classified as embayments or open estuary for the model skill comparison.*

Implications of model updates

In Figueroa-Kaminsky et al. (2025), the State describes updates to the point source and watershed loads used as inputs to the Salish Sea Model, as well as other targeted refinements and model evaluation made. Key refinements included adopting a more advanced version of the core model (FVCOM-ICM4) that provides improved light and hydrodynamic process simulation. In addition, refinements addressed: the reaeration scheme, stabilizing sediment oxygen demand through steady-state initialization, recalibrating particulate settling, nutrient cycling, algal growth parameters, and updating open boundary tidal constituents to the 2015 Eastern North Pacific database (Szpilka et al., 2018).

Following the model refinements, the State conducted model skill evaluation and targeted analyses. These included: parameter sensitivity testing, depth- and embayment-specific skill assessment, comparison of freshwater regressions to new continuous data, and evaluations against observations for sediment oxygen demand, microbial respiration, and primary productivity. Prior to these refinements, the University of Washington Puget Sound Institute convened a Model Evaluation Group of experts (Mazzilli et al., 2024) who recommend ways to improve the application of the Salish Sea Model for recovery goals and regulatory decisions. Figueroa-Kaminsky et al. (2025) have made significant advances to address these recommendations with the current model refinements and analysis.

While several opportunities remain to refine model skill, further refinements are unlikely to fully resolve the challenges associated with its regulatory application and associated uncertainties (discussed following). Key opportunities for refinement include, to:

1. **Conduct multi-year runs and validation** | The current range of single-year runs offers initial insight into interannual variability, and repeating a year during spin-up helps stabilized the model. However, neither simulates results across a "water cycle" year (and range of interannual variability) or captures the value of validation for a year that was not used in calibration. Nutrients, algae, and oxygen levels depend on prior seasons and years, as well as the natural sequence of wet and dry years, warm and cool conditions. Multi-year runs provide a more realistic picture of system response inter-annually and greater confidence that management strategies will remain effective under the full range of conditions Puget Sound experiences. Additionally, they offer an opportunity to conduct independent validation runs for time periods beyond those used in calibration.

2. **Expand monitoring in embayments with predicted non-compliance** | Consistent with the Model Evaluation Group's recommendations and subsequent State analysis, additional monitoring should be prioritized in embayments where the model predicts dissolved oxygen non-compliance. The State's recommended locations include Holmes Harbor, Dabob Bay/Quilcene Bay, Liberty Bay, Dyes Inlet, Sinclair Inlet, Case Inlet, Carr Inlet, Henderson Inlet, and Oakland Bay.

3. **Target sediment oxygen demand monitoring in areas with model-observation mismatches** | Additional data collection should be directed to areas where model skill is weaker for sediment oxygen demand and nutrient fluxes. This could be used to further improve sediment/water column parameterization, addressing spatial variability between regions of Puget Sound (Mazzilli et al., 2024). Priority sites include Skagit Bay, Sinclair Inlet, Saratoga Passage, Port Gardner, Commencement Bay, Case Inlet west of Devil's Head (Nisqually Reach), North Central Basin, Bellingham Bay (multiple stations), Central Basin North (Shilshole), Inner Budd Inlet, Central Puget Sound, West Sound San Juan, and Hood Canal at Hoodsport.

4. **Expand parameter evaluation for silicate and pH** | Future model refinements should also consider the Model Evaluation Group's recommendation to evaluate processes related to silicate and pH in greater detail, to improve representation of biogeochemical dynamics and their interactions with nutrient cycling and dissolved oxygen.

5. **Address the role of suspended sediments in light limitation** | The most recent updates to the Salish Sea Model includes sediment transport, influencing turbidity and light penetration and photosynthesis. This is especially critical near river mouths with high nutrient concentrations. Future validation (and potential refinement) should explicitly represent suspended sediment dynamics so that primary production calibration is not confounded with growth, decay, and settling parameters.

6. **Evaluate the need for refining nearshore modeling** | Nearshore areas are notoriously difficult to model due to high variability and limited monitoring data. At present, the model appropriately masks these zones where confidence is lower, which makes sense for regulatory purposes. However, as many areas that are identified as non-compliant have adjoining masked cells (and because water quality standards are designed to protect marine life in these near shores), it will be important to determine whether critical habitats exist within these masked nearshore areas. Identifying such habitats would help prioritize if targeted monitoring and model refinement are necessary to ensure vulnerable species and ecosystems receive adequate protection.

Despite the State's comprehensive and systematic refinements (and while additional improvements remain possible), the model may be approaching the limits of what can be achieved given the specific precision demands of regulatory applications in Washington State. The model's overall performance has improved modestly reflected in a decrease in annual, domain-wide RMSE from 0.78 in Ahmed et al. (2021) to 0.71 in Figueroa-Kaminsky et al. (2025). However, the magnitude of error in embayments (averaged across all locations and the entire year) remains at 0.94 and 0.99 annual RMSE in the mid- and bottom-waters, respectively. Model error in embayments is still several times greater than the 0.2 mg/L human use allowance used to assess regulatory compliance. Although the region-wide skill of the Salish Sea Model is on par with other regulatory water quality models used nationally, Washington's unique 0.2 mg/L threshold demands a higher level of precision than the model may currently provide in these embayments of concern.

Improvements between model versions have been relatively modest, suggesting the model may be approaching diminishing returns in terms of refining model skill further. Additionally, the State has suggested that subtracting two model scenarios will cancel out the error. In practice, the uncertainties in each scenario can combine in unpredictable ways, and there is no guarantee that positive and negative errors offset one another. This is especially important because the reference condition scenario cannot be validated against observations; by definition, its accuracy is unknowable (Mazzilli et al., 2024). As a result, when compliance is determined by comparing existing and reference scenarios, the true level of uncertainty in the outcome is likely larger than the model performance statistics alone suggest, and must be explicitly considered in regulatory applications. Taken together, the mismatch between achievable model precision and regulatory requirements suggests that the model may not be able to reduce uncertainty to the point that it is lower than the current human use allowance of 0.2 mg/L. However, the available model results could be used to more directly understand risk to marine life, which may increase confidence in the efficacy of management actions.

These findings highlight both the progress and the limitations of the Salish Sea Model as it is applied to nutrient management in Puget Sound.

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Biological sensitivity of Salish Sea taxa to low oxygen levels: determining observed metabolic demand thresholds of key taxa based on concomitantly measuring abundance, oxygen, and temperature

Critical Analysis Report, February 2025

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Summary:
The primary questions that this analysis proposed to address was: what are the critical oxygen thresholds of key taxa (across life stages), and when and where in Puget Sound do oxygen levels fall below these thresholds? In order to better understand dissolved oxygen (DO) thresholds for Salish sea species, we first processed and collated available Salish sea fish surveys that had concurrent oxygen and temperature information into an initial database repository (Table 1). This data is collated in a Github repository for future research use, and Tim Essington (essing@uw.edu) is the primary contact. Second, we conducted preliminary analysis of all suitable data both qualitatively and quantitatively, using a probabilistic generalized linear model. This was done to identify if critical oxygen and temperature ranges existed among species based on available survey data.

Based on the statistical analysis using all suitable data, we did not find evidence of a strong DO threshold for herring and Chinook salmon (data was collected by Fisheries & Oceans Canada and the University of Washington in the broader Puget Sound). However, exploration of the available presence and absence data provided qualitative information on thresholds for the taxa examined. Interestingly, we found that fish were present at depths with low DO levels even when there was more oxygen available higher in the water column. Specifically, fish are found at lower DO levels, as low as 1.3 mg/L for herring and 2.06 mg/L for Chinook salmon, even when DO levels higher in the water column were >6 mg/L (Figures 3 and 4). Overall, we suggest that the current data does not provide a clear threshold for herring or Chinook salmon. Qualitative analysis of presence and absence data does suggest that any thresholds are likely below 1.3 mg/L and 2.06 mg/L, respectively. Future survey efforts can provide better insight if CTD sampling is conducted immediately preceding or following trawl surveys and key metadata like tow time, distance, and depth are recorded. Additionally, conducting more surveys overall, and specifically targeting these surveys for the fall when lower and wider ranges of DO are typical will likely improve the model inference in future analyses.

Background and research objectives:
Maintaining adequate levels of DO is critical for the survival and well-being of benthic and pelagic marine organisms (Davis, 1975; Vaquer-Sunyer and Duarte, 2008). However, accurately predicting responses and impacts on aquatic species can be difficult (Moriarty et al., 2020; Sato et al., 2016). Currently, our scientific understanding and ability to forecast habitat and species shifts due to changes in oxygen demand and supply are limited by a lack of knowledge on Salish

Sea species' vulnerability to the synergistic impacts of low DO and warming waters. Synergistic impacts are due to the joint effects of oxygen and temperature and emerge from differences in temperature-dependent rates of oxygen intake vs. oxygen expenditure (Deutsch et al. 2015). As a result, the consequences of oxygen changes cannot be considered without also knowing the temperature that an organism will experience (Essington et al., forthcoming). Several topics associated with DO threshold values for Salish Sea species were identified as research needs and critical uncertainties by the Interdisciplinary Team during the Marine Water Quality Implementation Strategy development process. The research undertaken in this project is a first step towards addressing these critical uncertainties. The primary questions that this analysis will answer are: What are the critical oxygen thresholds of key taxa (across life stages), and when and where in Puget Sound do oxygen levels fall below these thresholds?

Methods:

Three steps, and associated methodologies, were applied in this project:

1) Collation and processing of available Salish Sea survey data where there were concurrent oxygen and temperature and fish surveys conducted. Tim Essington will serve as the primary contact for the compiled database for future research.
2) Preliminary data exploration and qualitative analysis of critical oxygen and temperature ranges were conducted for species with sufficient data.
3) Hypothesis testing and model selection to understand if temperature and oxygen levels predicted fish presence.

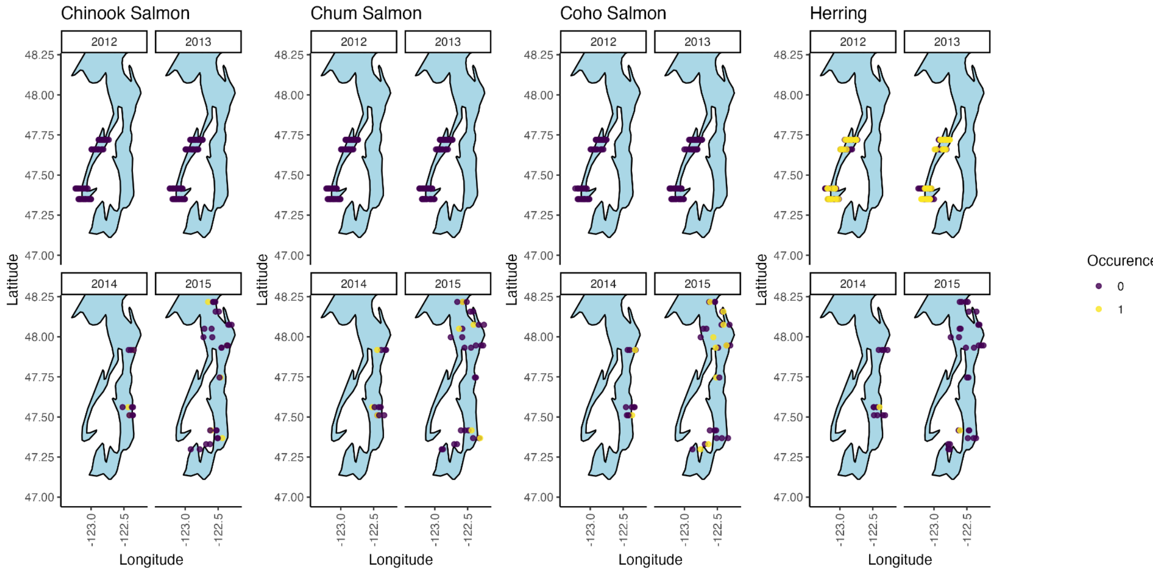
<u>Collation and Processing of Salish Sea Survey Data</u>

Multiple Salish Sea datasets that included fish abundance with concurrent CTD (a conductivity, temperature, and depth instrument) casts were collated and reviewed, including:

- Department of Fisheries and Oceans, Canada pelagic species surveys: RV Ricker mid-water trawl surveys (2014 and 2015 available) (hereafter, DFO).
- Long Live the Kings continuation of RV Ricker sampling sites in the Salish Sea - 2021 and 2022 available, but lacking tow depth and time information needed to calculate CPUE and match with CTD data (hereafter, LLTK).
- Washington Department of Fish and Wildlife bottom trawl surveys – biological data collated (1989-2007), but the availability and extent of associated DO and other physical datasets were unknown (hereafter, WDFW).
- University of Washington Hood Canal dataset, curated by Tim Essington and colleagues combining survey data from Hood Canal with CTD data (hereafter, UW).

After considering all four datasets, only the DFO and UW datasets were found to have the required physical (i.e., DO, temperature) and fish abundance (Catch Per Unit Effort- CPUE) information suitable for this current analysis. Additional information on future survey needs is provided in the discussion.

Figure 1. Map of fish occurrence and survey stations from both UW and DFO surveys in the Southern Salish Sea. Plots are grouped by species and years. Here, purple indicates that fish did not occur in a survey, and yellow indicates at least one fish was caught in that survey. Overlapping points were slightly "nudged' so that multiple surveys were visible in one region.



We received datasets in varied formats and processing levels, thus much of the effort in this project was dedicated to quality control and data processing. For each dataset (DFO and UW), we calculated the Catch Per Unit Effort, based on the net opening for each survey and the length of the tow. CTD data, which surveys the environment along the water column, was matched to the fish survey data to the closest survey depth.

The solubility of oxygen in water is affected by temperature, thus we calculated temperature-adjusted DO values for the analysis. The temperature adjusted DO equation took the following form,

Adjusted DO = DO * exp(KB * (1 / Temperature - Temperature/Temperature Reference))

The key components of the formula are:

- DO: The original dissolved oxygen concentration measurement.
- KB: A constant that represents the temperature coefficient for the solubility of oxygen in water. This value typically ranges from 0.0241 to 0.0272, depending on the specific water conditions.
- Temperature: The water temperature in Kelvin units.
- Temperature Reference: A reference temperature in Kelvin units, often 293.15 K (20°C), used as the baseline for the temperature adjustment.

By using this formula, we can reliably adjust DO measurements to a common temperature, facilitating meaningful comparisons and analysis of the data across different sampling points or time periods. All measurements presented below as DO mg/L, are temperature-adjusted DO values. We included covariates from the CTD in the analysis, with the main focus on DO. We included minimum water column DO, DO at the depth the fish were surveyed, and temperature at the depth the fish were surveyed. Datasets were evaluated for completeness and accuracy, coded based on the data source (i.e., source = “DFO” or “UW”), and assimilated into one dataset.

Exploration and Qualitative Analysis of Oxygen, Temperature and Taxa Data

To understand the range of DO and temperature values across available data we plotted the range of DO and temperature where fish were present and absent for herring and Chinook, chum, and coho salmon (Figure 2). To understand the entire DO profile that might be available to a fish relative to the DO at the depth they were found in surveys, we further analyzed the more detailed UW dataset. This included plotting Chinook salmon and herring CPUE data verses DO depth profiles (Figure 3 and 4).

Statistical Hypothesis Testing

We used generalized linear models to estimate the probability of Chinook salmon and herring occurrence with varying temperature and DO. The model was developed and applied using the Ime4 package in R (Bates et al., 2014). Due to a limitation of statistical power and limited overlap between surveys, we ran these models for just two species: Chinook salmon (*Oncorhynchus tshawytscha*) and Pacific herring (*Clupea pallasii*). We ran separate models for each species and used a binomial distribution to estimate the probability of fish occurrence across temperatures and DO levels. We expected that fish (Chinook salmon or herring) presence may be impacted by DO levels throughout the water column, in addition to the temperature and DO at the depth at which they are surveyed. Specifically, if fish presence was impacted by DO, we expected fish might be present in regions of the water column that had greater DO than other regions.

DO and temperature covariates were obtained from CTD data collected during the fish surveys in similar locations to the trawls. We included CTD temperature and DO at the mean net tow depth as a predictor. Additionally, we hypothesized that minimum DO present throughout the complete water column would have an effect on the presence of fish in the net surveys and thus included minimum DO as a covariate as well.

To control for differences in observed fish occurrence among data sources within the model framework, we included a data source factor (either DFO or UW). We also accounted for survey depth, location, day of year, and time of day (applying a diel factor for day or night survey). Specifically, we incorporated a linear predictor for latitude, to account for changes in fish occurrence based on latitudinal variation in survey locations (there was not enough variation in survey longitudes to necessitate incorporating a full spatial field). Further, we incorporated a linear predictor for depth and day of year to account for changes in fish occurrence based on sample depth and seasonality. We mean-scaled all environmental covariates to allow for meaningful comparison across conditions but present the actual covariate values in the following plots.

First, we constructed a null model that estimated fish occurrence while controlling for survey design (Table 1) and sequentially added covariate complexity to address hypotheses regarding temperature and oxygen impacts on fish occurrence (Table 1). The full model took the form:

$$logit\left(\gamma_i\right) = \alpha + S_l + V_m + \beta x_i + \beta y_i + \beta z_i + \beta m_i + \beta d_i + \beta t_i$$

where Yi is the expected occurrence, for the *i*-th observation in space and time with a logit-link function, α is the intercept, S_l is the factor for data source which controls for differences in observed fish occurrence among each data source (DFO or UW), V_m is a factor for diel survey time which controls for differences in observed fish occurrence among night and day surveys. βx_i represents the linear effect of latitude, where x_i the latitude for each observation, which is included to control for differences in fish presence that occurred across survey latitudes and β describes the slope of the relationship. βy_i represents the linear effect of depth, where y_i the depth for each observation, which is included to control for differences in fish presence that occurred across survey depth and β describes the slope of the relationship. βz_i represents the linear effect of DOY, where z_i the DOY for each observation, which is included to control for differences in fish presence that occurred across survey DOY and β describes the slope of the relationship. Finally, βm_i, βd_i and βt_i account for linear effects of minimum water column DO, DO at the depth fish were surveyed, and temperature at the depth fish were surveyed, respectively. The complete set of models tested, nested within this full model are presented in Table 1.

Table 1. Datasets considered for this analysis.

Dataset	**Years**	**Further notes and additional data required for analysis**
Department of Fisheries and Oceans Canada (DFO) Main contact: Chrys Neville (Chrys.Neville@dfo-mpo.gc.ca)	2014, 2015; Surveys conducted in July, October and November via mid-water pelagic trawl; sampled day only, 40 tows conducted in total.	NA, used in analysis
University of Washington (UW) Main contact: Tim Essington (essing@uw.edu)	2012 - 2013; approximately 80 tows per year at 4 stations in the Hood Canal, sampled day and night via midwater trawl, June - October.	NA, used in analysis
Long Live the Kings (LLTK) Main contact: Liz Duffy (eduffy@lltk.org)	2021-2023; approximately 47 total tows at stations across the Salish Sea, sampled day only via Purse Seine, July.	Collect gear depth and total tow effort (linear distance or tow time).
Washington Department of Fish and Wildlife (WDFW)	Did not receive data because of lacking CTD	No available CTD data, see accompanying

Main contact: Jennifer Blaine (Jennifer.Blaine@dfw.wa.gov)	information.	recommendations in text for all related CTD recommendations.

To test hypotheses regarding the importance of temperature and DO in predicting fish occurrence, we compared multiple models against a base model (Table 1) and judged the degree of support for each model using corrected Akaike information criterion (AICc) (Akaike 1973, Hurvich and Tsai 1989, Burnham and Anderson 2002). AICc was used to account for small sample sizes (Table 1). We present models in the results ranked by delta AICc (ΔAICc) which represents the difference between each model's AICc value and the lowest AICc value in your set of candidate models (Table 2). A ΔAICc greater than 2 is considered meaningful.

Table 2. Model structure and model selection criteria (ΔAIC_c) applied to the presence and absence of Chinook salmon and herring in the Salish Sea. We evaluated 7 candidate models per species. Overall differences in AIC_c values between the null model and B-D alternative models are small (<= 2) so the null model cannot be dismissed for either species. Covariates not included in the base model are highlighted in bold to demonstrate changes in model complexity.

Model Name	**Model**	**delta AICc**
Chinook Mod Null	Latitude + source + diel + depth + DOY	0
Chinook Mod B	Latitude + source + diel + depth + DOY + **min_DO**	0.9
Chinook Mod C	Latitude + source + diel + depth + DOY + **DO**	1.7
Chinook Mod D	Latitude + source + diel + depth + DOY + **temperature**	1.9
Chinook Mod E	Latitude + source + diel + depth + DOY + **DO + temperature**	2.8
Chinook Mod F	Latitude + source + diel + depth + DOY + **min_DO + temperature**	3
Chinook Mod Full	Latitude + source + diel + depth + DOY + **min_DO + DO + temperature**	4.5
Herring Mod Null	Latitude + source + diel + depth + DOY	0
Herring Mod B	Latitude + source + diel + depth + DOY + **min_DO**	1.4
Herring Mod C	Latitude + source + diel + depth + DOY + **DO**	1.9
Herring Mod D	Latitude + source + diel + depth + DOY + **temperature**	1.9
Herring Mod E	Latitude + source + diel + depth + DOY + **DO + temperature**	3.2
Herring Mod F	Latitude + source + diel + depth + DOY + **min_DO + temperature**	3.4

Herring Mod Full	Latitude + source + diel + depth + DOY + **min_DO + DO + temperature**	5.3

Results and Discussion:

Collation and Processing of Salish Sea Survey Data

We found that two of the available data sources could be applied in this analysis, DFO and UW. Unfortunately, WDFW was not able to access CTD data files that coincided with these fish surveys. The LLTK data will be viable for this type of analysis in future years, however, in previous years there was no record of trawl depth or trawl time (i.e. minutes), which is needed to calculate CPUE and to match the CPUE data with the DO data. For future integration of LLTK survey data into subsequent analyses we have two recommendations. First, we recommend that the linear distance traveled for each tow be recorded, or as a minimum, the tow start and end time (as was available with the DFO data). This allows standardization of catch data by sampling effort and across datasets. Second, we recommend that the depth(s) of the survey net is recorded (i.e. start and end net depth). Depth information allows the matching of depth specific CTD data and provides context to understand the conditions where fish were caught versus conditions throughout the water column.

The following is recommended for any future survey efforts aiming to collect data that can improve understanding of fish DO thresholds in the Salish Sea:

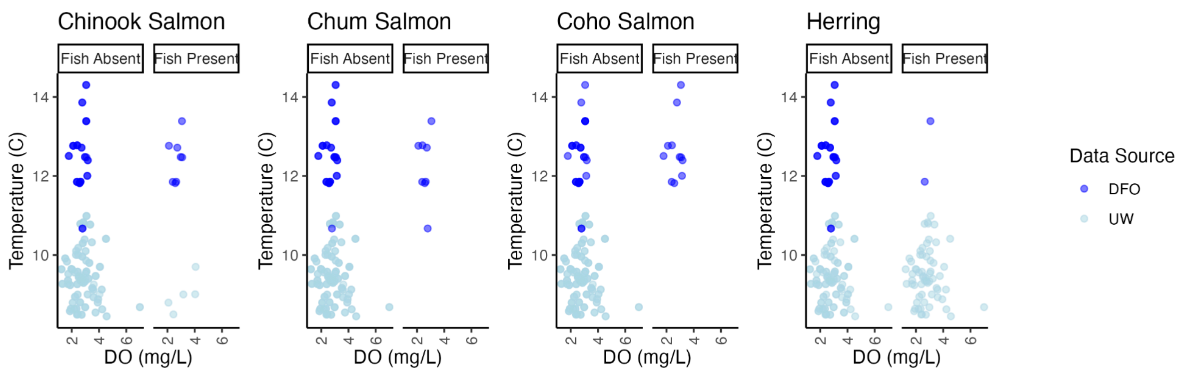
- Conduct CTD sampling (DO and temperature) immediately preceding or following trawl surveys for fish abundances, recording the tow effort (i.e. tow time or distance traveled), gear type, gear depth, location of trawl start and end (latitude and longitude). This is likely more accurate with two boats; however we acknowledge the added survey costs associated with a multi-boat approach likely make it not feasible.
- Ensure the instruments, for example a CTD, have been calibrated and tested, and data processed on a regular cadence.
- Focus surveys seasonally in the Fall to cover the widest range of water column DO concentrations. We suggest the Fall because this is when lower DO values are generally most likely to occur widely. Increased spatial effort across a range of DO values, and low DO values, will allow for increased inference related to DO and temperature thresholds.
- Provide consistent metadata for data-users to provide the necessary context to ensure that data is applied correctly.

Exploration and Qualitative Analysis of Oxygen, Temperature and Taxa Data

We qualitatively explored the oxygen threshold limits of herring and multiple salmon species by plotting fish presence and absence across temperature and DO values to demonstrate the range of conditions that these fish occurred in (Figure 2). Together, these datasets provide insight into the range of temperatures and DO conditions in which Chinook salmon and herring occur. That is that any threshold values must be beyond the range of the environmental conditions represented within the currently available data. We found that the DFO data captured a smaller range of DO values and overall warmer temperatures than the UW surveys (Figure 2). The UW CTD captured DO levels from 1.22 to 6.9 mg DO/L, while the DFO CTD dataset surveyed had a lower and narrower DO range, 1.78 to 3.17 mg/L (Figure 2). The UW CTD captured temperatures from 8.4 -10.9 ℃, while the DFO CTD dataset captured temperatures from 10.6 - 14.3 ℃ (Figure 2).

While chum and coho were not caught frequently enough to incorporate in a statistical model, plots of presents and absence (Figure 2) offer insight into the oxygen conditions that these fish experienced. Qualitatively, there did not appear to be a threshold where fish no longer occurred, fish were caught at very low DO levels (herring: 1.2 - 6.99 mg /L, Chinook salmon: 2.06 - 4.06 mg/L, chum: 2.1 - 3.1 mg/L, coho: 1.79 - 3.17 mg/L).

Figure 2. Fish occurrence by the range of temperature (C) and dissolved oxygen (DO mg/L, adjusted for temperature) values at the same depth where fish were caught. Plots are grouped by species, and colors indicate the data source.



Further examination of the more detailed UW data indicates that herring and Chinook salmon do not appear to "prefer" higher DO regions in the water column (Figures 3 and 4). We found that fish were present at depths with low DO levels even when there was more oxygen available higher in the water column. Specifically, fish were found at lower DO levels (as low as 1.3 mg/L for herring and 2.06 mg/L for Chinook), even when DO levels at other places in the water column were >6 mg/L (Figures 3 and 4). Overall, this qualitative review of the UW data do not indicate a specific threshold for herring or Chinook salmon, but the data do indicate that thresholds are likely below 1.3 mg/L and 2.06 mg/L, respectively, at least for the temperatures experienced in these sampling events.

Figure 3. Depth (ft) and water column DO for UW surveys that caught adult Chinook salmon. The catch per unit effort (CPUE) is represented by the size of the red dot, and the horizontal dashed line indicates the depth where the fish was caught. Plots are grouped by survey month and year (month.year) and the survey location. These surveys took place in Hood Canal, and Da = Dabob Bay, Hp = Hoodsport, and Un = Union.

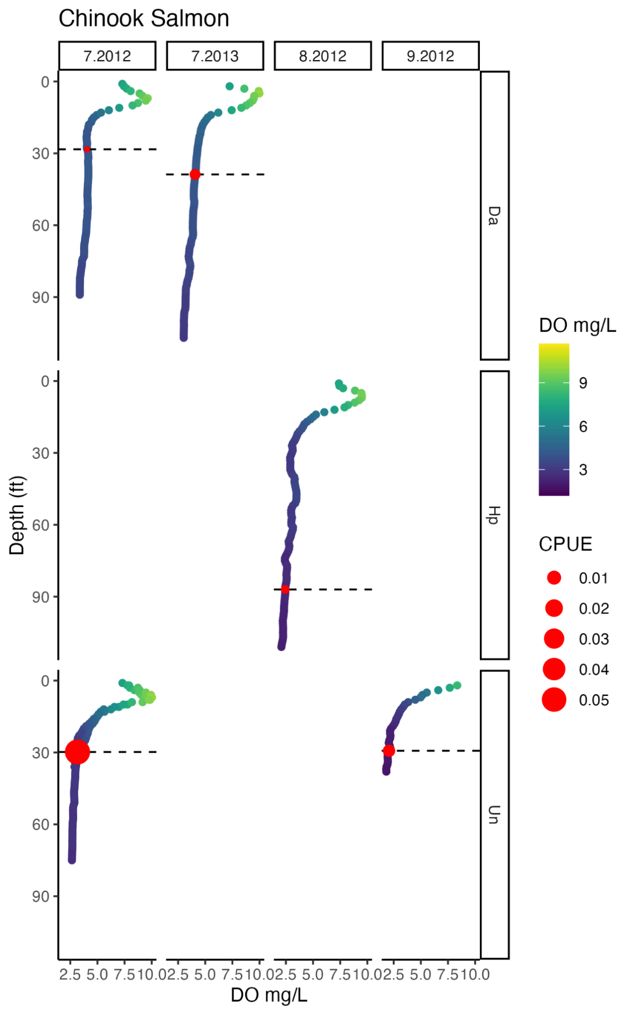
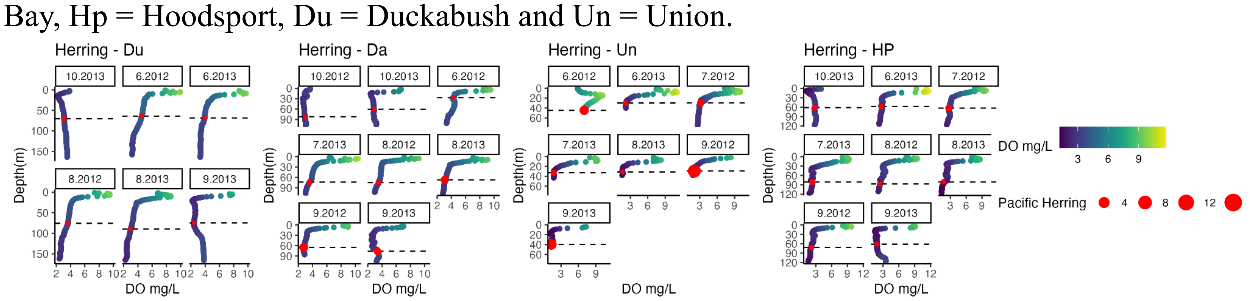


Figure 4. Depth (ft) and water column DO for UW surveys that caught adult Herring. The catch per unit effort (CPUE) is represented by the size of the red dot, and the horizontal dashed line indicates the depth where the fish was caught. Plots are grouped by survey month and year (month.year) and the survey location. These surveys took place in Hood Canal, and Da = Dabob Bay, Hp = Hoodsport, Du = Duckabush and Un = Union.



Hypothesis Testing and Modeling of Environmental Drivers

We used a generalized linear model to estimate the effects of DO on the probability of capturing a herring or a Chinook salmon. For both species, there was no support for models that contained any combination of DO or temperature covariates over a simpler (null) model that only considered location, depth, and day of year without environmental covariates (Table 2). We used AIC_c to identify the most appropriate model among the seven candidate models (Table 2). AIC_c balances model complexity against how well the model fits the data, with a specific correction for small sample sizes. We calculated ΔAIC_c by subtracting the lowest AIC_c from the remaining models. A Δ AIC_c greater than 2 is considered meaningful because it represents a substantial difference in model support based on statistical theory. We found that overall differences in AIC_c values between the null model and B-D alternative models were small (<= 2) so the null model cannot be dismissed for either species. This means that there was no support for the proposed hypotheses using the data collated for this project. We found that DO does not statistically predict the probability of observing a Chinook salmon or herring.

Given the lack of statistical support for including DO or temperature relationships in models estimating fish presence, we suggest that the best way to gain insight into DO and temperature limits from the current dataset is to evaluate the plots of the data qualitatively, as presented prior. This also provides insight into why the available data presents limitations in drawing inferences about DO thresholds. In particular, there was minimal overlap in survey location and timing between both data sets which resulted in fish species being caught in variable environmental conditions from each other (Figure 1 and Figure 2). Conducting more surveys overall, and specifically targeting these surveys for the fall when lower and wider ranges of DO are typical will likely improve the model inference in future analyses.

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Technical Memorandum

Nutrient Reduction Scenario Modeling: Straits of Georgia and Northern Bays

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Objectives

The primary objective of this study is to assess the magnitude of change in dissolved oxygen concentrations in Puget Sound resulting from elimination of nitrogen loadings from specific locations and source types (e.g., wastewater treatment plants and rivers). The operational version of the Salish Sea Model was used to explore the sensitivity of ambient dissolved oxygen conditions to altered nitrogen loadings in six scenarios, as described below. This study is designed to better quantify the response of the system to altered loadings rather than to predict the performance of specific engineering controls or management actions.

This study explores the impact of altering nitrogen loadings from rivers and wastewater treatment plants in the northernmost U.S. waters of the Puget Sound, referred here as the "Straits of Georgia/Northern Bays"). Potential impacts of each scenario are assessed throughout the Salish Sea Model domain and modeling results are presented for Puget Sound waters within Washington State for which dissolved oxygen criteria exist. The operational Salish Sea Model used here has been demonstrated to produce results nearly identical to those used by the State of Washington agencies (Appendix 1). Furthermore, scenarios used the same initialization files for current conditions runs for the year 2014, as well as pre-industrial 'reference' runs.

Description of Scenarios

Six scenarios are evaluated in this report. In each scenario, nitrogen loads from specific sources were altered by changing the 'current conditions' nitrogen concentrations in the source while leaving the temperature and flowrate unchanged, thus preserving the mixing, stratification, and dispersion characteristics among the scenarios. This allows the impact of altered loadings to be isolated from other potentially confounding factors.

1a. Current Conditions. This scenario represents the best current estimate of the nutrient loads and hydrodynamics within the model domain for calendar year 2014 and the results are virtually identical to the 'current' results in the Washington State Department of Ecology 'bounding scenarios' report (Ecology, 2021). This scenario is the baseline against which the remaining five scenarios are compared.

1b. Complete elimination of nitrogen loadings from wastewater treatment plants in the study area. The purpose of this scenario is to calculate the maximum change in dissolved oxygen possible by reducing nitrogen loadings from wastewater treatment plants. In this scenario, all nutrient loads and other conditions (hydrodynamics, meteorology, biogeochemical kinetics, ocean exchange, etc.) were identical to 1a except the nitrogen concentrations (both NO_2^-/NO_3^- and NH_4^+) were set to zero in the 15 wastewater treatment plants that discharge in the Strait of Georgia/Northern Bays region. Note that nitrogen loadings from all other plants within the model domain remained at their 'current condition' loadings.

1c. Complete elimination of nitrogen loadings from rivers in the study area. The purpose of this scenario is to calculate the maximum change in dissolved oxygen possible by reducing nitrogen loadings from the watershed. In this scenario, all nutrient loads and other conditions (hydrodynamics, meteorology, biogeochemical kinetics, ocean exchange, etc.) were identical to 1a except the nitrogen concentrations (both NO_2^-/NO_3^- and NH_4^+) were set to zero in the 7 rivers that flow into the Strait of Georgia/Northern Bays region. Note that nitrogen loadings from all other rivers within the model domain remained at their 'current condition' loadings.

1d. Elimination of nitrogen loadings from the smaller wastewater treatment plants (<100 TN Kg/day), i.e. all plants in the study area except the Post Point Resource Recovery Plant in Bellingham). The purpose of this scenario is to explore the magnitude and spatial extent of nutrient loading from the 14 smaller wastewater treatment plants in the study area. In this scenario, all nutrient loads and other conditions (hydrodynamics, meteorology, biogeochemical kinetics, ocean exchange, etc.) were identical to 1a except the nitrogen concentrations (both NO_2^-/NO_3^- and NH_4^+) were set to zero in the flow from the 14 smaller treatment plants.

1e. Elimination of nitrogen loadings from only the Post Point Resource Recovery Plant in Bellingham, Washington (>100 TN Kg/day). The purpose of this scenario is to explore the magnitude and spatial extent of nutrient loading from a single wastewater treatment plant effluent in the study area. In this scenario, all nutrient loads and other conditions (hydrodynamics, meteorology, biogeochemical kinetics, ocean exchange, etc.) were identical to 1a except the nitrogen concentrations (both NO_2^-/NO_3^- and NH_4^+) were set to zero in the flow from the Bellingham plant.

2b. Doubling nitrogen loads from the watershed. The purpose of this scenario is to better understand the response of Puget Sound water quality to increasing nitrogen loads from the rivers. This scenario is identical to scenario 1c except the nitrogen concentrations in the rivers were set at twice their 'current condition' values. The results of this scenario should add to the information about watershed nutrient impacts from scenarios 1a ('full strength" nitrogen concentrations in the rivers) and 1c (zero).

Table 1: Strait of Georgia/Northern Bays Nutrient Loading Scenarios (values are likely accurate to two significant figures, but are provided here to aid in subsequent calculations).

		Nitrogen Loading Scenarios (kg/year)					
	Annual Total Flow (MG/y)	**1a. Current Conditions**	**1b. WWTP off**	**1c. Rivers off**	**1d. Only Bellingham on**	**1e. Only Bellingham off**	**2b. 200% River Load**
WWTP							
Bellingham	4,540	380,670	-	380,670	380,670	-	380,670
Anacortes	774	63,550	-	63,550	-	63,550	63,550
Birch Bay	315	26,892	-	26,892	-	26,892	26,892
Blaine	234	5,008	-	5,008	-	5,008	5,008
Friday Harbor	101	4,194	-	4,194	-	4,194	4,194
Lummi Goose Pt	98	2,084	-	2,084	-	2,084	2,084
Whidbey Naval Station	97	2,086	-	2,086	-	2,086	2,086
Makah	92	1,956	-	1,956	-	1,956	1,956
Lummi Sandy Pt	44	951	-	951	-	951	951
Eastsound Water District	34	3,536	-	3,536	-	3,536	3,536
Roche Harbor	9.4	205	-	205	-	205	205
Fisherman Bay	9.1	642	-	642	-	642	642
Rosario Utilities	7.7	171	-	171	-	171	171
Larrabee State Park	1.2	30	-	30	-	30	30
Eastsound Orcas Village	1.1	24	-	24	-	24	24
Total WWTPs (altered in this report)		491,999	-	491,999	380,670	111,329	491,999
Total WWTPs (all in model domain)		26,237,735	25,745,736	26,237,735	26,126,406	25,857,065	26,237,735
Rivers							
Nooksack River	1,115,102	1,578,398	1,578,398	-	1,578,398	1,578,398	3,156,832
Whatcom Bellingham Northern	90,128	246,139	246,139	-	246,139	246,139	492,273
Birch Bay	63,523	99,776	99,776	-	99,776	99,776	199,553
Samish River	124,808	333,789	333,789	-	333,789	333,789	667,569
Orcas Island	26,356	68,636	68,636	-	68,636	68,636	137,275
San Juan Island	20,524	53,299	53,299	-	53,299	53,299	106,599
Lopez Island	11,784	30,588	30,588	-	30,588	30,588	61,176
Total Rivers (altered in this report)		2,410,625	2,410,625	-	2,410,625	2,410,625	4,821,277
Total Rivers (all in model domain)		25,511,237	25,511,237	23,100,613	25,511,237	25,511,237	27,921,890

Assumptions and Limitations

This set of scenario runs are designed to explore the response of the modeled water quality parameters to large systematic changes in nutrient loads. These scenarios are not designed to evaluate any specific engineering controls or management actions, but rather provide insight to the sensitivity of dissolved oxygen levels to altered anthropogenic nutrient loadings.

As in earlier applications of the Salish Sea model, the modeling results presented here represent conditions only during one fairly well-characterized calendar year (2014). Further work will be required to assess how the responses to nutrient load changes reported here are influenced by interannual variability in oceanographic and meteorological conditions, and to determine long term responses to altered loadings.

Model parameters, including wastewater treatment plant and river nitrogen loading information, were adopted from earlier applications of the Salish Sea Model by the Washington State Department of Ecology without independent assessment.

Modification of nutrient loads in these scenarios were applied uniformly throughout the year and to both nitrate/nitrite and ammonia so that the same temporal cycle was used in each scenario. Further work will be required to explore the impact of seasonal variations in nitrogen loading and speciation, as well as that for carbon.

Methods to Assess Modeling Results

The Salish Sea model estimates values for water movement, mixing, and biogeochemical parameters (including dissolved oxygen) in 10 water layers at each node in the model, with single values of each parameter stored once per hour for each node/depth location throughout the model year. This model output was analyzed in several ways in order to provide complementary methods to evaluate the scenarios.

First, the minimum dissolved oxygen concentration at each location on each day was extracted and stored, reducing the output file by 24x, and focusing on the lowest DO estimated for each day.

Second, the model results were groups by region (i.e., each model node was assigned to one of six regions in the U.S. waters of the Puget Sound).

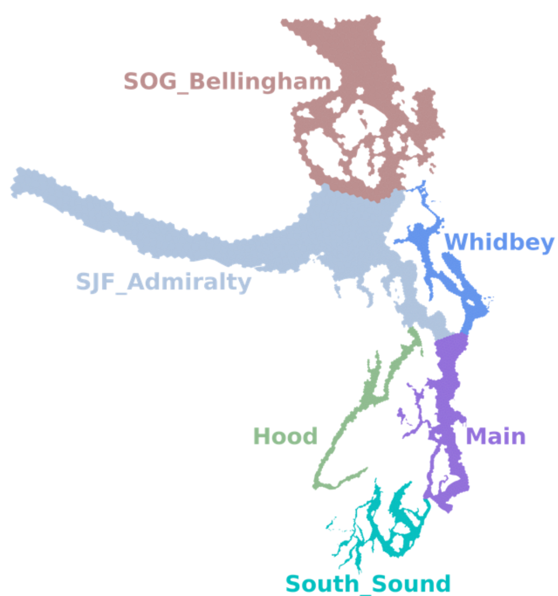


Figure 1: A map of the nodes included in the regional analyses presented in this report. The nodes in the six regions are given unique colors for identification, and these colors are used to represent these regions in the line graphics presented in this report.

These regions are identical to those used by the State of Washington in their water quality technical reports (Figure 1; Appendix 1).

Third, within each region the daily minimum DO values at each node/depth were evaluated for 'non-compliance' using information about the relevant DO standard for that region and the corresponding modeled 'reference' DO value. The entire region was counted as non-compliant on days when dissolved oxygen values were non-compliant at any depth within a node. Figure 2 illustrates this method, where 1 bottom cell-layer (or node-layer) in red for day 1 and 3 cell-layers for day 3 both trigger a day of non-compliance for the water-column at that location. The total number of days in the year with at least one non-compliant node within the region is reported here. A more detailed explanation of the non-compliance (or what might be considered impaired), are provided in Appendix 1 along with all relevant code and sources. This includes all other measures of DO and N presented in this report.

Fourth, the non-compliance determination used above was adapted to estimate the volume of water that met the criteria within each region on each day of the year. Figure 2 illustrates the cell-volumes in red in the water column that would count towards a non-compliant volume estimate each day. As described earlier, if any cell is red then that node is considered non-compliant. The sum of these volumes across a region for each day is used to calculate a percent of total volume that is non-compliant and plotted as time series for each region to demonstrate the seasonal nature of changing water quality conditions. These volumes are also summed over the year to create a single volume-day parameter that represents the time-integrated volume of water in each region that met the non-compliance determination.

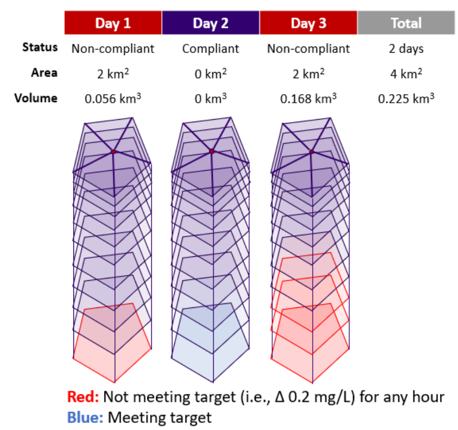


Figure 2: Schematic representation of the non-compliant area and volume calculation.

Finally, the volume-day non-compliant calculation above was normalized to the total volume of each region, resulting in a "percent volume-days" value.

Results

Number of Days non-compliant in Each Puget Sound Region

When analyzed at the region scale, the number of days each region experienced non-compliant DO levels under current (e.g., 2014) nutrient loadings and conditions range from 0 in the Straits of Juan de Fuca/Admiralty Inlet to 176 in the South Sound (Table 2 and Figure 3). Eliminating nitrogen loads from the wastewater treatment plants in the study area (1b) reduced the number of non-compliant days in the immediate area (Straits of Georgia/Northern Bays) from 39 to 20 but did not substantially alter conditions in the other five regions (≤ 2 days change). Not surprising given the relative size of the loads, most of the decrease in non-compliant days from eliminating all wastewater loads (1b) resulted from eliminating the load from the Post Point Resource Recovery Plant in Bellingham (1e). Controlling nitrogen loads from the remaining smaller plants (1d) had only a minor impact (2 days less in the immediate area).

Changing river loading from the watershed had an impact on the number of non-complaint days in the immediate area as well as the other regions of Puget Sound. In the scenarios examining the sensitivity to changes in river nitrogen loading, eliminating loads to the study area (primarily the Nooksack River, 1c) reduced the number of non-compliant days from 39 to 0 days in the immediate area (Straits of Georgia/Northern Bays), with varying impact on far-field areas; from Hood Canal which was the most improved (decreasing 12 days), to South Sound which showed no change. Conversely, increasing loads to two times that of current conditions (2b), resulted in an increase in non-compliant days the immediate area from 39 to 117 days and impacted other regions. As expected, Hood Canal was the most sensitive region (increasing 17 days) while all other regions exhibited an increase of 3 days or less outside of the immediate area.

Table 2: Number of predicted non-compliant days for each scenario by region in 2014.

	1a. Current Conditions	1b. WWTP off	1c. Rivers off	1d. Only Bellingham On	1e. Only Bellingham Off	2b. 200% River Load
Hood Canal	146	144	134	145	145	163
Main Basin	162	161	155	162	162	165
SJF/Admiralty	0	0	0	0	0	0
SOG/Northern Bays	39	20	0	37	20	117
South Sound	176	176	176	176	176	178
Whidbey	174	173	164	173	173	176

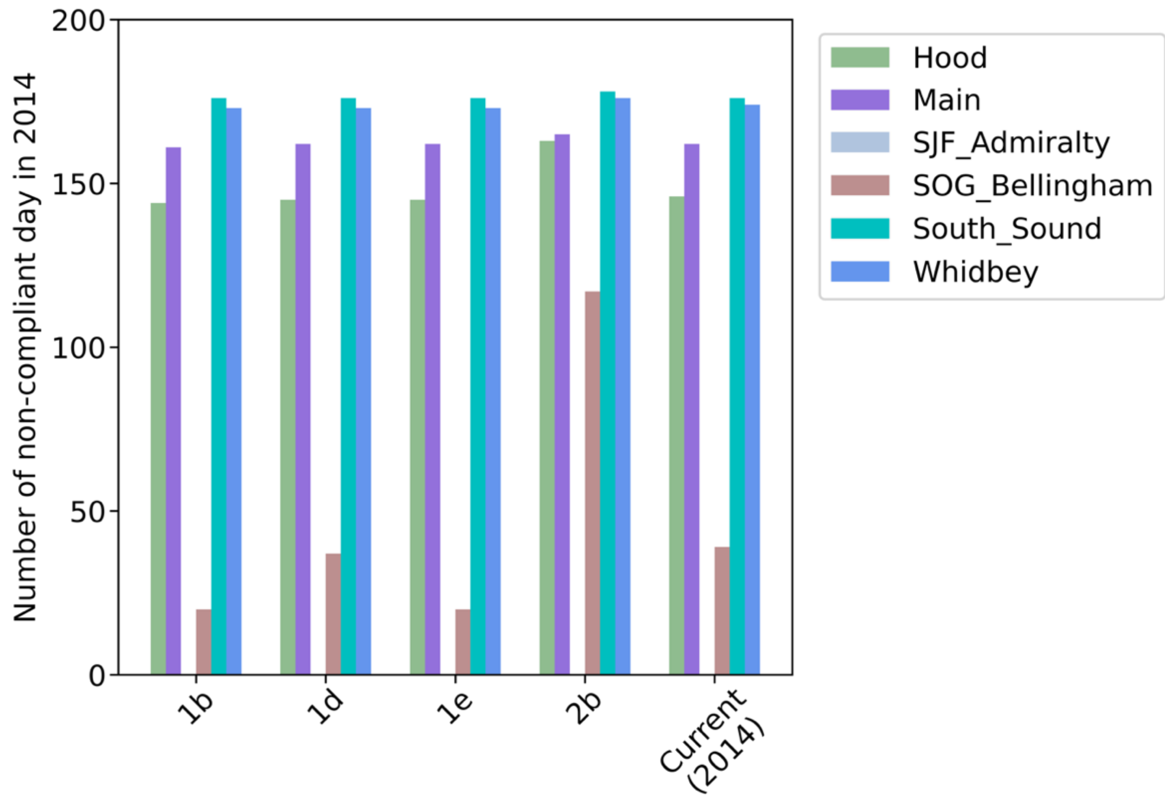


Figure 3: Number of predicted non-compliant days for each scenario in 2014 by region shown in Figure 1. Note that the Strait of Juan de Fuca/Admiralty region is not shown as zero days of non-compliance (Table 2), and SOG_Bellingham represents the immediate study region: Strait of Georgia/Northern Bays.

Percent of the Volume of Each Region Impaired

Model results for each of the scenarios were also analyzed to calculate the fraction of the water in each region which is non-compliant during each day of the year. This provides an index of how much of the available water in each region was depleted in dissolved oxygen as determined by the State of Washington non-compliance methodology. Results of this analysis for the waters adjacent to the Strait of Georgia/Northern Bays nutrient loadings examined in this report are shown summarized in Table 3 and in Figure 4 following.

*Table 3: Percent Volume-Days Non-Compliant in Each Region**

	1a. Current Conditions	1b. WWTP off	1c. Rivers off	1d. Only Bellingham On	1e. Only Bellingham Off	2b. 200% River Load
Hood Canal	0.0522	0.0504	0.0451	0.0517	0.0506	0.0613
Main	0.0065	0.0064	0.0062	0.0065	0.0064	0.0069
SJF/Admiralty	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SOG/Northern Bays	0.0012	0.0004	0.0000	0.0012	0.0004	0.0089
South Sound	1.1457	1.1384	1.0921	1.1444	1.1403	1.2031
Whidbey	0.5009	0.4923	0.4513	0.4988	0.4943	0.5551
All Combined	0.0509	0.0501	0.0470	0.0508	0.0502	0.0570

*The volume of non-compliant water in each region each day is totaled over the model year (the total annual volume on non-compliant water) and then divided by 365 times the total volume of the region (assumed constant throughout the year) to yield a fraction of the total volume. This result is then multiplied by 100 to show the percentage of volume that is non-compliant. For example, a value of 0.0509 means that 0.0509% of the water is non-compliant during the year.

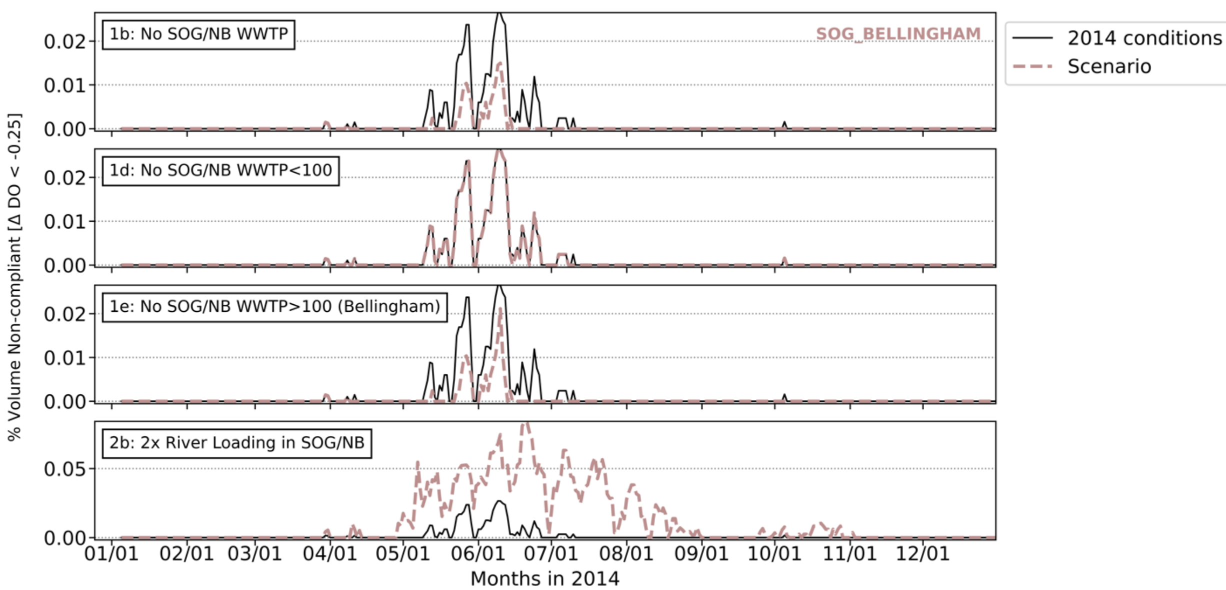


Figure 4: Percent volume non-compliant for the Strait of Georgia and North Bays region, as shown in Figure 1: (see Appendix 1 for details on methodology).

Under the 2014 conditions (solid line in Figure 4), up to 0.025% of the waters of the Straits of Georgia/Bellingham Bay region were estimated to be non-compliant, with maximum levels occurring during 2 months, peaking in both late May and early June. The model calculations suggest these waters are in compliance with respect to dissolved oxygen for the majority of the first four and last 6 calendar months. Eliminating nitrogen loadings from all wastewater treatment plants (1b, dashed line) reduces the maximum non-compliant volume from 0.025% to 0.015% in this region. Note that the temporal trends are largely preserved across all WWTP reduction scenarios, relative to the current 2014 conditions. However, removing loading from the largest plant (1e) did reduce the last non-compliance of the summer in late June. Lastly, when expressing the model results as 'number of non-compliant days', the smaller wastewater treatment plants exert a minimal influence on both the magnitude and the timing of non-compliant volume (1d), with the model results with no nitrogen loadings from these plants virtually identical to the 2014 conditions.

Changing river loadings from watersheds impacted the magnitude of percent non-complaint volume, as well as the number of months when non-compliance was modeled in the Straits of Georgia/Northern Bays region. Increasing loads by two times that of current conditions (2b) resulting in an increase in the maximum level from 0.025 to 0.085%, and a shift to a longer and later sustained volume non-complaint extending through summer (dashed line in 2b in Figure 4). The scenario where the river nitrogen loads to the study area were eliminated (1c) resulted in 0 % volume days non-compliant (Table 3). This to be expected for this scenario, which results in higher modeled dissolved oxygen concentrations than the reference condition (pre-development) scenario, since nitrogen loadings in the river water were set to zero – a value considerably lower than might be expected in a pre-development scenario.

The study area is highly energetic, and its water quality is not especially vulnerable to nutrient loadings from treatment plants, nor (to a lesser extent) from U.S. rivers. It is the least impacted of the Puget Sound regions after the Strait of Juan de Fuca/Admiralty. For comparison, Figure 5 shows both the magnitude and timing of the modeled dissolved oxygen non-compliance (again, expressed as a percentage of the region's volume that is non-compliant) for the Whidbey Region in 2014. Here non-compliance begins later in the summer and extends through October, reaching maximum non-compliance volumes of approximately 2.5% of the total water volume. Note that altering nitrogen loads from the Strait of Georgia/Northern Bays wastewater treatment plants and rivers does not appear to impact the Whidbey region in this analysis, while doubling riverine loading shows some increase in non-compliance in the region.

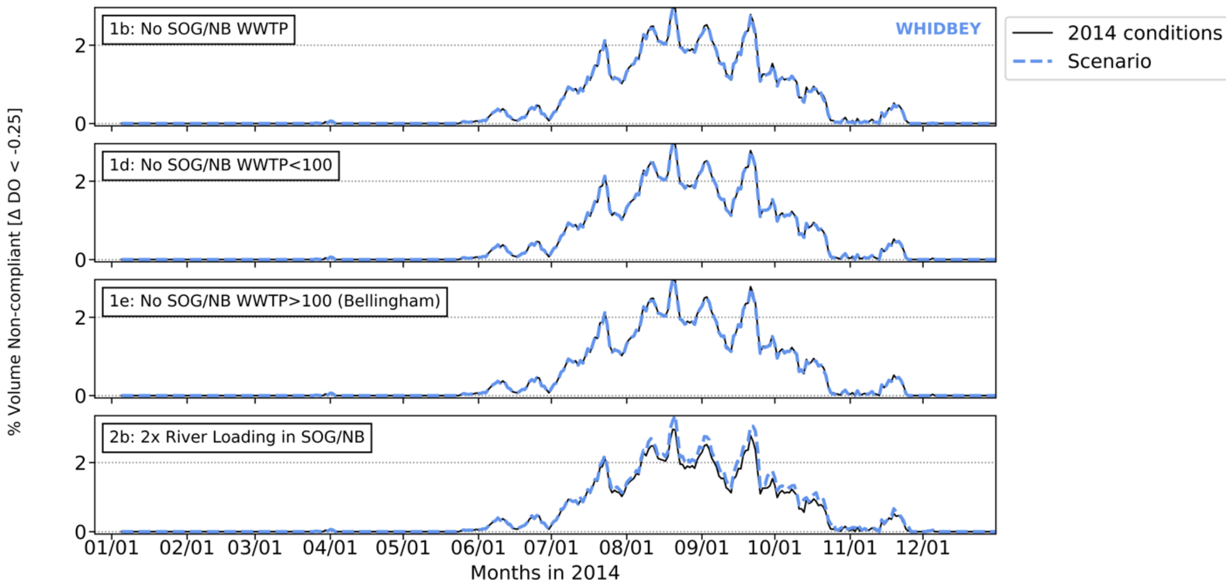


Figure 5: Percent volume non-compliant for nodes in the Whidbey region as a result of changes in nutrient loading to the Strait of Georgia and Northern Bays region.

Functional Relationship between Nitrogen Loadings and Dissolved Oxygen Levels

These modeled scenarios allow an initial assessment of the response of Puget Sound water quality to changes in nutrient loadings from wastewater treatment plants and from rivers. For this analysis, the total annual nitrogen loading (kg/year) to the Puget Sound from all treatment plants and rivers (within the U.S. as defined by prior analyses by the State of Washington) was calculated and compared to the change in the annual average volume of non-DO compliant water in Puget Sound as presented in the section above. Both parameters were normalized to the 2014 'current condition' scenario, as shown in Figure 6. In this figure, the points represent the 2014 current conditions run (e.g., the point at (1,1)) and the four scenarios presented earlier.

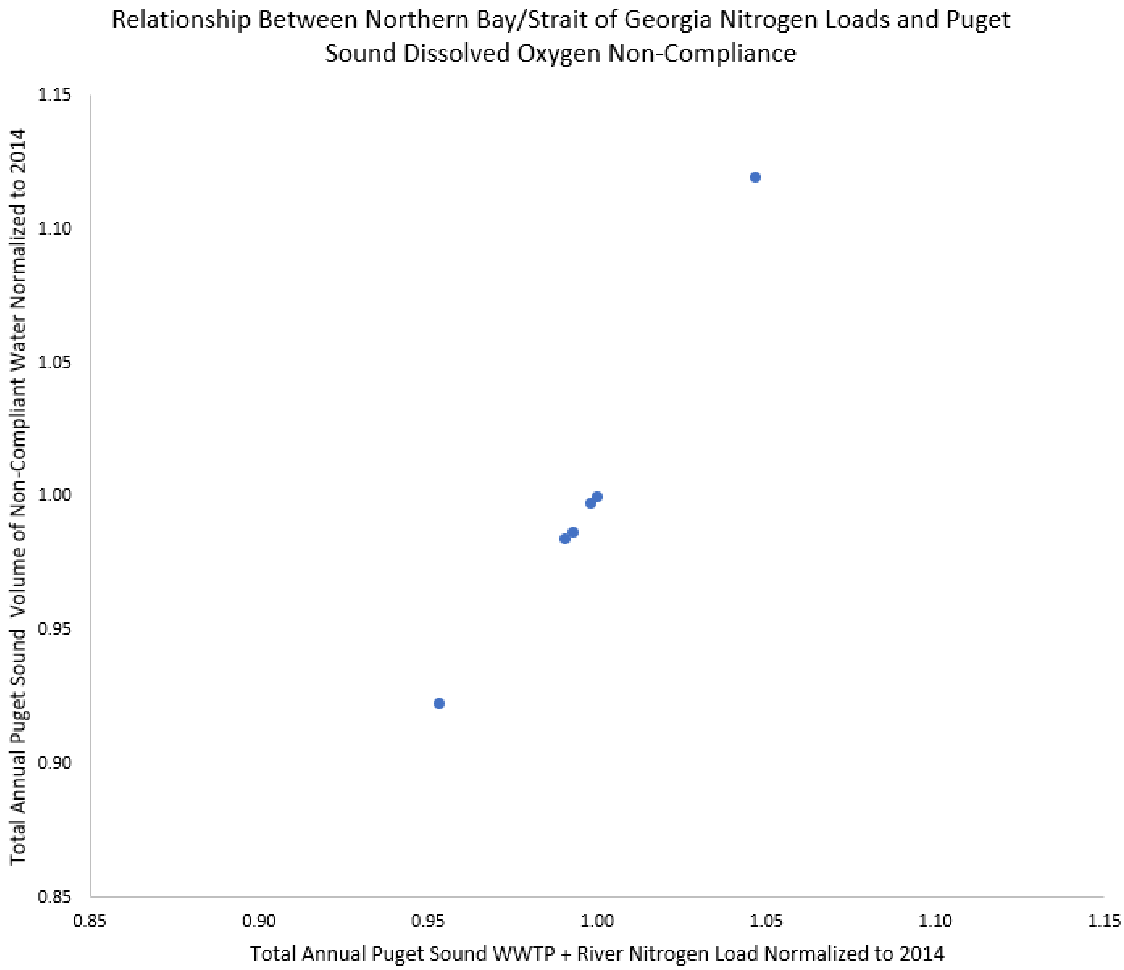


Figure 6. Relationship between annual nitrogen loadings and volume of non-compliant water (normalized to 2014).

This figure demonstrates the sensitivity of Puget Sound water quality to alteration in the magnitude of nitrogen loading, with no changes to the hydrodynamics. Over the range of loadings examined here, this figure shows that altered loads from wastewater treatment plants and from rivers appear to share a similar functional relationship, at least on an annual basis. Further work is required to verify this result and to establish whether the water quality will respond differently seasonally to altered nitrogen loads from the two source types. Note that this relationship was derived specifically for the area of the Straits of Georgia/Northern Bays within the larger Salish Sea system, and one might expect different nitrogen loading/water quality change relationships within other parts of Puget Sound or the Salish Sea.

As an initial assessment, Figure 6 above indicates that changing nitrogen loads by x% relative to a baseline will potentially change the volume of non-DO compliant water by 2x%; bearing in mind that in the level of non-compliance in this Strait of Georgia/Northern Bays study area is typically much less than 2% of the total volume. Further work is required to determine the feasibility and costs of nutrient removal strategies and to estimate the benefits to water quality and ecosystem services.

Summary

To assess the sensitivity of Puget Sound dissolved oxygen levels to nitrogen loadings from point sources (permitted wastewater treatment plants) and rivers in the Strait of Georgia/Northern Bays, an operational version of the Salish Sea Model was used to run various scenarios of nitrogen loading, along with postprocessing algorithms to calculate modeled impact. Scenarios were examined where nitrogen loadings from treatment plants and rivers were varied from the 2014 'current conditions' model scenario established by the State of Washington as one of their focal years. Results were interpreted both in terms of the number of days each year the water was modeled to be 'non-DO compliant' (following the State of Washington methodology) and as the percentage of the Sound's water that was modeled to be non-compliant throughout the year.

Results of this analysis are specific to the scenarios completed and only strictly apply to the study region in the northern Puget Sound. Further work is required to conduct similar analyses throughout other regions of Puget Sound.

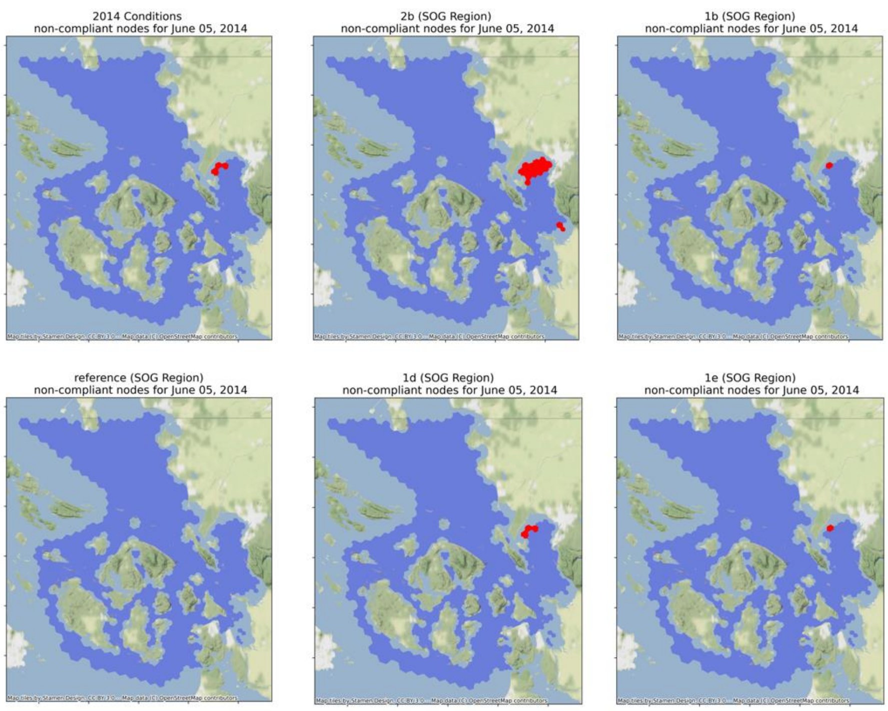
Results here suggest:

1. The U.S. waters of the Strait of Georgia and Northern Bays exhibit dissolved oxygen levels that trigger 'non-compliance' primarily during two months in spring and early summer. During these times, up to 0.025% of the water (by volume) is estimated to trigger non-compliance, compared to approximately 2.5% modeled in the Whidbey Region.
2. Estimated annual nitrogen loadings to the study area from the 15 wastewater dischargers is 0.5 million kg/year compared with 2.4 million kg/year from the 7 local rivers (which include upstream anthropogenic and natural sources of nitrogen)
3. Eliminating nitrogen loadings from the 14 smaller permitted wastewater dischargers in the study area has very little demonstrable effect on the dissolved oxygen levels in this highly energetic region of Puget Sound.
4. Eliminating nitrogen loadings from the largest permitted wastewater discharger reduces the estimated number of days the immediate region is considered 'non-DO compliant'; from 39 to 20 days per year.
5. The current modeling suggests that nitrogen loadings into the study area have minimal impact on dissolved oxygen levels in other Puget Sound regions. However, these differ by region. Hood Canal was the most impacted by both WWTPs and riverine loading (particularly by large increases in riverine loading), while the Main Basin and South Sound remained largely unchanged. Potential impacts on Canadian waters were not assessed here.

Appendix 1

1.1 Maximum Volume Day Non-Compliance
1.2 Other documentation - including code and sources for non-compliant and other calculations, as well as model run inputs

Appendix 1.1: Maximum Volume Day Noncompliance - on June 5 for 2014 Conditions



Appendix 1.2: Other documentation - including code and sources for non-compliant and other calculations, as well as model run inputs.

The non-compliance values reported were calculated using "Part B" non-compliance as determined by the Washington State Department of Ecology. In the Washington State Department of Ecology Optimization Report Appendix F (page 48), Part B noncompliance is calculated where:

1. Min DO for the reference case < DO standard + human allowance
2. Min DO (scenario) – Min DO (reference) < human allowance

A human allowance of -0.2 mg/L was used for all non-compliance estimates presented in this report. In addition, our calculations follow the department of Ecology's "rounding method," which effectively adds -0.05 mg/L to the human allowance for the second part of the assessment, with the result of flagging non-compliance where Min DO (existing or scenario) – Min DO (reference) < -0.25 mg/L. Table 4: A comparison of "Area non-compliant" and "Max days non-compliant" between those presented by the Department of Ecology Optimization Scenario Report (DOE values) and those calculated according to the method described here.

The method used in this report to calculate non-compliance provided similar results to that of the States, presented in the Bounding Scenarios Update (Ecology, 2021), and shown in Table 4. Furthermore, scenarios presented here used the same initialization files for reference and current condition runs for the year 2014 [11]. Total non-compliant area over all regions was 2.1% different, while maximum number of non-compliant days was 3.1% different, likely attributed to the simplified methodology applied here only to Part B of the standard. At the time of writing, the scripts used by Ecology were not available for direct review of the code, however the methodology are described in Appendix F of the Bounding Scenarios Update report [12].

Table 4: A comparison of "Area non-compliant" and "Max days non-compliant" between those presented by the Department of Ecology Optimization Scenario Report (DOE values) and those calculated according to the method described here.

	DOE values	PSI methodology	Relative Difference
Area	341	348	2.1%
Max Days	163	158	3.1%

Overview of computing process

The following code was used in the analysis presented in this report. Please contact rdmseas@uw.edu regarding access and collaboration on further development:
1. Configuration file used to collate information for this set of runs [1].
2. Shapefile used in this report to define regions, region names, node area, etc. [2]
3. Notebook to create maps of the regions described in this report [3]

4. Notebook used for QAQC of non-compliance calculation by comparing PSI non-compliance values of area non-compliant and max number of days non-compliant with Department of Ecology values [4].
5. Python script used to create of spreadsheets that provide the following information for each scenario (and within each region defined by the shapefile listed above): Non-compliant days, area non-compliant, volume days non-compliant, percent volume days non-compliant [5]. Note: A "readme" tab is included in the spreadsheet files that also provides links to the code. For the SOG/NB study, the spreadsheet is available here: SOG_NB_wc_noncompliant_m0p25.xlsx.
6. Python script used to create the spreadsheet with percent non-compliant values for every scenario with columns representing regions and rows for every days in 2014 (staring with day 6 to avoid "spin-up" days) [6]. SOG_NB spreadsheets can be found here: SOG_NB_noncompliance.
7. Python script used to create the spreadsheets with information on hypoxic conditions (DO<2) represented by: Number of days, volume days, and percent volume days [7]. The SOG_NB spreadsheets can be found here: SOG_NB_wc_DO-lt-2.xlsx.
8. Python script used to create the 4-panel time-series graphic showing non-compliance for each day in 2014, for all regions with a sub-plot for each scenario [8].
9. Python script used to create graphics showing non-compliant nodes (which can be combined using "ffmpeg" to create a movie[1]https://usc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en-US&rs=en-US&wopisrc=https://uwnetid.sharepoint.com/sites/og_uwt_psi/_vti_bin/wopi.ashx/files/743634ec121644d8bd338afdae0a8229&wdenableroaming=1&wdfr=1&mscc=1&hid=68927DA0-0021-2000-E79A-4206CDF7B196&wdorigin=Other&jsapi=1&jsapiver=v1&newsession=1&corrid=b7a8b204-d2a7-476a-a59e-74919684700c&usid=b7a8b204-d2a7-476a-a59e-74919684700c&sftc=1&cac=1&mtf=1&sfp=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush&rct=Medium&ctp=LeastProtected) [9].
10. Jupyter Notebook used to create the graphics of nutrient loading shown in this report [10].

References

[1] https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/etc/SSM_config_SOG_NB.ipynb
[2] https://github.com/UWModeling/SalishSeaModel-grid/blob/main/shapefiles/SSMGrid2_tce_ecy_node_info_v2_10102022/SSMGrid2_tce_ecy_node_info_v2_10102022.shp

[1] See, e.g., https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/bash_scripts/create_noncompliance_movie_whidbeyZoom.sh

[3] https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/notebooks/plot_region_maps.ipynb
[4] https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/notebooks/QAQC_days_noncompliant.ipynb
[5] https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/py_scripts/calc_noncompliance.py
[6] https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/py_scripts/calc_noncompliance_timeseries.py
[7] https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/py_scripts/calc_DO_below_threshold.py
[8] https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/notebooks/plot_noncompliance_timeseries.ipynb
[9] https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/py_scripts/plot_noncompliant_graphics4movie_SOGZoom.py
[10] https://github.com/UWModeling/SalishSeaModel-analysis/blob/main/notebooks/plot_nutrient_loading_SOG.ipynb
[11] Appendix F of Department of Ecology's Optimization Scenario report describing the State's non-compliant methodology: https://www.ezview.wa.gov/Portals/_1962/Documents/PSNSRP/Appendices%20A-G%20for%20Tech%20Memo.pdf.
[12] Department of Ecology website providing initialization files for current and reference condition scenario runs for 2014: https://fortress.wa.gov/ecy/ezshare/EAP/SalishSea/SalishSeaModelBoundingScenarios.html#OptimizationScenariosY1

United States
Environmental Protection
Agency

2023 Revision* to:

Life Cycle and Cost Assessments of Nutrient Removal Technologies in Wastewater Treatment Plants

* This 2023 revision entails errata regarding nitrous oxide emissions from wastewater biological treatment processes, as described on the next page.

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ERRATA

In 2023, EPA identified an error in Equation F-3, used to calculate nitrous oxide (N_2O) emissions from wastewater biological treatment processes. This equation, located on page F-2, included an incorrect molecular weight conversion factor of N to N_2O of 44/14. The correct conversation factor is 44/28. See the errata sheet located at the end of this document for more information.

EXECUTIVE SUMMARY

Human-caused nutrient enrichment of waterbodies from excessive nitrogen (N) and phosphorus (P) is one of the most pervasive environmental issues facing the United States (U.S. EPA, 2015a). In many watersheds, municipal and industrial wastewater treatment plants (WWTPs) can be major point sources of nutrients. Recent efforts to derive numeric nutrient criteria to protect the designated uses of waterbodies have resulted in limits that may be challenging to meet for most WWTPs in the United States with the treatment configurations currently in place. However, many stakeholders have expressed concern that there may be significant undesirable environmental and economic impacts associated with upgrading treatment configurations, as these configurations may require greater use of chemicals and energy, release more greenhouse gases, and generate greater volumes of treatment residuals for disposal.

The impacts can be assessed using holistic, systematic approaches using life cycle impact assessment (LCIA) and life cycle cost analysis (LCCA). These approaches provide a “cradle-to-grave” analysis of the environmental impacts and benefits as well as the economic costs and benefits associated with individual products, processes, or services throughout their life cycle. This study used LCIA and LCCA approaches to assess cost, human health, and ecosystem metrics associated with nine distinct wastewater treatment configurations designed to reduce the nutrient content of effluent from municipal WWTPs.

Table ES-1 depicts the five different total nitrogen and phosphorus treatment levels used to configure nine different wastewater treatment systems commonly used in the U.S. to achieve the specified nutrient concentrations. Level 1 represents a standard secondary treatment configuration with no additional processes for nutrient removal. For Levels 2-5, two configurations that could meet the performance target were selected per level, representing contrasts in factors such as biological processes, costs, and energy requirements. Each configuration was modeled with an average flow rate of 10 million gallons per day (MGD) and a maximum flow rate of 20 MGD.

Table ES-1. Target Effluent Nutrient Concentrations by Level

Level	Total Nitrogen, mg/L	Total Phosphorus, mg/L
1	no target specified	no target specified
2	8	1
3	4-8	0.1-0.3
4	3	0.1
5	<2	<0.02

For the life cycle impact assessment, this study considered 12 impact categories: eutrophication potential, cumulative energy demand, global warming potential, acidification potential, fossil depletion, smog formation potential, human health-particulate matter formation potential, ozone depletion potential, water depletion, human health-cancer potential, human health-noncancer potential, and ecotoxicity potential. The majority of impact categories address air and water environmental impacts, while three categories are human health impact indicators.

Eutrophication potential (i.e., potential for enrichment of waterbodies with nutrients) is the combined effect of direct nutrient discharges in the effluent, landfilled sludge leachate, and the water discharges and air emissions from upstream inputs such as electricity and chemical production. Eutrophication potential decreased dramatically between Level 1 and Level 2 and to a smaller degree between Level 2 to Levels 3 and 4, which were similar to each other. Level 5 had higher eutrophication potential than Level 4 due to the energy requirement of reverse osmosis and brine injection, which off-set the impact reduction associated with the lower effluent nutrient concentration. However, based on the uncertainty thresholds for impact results, the difference between Level 3, Level 4 and Level 5 is not considered significant.

Cumulative energy demand, acidification potential, fossil depletion, smog formation potential, particulate matter formation, and global warming potential all showed a roughly similar trend. The values for these categories all increased from Level 1 to Level 5 due to increasing electricity use and natural gas heating consumption required to achieve the lower nutrient values for the treatment systems selected.

Water depletion results were dominated by the high-water use of Level 5 treatment configurations, approximately 100 times the other configurations, primarily for deepwell injection of brine. The potential for reuse of wastewater following Level 5 treatment was not considered in this study.

Although not specifically designed for it, the treatment configurations may also remove trace pollutants (metals, toxic organics, and disinfection by-products [DBPs]) from effluent, providing a toxicity reduction co-benefit. For configuration Levels 1-3, metals in liquid effluent dominated toxicity impacts, whereas for Level 5, contributions from material and energy inputs dominated, with Level 4 configurations having significant contributions from both sources. For human health-cancer potential, Levels 1, 3, and 4 had lower impacts than Levels 2 and 5, whereas for human health-noncancer potential, toxicity impacts decreased as treatment became more advanced For ecotoxicity, Levels 3, 4, and 5 had lower toxicity than Levels 1 and 2. Overall, one of the Level 4 configurations and, to a lesser degree, one of the Level 3 configurations stood out in most effectively balancing effluent toxicity reductions against the increase in materials and energy required. Uncertainty for the toxicity impact assessment was greater than for other impacts due to trace pollutant data limitations and to uncertainty inherent in the impact estimation method (USEtox™).

The life cycle cost analysis provided results for capital costs, annual operation and maintenance costs, and net present value, which combines the capital and operation and maintenance costs into a single cumulative value (all in 2014$). In general, the net present value increased with increasing nutrient control levels. The Level 2 configurations were an exception to the trend due to the high annual costs associated with the three separate biological units.

Sensitivity analyses considered different interest rates, electricity grid composition, improved energy capture at the facility, and a retrofit scenario instead of building a new facility. Since electricity was a primary driver for many of the impact categories assessed, many of the trade-offs associated with greater nutrient reductions could be significantly reduced if the WWTP were to use an electrical grid with r with lower emissions and/or to use recovered resources (e.g., biogas) to generate on-site energy, reducing the need for purchased electricity.

Overall, two key findings emerged from this analysis. First, clear trade-offs in cost and potential environmental impact were demonstrated between treatment level configurations. This suggests that careful consideration should be given to the benefits from lower nutrient levels compared to the potential environmental and economic costs associated with treatment processes used to achieve those levels. Combining outcomes into metrics such as nutrients removed per dollar or per unit energy may help to identify configurations that strike an efficient balance between these objectives. For example, this analysis found that electricity per unit of total N and P equivalents removed remained consistent from Level 2 through Level 4 but was 2-3 times higher for Level 5 configurations. Second, this analysis demonstrated the value of a life cycle approach to assessing costs and benefits. For example, considering trace pollutants from a life cycle perspective illuminated that the benefits of increased trace pollutant removal from effluent could be outweighed by trace pollutant emissions from materials and energy usage for the Level 5 configuration, an insight that would not have been gained by analyzing on-site WWTP processes alone. In summary, considering multiple economic, social, and environmental costs and benefits from a life cycle perspective can provide critical insights for informed decision-making about wastewater treatment technologies.

FOREWORD

The objective of this study is to assess a series of wastewater treatment system configurations designed to reduce the nutrient content of effluent from municipal wastewater treatment facilities. The combination of life cycle assessment (LCA) and life cycle cost analyses (LCCA) provides a full picture of costs, both quantitative and qualitative, for the various wastewater treatment configurations evaluated. This technical report presents the results of the study. It does not discuss the policy implications of the analysis, nor does it discuss the EPA's policy on nutrient pollution, the development of nutrient criteria, approaches for addressing the problem, nor the full suite of benefits from the different treatment configurations that can be realized.

This report complements and supplements the EPA's May 2015 publication, *A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution* (https://www.epa.gov/nutrient-policy-data/compilation-cost-data-associated-impacts-and-control-nutrient-pollution), which provides the public with information to assist stakeholders and decision-makers in addressing cultural eutrophication.

Acronyms and Abbreviations

A2O	Anaerobic/Anoxic/Oxic
AS	Activated sludge
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAPDETWorks™	Computer Assisted Procedure for the Design and Evaluation of Wastewater Treatment Systems
CBOD	Carbonaceous biochemical oxygen demand
CEC	Contaminants of emerging concern
CED	Cumulative Energy Demand
CHP	Combined heat and power
COD	Chemical oxygen demand
DBP	Disinfection byproduct
DBPFP	Disinfection byproduct formation potential
DQI	Data quality indicator
EDC	Endocrine disrupting chemicals
EF	Emission factor
eGRID	Emissions & Generation Resource Integrated Database
EPA	Environmental Protection Agency (U.S.)
ERG	Eastern Research Group, Inc.
FP	Formation potential
GHG	Greenhouse gas
GT	Gravity thickener
GWP	Global warming potential
HAA	Haloacetic acid
HAB	Harmful algal blooms
HAN	Haloacetonitrile
HHV	High heating value
ICE	Internal combustion engine
ISO	International Standardization Organization
LCA	Life cycle assessment
LCCA	Life cycle cost analysis
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MBR	Membrane bioreactor
MCF	Methane conversion factor
N	Nitrogen
NNC	Numeric nutrient criteria
NOM	Natural organic matter
NPCC	NorthEast Power Coordinating Council
ORD	Office of Research and Development (U.S. EPA)
P	Phosphorus
PM	Particulate matter
PPCP	Pharmaceuticals and personal care products
PPI	Producer's price indices
RO	Reverse osmosis
THM	Trihalomethanes
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen

TP	Total phosphorus
TRACI	Tool for the Reduction and Assessment of Chemical and Environmental Impacts
UF	Ultrafiltration
UIC	Underground injection control
UNFCCC	United Nations Framework Convention on Climate Change
US LCI	United States Life Cycle Inventory Database
VFA	Volatile fatty acids
WWT	Wastewater treatment

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1. GOAL AND SCOPE DEFINITION

1.1 Introduction and Objective

Cultural eutrophication of waterbodies across the United States is one of the most pervasive environmental issues facing the country today. Whether in lakes or reservoirs, rivers or streams, estuaries or marine coastal waters, the human health, environmental, and economic impacts from excessive amounts of nitrogen (N) and phosphorus (P) continue to rise year after year. Communities struggle with harmful algal blooms (HABs) that produce toxins which can sicken people and pets, contaminate food and drinking water sources, destroy aquatic life, and disrupt the balance of natural ecosystems. HABs can raise the cost of drinking water treatment, depress property values, close beaches and fishing areas, and negatively affect the health and livelihood of many Americans (U.S. EPA, 2015a). Global climate change is only expected to exacerbate eutrophication even as Federal, state, and local governments struggle to address the sources of nutrient pollution (USGCRP, 2015).

In partnership with states, tribes, and other Federal agencies, the U.S. Environmental Protection Agency (EPA) has led the effort to address nutrient pollution by assisting states in prioritizing waters, providing scientific and technical assistance in the development of water quality standards for total nitrogen (TN) and total phosphorus (TP), and helping to guide implementation of nutrient criteria in waterbody assessments, including the development of total maximum daily loads for impaired waters and the inclusion of water-quality based effluent limits for point source dischargers.

In many watersheds, municipal and industrial wastewater treatment plants (WWTPs) can be major point sources of nutrients. Removal of TN and TP can vary significantly depending on the raw wastewater characteristics and the treatment technologies used at each WWTP. Recent efforts by states and the EPA to derive numeric nutrient criteria (NNC) that will protect the designated uses under the Clean Water Act reveal limits that clearly push the boundaries of treatment technologies currently in place for most facilities in the United States. Operators and other stakeholders have expressed concern that there may be potentially significant environmental and health implications and economic impacts associated with pushing those boundaries, given it can lead to greater use of chemicals, treatment residuals disposal, increased energy demands, and greater release of greenhouse gases. Studies in other countries also suggest a point of diminishing returns where the economic and environmental consequences may begin to outweigh the benefits of certain advanced treatment technologies (e.g., Foley et al., 2010). Such issues, which encompass economic, environmental, and social costs, are at the center of sustainability evaluations, and can be assessed using holistic, systematic approaches such as life cycle assessment (LCA) and life cycle cost analysis (LCCA).

LCA is a widely accepted technique to assess the environmental aspects and potential impacts associated with individual products, processes, or services. It provides a “cradle-to-grave” analysis of environmental impacts and benefits that can better assist in selecting the most environmentally preferable choice among the various options. The steps for conducting an LCA include (1) identifying goal and scope, (2) compiling a life cycle inventory (LCI) of relevant energy and material inputs and environmental releases, (3) evaluating the potential environmental impacts associated with identified inputs and releases, and (4) interpreting the results to help individuals make a more informed decision.

LCCA is a complementary process to LCA for evaluating the total economic costs of an asset by analyzing initial costs and discounted future expenditures over the life cycle of an asset (Varnier, 2004). It is used to evaluate differences in cost and timing of those costs between alternative projects. The LCCA conducted in this study is not "cradle-to-grave", but rather considers only costs incurred by the facility for establishing a new WWTP (i.e., greenfield project[1]). A retrofit case study was performed and described later in this report.

The objective of this study is to assess a series of wastewater treatment system configurations (hereafter referred to as "wastewater treatment configurations") designed to reduce the nutrient content of effluent from municipal WWTPs. The assessment considers treatment costs as well as human health and ecosystem impacts from a life cycle perspective. The combination of LCA and LCCA provides a full picture of costs, both quantitative and qualitative, for the various wastewater treatment configurations evaluated. This report uses the term wastewater treatment plant, or WWTP, while recognizing that an effort is underway to transition to a new term: "water resource recovery facility". The use of WWTP was selected only as a reflection of historical usage and is not intended to convey preference.

This study compares cost, human health, and ecosystem metrics associated with nine distinct wastewater treatment configurations to provide context for understanding the outcomes from an environmental, economic, and social/societal perspective. The nine wastewater treatment configurations fall into one of five different levels of nutrient reductions, as defined in Table 1-1. Level 1 is a baseline system consisting of a standard secondary treatment configuration with no specific nutrient removal target. The other four levels considered here specify nutrient removal targets with increasing stringency. The wastewater treatment configurations selected for assessment include two alternative configurations for each of the nutrient reduction levels 2 through 5. These configurations were selected because they generally represent configurations commonly used to achieve the specified nutrient performance levels. These configurations were also selected to provide contrast in factors such as the biological processes used, capital costs, operating costs, energy requirements, and sludge generation.

While effluent nutrient concentrations are the main driver of the treatment configuration upgrades analyzed by this study, there is also growing concern over the impacts associated with trace pollutants (Choubert et al., 2011a; Martin Ruel et al., 2012; Montes-Grajales et al., 2017). Trace pollutants are a broad class of compounds that are generally toxic to humans or the aquatic environment even at very low concentrations (U.S. EPA, 2015). Although the list of individual

[1] Greenfield areas are normally undeveloped areas highly recommended for new construction. The benefits of greenfield construction relate to pristine pieces of land with little to no contamination that contain no structures in the premises. The most beneficial advantage is that there is no cost related to environmental remediation and is ready to start building right away. The most important drawback is that greenfield are usually located outside city centers that might require additional infrastructure upgrades but those are offset by more accessible land costs. Another advantage is that they offer larger pieces of real estate ideally for future expansion and their zoning classification is easier to be changed or adjusted as required. Keep in mind that greenfield usually require deforestation and could affect environmental sensitive areas including the habitat of endangered species.

compounds is continually evolving, the class generally includes pharmaceuticals and personal care products (PPCPs), toxic organics, disinfection byproducts (DBPs) and heavy metals. Importantly, as the prevalence of trace pollutants in modern waste streams is increasing (Ellis, 2008; U.S. EPA, 2015; Ebele et al., 2017), with varying levels of persistence in the environment, they are becoming an important component of modern waste stream management. Many of these pollutants already factor into standard LCA inventories, where emissions of upstream processes are accounted for and contribute to human and environmental health impact categories. However, very little work has been done to incorporate the effects of their direct management at WWTPs, especially in the context of LCA. Such an assessment would provide valuable information as to the full benefits afforded by advanced treatment technologies, as many of the same processes that are effective for nutrient removal are also effective at trace pollutant removal. Preliminary studies have been conducted on certain pollutant groups such as PPCPs and other toxic organics (Montes-Grajales et al., 2017; Rahman et al., 2018) though they have omitted important pollutant groups such as heavy metals and DBPs. This study, therefore, looked in greater detail at a more encompassing list of trace pollutants, including heavy metals, toxic organics and DBPs, to provide a more comprehensive description of the full costs and benefits afforded by advanced nutrient removal technologies.

The metrics used in this assessment are cost and a suite of LCA-related impacts. The LCA-related impacts include eutrophication, global warming, particulate matter formation, smog formation, acidification, and ozone depletion based on the Tool for Reduction and Assessment of Chemicals and other Environmental Impacts (TRACI) 2.1 life cycle impact assessment (LCIA) method; water use and fossil energy use based on the ReCiPe[2] method; human and ecosystem toxicity impacts based on the USEtox™ methodology version 2.02; and cumulative energy demand (Bare, 2012; Goedkoop et al., 2009; Huijbregts et al., 2010). These metrics are discussed in detail in Section 1.2.5 and Section 4.6. The trace pollutant removal analysis is integrated with the toxicity impact category results.

1.2 Scope

This study design follows the guidelines for LCA provided by ISO 14040/14044 (ISO, 2006a, b). The following subsections describe the scope of the study based on the wastewater treatment configurations selected and the functional unit used for comparison, as well as the system boundaries, LCIA methods, and datasets used in this study.

1.2.1 Wastewater Treatment Configurations

This study compares nine alternative wastewater treatment configurations that achieve varying levels of nutrient removal, including a baseline wastewater treatment configuration that is not specifically designed to remove nutrients and eight wastewater treatment configurations that are designed to achieve varying advanced levels of nitrogen and phosphorus removal. The target effluent concentrations for TN and TP for each of the performance levels are presented in Table 1-1, and are based on performance levels analyzed in a study by Falk and colleagues (2011). The wastewater treatment configurations selected for this study are presented in Table

[2] The name of this method "ReCiPe" is derived from two factors. First, the method provides a recipe to calculate life cycle impact categories. Second, the acronym represents the initials of institutes that were the main contributors: RIVM and Radboud University, CML, and PRè (Goedkoop et al., 2008).

1-2 and described further in Section 1.2.4 and Appendix A. Table 1-2 also lists the abbreviated name used for each wastewater treatment configuration throughout this study. Selected configurations generally represent those most commonly used to achieve the desired performance levels for nutrient requirements and provide contrast in biological processes, capital and/or annual costs, or other factors such as energy requirements and sludge generation. The most common reasons wastewater treatment configurations were not selected include: 1) they are unique retrofits and otherwise not commonly used, 2) they are very similar to another selected technology, or 3) they exhibit a wide range of performance, which raises uncertainty as to the reliability with which the process can achieve a specific performance level. Ultimately, two wastewater treatment configurations were selected for each of Levels 2 through 5 to illustrate the range of costs and environmental impacts associated with varying levels of treatment performance. More detail on the system configuration selection process is included in Appendix A.

Table 1-1. Target Effluent Nutrient Concentrations by Level

Level	Total Nitrogen, mg/L	Total Phosphorus, mg/L
1	[a]	[a]
2	8	1
3	4-8	0.1-0.3
4	3	0.1
5	<2	<0.02

a – No target effluent concentration specified.

Table 1-2. Wastewater Treatment Configurations Selected for this Study

Full Name [a]	Performance Level	Abbreviated Name	Phosphorus Precipitation	Fermenter	Sand Filter	Denitrification Filter	Ultra-filtration	Reverse Osmosis
Conventional Plug Flow Activated Sludge	1	Level 1, AS						
Anaerobic/ Anoxic/Oxic	2	Level 2-1, A2O						
Activated Sludge, 3-Sludge System	2	Level 2-2, AS3	✓					
5-Stage Bardenpho	3	Level 3-1, B5	✓	✓	✓			
Modified University of Cape Town Process	3	Level 3-2, MUCT	✓	✓	✓			
5-Stage Bardenpho with Denitrification Filter	4	Level 4-1, B5/Denit	✓	✓	✓	✓		
4-Stage Bardenpho Membrane Bioreactor	4	Level 4-2, MBR	✓					
5-Stage Bardenpho with Sidestream Reverse Osmosis	5	Level 5-1, B5/RO	✓	✓	✓	10% [b]	90% [b]	90% [b]
5-Stage Bardenpho Membrane Bioreactor with Sidestream Reverse Osmosis	5	Level 5-2, MBR/RO	✓	✓				85% [b]

✓ Indicates technology is used in wastewater treatment configuration.

a – Refer to Section 1.2.4 for the system descriptions.

b – Percentages describe the relative flow of wastewater entering these processes at the WWTP.

1.2.2 Functional Unit

A functional unit provides the basis for comparing results in an LCA. The key consideration in selecting a functional unit is to ensure the wastewater treatment configurations are compared on the basis of equivalent performance. In other words, an appropriate functional unit allows for an apples-to-apples comparison. The functional unit for this study is the treatment of a cubic meter of municipal wastewater with the composition described in Table 1-3. The pH of the reference wastewater is 7.6 and the temperature averages are 23°C summer and 10°C winter.

The study evaluated theoretical wastewater treatment configurations with an average flow rate of 10 million gallons per day (MGD) and a maximum flow rate of 20 MGD[3]. The study results do not represent a specific, existing WWTP. As discussed in Section 3 the operational calculations are based on a year of treatment and standardized to a cubic meter basis using the total volume of water treated in the year. Infrastructure requirements are amortized over individual lifetimes associated with the equipment or buildings. Section 3 provides the lifetimes modeled for all infrastructure components captured in the study. While the WWTP infrastructure requirements are modeled, plant decommissioning is outside of the scope of the study.

It is important to note that the composition of effluent resulting from the wastewater treatment configurations is not part of the definition of the functional unit. Rather the level of treatment performance is a key differentiator of the configurations. Differences in effluent composition are captured in the estimation of impacts associated with the effluent discharges for each system. Effluent quality values for standard water quality parameters for the nine wastewater treatment configurations are depicted in Table 1-4. The effluent quality in Table 1-4 is based on the CAPDETWorks™ output and may vary from actual WWTP effluent for the same wastewater treatment configuration. However, these wastewater treatment configurations were chosen based on actual effluent nutrient concentrations from literature as discussed in Appendix A. Effluent quality values for trace pollutants, which include toxic organics, DBPs and heavy metals, are discussed in further detail in Section 2.

Table 1-3. Composition of Influent Wastewater Considered in this Study

Characteristic	Value	Unit	Reference(s)
Suspended Solids	220	mg/L	1, 2, 3, 4
Volatile Solids	75	%	1, 2, 3, 4
Biological Oxygen Demand (BOD)	220	mg/L	1, 2, 3, 4
Soluble BOD	80	mg/L	2, 3, 4
Chemical Oxygen Demand (COD)	500	mg/L	1, 2, 3, 4
Soluble COD	300	mg/L	2, 3, 4
Total Nitrogen (TN) [a]	40	mg/L N	calculated

[3] ERG used a 2.0 peaking factor for the study, assuming the WWTP served approximately 100,000 people (Health Research, Inc., 2014).

Table 1-3. Composition of Influent Wastewater Considered in this Study

Characteristic	Value	Unit	Reference(s)
Total Kjeldahl Nitrogen (TKN) [b]	40	mg/L N	1, 2, 3, 4
Soluble TKN	25	mg/L N	2, 3
Ammonia	22	mg/L N	1, 4
Nitrate	0	mg/L N	1, 2, 3, 4
Nitrite	0	mg/L N	1, 2, 3, 4
Total Phosphorus (TP)	5	mg/L P	2, 3
Cations	160	mg/L	3, 4
Anions	160	mg/L	3, 4
Settleable Solids	10	mg/L	1, 3, 4
Oil and Grease	100	mg/L	1, 3, 4
Nondegradable Fraction of Volatile Suspended Solids (VSS)	40	%	3, 4

[1] Tchobanoglous and Burton, 1991; [2] U.S. EPA OWM, 2008b; [3] ERG, 2009; [4] Hydromantis, 2014

a – TN is the sum of TKN, nitrate, and nitrite.

b – TKN is the sum of ammonia, organic nitrogen, and reduced nitrogen.

Table 1-4. Effluent Composition for the Nine Wastewater Treatment Configurations (mg/L)

Constituent	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Suspended Solids	20	20	20	8.0	8.0	8.0	9.0	1.3	1.9
BOD	7.7	4.7	3.1	2.3	2.3	7.0	3.1	1.2	0.62
Soluble BOD	3.9	2.3	1.5	2.3	2.3	7.0	2.1	1.2	0.45
COD	28	25	8.9	3.5	3.5	11	13	1.8	2.6
Soluble COD	5.8	3.5	2.3	3.5	3.5	11	3.21	1.8	0.70
Total Phosphorus	4.9	0.28	1.0	0.20	0.20	0.10	0.10	0.02	0.02
Total Nitrogen	30	8.0	7.8	6.0	6.0	3.0	3.0	0.73	2.0
TKN	30	1.9	2.1	0.52	0.52	0.52	1.0	0.15	0.20
Soluble TKN	29	0.52	1.6	0.52	0.52	0.52	0.42	0.09	0.08
Ammonia	15	0.52	0	0.52	0.52	0.52	0.42	0.09	0.08
Nitrate	0	6.1	5.7	5.5	5.5	2.4	2.0	0.63	1.8
Organic Nitrogen	15	1.4	2.1	0	0	0	0.58	0.06	0.12

1.2.3 System Definition and Boundaries

This section describes general aspects of each wastewater treatment configuration that are included in the LCA system boundary. The boundary for processes included in the assessment of each of the wastewater treatment configurations selected for evaluation includes all onsite wastewater and sludge treatment processes from the municipal WWTP headworks through final discharge of the treated effluent and disposal of sludge and other wastes. Off-site costs and environmental impacts associated with release of the effluent to the receiving stream, sludge transport and disposal, and for facilities with reverse osmosis (RO) units, brine disposal into onsite underground injection control (UIC) wells are also considered. The system boundary includes all relevant details of the wastewater treatment processes, environmental releases from each process, and the supply chains associated with the inputs to each process. Chemicals associated with periodic cleaning of equipment (e.g., membranes) are within the system boundary. Production of concrete, excavation activities, building materials, and a limited quantity of steel are included as infrastructure materials in the LCA. Pumps, in-unit mechanical systems, and electronics are excluded from the LCA study boundary due to lack of detailed information, although these types of equipment are included in the LCCA. The LCCA also includes costs for engineering and professional services that are not part of the LCA. A simplified system diagram is presented in Figure 1-1, which depicts the main materials and emission sources included in the model.

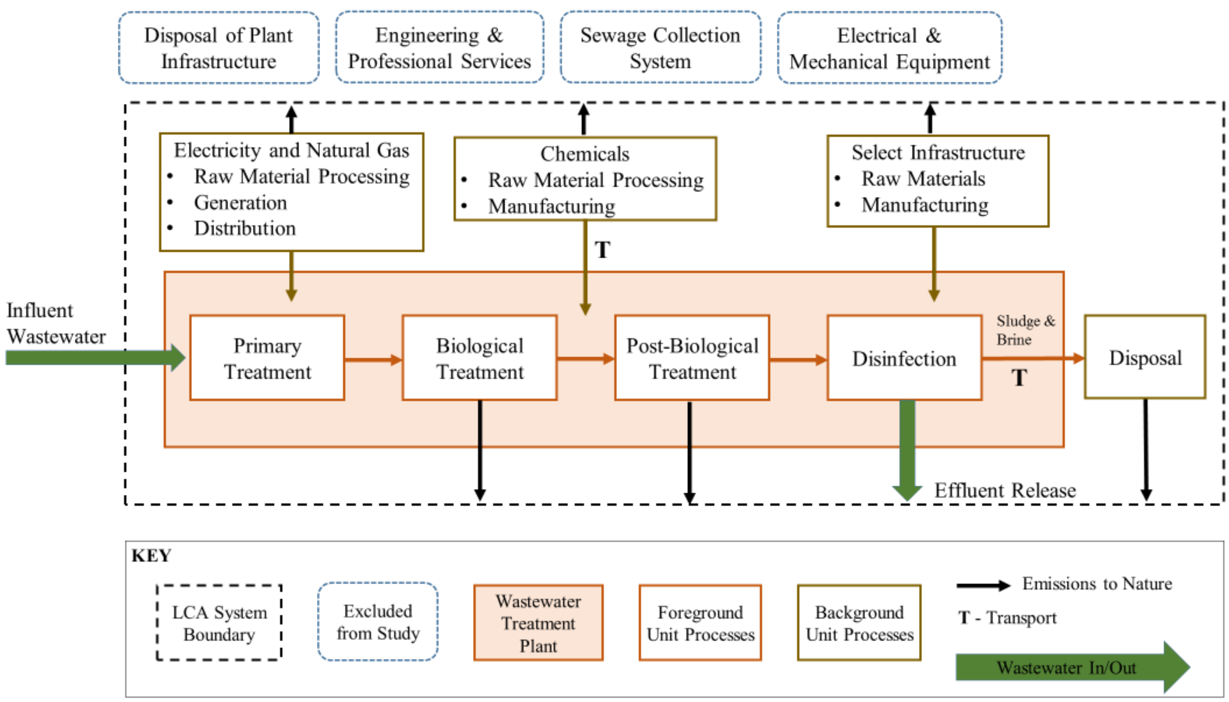


Figure 1-1. Generalized Study System Boundary

The four orange boxes in Figure 1-1 comprise the foreground unit processes that make up the wastewater treatment configuration at each WWTP. Electricity generation, chemical production, material extraction and manufacturing, and disposal processes are considered background unit processes. Disposal processes include landfilling of treated sludge and underground injection of brine solution. Background processes are still within the system boundary and are quantified within the analysis, although they exist beyond the physical boundaries of the wastewater treatment plant. The exterior dotted line in Figure 1-1 represents the system boundary considered in this LCA. The emissions to various compartments within nature (soil, air, water) are used in the estimation of environmental impacts. Details related to the calculation procedure and the environmental impacts included in this study are discussed in Section 4.

Excluded from the system boundaries are production of the components that make up the wastewater (e.g., drinking water treatment, residential organic waste, industrial wastewater pretreatment) and the collection system, including any raw sewage pump stations. It is assumed that these elements would be equivalent for all examined wastewater treatment configurations, and, therefore can be excluded from the scope of the analysis.

It is important to note that some potential benefits that may be realized from level 4 and level 5 wastewater treatment configuration are not captured in the system boundaries of this study. For instance, it may be possible to recycle the effluent from wastewater treatment for non-potable uses like toilet flushing or irrigation as the effluent quality may achieve non-potable requirements. Utilization of this recycled water would avoid production of potable water elsewhere. In an expanded system boundary, avoided production of potable water would result in an overall credit for these higher nutrient removal wastewater treatment configurations that is not included in this LCA study. Another potential benefit not included is the pathogen or other microbial contaminant removal.

1.2.4 System Descriptions of Wastewater Treatment Configurations

Flow diagrams of each wastewater treatment configuration are provided in Figure 1-2 through Figure 1-10. Each of these figures provides a visual representation of the detailed unit processes included in the relevant wastewater treatment configuration. The figures also show the source of process greenhouse gas (GHG) emissions and the type of chemical inputs.

In each wastewater treatment configuration, wastewater is first treated by screening, grit removal, and primary clarification. Screening removes large debris from the wastewater flow and grit removal extracts stone, grit, and other separable debris. Debris from this stage is transported to a landfill. In the next stage, primary clarification, solids are allowed to settle from the wastewater and grease to float to the top. Solids are pumped out from the bottom of the tank and scum and grease are skimmed off the top. These materials are either sent directly to a gravity thickener (configuration levels 1, 2-1, 2-2, 4-2) or first sent to a fermenter and then to the gravity thickener (configuration levels 3-1, 3-2, 4-1, 5-1, and 5-2) then to anaerobic digestion, and ultimately hauled away by truck for disposal in a landfill. The assumed distance from the wastewater treatment plant to the landfill is 25 miles one-way. In all cases, it is assumed the biogas from anaerobic digestion is flared. A detailed emission inventory associated with biogas flaring process is included in Appendix F. The sludge is assumed to be disposed in an average

U.S. municipal solid waste landfill in which methane is recovered for energy. The same biogas flaring and sludge landfilling assumptions were made for all wastewater treatment configurations as the study focuses on differentiating factors for nutrient removal technologies rather than options for sludge handling. Alternative treatment options for biogas is addressed later in the sensitivity analysis later in this report (Section 9.5).

After pretreatment and primary treatment, the processes involved in each wastewater treatment configuration varies. A description of each wastewater treatment configuration is provided in the subsequent sections, while a summary of their relevant attributes is given in Table 1-5.

1.2.4.1 Level 1: Conventional Plug Flow Activated Sludge (Level 1, AS)

The Level 1 configuration represents typical secondary treatment used by municipal WWTPs in the United States. This system focuses on reducing BOD and TSS concentrations to 30 mg/L and has no specific nutrient removal targets. In the conventional plug flow activated sludge wastewater treatment configuration, following pretreatment and primary treatment, wastewater is sent to a plug flow activated sludge reactor for carbonaceous biochemical oxygen demand (CBOD) removal. After plug flow activated sludge treatment, wastewater is sent to secondary clarification where solids are allowed to settle from the wastewater. Clarified effluent is disinfected using chlorine gas[4] followed by dechlorination using sodium bisulfite to remove residual chlorine prior to discharge. Effluent from the wastewater treatment process is discharged to surface water. Secondary clarifier sludge is pumped out from the bottom of the clarifier. Of this sludge, a portion is sent back to the plug flow activated sludge treatment process (return activated sludge) and the remainder (waste activated sludge) is combined with primary sludge before being sent to gravity thickening. Following the gravity thickener, the sludge is sent for anaerobic digestion followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are returned to the influent stream at the headworks to the wastewater treatment system. Dewatered sludge is transported to a landfill by truck.

1.2.4.2 Level 2-1: Anaerobic/Anoxic/Oxic (Level 2-1, A2O)

In the Level 2-1 anaerobic/anoxic/oxic (A2O) wastewater treatment configuration, following pretreatment and primary treatment, wastewater is sent to the A2O process, which consists of an anaerobic zone, an anoxic zone, and an oxic zone for biological phosphorus removal, CBOD removal, nitrification (conversion of ammonia to nitrate), and denitrification (conversion of nitrate to nitrogen gas, which is released to the atmosphere). There is an internal recycle that returns nitrified mixed liquor from the oxic zone to the anoxic zone. A secondary clarifier follows the A2O process where solids are allowed to settle from the wastewater. Clarified effluent is disinfected using chlorine gas followed by dechlorination using sodium bisulfite to remove residual chlorine prior to discharge. Effluent from the wastewater treatment process is discharged to surface water. Secondary clarifier sludge is pumped out from the bottom

[4] Chlorination using hypochlorite is more common than gaseous chlorine due to safety concerns and regulations on the handling and storage of pressurized liquid chlorine (Tchobanoglous et al., 2014). However, CAPDETWorks™ only includes disinfection using chlorine gas (Hydromantis, 2014). As a result, ERG used chlorine gas for this study.

of the tank with a portion returned to the influent of the A2O process (return activated sludge) and the remainder (waste activated sludge) is combined with primary sludge before being sent to gravity thickening. Following the gravity thickener, the sludge is sent for anaerobic digestion followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are returned to the influent stream at the headworks to the wastewater treatment system. Dewatered sludge is transported to a landfill by truck.

1.2.4.3 Level 2-2: Activated Sludge, 3-Sludge System (Level 2-2, AS3)

In the Level 2-2 activated sludge, 3-sludge wastewater treatment configuration, wastewater undergoes pretreatment and primary treatment before entering a plug flow activated sludge reactor for CBOD removal. Wastewater is then sent to the secondary clarifier where solids are allowed to settle from the wastewater. Sludge is pumped out from the bottom of the clarifier. Of this sludge, a portion is sent back to the plug flow activated sludge treatment process (return activated sludge) and the remainder (waste activated sludge) is combined with primary sludge before being sent to gravity thickening. Wastewater from the secondary clarifier is sent to a suspended growth nitrification reactor to convert ammonia nitrogen to nitrate, followed by a tertiary clarifier where solids are allowed to settle from the wastewater. A portion of the tertiary clarifier sludge is sent back to the nitrification reactor (return activated sludge) and the remainder (waste activated sludge) is sent to gravity thickening. Wastewater from the tertiary clarifier is sent to a suspended growth denitrification reactor to convert nitrate to nitrogen gas. Methanol is added immediately preceding the denitrification reactor as a supplemental carbon source. Prior to a final clarification step, the wastewater undergoes chemical phosphorus precipitation using aluminum salts, where solids are allowed to settle from the wastewater. A portion of the final clarifier sludge is sent back to the denitrification reactor (return activated sludge) and the remainder (waste activated sludge) is sent to gravity thickening. Clarified effluent is disinfected using chlorine gas followed by dechlorination using sodium bisulfite to remove residual chlorine prior to discharge. Effluent from the wastewater treatment process is discharged to surface water. Following the gravity thickener, the sludge is sent for anaerobic digestion followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are returned to the influent stream at the headworks to the wastewater treatment system. Dewatered sludge is transported to a landfill by truck.

1.2.4.4 Level 3-1: 5-Stage Bardenpho (Level 3-1, B5)

In the Level 3-1 5-Stage Bardenpho wastewater treatment configuration, wastewater undergoes pretreatment and primary treatment. Sludge from the primary clarifier enters a fermentation vessel to convert complex proteins and carbohydrates to volatile fatty acids (VFAs) that provide an internal carbon source for biological nutrient removal. Sludge from the fermenter is sent to gravity thickening. Primary clarifier effluent and fermenter supernatant enter a 5-stage Bardenpho nutrient removal reactor wherein the wastewater enters an anaerobic stage before alternating between anoxic and aerobic conditions in a total of five successive stages for biological phosphorus removal, CBOD removal, and enhanced nitrification and denitrification. There is an internal mixed liquor recycle that returns wastewater from the first aerobic zone to the first anoxic zone. Following the Bardenpho reactor, part of the remaining phosphorus in the wastewater is chemically precipitated, using aluminum salts, after which the effluent moves along to secondary clarification where solids are allowed to settle from the wastewater. Clarified effluent is passed through a sand filter for tertiary solids removal prior to disinfection using chlorine gas and dechlorination using sodium bisulfite to remove residual chlorine prior to discharge. Effluent from the wastewater treatment process is discharged to surface water. Sludge is removed from the bottom of the secondary clarifier. Of this sludge, a portion is sent back to the influent of the Bardenpho reactor (return activated sludge) while the remainder (waste activated sludge) is combined with primary sludge before being sent to gravity thickening. Following the gravity thickener, the sludge is sent for anaerobic digestion followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are returned to the influent stream at the headworks to the wastewater treatment system. Dewatered sludge is transported to a landfill by truck.

1.2.4.5 Level 3-2: Modified University of Cape Town Process (Level 3-2, MUCT)

In the Level 3-2 modified University of Cape Town process wastewater treatment configuration, wastewater first undergoes pretreatment and primary treatment. Sludge from primary clarification enters a fermentation vessel to convert complex proteins and carbohydrates to VFAs that provide an internal carbon source for biological nutrient removal. Sludge from the fermenter is sent to gravity thickening. Primary clarifier effluent and fermenter supernatant enter a 4-stage biological nutrient removal (BNR) reactor, referred to as the modified University of Cape Town process. Within the reactor, wastewater enters an anaerobic phase and passes through two successive anoxic stages before a final aerobic stage for biological phosphorus removal, CBOD removal, and enhanced nitrification and denitrification. There is an internal mixed liquor recycle that returns wastewater from the end of the first anoxic stage to the head of the anaerobic stage, and an additional internal recycle that returns wastewater from the aerobic stage to the second anoxic stage. Following biological nutrient removal, phosphorus in the wastewater is chemically precipitated, using aluminum salts, after which the effluent moves along to secondary clarification where solids are allowed to settle from the wastewater. Clarified effluent is passed through a sand filter for tertiary solids removal prior to disinfection using chlorine gas and dechlorination using sodium bisulfite to remove residual chlorine prior to discharge. Effluent from the wastewater treatment process is discharged to surface water. Sludge is removed from the bottom of the secondary clarifier. Of this sludge, a portion is returned to the first anoxic stage in the BNR reactor (return activated sludge) while the remainder (waste activated sludge) is combined with primary sludge before being sent to gravity thickening. Following the gravity thickener, the sludge is sent for anaerobic digestion followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are also returned to the influent stream at the headworks to the wastewater treatment system. Dewatered sludge is transported to a landfill by truck.

1.2.4.6 Level 4-1: 5-Stage Bardenpho with Denitrification Filter (Level 4-1, B5/Denit)

In the Level 4-1 5-Stage Bardenpho with denitrification filter wastewater treatment configuration, wastewater first undergoes pretreatment and primary treatment. Sludge from primary clarification enters a fermentation vessel to convert complex proteins and carbohydrates to VFAs that provide an internal carbon source for biological nutrient removal. Sludge from the fermenter is sent to gravity thickening. Primary clarifier effluent and fermenter supernatant enter a 5-stage Bardenpho nutrient removal reactor wherein the wastewater enters an anaerobic stage before alternating between anoxic and aerobic conditions in a total of five successive steps for biological phosphorus removal, CBOD removal, and enhanced nitrification and denitrification. There is an internal mixed liquor recycle that returns wastewater from the first aerobic zone to the first anoxic zone. Following the Bardenpho reactor, phosphorus in the wastewater is chemically precipitated, using aluminum salts, after which the effluent moves along to secondary clarification where solids are allowed to settle from the wastewater. Clarified effluent then enters an upflow, attached growth denitrification filter for additional nitrogen removal. Methanol is added immediately preceding the denitrification filter as a supplemental carbon source. Wastewater is finally passed through a sand filter for tertiary solids removal prior to disinfection using chlorine gas and dechlorination using sodium bisulfite to remove residual chlorine prior to discharge. Effluent from the wastewater treatment process is discharged to surface water. Sludge is removed from the bottom of the secondary clarifier. Of this sludge, a portion is returned to the influent of the Bardenpho reactor (return activated sludge) while the remainder (waste activated sludge) is combined with primary sludge before being sent to gravity thickening. Following the gravity thickener, the sludge is sent for anaerobic digestion followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are returned to the influent stream at the headworks to the wastewater treatment system. Dewatered sludge is transported to a landfill by truck.

1.2.4.7 Level 4-2: 4-Stage Bardenpho Membrane Bioreactor (Level 4-2, MBR)

In the Level 4-2 4-Stage Bardenpho membrane bioreactor wastewater treatment configuration, wastewater undergoes primary treatment before entering a 4-stage Bardenpho nutrient removal reactor. Within the reactor wastewater alternates twice between anoxic and aerobic stages for CBOD removal, and enhanced nitrification and denitrification. There is an internal mixed liquor recycle that returns wastewater from the first aerobic zone to the first anoxic zone. Methanol is added as a supplemental carbon source in the Bardenpho reactor in the second anoxic zone. Following the Bardenpho reactor, phosphorus in the wastewater is chemically precipitated, using aluminum salts, after which the effluent moves on for membrane filtration to remove solids from the wastewater, generating a permeate (effluent) and reject stream (sludge). Effluent is sent to disinfection using chlorine gas and dechlorination using sodium bisulfite to remove residual chlorine prior to discharge. Effluent from the wastewater treatment process is discharged to surface water. A portion of the sludge from the membrane filter is returned to the influent to the 4-stage Bardenpho (return activated sludge) while the remainder (waste activated sludge) is combined with primary sludge before being sent to gravity thickening. Following the gravity thickener, the sludge is sent for anaerobic digestion followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are returned to the influent stream at the headworks to the wastewater treatment system. Dewatered sludge is transported to a landfill by truck.

1.2.4.8 Level 5-1: 5-Stage Bardenpho with Sidestream Reverse Osmosis Treatment (Level 5-1, B5/RO)

In the Level 5-1 5-Stage Bardenpho with sidestream reverse osmosis (RO) wastewater treatment configuration, wastewater first undergoes pretreatment and primary treatment. Sludge from primary clarification enters a fermentation vessel to convert complex proteins and carbohydrates to VFAs that provide an internal carbon source for biological nutrient removal. Sludge from the fermenter is sent to gravity thickening. Primary clarifier effluent and fermenter supernatant enters a 5-stage Bardenpho nutrient removal reactor wherein the wastewater goes through an anaerobic stage before alternating between anoxic and aerobic conditions in a total of five successive steps for biological phosphorus removal, CBOD removal, and enhanced nitrification and denitrification. There is an internal mixed liquor recycle that returns wastewater from the first aerobic zone to the first anoxic zone. Following the Bardenpho reactor, additional phosphorus in the wastewater is chemically precipitated, using aluminum salts, after which the effluent moves along to secondary clarification where solids are allowed to settle from the wastewater. Clarified effluent is split into two streams for further treatment. In order to meet the designed effluent quality, ten percent of the flow enters an upflow, attached growth denitrification filter for additional nitrogen removal, followed by a sand filter for tertiary solids removal. Methanol is added immediately preceding the denitrification reactor as a supplemental carbon source. The remaining 90 percent of the flow first undergoes a series of RO pre-treatment steps, including ultrafiltration for solids removal; chlorine gas addition for biofouling control (followed by dechlorination with sodium bisulfite due to low chlorine tolerance of the RO membranes); and antiscalant addition for scale control. Following pretreatment, the effluent underdoes RO treatment, generating a permeate (effluent) and reject stream (brine). Effluent from the 10 percent and 90 percent side stream steps are then recombined for final disinfection using chlorine gas and dechlorination using sodium bisulfite to remove residual chlorine prior to discharge to surface water. Brine from the RO unit is disposed of by injection into an onsite disposal well. A portion of the clarified sludge is returned to the influent of the Bardenpho reactor (return activated sludge) while the remainder (waste activated sludge) is combined with primary sludge before being sent to gravity thickening. Following the gravity thickener, the sludge is sent for anaerobic digestion followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are returned to the influent stream at the headworks to the wastewater treatment system. Dewatered sludge is transported to a landfill by truck.

1.2.4.9 Level 5-2: 5-Stage Bardenpho Membrane Bioreactor with Sidestream Reverse Osmosis Treatment (Level 5-2, MBR/RO)

In the Level 5-2 5-Stage Bardenpho membrane bioreactor with sidestream RO wastewater treatment configuration, wastewater first undergoes pretreatment and primary treatment. Sludge from primary clarification enters a fermentation vessel to convert complex proteins and carbohydrates to VFAs that provide an internal carbon source for biological nutrient removal. Sludge from the fermenter is sent to gravity thickening. Primary clarifier effluent and fermenter supernatant enters a 5-stage Bardenpho nutrient removal reactor wherein the wastewater enters an anaerobic stage before alternating between anoxic and aerobic conditions in a total of five successive steps for biological phosphorus removal, CBOD removal, and enhanced nitrification and denitrification. There is an internal mixed liquor recycle that returns wastewater from the first aerobic zone to the first anoxic zone. Following the Bardenpho reactor, additional phosphorus in the wastewater is chemically precipitated, using aluminum salts, after which the effluent moves along to membrane filtration to remove solids from the wastewater, generating permeate (effluent) and a reject stream (sludge). In order to meet the designed effluent quality, effluent then splits into two streams with 15 percent of the flow receiving no sidestream treatment. The remaining 85 percent of flow undergoes a series of RO pre-treatment steps, including chlorine gas addition for biofouling control (followed by dechlorination with sodium bisulfite due to low chlorine tolerance of the RO membranes); and antiscalant addition for scale control. Following pretreatment, the effluent undergoes RO treatment, generating a permeate (effluent) and reject stream (brine). Effluent from the RO unit is recombined with the 15 percent stream for final disinfection using chlorine gas and dechlorinated using sodium bisulfite to remove residual chlorine prior to discharge to surface water. Brine from the RO unit is disposed of by injection into an onsite disposal well. A portion of sludge from the membrane filter is returned to the influent of the Bardenpho (return activated sludge) while the remainder (waste activated sludge) is combined with primary sludge before being sent to gravity thickening. Following the gravity thickener, the sludge is sent for anaerobic digestion followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are returned to the influent stream at the headworks to the wastewater treatment system. Dewatered sludge is transported to a landfill by truck.

Table 1-5. Study Treatment Configuration Characteristics

Treatment Level ID		L1	L2-1	L2-2	L3-1	L3-2	L4-1	L4-2	L5-1	L5-2
Characteristic	***Description***	**Level 1, AS**	**Level 2-1, A2O**	**Level 2-2, AS3[a]**	**Level 3-1, B5**	**Level 3-2, MUCT**	**Level 4-1, B5/Denit**	**Level 4-2, MBR[c]**	**Level 5-1, B5/RO**	**Level 5-2, MBR/RO[c]**
SRT (days)	Primary Biological Process	10	15	10	15	15	15	19	15	21
	Secondary Biological Process	-	-	50	-	-	attached[b]	-	attached[b]	-
	Tertiary Biological Process	-	-	10	-	-	-	-	-	-
Quantify nitrification	Primary Biological Process	Minimal	Partial	Minimal	High	High	High	High	High	High
	Secondary Biological Process	-	-	High	-	-	N/A	Minimal	N/A	Minimal
	Tertiary Biological Process	-	-	N/A	-	-	-	-	-	-
HRT (hours)[d]	Aerobic	5.7	8.8	6.0	10	10	10	5.3	10	6.2
	Anoxic	-	6.0	6.2	7.4	8.2	10	2.6	9.2	3.7
	Anaerobic	-	2.5	4.3	2.5	1.6	0.77	0.94	1.7	0.69
	Total	*5.7*	*17*	*16*	*20*	*20*	*21*	*8.8*	*21*	*11*
Redox condition summary[d]		Aero	An-Anox-Aero	Aero-Aero-An	An-Anox-Aero-Anox-Aero	An-Anox-Anox-Aero	An-Anox-Aero-Anox-Aero-Anox	Anox-Aero-Anox-Aero	An-Anox-Aero-Anox-Aero-Anox	An-Anox-Aero-Anox-Aero
MLSS Concentration (mg/L)	Primary Biological Process	2500	3000	2500	3000	3000	3000	9000	3000	9000
	Secondary Biological Process	-	-	2500	-	-	N/A	9000	N/A	9000
	Tertiary Biological Process	-	-	2500	-	-	-	-	-	-

a - Secondary biological process is a nitrification reactor. Tertiary biological process is denitrification reactor.

b - Secondary biological process is an attached growth denitrification reactor with an HRT of 1 hour.

c - Secondary biological process is membrane filter with an HRT of 1.78 hours.

d - Aggregates information for primary, secondary and tertiary biological processes.

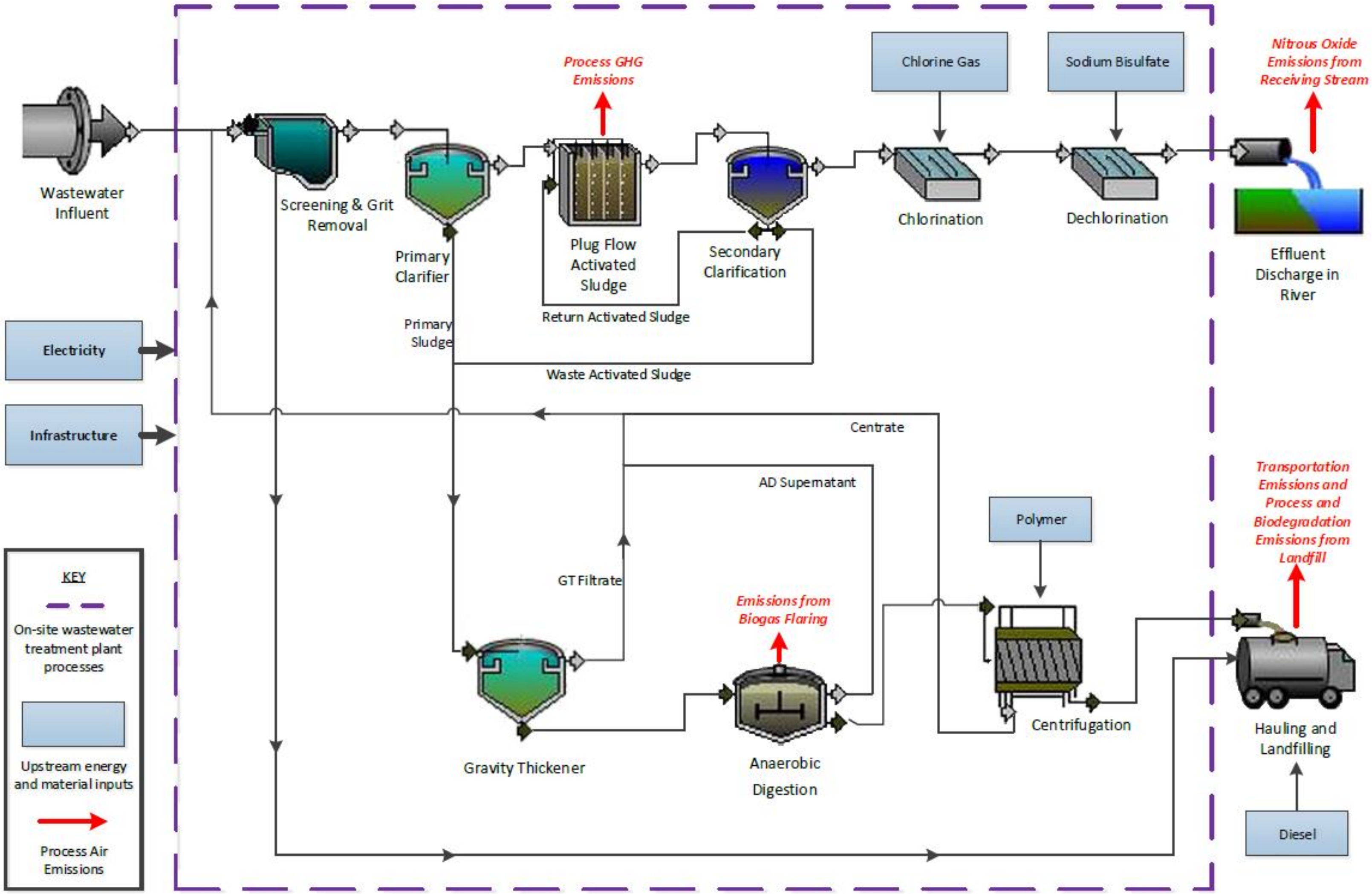


Figure 1-2. Level 1: Conventional Plug Flow Activated Sludge Wastewater Treatment Configuration

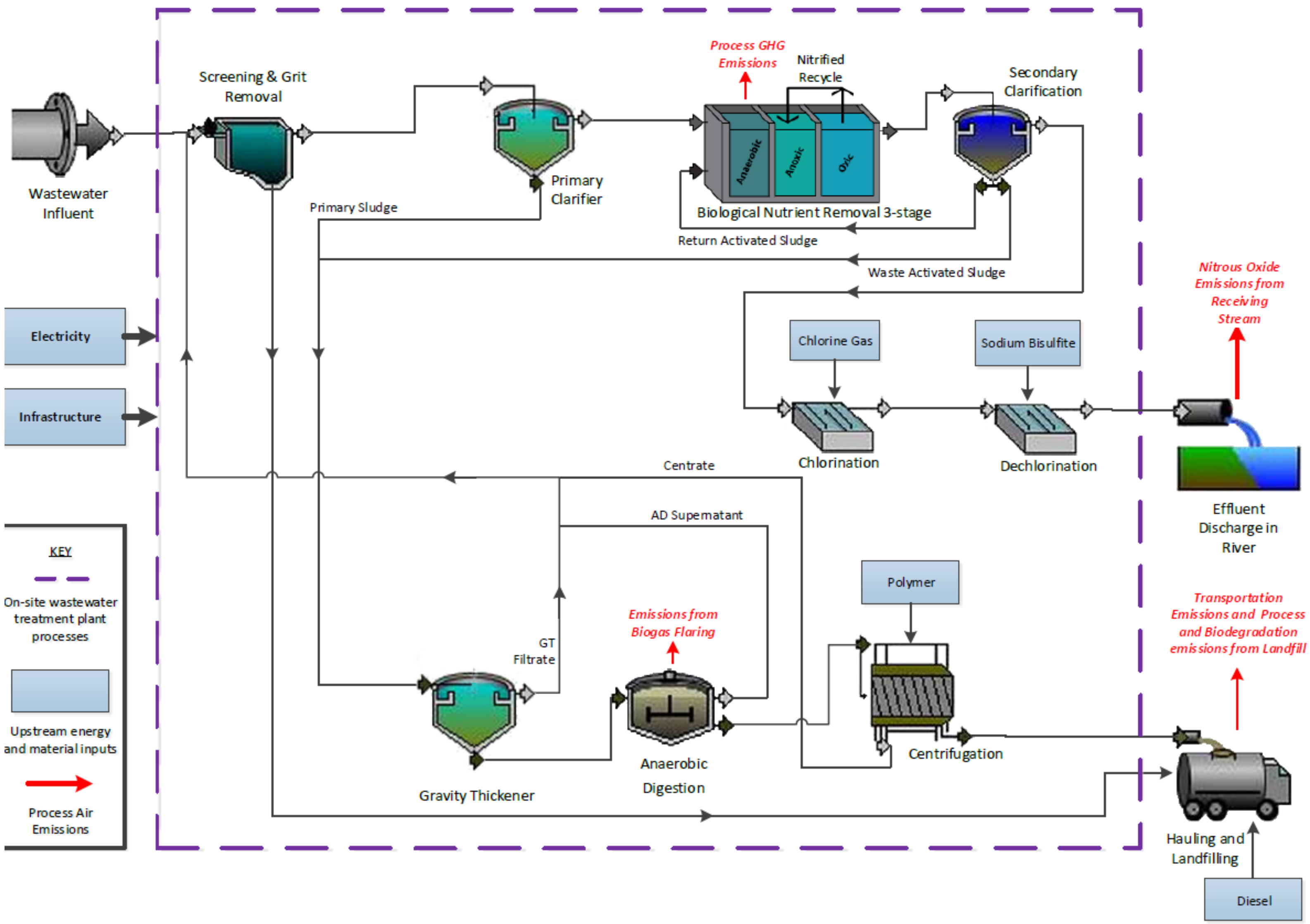


Figure 1-3. Level 2-1: Anaerobic/Anoxic/Oxic Wastewater Treatment Configuration

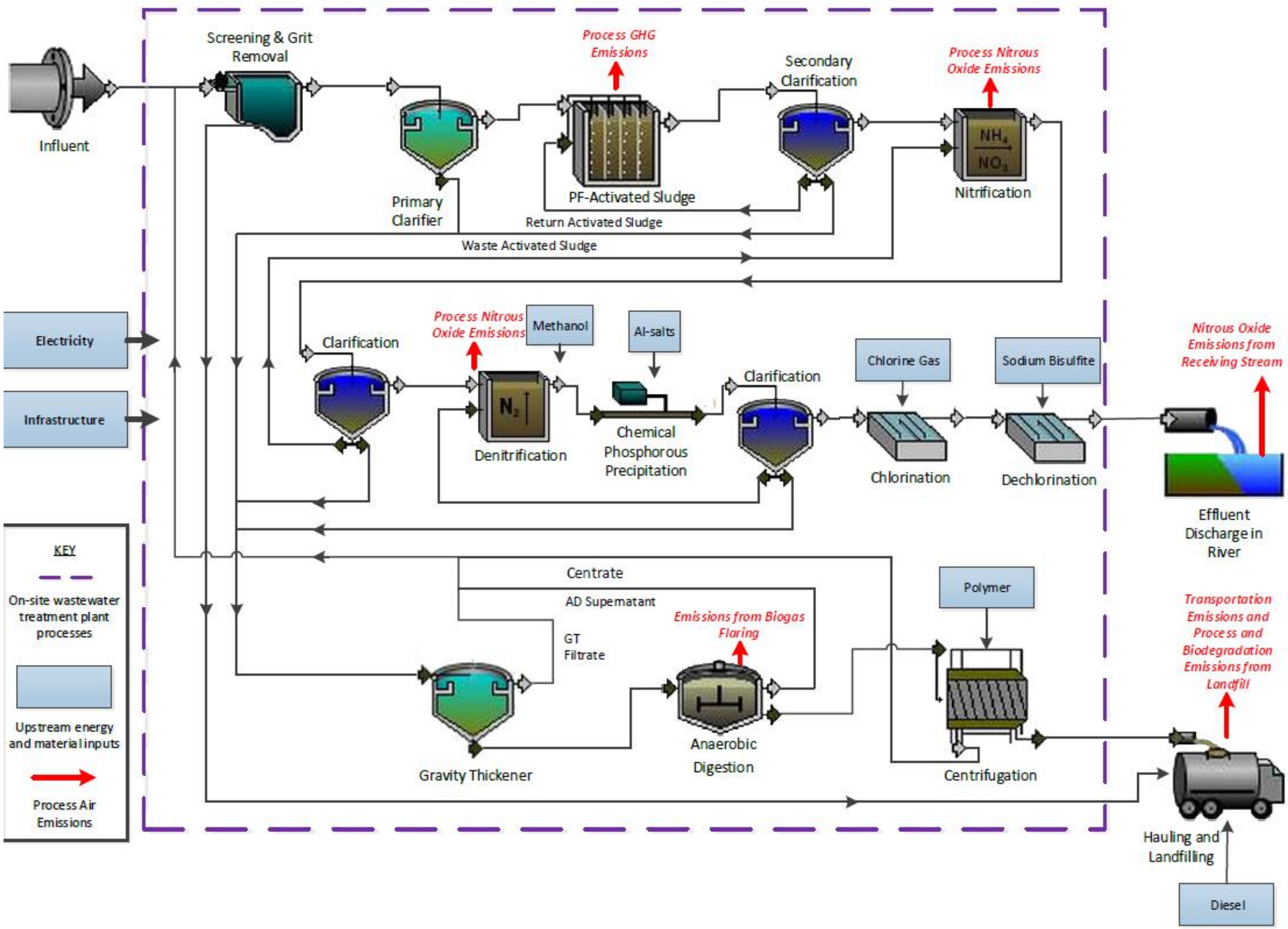


Figure 1-4. Level 2-2: Activated Sludge, 3-Sludge System Wastewater Treatment Configuration

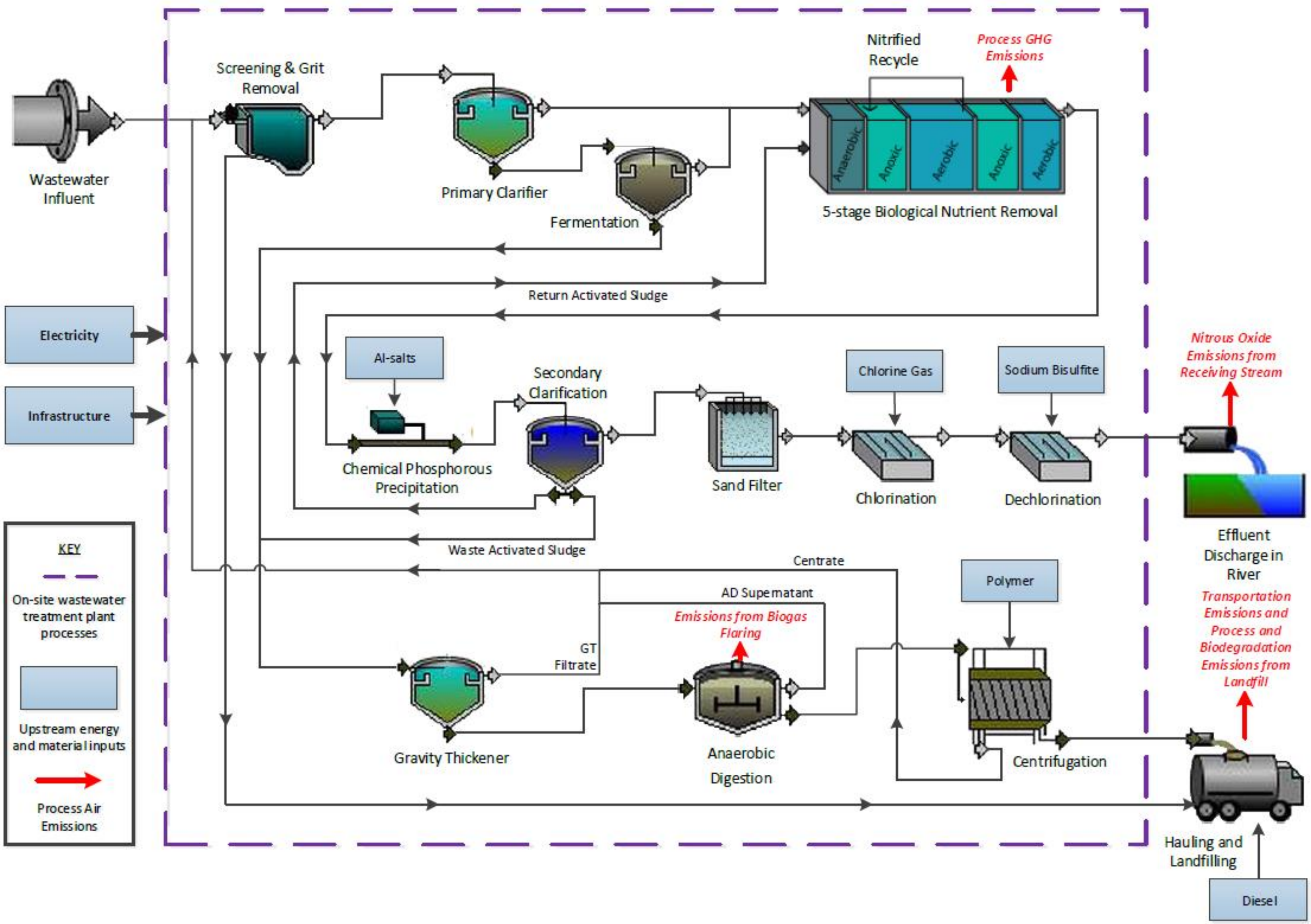


Figure 1-5. Level 3-1: 5-Stage Bardenpho System Wastewater Treatment Configuration

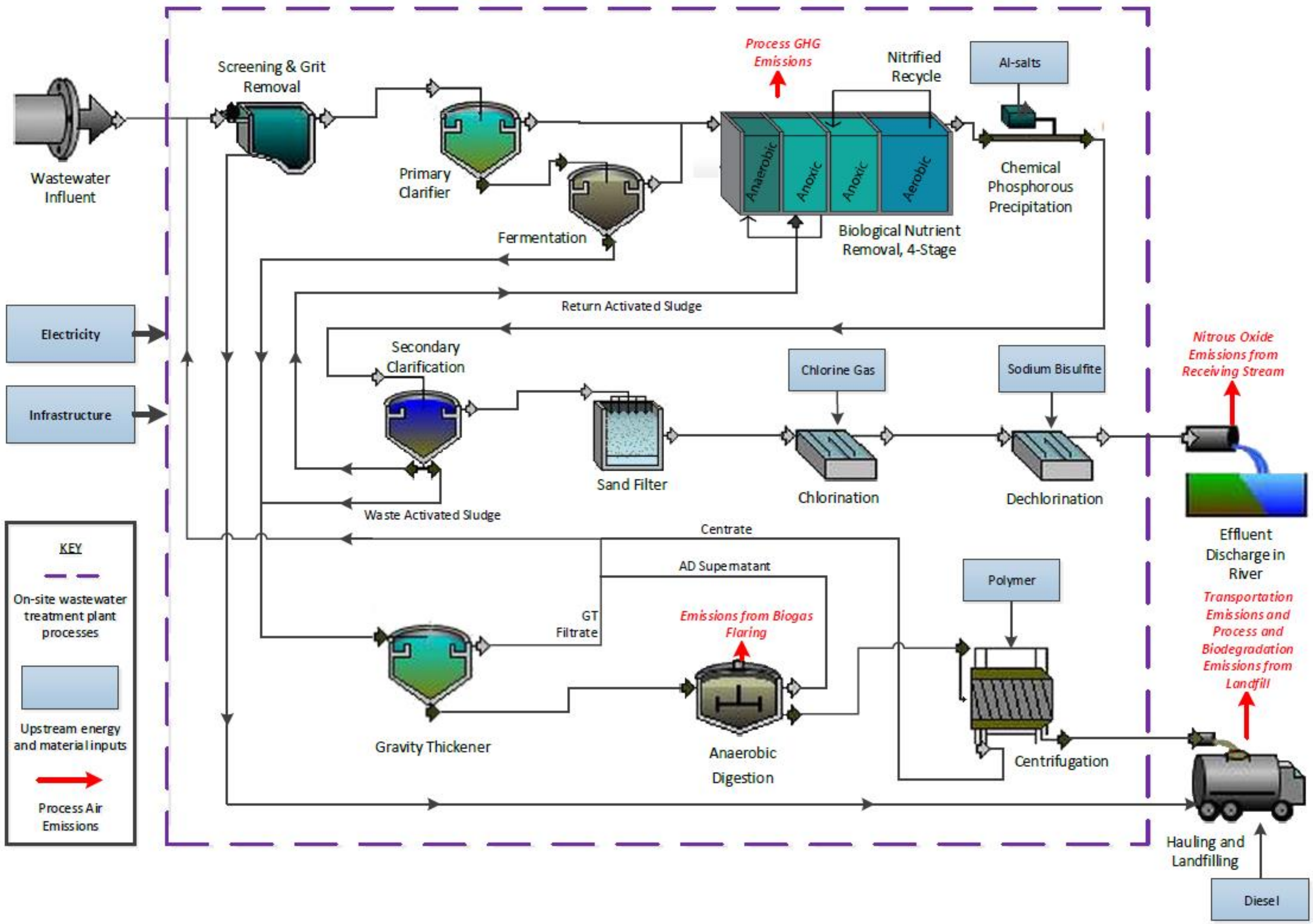


Figure 1-6. Level 3-2: Modified University of Cape Town Process Wastewater Treatment Configuration

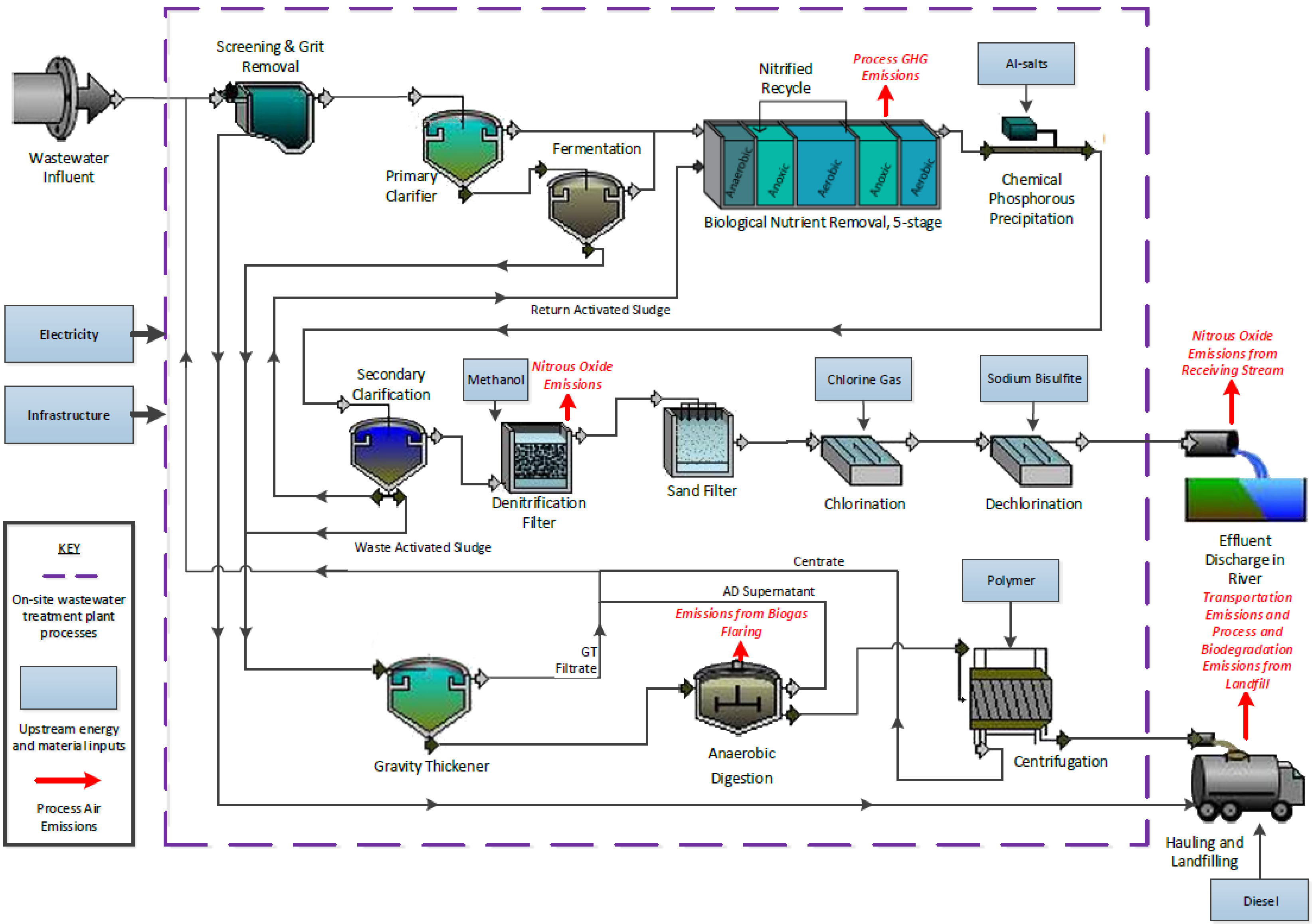


Figure 1-7. Level 4-1: 5-Stage Bardenpho System with Denitrification Filter Wastewater Treatment Configuration

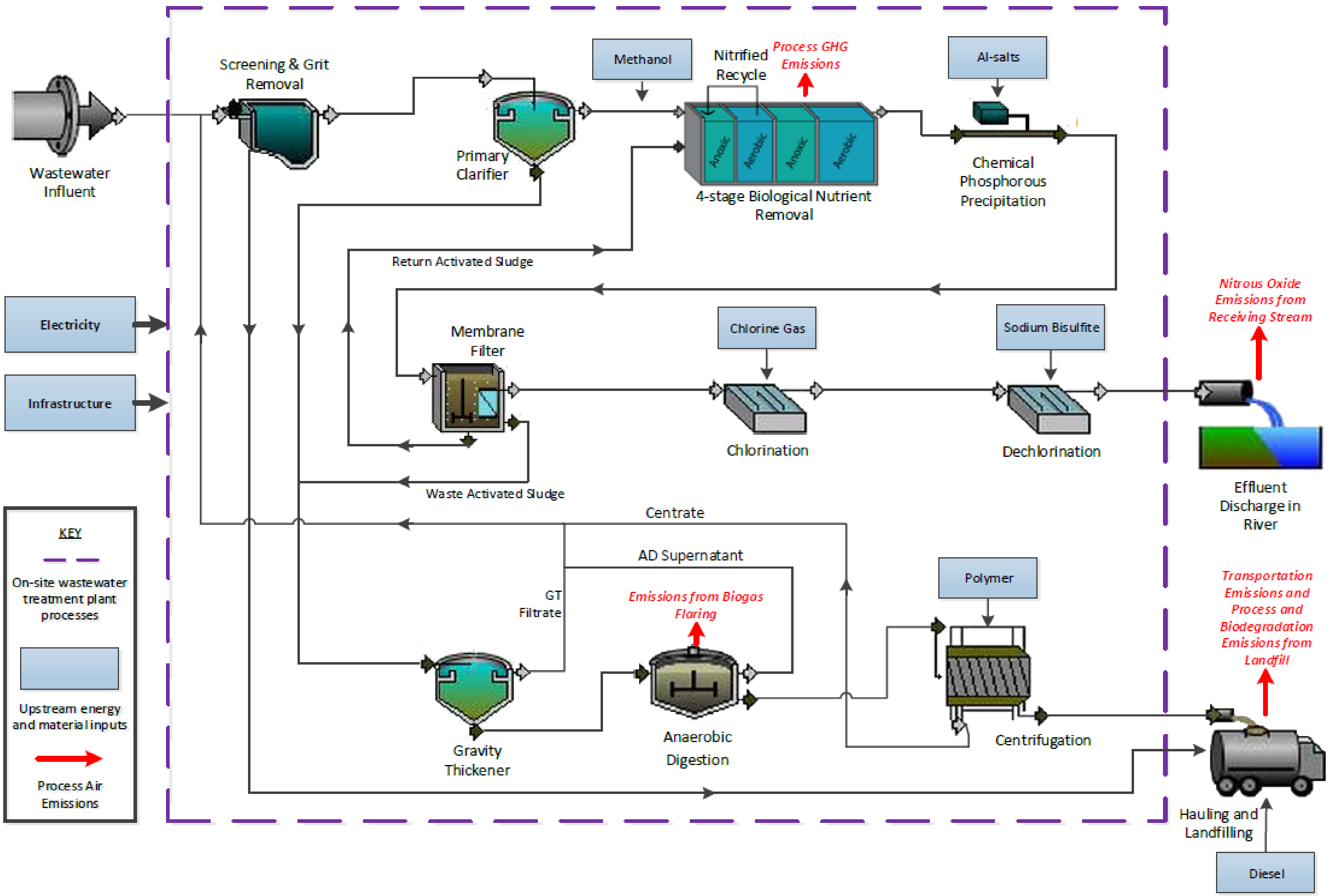


Figure 1-8. Level 4-2: 4-Stage Bardenpho Membrane Bioreactor System Wastewater Treatment Configuration

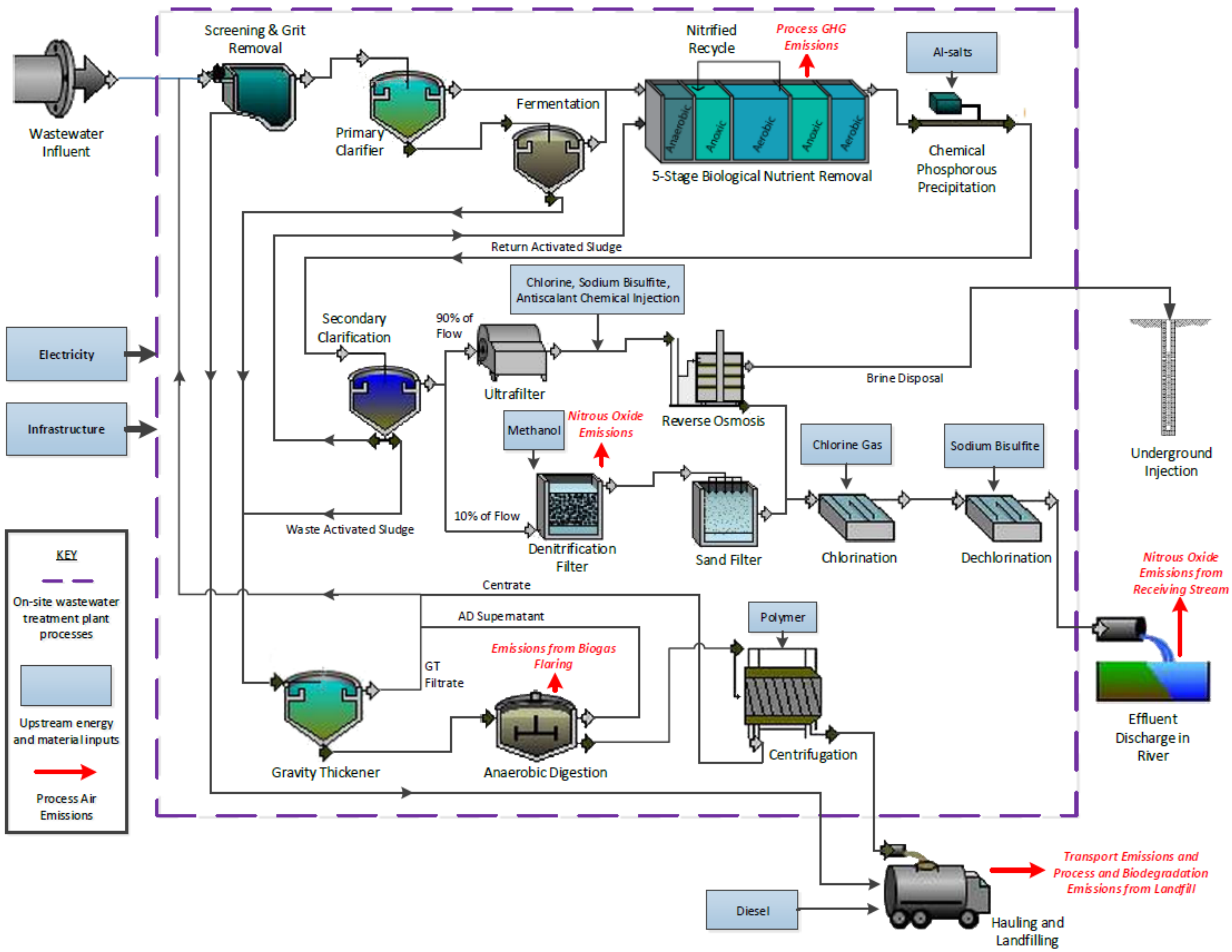


Figure 1-9. Level 5-1: 5-Stage Bardenpho with Sidestream Reverse Osmosis Wastewater Treatment Configuration

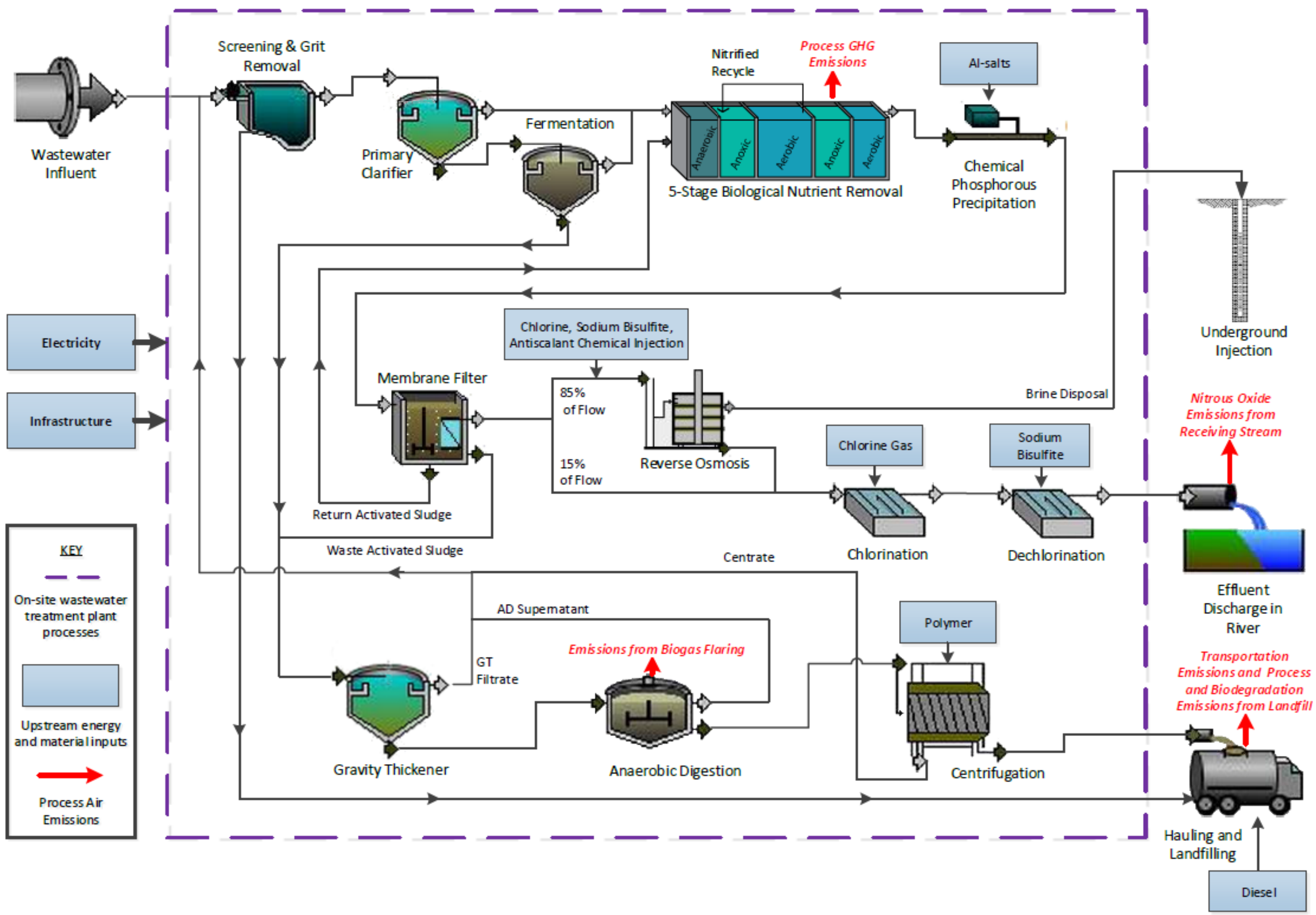


Figure 1-10. Level 5-2: 5-Stage Bardenpho Membrane Bioreactor with Sidestream Reverse Osmosis Wastewater Treatment Configuration

1.2.5 Metrics and Life Cycle Impact Assessment

Table 1-6 summarizes the metrics estimated in connection with each of the system configurations, together with the method and units used to characterize each.

The cost of each system configuration is estimated using standard approaches for life cycle costing, with more detail on the costing methodology provided in Section 2. Most of the LCIA metrics are estimated using the Tool for the Reduction and Assessment of Chemical and Environmental Impacts (TRACI), version 2.1 (Bare et al., 2003; Bare, 2011). TRACI is an LCIA method developed by the U.S. EPA. It includes a compilation of methods representing current best practice for estimating human health and ecosystem impacts based on U.S. conditions in conjunction with the information provided by life cycle inventory models. Toxicity impacts (e.g., human health toxicity – cancer, human health toxicity – non-cancer, and ecotoxicity) are based on the USEtox™ method (Rosenbaum et al., 2011) version 2.02. Global warming potential (GWP) is estimated in the baseline results using the 100-year characterization factors provided by the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report, which are the GWPs currently used for international reporting (Myhre et al., 2013). GWPs are also estimated in a sensitivity analysis using the more recent 100-year characterization factors provided by the IPCC 5th Assessment Report. In addition to TRACI, the ReCiPe LCIA method is used to characterize water consumption and fossil energy use (Goedkoop et al., 2008), impacts which are not included in the current version of TRACI. To provide another perspective on energy, cumulative energy demand including the energy content of all non-renewable and renewable energy resources extracted throughout the supply chains associated with each configuration is estimated using a method adapted from one provided by the Ecoinvent Centre (Ecoinvent Centre, 2010a). Detailed descriptions of each of the LCIA impact categories are also provided in Section 4.6.

The metrics included in this study range in geographic scale from global metrics such as GWP and fossil fuel depletion potential, to impact categories such as ecosystem toxicity potential, smog formation potential, and eutrophication potential that tend to be more local or regional in nature. In other words, some emissions/pollutants result in environmental impacts on a global level (e.g., emissions with long atmospheric lifetimes like greenhouse gases), while other pollutants primarily impact the regions or locations close to the point of release.

Table 1-6. Metrics Included in the LCA and LCCA Results

Metric	Method	Unit
Cost	LCCA	USD2014
Eutrophication Potential	TRACI 2.1	kg N eq.
Cumulative Energy Demand	ecoinvent	MJ-eq.
Global Warming Potential	TRACI 2.1	kg CO_2 eq.
Acidification Potential	TRACI 2.1	kg SO_2 eq.
Fossil Depletion	ReCiPe	kg oil eq.
Smog Formation Potential	TRACI 2.1	kg O_3 eq.
Human Health - Particulate Matter Formation	TRACI 2.1	$PM_{2.5}$ eq.

Table 1-6. Metrics Included in the LCA and LCCA Results

Metric	Method	Unit
Ozone Depletion Potential	TRACI 2.1	kg CFC-11 eq.
Water Depletion	ReCiPe	m^3
Human Health Toxicity – Cancer Potential	USEtox™ 2.02	CTUh
Human Health Toxicity – Noncancer Potential	USEtox™ 2.02	CTUh
Ecotoxicity Potential	USEtox™ 2.02	CTUe

2. TRACE POLLUTANT REMOVAL PERFORMANCE CHARACTERIZATION

Although the nine wastewater configurations evaluated in this study are designed to achieve various levels of nutrient removal targets, these treatment trains also remove other trace pollutants in the influents. It is important to capture these treatment performances in the holistic analysis in order to have a complete understanding of treatment strategies. This section summarizes the steps taken to characterize three major groups of trace pollutants with respect to their expected influent concentrations, fate within the study's nine wastewater treatment configurations, and final discharge into the environment. The groups include heavy metals, toxic organics and disinfection byproducts (DBPs). Depending on the pollutant, the final receiving environment (and thus the potential for impact) may include surface water discharge from the WWTP, partitioning to sludge with subsequent landfill disposal, or deep well injection in the case of RO brine. It was assumed that no toxicity-related impacts were associated with deep well injection. Volatilization was not found to be a major loss pathway for any of the included pollutants.

In the case of landfill disposal, environmental impact only occurs if the landfill liner fails and leachate is released. However, little data exists on actual failure rates. For this study, a failure rate of 5% was assumed based on a probabilistic modeling study that found, given typical landfill construction, failures generally occur within 10-30 years after landfill closure (Pivato, 2011).

For further reference, a full description of background, methods and results is provided in Appendix B, Appendix C and Appendix D, for heavy metals, toxic organics and DBPs, respectively.

2.1 Heavy Metals

The discharge of metals to the environment represents an ever-present concern, given their potential toxicity at even trace levels. WWTPs receive variable but sometimes high loads of metals depending on the mix of sources in their watershed, which can include industrial activities, domestic sources and stormwater (Yost et al., 1981; Ruel et al., 2011; Choubert et al., 2011b).

The direct management of metals has generally not been the focus of municipal WWTP design given the prioritization of organics and nutrient treatment. Heavy metals from industrial source are subject to other more targeted regulatory programs like the National Pretreatment Program (U.S. EPA, 2019a) which applies to industrial facilities. Nevertheless, trace heavy metals may still be present in municipal influents. Many common treatment processes allow for effective partitioning of metals to the sludge fraction, thus greatly reducing the quantity discharged in effluent.

Seven metals were included in this study that are commonly regulated and prevalent in the case study literature. Both criteria were assumed to be indirect indicators of the metal's demonstrated potential to cause environmental or human health impacts. The metals include Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), and Zinc (Zn). Table 2-1 summarizes ranges of influent concentrations established in several literature reviews, relevant effluent limits, and ranges of influent concentrations observed in the case studies used herein.

Table 2-1. Summary of Literature and Case Study Metal Influent Concentrations and Regulatory Effluent Concentrations.

Value		Concentrations in µg/L							Notes	Source
		Pb	**Cu**	**Zn**	**Ni**	**Cr**	**Cd**	**Hg**		
Influent Concentrations - Literature Reviews		5.7	63	181	11	10	0.21	0.36	19 Plants, France	1
		25	78	155	14	12.0	0.8	0.5	30 Plants, UK	2
		140-600	--	--	--	--	--	--	Combined WW	3
		232	489	968	455	378	19	--	12+ Cities, US	4
Case Study Ranges	High	68	118	493	77	290	10	7.0	This Study	5
	Medium	21	65	350	24	59	4.9	3.8	This Study	5
	Low	10.8	25	204	11	19	0.94	0.37	This Study	5
US CCC[a]		2.5	9	120	52	74/11[b]	0.25	0.77	Effluent Limits	6
US CMC[a]		65	13	120	470	570/16[b]	2	1.4	Effluent Limits	6

a - Criterion Continuous Concentration/Criteria Maximum Concentration, hardness dependent except for Cr (VI) and Hg. Values shown assume a hardness of 100 mg/L.

b - Chromium (III/VI)

1 - Choubert et al., 2011b; Ruel et al., 2012

2 - Rule et al., 2006

3 - Metcalf and Eddy, 2014

4 – Yost et al., 1981

5 - Linstedt et al., 1971; Brown et al., 1973; Chen et al., 1974; Oliver and Cosgrove, 1974; Aulenbach and Chan, 1988; Huang et al., 2000; Innocenti et al., 2002; Chipasa, 2003; Karvelas et al., 2003; Qdais and Moussa, 2004; Buzier et al., 2006; da Dilva Oliveira et al., 2007; Mohsen et al., 2007; Obarska-Pempkowiak and Gajewska, 2007; Carletti et al, 2008; Johnson et al., 2008; Dialynas and Diamadopoulos, 2009; Renman et al., 2009; Malamis et al., 2012; Arevalo et al., 2013; Garcia et al., 2013; Salihoglu, 2013; Inna et al., 2014; Reddy et al., 2014

6 - U.S. EPA, 2019b

Metal removal efficiencies for study system configurations were estimated based on a detailed literature review of performance results from similar systems. For system levels where no representative equivalent was identified but the important components were characterized, a composite removal efficiency was calculated based upon case study performance data of its major unit processes. For example, Level 3-1 includes a 5-stage Bardenpho process with subsequent sand filtration. However, results of the literature review only identified 5-stage Bardenpho WWTPs without sand filtration, and sand filtration as a standalone process. Therefore, a composite removal efficiency was calculated assuming a realistic stepwise removal, combining removal efficiencies for a 5-stage Bardenpho process with removal efficiencies for sand filtration. Table 2-2 summarizes the resulting minimum, average and maximum removal efficiencies for each treatment configuration. Supporting details for calculations and calculation assumptions are provided in Appendix B.

Table 2-2. Summary of Estimated Metal Removal Efficiencies[a]

Metal		Level 1 AS	Level 2-1 A2O	Level 2-2 AS3	Level 3-1 B5	Level 3-2 MUCT	Level 4-1 B5/Denit	Level 4-2 MBR	Level 5-1 B5/RO	Level 5-2 MBR/RO
Cu	Min	35%	35%	35%	75%	52%	75%	68%	93%	96%
	Mean	62%	62%	62%	80%	77%	80%	90%	97%	99%
	Max	84%	84%	84%	83%	96%	83%	99%	98%	100%
Pb	Min	40%	40%	40%	55%	39%	55%	68%	95%	97%
	Mean	65%	65%	65%	66%	70%	66%	88%	96%	99%
	Max	97%	97%	97%	75%	94%	75%	100%	97%	100%
Ni	Min	16%	16%	16%	42%	66%	42%	64%	82%	91%
	Mean	39%	39%	39%	45%	67%	45%	82%	90%	97%
	Max	91%	91%	91%	47%	68%	47%	100%	94%	100%
Zn	Min	12%	12%	12%	57%	83%	57%	75%	94%	97%
	Mean	42%	42%	42%	72%	89%	72%	85%	96%	99%
	Max	77%	77%	77%	83%	94%	83%	91%	98%	99%
Cd	Min	11%	11%	11%	40%	23%	40%	96%	93%	99%
	Mean	59%	59%	59%	47%	41%	47%	97%	94%	100%
	Max	83%	83%	83%	57%	59%	57%	98%	95%	100%
Cr	Min	16%	16%	16%	78%	88%	78%	83%	97%	99%
	Mean	64%	64%	64%	81%	88%	81%	91%	98%	100%
	Max	79%	79%	79%	84%	89%	84%	95%	98%	100%
Hg[b]	Min	17%	17%	17%	17%	17%	17%	93%	84%	98%
	Mean	53%	53%	53%	53%	53%	53%	97%	93%	100%
	Max	85%	85%	85%	85%	85%	85%	99%	98%	100%

a – "Removal Efficiency" used loosely; data more explicitly represents partitioning to sludge. Min and max represent minimum and maximum removal efficiencies reported in the literature. Where removal efficiencies are composites of multiple processes, minimum represents the composite of both contributing minimums, likewise for maximum.

b – No data for Hg removal found for 4-stage Bardenpho, 5-stage Bardenpho or MUCT. Therefore, conservatively assumed same removal for these biological treatment processes as documented for CAS (Level 1). Data for Levels 4-2, 5-1 and 5-2 represent the effect of tertiary polishing step alone, i.e. MBR and RO.

2.2 Toxic Organic Pollutants

Toxic organics are a diverse and growing category of chemical substances that includes commonly referred to pollutant groups such as contaminants of emerging concern (CECs), pharmaceuticals and personal care products (PPCPs), and endocrine disrupting chemicals (EDCs). The pollutant category includes medications, fragrances, insect repellents and other household items that can be harmful to environmental and human health at even trace levels (U.S. EPA, 2015; Montes-Grajales et al., 2017). Per- and polyfluoroalkyl substances (PFAS) are not included in this study.

Toxic organics are present in surface waters, groundwater, wastewater and WWTP effluent, both in the U.S. and globally (Ellis, 2008; Ebele et al., 2017; Montes-Grajales et al., 2017). No comprehensive list exists, though based on a diverse literature the number of contaminants is at least in the hundreds (if not thousands) and is continually being expanded upon as analytical techniques for measuring both presence and toxicity are continually refined. In order to provide a targeted analysis of their behavior in WWTPs, a restricted group of 43 pollutants (Table 2-3) has been included in this study. The list has been adapted and updated from two previous studies (Montes-Grajales et al., 2017; Rahman et al., 2018) where pollutants were selected based on frequency of detection in WWTPs and the availability of information regarding concentration, degradation, transformation and removal.

The concentration of trace pollutants can vary considerably on a daily and seasonal basis and between WWTPs (Martin Ruel et al., 2012). Based on a detailed review of the literature, influent concentration ranges were established for each pollutant (Table 2-3). For subsequent calculations, the medians of pollutant influent concentrations were used as means had a tendency to be biased by a small number of very high concentrations.

Table 2-3. Occurrence of the Selected Toxic Organic Compounds in WWTP Influent

Chemical Name	Chemical Type/Use	Influent Concentration (µg/L)				Sample Size
		Average	Median	Minimum	Maximum	
acetaminophen[a]	pain reliever, anti-inflammatory	97	19	0.02	400	12
androstenedione[a]	steroid hormone	0.29	0.10	0.02	1.3	7
atenolol	beta blocker	4.3	1.1	0.03	26	10
atorvastatin	lipid regulator	0.49	0.22	0.07	1.6	6
atrazine[b]	pesticide	0.02	0.02	1.0E-3	0.06	5
benzophenone	PCP, sunscreen	0.24	0.27	7.0E-3	0.42	4
bisphenol A	EDC, plasticizer	4.6	0.84	0.01	44	16
butylated hydroxyanisole[c]	beta blocker	1.3	0.16	0.13	3.5	3
butylated hydroxytoluene	beta blocker, cosmetic	0.93	0.41	0.05	3.5	5
butylbenzyl phthalate[d]	plasticizer	0.11	0.11	0.08	0.14	2
carbamazepine[a]	anti-convulsant	0.92	0.69	0.04	3.8	28
N,N-diethyl-meta-toluamide (DEET)	insect repellent	1.4	0.40	0.02	6.9	6
diclofenac	analgesics, anti-inflammatory	2.1	0.96	1.0E-3	17	20
dilantin	anti-seizure medication	0.16	0.17	0.05	0.24	4
dioctyl phthalate[b]	plasticizer, industry	23	1.4	1.1	67	3
estradiol[a,c]	EDC, steroid hormone	0.59	0.03	8.0E-3	5.0	11
estrone[a,c]	EDC, steroid hormone	0.17	0.05	0.01	1.0	9
galaxolide	beta blocker, PCP, fragrance	4.3	2.3	1.4E-3	25	16
gemfibrozil[a]	lipid regulator	3.1	1.6	0.02	22	15
hydrocodone	analgesic, opioid	0.08	0.11	0.02	0.12	5
ibuprofen[a]	analgesics, anti-inflammatory	7.8	2.4	1.0E-3	39	27
iopromide	contrast agent	7.4	0.05	0.01	38	6
meprobamate	tranquilizer, medication	0.40	0.35	0.01	0.97	5
naproxen[a]	analgesics, anti-inflammatory	8.5	2.5	2.0E-3	53	20
nonylphenol[b,c]	EDC, disinfectant, surfactant, solvent	3.4	2.3	0.02	9.7	14

Table 2-3. Occurrence of the Selected Toxic Organic Compounds in WWTP Influent

Chemical Name	Chemical Type/Use	Influent Concentration (μg/L)				Sample Size
		Average	Median	Minimum	Maximum	
octylphenol[b]	EDC, surfactant, solvent	1.9	0.41	0.12	8.7	12
o-hydroxy atorvastatin	lipid regulator	0.12	0.12	0.10	0.14	2
oxybenzone	PCP	1.2	0.39	0.03	3.8	4
p-hydroxy atorvastatin	lipid regulator	0.12	0.12	0.10	0.14	2
progesterone[a]	EDC	0.02	0.01	3.1E-3	0.06	4
sulfamethoxazole[a]	antibiotic	1.1	0.43	0.04	4.5	14
tris(2-chloroethyl) phosphate (TCEP)	flame retardant, plasticizer	0.35	0.24	0.17	0.65	3
tris(2-chloroisopropyl) phosphate (TCPP)	flame retardant	1.2	1.2	1.1	1.3	2
testosterone[a]	EDC	0.06	0.05	0.01	0.14	5
triclosan[a]	pesticide, disinfectant	2.7	0.80	2.3E-3	24	17
trimethoprim[a]	antibiotic	0.52	0.53	0.10	1.4	8
triclocarban[a]	disinfectant	0.42	0.42	0.29	0.54	2
tonalide	beta blocker, PCP, fragrance	1.5	0.80	5.0E-5	7.6	13
celestolide	PCP, fragrance	5.1	0.07	0.04	15	3
phantolide	fragrance	0.10	0.10	0.04	0.15	2
clofibric acid	lipid regulator	0.46	0.29	0.03	1.1	3
musk ketone	fragrance	0.12	0.12	0.10	0.15	3
diuron[b, c]	fragrance	0.14	0.11	0.05	0.25	3

a – Identifies substances with EPA developed analytical methods for detection of contaminants of emerging concern per (EPA, 2017).

b –Identifies substances with a European Quality Standard per (European Parliament, 2008).

c – Identifies substances identified in EPA's Candidate Contaminant List (CCL), version 4 (U.S. EPA, 2016c). The CCL identifies chemicals that are currently unregulated but may pose a risk to drinking water.

d - Identifies substances identified as human health criteria in Section 304(a) of the Clean Water Act (U.S. EPA, 2019c).

Table Acronyms: EDC – endocrine disrupting chemical, PCP – personal care product.

The behavior of toxic organics within study treatment configurations was estimated based on a review of the relevant literature for major unit processes, including:

- Biological Treatment
- Chemical Phosphorus Removal
- Membrane Filtration
- Anaerobic Digestion

Given the large list of pollutants and varying levels of available information, a combination of quantitative and qualitative information was used to arrive at final treatment performance ranges. The ranges take into account possible loss pathways that include transformation or degradation within biological unit processes, partitioning to solids and transformation or degradation during anaerobic digestion. Table 2-4 provides the resulting estimated range of cumulative removal efficiency for each of the nine WWTP configurations. Degradation and removal efficiency estimates were calculated as a weighted average of values for the 43 included pollutants. Relative influent concentration was used as the weighting factor. Additional background discussion and supporting calculations are provided in Appendix C.

Table 2-4. Summary of Cumulative Toxic Organics Degradation and Removal Efficiency in Study Treatment Configurations[a]

Treatment Level	Fraction Degraded			Fraction Removed (includes solids)		
	Minimum	Median	Maximum	Minimum	Median	Maximum
L1	52%	70%	85%	67%	81%	89%
L2-1	52%	73%	90%	67%	86%	95%
L2-2	52%	73%	90%	67%	86%	95%
L3-1	52%	75%	92%	67%	88%	97%
L3-2	52%	75%	92%	67%	88%	97%
L4-1	52%	75%	92%	67%	88%	97%
L4-2	52%	75%	91%	67%	88%	97%
L5-1	52%	75%	91%	94%	99%	100%
L5-2	52%	75%	91%	93%	98%	99%

a – Table values represent the cumulative effect of all the described treatment processes, calculated as a weighted average of the 43 toxic organics using influent concentration as the weighting factor.

2.3 Disinfection Byproducts

Disinfection of WWTP effluent is a necessary practice to minimize the acute risk associated with exposure to microbial pathogens, however it must be balanced with the chronic risk posed by the creation of disinfection byproducts (DBPs). DBPs are a class of chemical compounds that can be harmful to both aquatic and human health (Boorman, 1999; Nieuwenhuijsen et al., 2000; Mizgireuv et al., 2004; Villanueva et al., 2004; Muellner et al., 2007; Richardson et al., 2007; Watson et al., 2012).

DBPs are formed when DBP precursors, generally organic carbonaceous or nitrogenous compounds, are oxidized during chlorination or chloramination (Christman et al., 1983). By regulation, certain DBPs are managed at drinking water treatment plants, as their presence in water supplies poses a direct threat to human health (Sedlak and Gunten, 2011; US EPA, 2015c). Furthermore, as water recycling and reclamation programs expand (and as indirect potable reuse continues), management of DBPs and DBP precursors has become increasingly important at the WWTP as well (Krasner et al., 2008; Tang et al., 2012).

The importance of DBP and DBP precursor control at WWTPs has been growing in recent years for several reasons. First, the type of precursors formed through biological wastewater treatment are complex and, although overlapping with, are in many ways dissimilar from the natural organic matter (NOM)-derived precursors of drinking water-based DBPs. Therefore, lessons learned in drinking water DBP formation prediction and control are not directly translatable to WWTPs (Drewes and Croue, 2002; Tang et al., 2012). Additionally, there has been increasing concern over emerging and more toxic nitrogenous DBPs such as nitrosamines, halonitroalkanes, haloacetonitriles (HANs) and haloacetamides (Westerhoff and Mash, 2002; Joo and Mitch, 2007; Lee et al., 2007), which can be produced to varying degrees from dissolved organic nitrogen (DON) found in wastewater and WWTP effluent. Haloacetamides and HANs in particular are approximately two orders of magnitude more cytotoxic and genotoxic than the regulated trihalomethanes (THMs) and haloacetic acids (HAAs) (Muellner et al., 2007; Plewa and Wagner, 2009). The concentration of ammonia further complicates DBP formation kinetics, favoring the formation of certain groups at high concentrations and others at low (Krasner et al., 2008; Krasner et al., 2009b; Sedlak and Gunten, 2011). Similarly, chlorination practices, which can vary considerably between WWTPs, can have large effects on the overall formation of DBPs and, in combination with ammonia concentrations, can favor certain DBP groups over others. It is therefore important that comparisons of treatment configurations with differing nitrification and denitrification capabilities take into account multiple groups of DBPs that can capture these relative benefits and drawbacks.

For this study, models for DBP formation potential (FP) were used to compare the differences in DBP formation between study treatment configurations. FP is determined using a standardized procedure, eliminating variability from case study data that may arise owing to different disinfection practices. Ultimately, this allows for a clearer distinction between the effects of different treatment approaches on precursor control. To model disinfection byproduct formation potential (DBPFP), a comprehensive dataset linking effluent water quality of 23 different WWTPs to DBPFP was used (Krasner et al., 2008). The DBP and DBP groups included in the study include the regulated carbonaceous DBPs (THMs and HAAs) along with emerging and more toxic carbonaceous and nitrogenous DBPs (Table 2-5).

Table 2-5. Summary of Study Disinfection Byproducts

DBP (group/compound)	Characteristics	Precursors	Limit	Regulatory Authority
Trihalomethanes (THM)[a,b]				
Chloroform	carbonaceous, halogenated	influent refractory NOM, EfOM, nitrified effluent, humic compounds	80 µg/L (TTHM)	U.S. EPA, Stage 1/2 DBP Rule
Bromodichloromethane (BDCM)				
Chlorodibromomethane (DBCM)				
Bromoform				

Table 2-5. Summary of Study Disinfection Byproducts

DBP (group/compound)	Characteristics	Precursors	Limit	Regulatory Authority
Haloacetic Acids (HAA)[b,c]				
Monochloroacetic acid	carbonaceous, halogenated	influent refractory NOM, EfOM, nitrified effluent, humic compounds	60 µg/L (HAA5)	U.S. EPA, Stage 1/2 DBP Rule
Dichloroacetic acid (DXAA)				
Trichloroacetic acid (TXAA)				
Bromoacetic acid				
Dibromoacetic acid				
Nitrosamines[d]				
N-nitrosodimethylamine (NDMA)	nitrogenous, unhalogenated	DON, dimethylamine	10 ng/L	CA (action level)
Aldehydes				
Formaldehyde	carbonaceous, halogenated	DON, amino acids	N/A	N/A
Acetaldehyde				
Chloroacetaldehyde				
Dichloroacetaldehyde				
Trichloroacetaldehyde (chloral hydrate)				
Haloacetonitriles (HANs)				
Chloroacetonitrile	nitrogenous, halogenated	DON, amino acids	N/A	N/A
Bromoacetonitrile				
Iodoacetonitrile				
Trichloroacetonitrile				
Bromodichloroacetonitrile				
Dibromochloroacetonitrile				
Tribromoacetonitrile				

a - The four compounds together comprise the four primary trihalomethanes, sometimes referred to as TTHM or THM4

b - https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100C8XW.txt (U.S. EPA, 2015b)

c - These five compounds together comprise the five primary haloacetic acids, sometimes referred to as HAA5

d - California Department of Health Services, action level (CDHS, 2018)

Multiple linear regression models were constructed linking relevant water quality parameters with DBPFP. This was done by first performing a linear correlation analysis, which indicated COD and TKN to be the most influential predictors. Next, models were built for each DBP group (Table 2-5) using the adjusted coefficient of determination (R^2). Final models were significant at a >95% confidence level with the exception of NDMA, which was significant at a 93% confidence level. Table 2-6 gives model results for the nine study treatment configurations. Further discussion of methods, model construction and model results can be found in Appendix D.

Table 2-6. DBPFP Model Results for Study Treatment Configurations

Study Configuration	THMs	HANs	DXAAs	TXAAs	dihaloacet-aldehydes	trihaloacet-aldehydes	NDMA
	µg/L						ng/L
Level 1, AS	204	32	145	127	8.8	95	692
Level 2-1, A2O	274	14	129	113	4.9	54	680
Level 2-2, AS3	95	4.9	43	40	1.5	18	230
Level 3-1, B5	41	0.78	14	15	0.16	3.3	83
Level 3-2, MUCT	41	0.78	14	15	0.16	3.3	83
Level 4-1, B5/Denit	124	5.2	54	49	1.7	21	292
Level 4-2, MBR	144	6.6	65	59	2.2	26	347
Level 5-1, B5/RO	23	0.010	5.4	7.4	0.010	0.010	36
Level 5-2, MBR/RO	32	0.066	10	11	0.010	0.87	58

3. LIFE CYCLE COST ANALYSIS METHODOLOGY

This section presents ERG's methodology for developing life cycle costs for the nine greenfield wastewater treatment configurations included in this study. As such, the costs presented in the report are not applicable to operations that retrofit existing treatment systems to achieve further nutrient removal, and the difference from one treatment level to another may not represent the incremental retrofit costs due to existing infrastructure and site-specific conditions. In addition, the costs (as well as life cycle impacts discussed later in the report) are for the entire wastewater treatment configuration, not just those steps used to achieve nutrient removal.

The life cycle costs in the study are based primarily on the use of CAPDETWorks™, a model that performs planning-level design and cost estimation of WWTP construction projects. These planning-level costs do not include site-specific factors that may impact the costs (e.g., high groundwater table, shallow bedrock, deep excavation) as they are intended to represent the national average. These costs are supplemented with costs for additional unit processes that are not included in CAPDETWorks™ to provide costs for the entire wastewater treatment configuration. Section 3.1 describes CAPDETWorks™ and the data sources used for the additional unit processes. Section 3.2 describes the engineering cost estimation methodology. To the extent possible, purchased equipment and annual cost results are developed by unit process to allow for consistent presentation alongside results of the LCA model. Section 3.3 describes the life cycle cost analysis (LCCA) calculations that provide for a plant-level comparison of costs that occur throughout the life of the wastewater treatment configurations. The total plant costs are presented as: 1) total capital costs and total annual costs and 2) net present value that combines the one-time capital costs and annual costs into one value. The capital costs include the purchased equipment, direct costs (e.g., site preparation, site electrical, yard piping), and indirect costs (e.g., land, engineering design fee, interest during the 3-year construction period). The annual costs include the operating and maintenance labor, materials including replacement equipment, chemicals, and energy. In general, the purchased equipment costs were based on equipment sizing for the 20 MGD peak flow rate, while the annual costs were based on the 10 MGD annual average flow rate. For the net present value, the construction costs (in present value) are combined with the discounted annual costs during the WWTP planning period. Section 3.4 describes the quality of the data sources used in the LCCA.

3.1 Data Sources

ERG obtained cost data from the following sources or categories of sources:

- CAPDETWorks™ Version 3.0 (Hydromantis, 2014)
- EPA reports and fact sheets
- Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability (Falk et al, 2011)
- Wastewater treatment design textbooks
- Personal communication with technology vendors
- RSMeans Building Construction Cost Data (RSMeans, 2010)
- RSMeans Construction Cost Index (RSMeans, 2017)

The majority of the life cycle costs are based on CAPDETWorks™ Version 3.0 (Hydromantis, 2014) modeling output, supplemented with costs for unit processes that are not in CAPDETWorks™ (see Section 3.2.2 for details). EPA and the U.S. Army Corps of Engineers originally developed CAPDETWorks™ as a planning tool for WWTPs; Hydromantis Corporation now maintains and updates CAPDETWorks™. As described in Section 4.2.1 of *Municipal Nutrient Removal Technologies Reference Document* (U.S. EPA, 2008b), CAPDETWorks™ is used as follows:

> The user generates a process layout involving a number of unit operations. The user can also define input variables, including wastewater flow rate, wastewater influent quality, and desired effluent quality or other performance coefficients. Alternatively, the user can choose to use default values developed by Hydromantis. The software then calculates the required sizes of the unit operations and uses cost-curve models from the software's database to estimate the capital, labor, chemical, and energy costs that would be incurred. …The model uses several standard indices to update costs to current dollars: the Engineering News-Record (ENR) Construction Cost Index, the Marshall & Swift Index, and the Pipe Index. Values were obtained from a U.S. Department of Agriculture Web site (USDA, 2007) that transcribes historical values of these indices.

The cost functions included in CAPDETWorks™ Version 3.0 (the version used for this study) were updated in 2014. CAPDETWorks™ also allows users to input design values for each unit process (e.g., solids retention time, surface overflow rate) or use the default values developed by Hydromantis. CAPDETWorks™ also allows users to input unit costs (e.g., concrete, construction labor rate, polymer).

ERG relied primarily on the following two EPA reports to evaluate and modify, as necessary, the default input design values in CAPDETWorks™ and support development of costs for the unit processes that are not in CAPDETWorks™:

- *Municipal Nutrient Removal Technologies Reference Document* (U.S. EPA, 2008b)
- *Nutrient Control Design Manual* (U.S. EPA, 2010)

The *Municipal Nutrient Removal Technologies Reference Document* (U.S. EPA, 2008b) is intended to provide information to assist local decision makers and regional and state regulators in planning cost-effective nutrient removal projects for WWTPs. This EPA report provides capital and operation and maintenance costs for case study WWTPs, as well as costs estimated using CAPDETWorks™. The purpose of the *Nutrient Control Design Manual* (U.S. EPA, 2010) is to provide guidance and design considerations for nitrogen and phosphorus control using biological nutrient removal and chemical phosphorus removal for WWTPs.

ERG also relied on *Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability* (Falk et al, 2011), a report published by Water Environment Research Foundation (WERF). This report is an LCA/LCCA evaluation of WWTPs with nitrogen and phosphorus treatment technologies to achieve five levels of effluent nutrient targets that match the five levels included in this study. While the WERF study used a different cost estimation tool, ERG used the WERF design input values to evaluate and modify, as necessary, the default input design values in CAPDETWorks™. ERG also used *Wastewater Engineering –*

Treatment and Resource Recovery (Tchobanoglous et al., 2014), a wastewater treatment design textbook, and the following documents to verify the default input design values and unit costs in CAPDETWorks™:

- *Wastewater Technology Fact Sheet – Screening and Grit Removal* (U.S. EPA, 2003b)
- Biosolids Technology Fact Sheet – Gravity Thickening (U.S. EPA, 2003a)
- *May 2016 National Industry-Specific Occupational Employment and Wage Estimates for NAICS 221300 – Water, Sewage and Other Systems* (U.S. DOL, 2017)

EPA's wastewater and biosolids technology fact sheets provide general design and cost information. ERG used these technology fact sheets to evaluate and modify, as necessary, the default input design values in CAPDETWorks™. ERG also compared the purchased equipment process costs from CAPDETWorks™ to the technology fact sheets and updated the purchased equipment costs where appropriate. The May 2016 National Industry-Specific Occupational Employment and Wage Estimates for NAICS 221300 – Water, Sewage and Other Systems (U.S. DOL, 2017) calculates average wages from data collected in a national survey of employers of every size, state, and industry for metropolitan and nonmetropolitan areas. ERG used this report to verify and update as necessary the labor rates in CAPDETWorks™ where appropriate.

The primary source of costs for the unit processes that are not in CAPDETWorks™ are from personal communication with technology vendors. ERG contacted companies that manufacture, distribute, or install dechlorination, ultrafiltration, reverse osmosis, and deep well injection systems. The vendors provided the following types of information for EPA's analysis:

- Operations and maintenance requirements (e.g., equipment replacement frequency)
- Ancillary equipment required for the system (e.g., antiscalant chemicals)
- Capital cost information
- Operations and maintenance cost information, including energy requirements

ERG used vendor contacts from previous studies for the dechlorination system costs (ERG, 2011a; ERG, 2011b; ERG, 2011c) and contacted vendors for information on ultrafiltration, reverse osmosis, and deep well injection as part of this study (ERG, 2015a; ERG, 2015b). The majority of the vendors provided supporting documentation, which were also used to develop the cost estimates for the unit processes not included in CAPDETWorks™.

ERG supplemented the information provided by vendors with unit costs for building components from the RSMeans Building Construction Cost Data (RSMeans, 2010) to calculate costs for general components of the unit processes not in CAPDETWorks™ (e.g., reinforced concrete basins). ERG used RSMeans Construction Cost Index (RSMeans, 2017) to convert costs obtained outside of CAPDETWorks™ to 2014 $ for consistency.

3.2 Engineering Cost Estimation

ERG developed engineering cost estimates that included the following components:

- Capital costs (one-time costs).

- Operation and maintenance costs that reoccur annually or on a set frequency (e.g., 5-year recurring costs for equipment replacement).

Capital costs include the purchased equipment, direct, and indirect costs to design and build the wastewater treatment configuration. Operating and maintenance costs include the operation and maintenance labor, materials, chemicals, and energy required to ensure long-term operation of the WWTP. In general, the capital costs are based on the 20 MGD maximum flow rate, while the operating and maintenance costs are based on the 10 MGD average flow rate.

Section 3.2.1 presents the calculations to convert all of the costs to a consistent dollar basis. Section 3.2.2 presents ERG's methodology for calculating the capital and operating and maintenance costs for the individual unit processes included in the wastewater treatment configurations. These unit process costs are presented alongside results from the LCA model and used in the LCCA. Discussion of the methodology for estimating the wastewater treatment configuration-wide direct and indirect costs is presented in Section 3.3.

3.2.1 Dollar Basis

The majority of the life cycle costs are based on CAPDETWorks™ modeling output, supplemented with costs for unit processes that are not in CAPDETWorks™. output is provided in 2014 dollars. As a result, ERG standardized and presented all costs in 2014 dollars using Equation 1 and the RS Means Historical Cost Index, presented in Figure 3-1.

$$\text{Cost (2014 \$)} = \text{Cost (20XX \$)} \times \frac{\text{2014 Cost Index}}{\text{20XX Cost Index}}$$

Equation 1

where:

Cost (2014 $) = Cost in 2014 dollars

Cost (20XX $) = Cost in pre- or post-2014 dollars, where XX represents the specific year

2014 Cost Index = 204.9

20XX Cost Index = See Figure 3-1, using the Historical Cost Index where January 1, 1993=100

Historical Cost Indexes

The table below lists both the RSMeans® historical cost index based on Jan. 1, 1993 = 100 as well as the computed value of an index based on Jan. 1, 2017 costs. Since the Jan. 1, 2017 figure is estimated, space is left to write in the actual index figures as they become available through the quarterly *RSMeans Construction Cost Indexes*.

To compute the actual index based on Jan. 1, 2017 = 100, divide the historical cost index for a particular year by the actual Jan. 1, 2017 construction cost index. Space has been left to advance the index figures as the year progresses.

Year	Historical Cost Index Jan. 1, 1993 = 100		Current Index Based on Jan. 1, 2017 = 100		Year	Historical Cost Index Jan. 1, 1993 = 100	Current Index Based on Jan. 1, 2017 = 100		Year	Historical Cost Index Jan. 1, 1993 = 100	Current Index Based on Jan. 1, 2017 = 100	
	Est.	Actual	Est.	Actual		Actual	Est.	Actual		Actual	Est.	Actual
Oct 2017*					July 2002	128.7	61.7		July 1984	82.0	39.3	
July 2017*					2001	125.1	60.0		1983	80.2	38.4	
April 2017*					2000	120.9	58.0		1982	76.1	36.5	
Jan 2017*	208.5		100.0	100.0	1999	117.6	56.4		1981	70.0	33.6	
July 2016		207.3	99.4		1998	115.1	55.2		1980	62.9	30.2	
2015		206.2	98.9		1997	112.8	54.1		1979	57.8	27.7	
2014		204.9	98.3		1996	110.2	52.9		1978	53.5	25.7	
2013		201.2	96.5		1995	107.6	51.6		1977	49.5	23.7	
2012		194.6	93.3		1994	104.4	50.1		1976	46.9	22.5	
2011		191.2	91.7		1993	101.7	48.8		1975	44.8	21.5	
2010		183.5	88.0		1992	99.4	47.7		1974	41.4	19.9	
2009		180.1	86.4		1991	96.8	46.4		1973	37.7	18.1	
2008		180.4	86.5		1990	94.3	45.2		1972	34.8	16.7	
2007		169.4	81.2		1989	92.1	44.2		1971	32.1	15.4	
2006		162.0	77.7		1988	89.9	43.1		1970	28.7	13.8	
2005		151.6	72.7		1987	87.7	42.1		1969	26.9	12.9	
2004		143.7	68.9		1986	84.2	40.4		1968	24.9	11.9	
2003		132.0	63.3		1985	82.6	39.6		1967	23.5	11.3	

Source: (RSMeans, 2017).

Figure 3-1. RSMeans Historical Cost Indexes

3.2.2 Unit Construction and Labor Costs

As mentioned in Section 2, ERG developed the purchased equipment and annual cost results by unit process to allow for consistent presentation alongside results of the LCA model and use in the LCCA. ERG used CAPDETWorks™ Version 3.0 (Hydromantis, 2014), a software package designed for estimating the cost of wastewater treatment configurations, to calculate the unit process costs for each wastewater treatment configuration. Each of the wastewater treatment configurations used the same influent wastewater composition and flow rate discussed in Section 1.2.2 and presented in Table 1-3.

CAPDETWorks™ includes default unit construction and labor costs that are used to calculate the purchased equipment and annual costs. ERG reviewed the CAPDETWorks™ default unit construction and labor costs against those used in *Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability* (Falk et al, 2011). The most notable differences were for wall and slab concrete, and construction labor rate. For wall and slab concrete, ERG used the average of the costs from CAPDETWorks™ and *Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability* (Falk et al, 2011), as presented in Table 3-1.

Table 3-1. Unit Construction and Labor Costs

Unit Construction Cost	CAPDETWorks™ Default Cost ($/cuyd)	Falk et al, 2011 Cost ($/cuyd)	Average Cost ($/cuyd)
Wall Concrete	350	750	550
Slab Concrete	650	1,250	950

For the construction labor rate, ERG used the average of seven labor rates for construction activities relevant to construction of a WWTP from the May 2016 National Industry-Specific Occupational Employment and Wage Estimates for NAICS 221300 – Water, Sewage and Other Systems (U.S. DOL, 2017). The seven labor categories that ERG used and their labor rates in 2016 $ were:

- First-Line Supervisor of Construction Trades: $34.38/hr
- Construction Laborers: $17.88/hr
- Construction Equipment Operators: $23.12/hr
- Electricians: $31.60/hr
- Pipelayers, Plumbers, Pipefitters, and Steamfitters: $22.16/hr
- Construction Trades Helpers: $15.91/hr
- Other Construction and Related Workers: $21.91/hr

The resulting average labor rate is $23.85/hr in 2016 $, which is $23.58/hr in 2014 $ using Equation 1 in Section 3.2.1. The U.S. DOL wages do not include overhead to account for employee benefits. ERG assumed that contractors would be used for the construction and applied a 2.1 private industry (i.e., contractors) multiplier (consultant multipliers typically range from 2-2.2), resulting in an average construction labor rate of $49.51/hr. ERG rounded the construction labor rate to $50/hr for use in this study.

3.2.3 Unit Process Costs

As mentioned in Section 2, ERG developed the purchased equipment and annual cost results by unit process to allow for consistent presentation alongside results of the LCA model and use in the LCCA. ERG used CAPDETWorks™ Version 3.0 (Hydromantis, 2014), a software package designed for estimating the cost of wastewater treatment configurations, to calculate the unit process costs for each wastewater treatment configuration. Each of the wastewater treatment configurations used the same influent wastewater composition and flow rate discussed in Section 1.2.2 and presented in Table 1-3.

CAPDETWorks™ includes all of the unit processes included in the nine wastewater treatment configurations for this study with the exception of:

- Dechlorination. Included in all nine wastewater treatment configurations.
- Fermentation. Included in:
  - — Level 3-1 B5
  - — Level 3-2 MUCT

- Level 4-1 B5/Denit
- Level 5-1 B5/RO
- Level 5-2 MBR/RO

- 4-Stage Biological Nutrient Removal. Included in:
  - Level 3-2 MUCT
  - Level 4-2 MBR
- Methanol addition as a biological nutrient removal supplemental carbon source. Included in Level 4-2 MBR.[5]
- Ultrafiltration. Included in Level 5-1 B5/RO.
- Reverse Osmosis and Antiscalant Chemical Injection Pretreatment. Included in:
  - Level 5-1 B5/RO
  - Level 5-2 MBR/RO
- Deep Well Injection. Included in:
  - Level 5-B5/RO
  - Level 5-2 MBR/RO

Details on the approach developed for these unit processes are presented in the following subsections. The unit process costs for these unit processes were incorporated into the CAPDETWorks™ output for comparison to the LCA model results and development of the total plant costs.

Each of the nine wastewater treatment configurations was developed in CAPDETWorks™. As part of this study, ERG reviewed the *Municipal Nutrient Removal Technologies Reference Document* (U.S. EPA, 2008b), *Nutrient Control Design Manual* (U.S. EPA, 2010), *Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability* (Falk et al., 2011), *Wastewater Engineering: Treatment and Resource Recovery* (Tchobanoglous et al., 2014), and additional EPA wastewater treatment process fact sheets to confirm that the CAPDETWorks™ default design values were appropriate for use for this study. Based on our review, ERG used the CAPDETWorks™ default design values for the unit processes below that are included in one or more of the wastewater treatment configurations. Appendix E.1 includes the key parameters and default design values for the unit processes that were modeled using the CAPDETWorks™ default design values. For the remaining unit processes below, ERG revised the CAPDETWorks™ default design values. See Appendix E.1 for the details on the revised default design values. Note that ERG used these design values in the initial CAPDETWorks™ model for each wastewater treatment configuration. ERG then revised some of the design values to eliminate errors in CAPDETWorks™ (e.g., subsequent unit process designs were outside recommended design values) and achieve the effluent wastewater objectives for each of the treatment levels. The final design values used for each wastewater

[5] Methanol addition is also required for Level 2-2 AS3 for the denitrification – suspended growth unit process and Level 4-1 B5/Denit and Level 5-1 B5/RO for the denitrification filters. However, CAPDETWorks™ includes the methanol addition for these unit processes.

treatment configuration are included in the final CAPDETWorks™ cost output discussed in Section 5.

- Default Design Values Used:
  - Membrane Bioreactor
  - Sand Filter
  - Centrifugation – Sludge
- Design Values Revised:
  - Preliminary Treatment – Screening
  - Preliminary Treatment – Grit Removal
  - Primary Clarifier
  - Plug Flow Activated Sludge
  - Biological Nutrient Removal 3/5 Stage
  - Denitrification – Suspended Growth
  - Denitrification – Attached Growth
  - Nitrification – Suspended Growth
  - Chemical Phosphorus Removal
  - Secondary Clarifier
  - Chlorination
  - Gravity Thickener
  - Anaerobic Digestion – Sludge
  - Haul and Landfill – Sludge

ERG updated the CAPDETWorks™ default anaerobic digestion energy costs for all nine wastewater treatment configurations to rely on natural gas rather than using the produced gas for the reasons discussed in Section 3.2.3.8. ERG also determined that the CAPDETWorks™ default electricity cost of $0.10/kWh was appropriate for use for this study based on the national average electricity price as of May 2014 (U.S. EIA, 2015). The 2014 electricity costs match the 2014-dollar basis discussed in Section 3.2.1.

3.2.3.1 Dechlorination

Dechlorination is not a unit process available in CAPDETWorks™. Therefore, ERG developed a costing methodology for dechlorination based on the CAPDETWorks™ chlorination unit process and vendor costs, which was then incorporated into the CAPDETWorks™ outputs to calculate the total costs of all nine wastewater treatment configurations.

Capital cost elements for dechlorination include the dechlorination contact tank, dechlorination building, chemical storage building, sodium bisulfite liquid feed system, and miscellaneous items (e.g., grass seeding, site cleanup, piping). The dechlorination contact tank, dechlorination building, chemical storage building, and miscellaneous items are similar to the components included in the CAPDETWorks™ chlorination unit process. As a result, ERG estimated costs for these capital cost elements using the CAPDETWorks™ chlorination unit process with design values for contact time and chemical dose to simulate dechlorination. ERG estimated purchase costs for the sodium bisulfite liquid feed system based on cost information provided by a vendor.

Operating and maintenance cost elements for dechlorination include operating labor, maintenance labor, materials and supplies costs, sodium bisulfite chemicals, and energy. ERG estimated operating and maintenance labor, materials, and supplies costs using the CAPDETWorks™ chlorination unit process with design values for contact time and chemical dose to simulate dechlorination. Estimated energy costs for the sodium bisulfide feed system pump is based on energy usage provided by the vendor and the energy rate used for the CAPDETWorks™ costing ($0.10/kWh). Sodium bisulfite chemical costs are estimated using the following sodium bisulfite dosages with the chlorination effluent flow rate provided from the CAPDETWorks™ chlorination unit process:

- 1.5 mg/L for Levels 1, 2-1, 2-2, 3-1, 3-2, 4-1, and 4-2 wastewater treatment configurations.
- 3.0 mg/L for Levels 5-1 and 5-2 that includes 1.5 mg/L for the dechlorination requirement and 1.5 mg/L for the reverse osmosis pretreatment requirement.

ERG used a 40% sodium bisulfite solution cost of $344/ton in 2010 $ as provided by a vendor, converted to 2014 $ using the methodology presented in Section 3.2.1.

Detailed descriptions of the dechlorination costing approach are provided in Appendix E.2, including all cost bases, assumptions, and calculations.

3.2.3.2 Fermentation

Fermentation is not a unit process available in CAPDETWorks™. However, as detailed in *Municipal Nutrient Removal Technologies Reference Document* (EPA, 2008), a fermenter is an oversized gravity thickener with additional piping and mixers. In the *Municipal Nutrient Removal Technologies Reference Document*, the fermenter was modeled using the CAPDETWorks™ gravity thickener module and escalating the results by 50 percent (EPA, 2008). ERG used best professional judgement to confirm this approach and modeled the gravity thickener unit process in CAPDETWorks™ and multiplied the capital, operating, and maintenance costs by 1.5 to account for the larger size, additional equipment, and associated increased energy.

3.2.3.3 4-Stage Biological Nutrient Removal (Modified UCT and 4-Stage Bardenpho)

CAPDETWorks™ does not include a 4-stage biological nutrient removal (BNR) unit process, like those included in Level 3-2 as a 4-stage Modified University of Cape Town (UCT) and Level 4-2 as a 4-stage Bardenpho with membrane bioreactor. However, CAPDETWorks™ includes 3-stage and 5-stage BNR unit processes. For each of the wastewater treatment configurations with 4-stage BNR unit processes, ERG developed two separate CAPDETWorks™ models that included all of the same unit processes, except model 1 included the 3-stage BNR unit process and model 2 included the 5-stage BNR unit process. ERG combined the CAPDETWorks™ output from models 1 and 2 to estimate the capital, operating, and maintenance costs for the 4-stage BNR units, as described below.

Capital cost elements for BNRs include the BNR tank, blower system, internal recycle pumps, and sludge recycle pumps. Operating and maintenance cost elements for BNRs include operating labor, maintenance labor, materials costs, and energy.

For the 4-stage Modified UCT in Level 3-2, ERG modeled the 3-stage version using a 3-stage BNR with two internal recycle pumps to reflect the multiple recycles in the Modified UCT. ERG used the Level 3-1 wastewater treatment configuration for the 5-stage version. The capital costs for the BNR tanks, blower system, and BNR sludge recycle pumps were averaged for the 3- and 5-stage models, while the capital costs from the 3-stage model were used for the BNR internal recycle pumps. The capital costs for all other unit processes in these models had the same capital costs. The operating and maintenance costs for the BNR tank, BNR sludge recycle pumps, and blower system were averaged for the 3- and 5-stage models; the 3-stage model costs were used for the BNR internal recycle pumps; and the 5-stage model costs were used for the chemical phosphorus removal and alum feed system because the Modified UCT will achieve biological phosphorus removal closer to the 5-stage BNR model and, therefore, would require less alum to achieve the target effluent phosphorus concentration. The operating and maintenance costs for all other unit processes in these models had negligible differences between the 3- and 5-stage models.

For the 4-stage Bardenpho with membrane bioreactor, ERG modeled the 3-stage model using the 3-stage BNR with membrane bioreactor and 5-stage model using the 5-stage BNR with membrane bioreactor. The capital, operating, and maintenance costs for the BNR tank, BNR internal recycle pumps, and BNR sludge recycle pumps were averaged for the 3- and 5-stage models. The capital costs for all other unit processes in these models had negligible differences in the capital costs. The operating and maintenance costs for the chemical phosphorus removal and alum feed system from the 5-stage model were used because the 4-stage Bardenpho with membrane bioreactor will achieve biological phosphorus removal closer to the 5-stage BNR model and, therefore, would require less alum to achieve the target effluent phosphorus concentration. The operating and maintenance costs for all other unit processes in these models had negligible differences between the 3- and 5-stage models.

Details on how the 3- and 5-stage models were combined for the Level 3-2 and Level 4-2 wastewater treatment configurations are included in Section 5.

3.2.3.4 Methanol Addition for Biological Nutrient Removal Supplemental Carbon for Level 4-2 MBR

Biological nitrogen removal requires an adequate supply of carbon for denitrification. CAPDETWorks™ includes an external carbon source (i.e., methanol addition) to:

- Level 2-2 AS3's denitrification – suspended growth
- Level 4-1 B5/Denit's denitrification filter
- Level 5-1 B5/RO's denitrification filter

ERG included fermenters to provide an internal carbon source for biological nitrogen removal occurring in the Bardenpho and Modified University of Cape Town reactors in:

- Level 3-1 B5
- Level 3-2 MUCT
- Level 4-1 B5/Denit
- Level 5-1 B5/RO
- Level 5-2 MBR/RO

However, there is no internal carbon source for denitrification in Level 4-2 MBR. As a result, the Level 4-2 wastewater treatment configuration required methanol addition from an external carbon source. CAPDETWorks™ Version 3.0 does not include a stand-alone methanol addition unit process. Therefore, ERG developed a costing methodology for supplemental methanol addition based on the effluent nitrate target in CAPDETWorks™ denitrification filter unit process, which was then incorporated into the CAPDETWorks™ outputs to calculate the total costs for the Level 4-2 wastewater treatment configuration. CAPDETWorks™ calculates the methanol addition in the denitrification filter unit process based on 3 mg methanol per mg nitrate removed (Hydromantis, 2014). ERG determined the CAPDETWorks™ effluent nitrate target for the denitrification filter unit process as 1.95 mg/L nitrate based on the required denitrification to achieve the 3 mg/L total nitrogen for Level 4 (total Kjeldahl nitrogen effluent is 1.05 mg/L).

Capital cost elements for methanol addition include a methanol liquid feed system, chemical storage area, and miscellaneous items (e.g., grass seeding, site cleanup, piping). The methanol liquid feed system is the same as the methanol liquid feed system included in CAPDETWorks™ denitrification filter unit process with design values for the effluent nitrate target to simulate the denitrification requirement. CAPDETWorks™ does not include separate methanol storage area costs or miscellaneous items in the denitrification filter unit process. As such, ERG assumed that these costs are minimal and would be accounted for in the 4-stage Bardenpho costs.

Operating and maintenance cost elements for methanol addition include operating labor, maintenance labor, materials and supplies costs, methanol chemicals, and energy. ERG estimated methanol chemicals using the CAPDETWorks™ denitrification filter unit process with design values for the effluent nitrate target to simulate the denitrification requirement. CAPDETWorks™ does not include separate operating labor, maintenance labor, materials and supplies costs, and energy costs for the methanol system in the denitrification filter unit process. As a result, ERG assumed that these costs are minimal and would be accounted for in the 4-stage Bardenpho operating and maintenance costs. Methanol chemical costs are based on the CAPDETWorks™ default cost of $0.60/lb methanol in 2014 $ (Hydromantis, 2014).

Detailed descriptions of the methanol addition for biological nutrient removal supplemental carbon are provided in Appendix E.4, including all cost bases, assumptions, and calculations.

3.2.3.5 Ultrafiltration

Ultrafiltration is not a unit process available in CAPDETWorks™ Version 3.0. Therefore, ERG developed a costing methodology for ultrafiltration outside of CAPDETWorks™ and then incorporated the cost elements into the CAPDETWorks™ outputs to calculate the total cost of each wastewater treatment configuration that includes ultrafiltration (Level 5-1 B5/RO).

Capital cost elements for ultrafiltration include the membrane filtration system (membrane equipment and all appurtenances such as feed pumps, backwash system, and clean-in-place system) and a building to house the membrane filtration system. ERG estimated purchased equipment costs for the membrane filtration system based on cost information provided by a vendor. ERG estimated capital costs for the building using a CAPDETWorks™ building unit total capital cost of $110/square foot and an estimated building footprint provided by the vendor.

Operating and maintenance cost elements for ultrafiltration include operating labor, maintenance labor, materials costs (assumed a 7-year membrane life), chemicals (membrane cleaning), and energy. Operating and maintenance labor costs were estimated using a combination of information provided by the vendor, best professional judgement, and labor rates from CAPDETWorks™. Membrane replacement and chemicals costs are based on cost information provided by the vendor. Estimated energy usage for the membrane filtration system is based on a combination of information provided by the vendor and literature sources. ERG then calculated estimated energy costs by multiplying the estimated energy usage by the energy rate used for the CAPDETWorks™ costing ($0.10/kWh).

Detailed descriptions of our ultrafiltration costing approach are provided in Appendix E.5, including all cost bases, assumptions, and calculations.

3.2.3.6 Reverse Osmosis (RO)

RO is not a unit process available in CAPDETWorks™ Version 3.0. Therefore, ERG developed a costing methodology for RO outside of CAPDETWorks™ and then incorporated the cost elements into the CAPDETWorks™ outputs to calculate the total cost of for each wastewater treatment configuration that includes RO (Level 5-1 B5/RO and Level 5-2 MBR/RO).

Capital cost elements for RO include the RO system (membrane equipment and all appurtenances such as feed pumps, backwash system, and clean-in-place system), a chlorine gas feed system, a dechlorination feed system, an antiscalant feed system, a brine surge sump, and a building to house the RO system. ERG estimated purchased equipment costs for the RO system based on cost information provided by a RO vendor. ERG estimated capital costs for the building using a CAPDETWorks™ building unit total capital cost of $110/square foot and an estimated building footprint provided by the RO vendor. Costs for the chlorination feed system are included within the CAPDETWorks™ chlorination module discussed previously in this section. Costs for the dechlorination and antiscalant feed systems were estimated based on cost information provided by a feed system vendor. For the brine surge sump, ERG first estimated the required sump volume, assuming a 60-minute hydraulic residence time, based on best professional judgement. ERG then estimated the brine sump total capital costs using online RS Means Building Construction Cost Data.

Operating and maintenance cost elements for RO include operating labor, maintenance labor, materials costs (assumed a 4-year membrane life), chemicals (membrane cleaning, antiscalant, chlorine gas, and sodium bisulfite dechlorination), and energy. Operating and maintenance labor costs were estimated using a combination of information provided by the RO vendor, best professional judgement, and labor rates from CAPDETWorks™. Membrane replacement and membrane cleaning chemical costs are based on cost information provided by the vendor. Antiscalant chemical costs were estimated using the dosage rate provided by the RO vendor and a chemical cost provided by a chemical vendor. Chlorine gas and sodium bisulfite chemical costs are included within the CAPDETWorks™ chlorination module and the supplemental dechlorination module developed by ERG discussed previously in this section. Estimated energy usage for the RO system is based on a combination of information provided by the RO vendor and literature sources; estimated energy usage for the dechlorination and antiscalant feed systems is based on information provided by the chemical feed system vendor. ERG then calculated estimated RO and feed system energy costs by multiplying the estimated energy usage by the energy rate used for the CAPDETWorks™ costing ($0.10/kWh).

Detailed descriptions of our RO system costing approach are provided in Appendix E.6, including all cost bases, assumptions, and calculations.

3.2.3.7 Deep Injection Well

Deep well injection is not a unit process available in CAPDETWorks™ Version 3.0. Therefore, ERG developed a costing methodology for deep well injection outside of CAPDETWorks™ and then incorporated the cost elements into the CAPDETWorks™ outputs to calculate the total cost of each wastewater treatment configuration that includes brine disposal (Level 5-1 B5/RO and Level 5-2 MBR/RO).

Capital cost elements for deep well injection include injection well pumps, a building to house the injection pumps and electrical control panel and drilling the underground injection well. Purchase costs for the injection well pumps were based on information provided by a pump vendor; pump freight costs were estimated based on information from an equipment supply vendor. ERG estimated capital costs for the building using a CAPDETWorks™ building unit total capital cost of $110/square foot and an estimated building footprint developed based on best professional judgement. ERG estimated costs for drilling a new underground injection well based on cost information provided by a waste disposal vendor.

Operating and maintenance cost elements for deep well injection include operating labor, maintenance labor, materials costs, and energy. Operating and maintenance labor costs were estimated using a combination of best professional judgement and labor rates from CAPDETWorks™. Materials costs were estimated as 2 percent of injection well pump purchase cost, based on CAPDETWorks™ methodology. ERG estimated energy usage for the injection well pumps using the pump HP rating and assuming continuous operation. ERG then calculated estimated injection well pump energy costs by multiplying the estimated energy usage by the energy rate used for the CAPDETWorks™ costing ($0.10/kWh).

Detailed descriptions of our deep well injection costing approach are provided in Appendix E.7, including all cost bases, assumptions, and calculations.

3.2.3.8 Anaerobic Digester Natural Gas Usage

CAPDETWorks™ assumes that the gas produced by the anaerobic digester is used to supply heat to the anaerobic digester. If the digester gas produced is insufficient, CAPDETWorks™ uses natural gas for the difference. Because most WWTPs flare the digester gas, ERG revised the energy calculations for the anaerobic digester to assume that all the heat required was provided by natural gas using Equation 2 and Equation 3, and that all digester gas produced was flared.

$$\text{Energy Costs} = \text{Electricity Cost} + \text{Total Natural Gas Required} \times \text{Natural Gas Cost}$$

Equation 2

where:

Energy Costs (2014 $/yr) = Energy cost to run the anaerobic digester for a year

Electricity Cost (2014 $/yr) = Electricity cost from CAPDETWorks™ to run the anaerobic digester for a year

Total Natural Gas Required (1,000 cuft/yr) = Natural gas required to heat the anaerobic digester (see Equation 3)

Natural Gas Cost (2014 $/1,000 cuft) = $15,500/1,000 cuft

$$\text{Total Natural Gas Required} = \frac{\text{Heat Required}}{\text{Boiler Efficiency} \times \text{Heat Exchanger Efficiency}} \times \frac{\text{Hours per Year Conversion}}{\text{Natural Gas Heating Value}} \times \text{Unit Conversion}$$

Equation 3

where:

Total Natural Gas Required (1,000 cuft/yr) = Natural gas required to heat the anaerobic digester

Heat Required (BTU/hr) = Heat required to heat the anaerobic digester

Boiler Efficiency (%) = 80%

Heat Exchanger Efficiency (%) = 90%

Hours per Year Conversion (hr/yr) = 8,760 hr/yr

Natural Gas Heating Value (BTU/cuft) = 1,000 BTU/cuft

Unit Conversion (1,000 cuft/cuft) = 1,000 cuft (with 1,000 cuft as the unit)/ 1,000 cuft (with cuft as the unit)

3.3 LCCA

LCCA enables a total cost comparison of the nine wastewater treatment configurations including all of the relevant costs that occur throughout the life of the treatment alternatives. The total plant costs are presented in two ways: 1) total capital costs along with total annual costs (see Section 3.3.1) and 2) net present value (see Section 3.3.2). The net present value is a method to combine one-time capital costs and periodic (annual) operating and maintenance costs into one value for direct comparison of costs for alternative wastewater treatment configurations.

3.3.1 Total Capital and Total Annual

The total capital costs include the purchased equipment, direct costs, and indirect costs. The purchased equipment includes the cost to purchase the equipment and freight to get the equipment to the WWTP site. The direct costs are costs incurred as a direct result of installing the WWTP. For this study, the direct costs include mobilization, site preparation, site electrical, yard piping, instrumentation and control, and lab and administration building. The indirect costs are non-direct costs incurred as a result of installing the WWTP. For this study, the indirect costs include land, miscellaneous items, legal costs, engineering design fee, inspection costs, contingency, technical, interest during construction, and profit. The total capital costs are calculated using Equation 4 for each wastewater treatment configuration.

$$\text{Total Capital Costs} = \text{Purchased Equipment Costs} + \text{Direct Costs} + \text{Indirect Costs}$$

Equation 4

where:

Total Capital Cost (2014 $) = Total capital costs

Purchased Equipment Costs (2014 $) = Costs to purchase the equipment for the WWTP, including ancillary equipment and freight costs (see the following subsection for details)

Direct Costs (2014 $) = Costs incurred as a direct result of installing the WWTP (see the following subsection for details)

Indirect Costs (2014 $) = Costs for all non-direct costs incurred as a result of installing the WWTP (see the following subsection for details)

The total annual costs (often referred to as O&M) include the operation and maintenance labor, materials, chemicals, and energy. CAPDETWorks™ includes the periodic replacement of equipment parts (e.g., membranes, filter media, pumps) in the materials' annual costs. ERG used the same methodology for the membrane replacement costs for ultrafiltration and RO, which are detailed in Sections 3.2.3.4 and 3.2.3.6. ERG calculated total annual costs using Equation 5.

$$\text{Total Annual Costs} = \text{Operation Costs} + \text{Maintenance Costs} + \text{Materials Costs} + \text{Chemical Costs} + \text{Energy Costs}$$

Equation 5

where:

Total Annual Costs (2014 $/year) = Total annual operation and maintenance costs

Operation Costs (2014 $/year) = Labor costs for manual labor required to operate the WWTP for a year, including operation, administrative, and laboratory labor

Maintenance Costs (2014 $/year) = Labor costs for manual labor required to maintain the WWTP for a year

Materials Costs (2014 $/year) = Materials costs for operation and maintenance of the WWTP for a year, including replacement equipment

Chemical Costs (2014 $/year) = Chemical costs for chemicals required for WWTP operation (e.g., alum, polymer) for a year

Energy Costs (2014 $/year) = Electricity costs to run the WWTP for a year

CAPDETWorks™ calculates the operation and maintenance costs based on labor required and average salary for each job description: administrative, operation, maintenance, and laboratory. The administrative and laboratory labor hours are based on the WWTP flow rate, while the operation and maintenance hours are calculated for each process based on factors like the flow rate, number of units in each process, wastewater characteristics (e.g., total dissolved solids), and process design factors (e.g., required air rate). CAPDETWorks™ calculates the materials costs for operation and maintenance for each unit process based on factors like flow rate, unit capacity, and total construction cost. CAPDETWorks™ calculates the chemical costs based on the specific unit processes and the dosage rate. CAPDETWorks™ calculates the energy costs using the energy consumption requirements for the unit processes and $0.10/kWh. As of May 2014, the average price of electricity for all sectors was $0.1023/kWh as published by the U.S. Energy Information Administration (US EIA, 2015). As a result, ERG used the CAPDETWorks™ default electricity price, which is reflective of 2014 to match the 2014-dollar basis discussed in Section 3.2.1.

ERG used the CAPDETWorks™ total annual costs for unit processes in CAPDETWorks™. For unit processes not in CAPDETWorks™, ERG calculated total annual costs including the same components as CAPDETWorks™, as applicable for the specific unit process.

Purchased Equipment Costs

ERG costed the purchased equipment primarily using CAPDETWorks™, as described in Section 3.2.2 above. However, certain unit processes comprising the system configurations are not available in CAPDETWorks™. For these unit processes, ERG developed costs outside of CAPDETWorks™ and then incorporated these cost elements into the CAPDETWorks™ outputs to calculate the total purchased equipment costs for each wastewater treatment configuration, as presented in Equation 6.

$$\text{Purchased Equipment Costs} = \sum \text{Unit Process Equipment Costs} \qquad \text{Equation 6}$$

where:

Purchased Equipment Costs (2014 $) = Costs to purchase the equipment for the WWTP, including ancillary equipment and freight costs

Unit Process Equipment Costs (2014 $) = Costs to purchase the equipment for each unit process at the WWTP, including costs from CAPDETWorks™ and developed outside of CAPDETWorks™ (see Section 3.2.2 for details)

Direct Costs

CAPDETWorks™ includes direct costs for mobilization, site preparation, site electrical, yard piping, instrumentation and control, and lab and administration building. These direct costs account for the portions of the wastewater treatment configuration that are not directly associated with a unit process. CAPDETWorks™ calculates direct costs proportional to the WWTP flow based on cost curves generated from EPA's *Construction Costs for Municipal Wastewater Treatment Plants: 1973-1978* (U.S. EPA, 1980). Using this approach would not account for differences in the direct costs due to the increasing complexity of the nine wastewater treatment configurations. The CAPDETWorks™ approach is also inconsistent with standard engineering costing that calculates direct costs as a percentage of purchased equipment costs (Peters and Timmerhaus, 1991; Falk et al., 2011). As a result, ERG used the CAPDETWorks™ results from the Level 1 wastewater treatment configuration with the CAPDETWorks™ default unit process inputs to calculate direct cost factors for each direct cost element as a percentage of total purchased equipment cost as presented in Equation 7. Because CAPDETWorks™ calculates the same direct costs for all nine wastewater treatment configurations, calculating the direct cost factors using the lowest purchased equipment costs of the nine wastewater treatment configurations (i.e., Level 1), will result in the highest direct costs factors. ERG confirmed the calculated direct cost factors were reasonable based on other engineering sources (Falk et al., 2010).

$$\text{Direct Cost Factor} = \frac{\text{Level 1 Direct Cost}}{\text{Level 1 Purchased Equipment Cost}}$$

Equation 7

where:

Direct Cost Factor (%) = Direct cost factor for each direct cost element, see Table 1 below

Level 1 Purchased Equipment Cost (2014 $) = $19,600,000 (see Appendix E.8)

Level 1 Direct Cost (2014 $) = see Table 3-2 below

Table 3-2. Direct Cost Factors

Direct Cost Elements	Level 1 Direct Costs (2014 $)	Direct Cost Factor (%)
Mobilization	$818,000	4%
Site Preparation	$1,090,000	6%
Site Electrical	$2,360,000	12%

Table 3-2. Direct Cost Factors

Direct Cost Elements	Level 1 Direct Costs (2014 $)	Direct Cost Factor (%)
Yard Piping	$1,550,000	8%
Instrumentation and Control	$1,240,000	6%
Lab and Administration Building	$1,930,000	10%

Source: Appendix E.8.

ERG applied the direct cost factors from Table 3-2 to the total purchased equipment cost for each of the nine wastewater treatment configurations using Equation 8 to calculate the direct costs for each direct cost element.

$$\text{Direct Cost} = \text{Direct Cost Factor} \times \text{Purchased Equipment Cost}$$

Equation 8

where:

Direct Cost (2014 $) = Direct cost for each direct cost element

Direct Cost Factor (%) = Direct cost factor for each direct cost element, see Table 3-2

Purchased Equipment Cost (2014 $) = Total purchased equipment cost for each wastewater treatment configuration (see Equation 6)

Indirect Costs

CAPDETWorks™ includes indirect costs for land, miscellaneous items, legal costs, engineering design fee, inspection costs, contingency, technical, interest during construction, and profit. ERG used Equation 9 to calculate the total indirect costs.

$$\text{Indirect Costs} = \text{Land Cost} + \text{Remaining Indirect Costs} + \text{Interest During Construction}$$

Equation 9

where:

Indirect Costs (2014 $) = Costs for all non-direct costs incurred as a result of installing the WWTP

Land Cost (2014 $) = Total cost for the land required for the WWTP, see Equation 10 below

Remaining Indirect Costs (2014 $) = Indirect costs associated with miscellaneous costs, legal costs, engineering design fee, inspection costs, contingency, technical, and profit, see Equation 11 below

Interest During Construction (2014 $) = Interest paid during construction, see Equation 12 below

ERG used CAPDETWorks™ land costs, which are calculated using Equation 10.

$$\text{Land Cost} = \text{Treatment Area} \times \text{Land Unit Cost}$$

Equation 10

where:

Land Cost (2014 $) = Total cost for the land required for the WWTP

Treatment Area (acres) = Required treatment area for the WWTP based on the unit processes costed from CAPDETWorks™[6]

Land Unit Cost (2014 $/acre) = $20,000/acre, the CAPDETWorks™ default land unit cost, (Hydromantis, 2014)

For the remaining indirect costs ERG used contingency cost percentage based on cost estimate recommended practices (ACCEI, 2016) and CAPDETWorks™' indirect cost percentages (Table 3-3) to calculate indirect costs as a percentage of purchased equipment cost and direct construction costs for each wastewater treatment configuration as presented in Equation 11.

$$\text{Remaining Indirect Costs} = \text{Indirect Cost Factor} \times (\text{Purchased Equipment Cost} + \text{Direct Cost})$$

Equation 11

where:

Remaining Indirect Cost (2014 $) = Indirect costs associated with miscellaneous costs, legal costs, engineering design fee, inspection costs, contingency, technical, and profit

Indirect Cost Factor (%) = Indirect cost factor for each indirect cost element, see Table 3-3

Purchased Equipment Cost = Total purchased equipment cost (see Equation 6)

Direct Cost (2014 $) = Total direct costs (see Equation 8)

Table 3-3. Indirect Cost Factors

Indirect Cost Elements	Indirect Cost Factor (%)
Miscellaneous Costs	5%
Legal Costs	2%
Engineering Design Fee	15%

[6] All unit processes in the wastewater treatment configurations for Levels 1 through 4 are included in CAPDETWorks™ land area calculations. For the Level 5 wastewater treatment configurations, ERG determined that the land requirements for the non-CAPDETWorks™ unit processes (i.e., Level 5-1: ultrafiltration, reverse osmosis, and deep injection well; Level 5-2: reverse osmosis and deep injection well) was minimal and would fit within the CAPDETWorks™ land area.

Table 3-3. Indirect Cost Factors

Indirect Cost Elements	Indirect Cost Factor (%)
Inspection Costs	2%
Contingency	20%
Technical	2%
Profit	15%

Source: Hydromantis, 2014; AACEI, 2016.

For the interest during construction, ERG used Equation 12.

$$\text{Interest During Construction} = (\text{Purchased Equipment Cost} + \text{Direct Costs} + \text{Select Indirect Costs}) \times \text{Construction Period} \times \frac{\text{Interest Rate During Construction}}{2}$$

Equation 12

where:

Interest During Construction (2014 $) = Interest paid during construction

Purchased Equipment Cost (2014 $) = Total purchased equipment cost for each wastewater treatment configuration (see Equation 6)

Direct Costs (2014 $) = Total direct costs (see Equation 8)

Select Indirect Costs (2014 $) = Indirect costs, including miscellaneous items, legal costs, engineering design fee, inspection costs, contingency, and technical

Construction Period (years) = 3 years based on CAPDETWorks™ default construction period (Hydromantis, 2014)

Interest Rate During Construction (%) = Interest rate during construction

ERG used 3% and 5% interest rates during construction, which are the same values ERG used for the discount rates discussed in Section 3.3.2. The 3% interest rate represents a conservative interest rate for a State Revolving Fund (SRF) loan as the SRF average loan rate was 1.7% in April 2016 (U.S. EPA, 2016a). The 5% interest rate represents a worse-case scenario reflective of rates that WWTPs in poor financial shape, but still able to borrow, would be able to obtain.

3.3.2 Net Present Value

ERG calculated the net present value using Equation 13. This equation assumes that the only value remaining in the WWTP at the end of the planning period is in the land, which increases in value by 3% over the planning period using CAPDETWorks™' approach.

$$NPV = \frac{(1+i)^{PP}-1)}{i \times (1+i)^{PP}} \times (\text{Amortized Construction Cost} + \text{Total O\&M Cost})$$

$$+ \text{Land} \times \left(1 - (1.03^{PP}) \times \frac{1}{(1+i)^{PP}}\right)$$

Equation 13

where:

NPV (2014 $) = Net present value of all costs necessary to construct and operate the WWTP

Amortized Construction Cost (2014 $/yr) = Total construction costs amortized over the WWTP planning period, see Equation 14 below

Total O&M Costs (2014 $/yr) = Total annual operation and maintenance costs, see the previous subsection

Land (2014 $) = Land costs from CAPDETWorks™ models for each wastewater treatment configuration

i (%) = Real discount rate

PP (years) = WWTP planning period

1.03 = Factor to account for a 3% increase in land value over the WWTP planning period

ERG used 3% and 5% real discount rates, which are the same values ERG used to calculate the interest during construction. See the indirect costs subsection within Section 3.3.1 for a discussion on the basis for the selected interest rates. The real discount rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years and has been adjusted to eliminate the effect of expected inflation. As a result, ERG did not adjust the construction or O&M costs for inflation. ERG used 20 years as the WWTP planning period.

ERG calculated amortized construction costs using Equation 14.

$$\text{Amortized Construction Cost} = -12 \times \text{PMT}\left(\frac{i}{12}, \text{PP, Total Capital Cost, 0, 0}\right)$$

Equation 14

where:

Amortized Construction Cost (2014 $) = Total construction costs amortized over the WWTP planning period

PMT = Excel® function that calculates the stream of equal periodic payments that has the same present value as the actual stream of unequal payments over the project life at a constant interest rate (for example, a mortgage converts the one-time cost of a house to a stream of constant monthly payments)

i (%) = 3% and 5% discount rates

PP (years) = WWTP planning period (20 years)

Total Capital Cost (2014 $) = Total capital costs, see Equation 4

3.4 Data Quality

In accordance with the project's Quality Assurance Project Plan (QAPP) entitled *Quality Assurance Project Plan for Life Cycle and Cost Assessments of Nutrient Removal Technologies in Wastewater Treatment Plants* approved by EPA on March 25, 2015 (ERG, 2015c), ERG collected existing data[7] to develop cost estimates for the nine wastewater treatment configurations in this study. As discussed in Section 3.1, the cost estimate data sources include CAPDETWorks™ Version 3.0 (Hydromantis, 2014), EPA reports, peer-reviewed literature, publicly available equipment costs from and communication with technology vendors, and industry-accepted construction cost data and indices. ERG evaluated the collected information for completeness, accuracy, and reasonableness. In addition, ERG considered publication date, accuracy/reliability, and costs completeness when reviewing data quality. Finally, ERG performed conceptual, developmental, and final product internal technical reviews of the costing methodology and calculations for this study.

Table 3-4 presents the data quality criteria ERG used when evaluating collected cost data. ERG documented the data quality for each data source for each criterion in a spreadsheet for EPA's use in determining whether the cost data are acceptable for use. All of the references used to develop the costs met all of the data quality criteria with the exceptions of EPA's Wastewater Technology Fact Sheet – Dechlorination (U.S. EPA. 2000), EPA's Biosolids Technology Fact Sheet – Gravity Thickening (U.S. EPA, 2003a), and EPA's Wastewater Technology Fact Sheet – Screening and Grit Removal (U.S. EPA, 2003b). These references did not meet the criteria for currency (up to date). ERG used the Wastewater Technology Fact Sheet – Dechlorination to develop the contact time required to dechlorinate the residual chlorine. Although this EPA report is not current, the contact time for dechlorination has not changed since the fact sheet was published. ERG used the Biosolids Technology Fact Sheet – Gravity Thickening to revise the gravity thickener default CAPDETWorks™ values for depth and standard cost for a 90 ft diameter thickener. ERG used the Wastewater Technology Fact Sheet – Screening and Grit Removal to revise the CAPDETWorks™ purchased equipment cost for the preliminary treatment unit process (i.e., screening and grit removal). Although these EPA reports are not current, ERG revised the default values based on feedback from Falk et al. (2017) that the CAPDETWorks™ default values, designed in the 1970s, were no longer appropriate.

Table 3-4. Cost Data Quality Criteria

Quality Criterion: Cost Data	Description/Definition
Current (up to date)	Report the time period of the data. Year of publication (or presentation, if a paper presented at a conference) is 2005 or after.
Complete	Identify if all units are reported. Identify the cost per year basis reported. [a]
Representative	Report if the costs are for unit processes used in the selected nutrient wastewater treatment configurations.

[7] *Existing data* means information and measurements that were originally produced for one purpose that are recompiled or reassessed for a different purpose. Existing data are also called secondary data. Sources of existing data may include published reports, journal articles, LCI and government databases, and industry publications.

Table 3-4. Cost Data Quality Criteria

Quality Criterion: Cost Data	Description/Definition
Accurate/Reliable	Document the source of the data. Were the data (1) obtained from well-known technical references for engineering design and cost information, as well as for general cost factors (e.g., engineering, permitting, scheduling), or (2) from selected vendors that are the leaders within their areas of expertise determined based on the use of their technologies at municipal facilities that have well designed and operated wastewater treatment systems?

a – See Section 3.2.1 for the calculation ERG used to convert all costs to a standard year basis using RSMeans Construction Cost Index (RSMeans, 2017).

ERG developed the CAPDETWorks™ input files containing all the necessary information and data required for the tool to execute the wastewater treatment designs and engineering costing. All CAPDETWorks™ input files were reviewed by a team member knowledgeable of the project, but who did not develop the input files. The reviewer ensured the accuracy of the data transcribed into the input files, the technical soundness of methods and approaches used (i.e., included all of the cost components and LCA inputs) and the accuracy of the calculations (i.e., used the methodology in Section 3.3 to calculate the costs).

ERG developed the supplemental cost estimates for ultrafiltration, reverse osmosis, and deep well injection in an Excel® Workbook. A team member knowledgeable of the project, but who did not develop the Excel® workbook, reviewed the workbook to ensure the accuracy of the data transcribed into the workbook, the technical soundness of methods and approaches used, and the accuracy of calculations.

4. LCA METHODOLOGY

This chapter covers the data collection process, data sources, assumptions, methodology and parameters used to construct the LCI model for this study. Following the LCI discussion, details on the impact assessment are provided.

4.1 Life Cycle Inventory Structure

LCI data are the foundation of any LCA study. Every element included in the analysis is modeled as its own LCI unit process entry (see Appendix G for an example). It is the connection of LCI unit process data that constitutes the LCA model. A simplified depiction of a subset of this structure for this study is shown in Figure 4-1. The overall system boundaries were previously presented in Figure 1-1, and include all unit processes associated with plant operations and disposal of sludge, not just those processes associated with nutrient removal. It is not possible to display this type of figure for the entire LCA model, as each LCA model includes thousands of connected unit process inputs and outputs. Each box in the figure represents an LCI unit process. The full system is a set of nested LCIs where the primary process outputs, in red, of one process serve as inputs, in blue, to another process. Within each nested level, there can be flows both to and from the environment. Flows from the environment are written in black in Figure 4-1 and are represented by the thin black arrows crossing the system boundary from nature. Emissions to the environment are listed in green, and it is these flows that are tabulated in the calculation of environmental impacts. Intermediate inputs are shown in blue text. Intermediate inputs are those that originate from an extraction or manufacturing process within the supply-chain.

The distinction between the foreground and background systems is not a critical one. The foreground system tends to be defined as those LCIs that are the focus of the study. In this case, that is the WWTP itself. Foreground information was drawn directly from the CAPDETWorks™ Version 3.0 modeling software or calculated separately for input and output flows not captured by the software. Background LCI information is comprised of extractive and manufacturing processes that create material and energy inputs required by the wastewater treatment systems. Background data are drawn from a version of the U.S. LCI as well as ecoinvent databases that have been harmonized and modified by EPA's Office of Research and Development (ORD) (LCA Research Center, 2015). Details on the data sources for the background databases used is provided in Section 4.2 and detailed data sources and input and output flow values for the foreground unit processes are provided in Section 4.3.

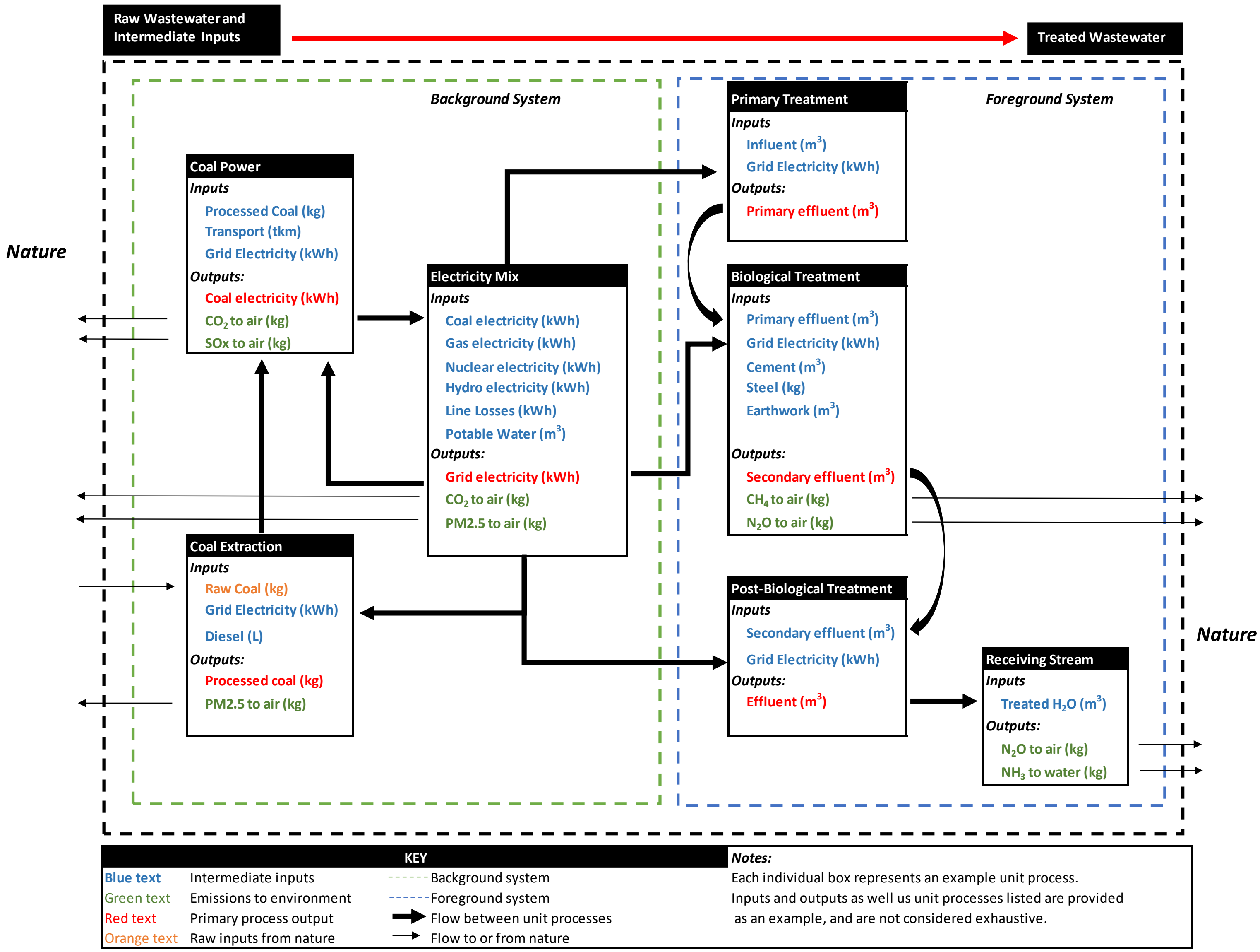


Figure 4-1. Subset of LCA Model Structure with Example Unit Process Inputs and Outputs

4.2 LCI Background Data Sources

The supply chains of inputs to the wastewater treatment processes are represented where possible using the EPA ORD LCA database (U.S. EPA, 2015f), which is a modified combination of the National Renewable Energy Laboratory's U.S. Life Cycle Inventory database (U.S. LCI) and ecoinvent Version 2.2 (NREL, 2015; Ecoinvent Centre, 2010b). The U.S. LCI is a publicly available life cycle inventory database widely used by LCA practitioners. Ecoinvent is also a widely used global LCI database available by paid subscription. Both allow the user access to inputs to and outputs from each unit process. Ecoinvent Version 3.2 is used to fill any gaps where data do not exist in the EPA ORD LCA database, U.S. LCI or ecoinvent Version 2.2 (Ecoinvent Centre, 2015). The list of background unit processes and their associated database source used in the LCA model is presented in Table 4-1.

Table 4-1. Background Unit Process Data Sources

Background Input	Original Unit Process Name	LCI Database
Electricity	Electricity, at industrial user	EPA ORD LCA Database
Natural Gas	Natural gas, combusted in industrial equipment	U.S. LCI
Chlorine Gas	chlorine, gaseous, diaphragm cell, at plant	ecoinvent v2.2
Polymer	polyacrylamide	ecoinvent v3.2
Sodium Bisulfite (40%)	Sodium hydrogen Sulfite, 40% in solution	ecoinvent v3.2
Sodium Bisulfite (12.5%)	Sodium hydrogen Sulfite, 12.5% in solution	ecoinvent v3.2
Truck Transport	Truck transport, class 8, heavy heavy-duty (HHD), diesel, short-haul, load factor 0.5	ecoinvent v2.2
Al Sulfate	Aluminium sulphate, powder, at plant	ecoinvent v2.2
Calcium Carbonate	Lime, from carbonation, at regional storehouse	ecoinvent v2.2
Methanol	Methanol, at plant	ecoinvent v2.2
Antiscalant	Polycarboxylates, 40% active substance | polycarboxylates production, 40% active substance	ecoinvent v3.2
Citric Acid	Citric acid | citric acid production	ecoinvent v3.2
Sodium Hypochlorite	Sodium hypochlorite, 15% in H2O, at plant	ecoinvent v2.2
Sulfuric Acid	Sulphuric acid, liquid, at plant_50% in solution	ecoinvent v2.2
Sodium Hydroxide	Sodium hydroxide, 50% in H2O, production mix, at plant	ecoinvent v2.2
Earthwork	Excavation, hydraulic digger	ecoinvent v2.2
Concrete	Ready mixed concrete, 20 MPa, at plant	EPA ORD LCA Database

Table 4-1. Background Unit Process Data Sources

Background Input	Original Unit Process Name	LCI Database
Building	Building, hall, steel construction	ecoinvent v2.2
Steel	Steel, low-alloyed, at plant	ecoinvent v2.2
Gravel	Gravel, crushed, at mine	ecoinvent v2.2
Anthracite	Anthracite, sand filter media	ecoinvent v2.2
Sand	Silica sand, at plant	ecoinvent v2.2

Electricity is a key background unit process for all the wastewater treatment configurations investigated. Table 4-2 displays the U.S. average electrical grid mix applied in the LCA model. This grid mix represents the weighted average of all U.S. grid regions, and as such is not representative of the grid mix in any specific location. For electricity at an industrial user, there is assumed to be a 21% increase in required electrical production attributable to losses during distribution and the energy industries own use. These data are based on the Emissions & Generation Resource Integrated Database (eGRID) information from 2009, which is currently applied in the EPA ORD LCA Database (LCA Research Center, 2015).

Table 4-2. U.S. Average Electrical Grid Mix

Fuel	%
Coal	44.8%
Natural Gas	24.0%
Nuclear	19.6%
Hydro	6.18%
Wind	2.29%
Woody Biomass	1.36%
Oil	1.02%
Geothermal	0.37%
Other Fossil	0.35%
Solar	0.03%

4.3 LCI Foreground Data Sources

As discussed earlier, for this study, the foreground system is defined as the WWTP itself. For each of the nine wastewater treatment configurations evaluated, foreground information was drawn directly from the CAPDETWorks™ Version 3.0 modeling software or calculated separately for input and output flows not captured by the software. This section describes the unit process LCI calculations, the methods used to estimate wastewater treatment process air emissions, and a summary of the LCI foreground data used. The foreground LCI unit process data developed for this study for all levels are summarized in Appendix H in Table H-1 through Table H-10. Table H-11 displays the sludge quantity produced and sent to landfill for each of the nine wastewater treatment configurations.

4.3.1 *Foreground Unit Processes Calculations*

Table 4-3 provides an overview of the foreground unit processes that make up each of the wastewater treatment configurations evaluated in this study. The quantity and quality of water inputs to and outputs from each unit process are tracked throughout the wastewater treatment configurations. Energy, chemical, and material inputs (e.g., background unit processes) to each of the unit processes are tracked in terms of energy, mass, or volume units. Also, rough estimates of the construction and maintenance requirements of the infrastructure for each unit process are tracked based on greenfield installations of the wastewater treatment configurations. In the case of infrastructure and capital equipment requirements, past analyses have shown the contribution of infrastructure to the overall results to be relatively insignificant (Emmerson et al., 1995). In general, these types of capital equipment are used to treat large volumes of wastewater over a useful life of many years. Thus, energy and emissions associated with the production of these facilities and equipment generally become negligible. Only major infrastructure elements such as concrete, earthwork, and buildings were, therefore, included in the study. Buildings were modeled using a general material inventory per square meter of floor area (Ecoinvent, 2010b).

Releases to air and water as well as waste outputs are also tracked for each unit process. Releases to air and water are tracked together with information about the environmental compartment to which they are released to allow for appropriate characterization of their impacts. Waste streams are connected to supply chains associated with providing waste management services such as landfilling.

Table 4-3. Foreground Unit Processes Included in Each Wastewater Treatment Configuration

Unit Process	Wastewater Treatment Configuration								
	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Preliminary Treatment – Screening	✓	✓	✓	✓	✓	✓	✓	✓	✓
Preliminary Treatment – Grit Removal	✓	✓	✓	✓	✓	✓	✓	✓	✓
Primary Clarification	✓	✓	✓	✓	✓	✓	✓	✓	✓
Plug Flow Activated Sludge	✓		✓						
Biological Nutrient Removal – 3-Stage		✓							
Fermenter				✓	✓	✓		✓	✓
Biological Nutrient Removal – 4-Stage					✓		✓		
Biological Nutrient Removal – 5-Stage				✓		✓		✓	✓
Chemical Phosphorus Removal			✓	✓	✓	✓	✓	✓	✓

Table 4-3. Foreground Unit Processes Included in Each Wastewater Treatment Configuration

Unit Process	Wastewater Treatment Configuration								
	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Nitrification – Suspended Growth			✓						
Denitrification – Suspended Growth			✓						
Secondary Clarifier	✓	✓	✓	✓	✓	✓		✓	
Membrane Filter [a, b]							✓		✓
Tertiary Clarification			✓ [c]						
Denitrification – Attached Growth						✓		✓	
Filtration – Sand Filter				✓	✓	✓		✓	
Chlorination	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dechlorination	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ultrafiltration [a]								✓	
Reverse Osmosis [a, d]								✓	✓
WWTP Effluent Discharge	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sludge – Gravity Thickening	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sludge – Anaerobic Digestion	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sludge – Centrifugation	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sludge – Haul and Landfill	✓	✓	✓	✓	✓	✓	✓	✓	✓
Brine – Underground Inject								✓	✓

✓ Indicates unit process is relevant for select wastewater treatment configuration.

a – Periodic chemical cleaning is included for all membranes.

b – Membrane bioreactor wastewater treatment configurations use a membrane filter for the solid-liquid separation process instead of a traditional secondary clarifier.

c – This configuration includes two instances of tertiary clarification.

d – Includes chlorination and dechlorination pretreatment.

Foreground information was drawn directly from the CAPDETWorks™ Version 3.0 modeling software or calculated separately for input and output flows not captured by the software. Although CAPDETWorks™ is designed for cost estimation, the underlying models include a number of parameters which can be accessed and used to describe the physical processes involved at each stage in the wastewater treatment configurations, such as sludge generation or treatment chemical usage. An example of converting CAPDETWorks™ output to

LCI is provided in Appendix G. Where CAPDETWorks™ parameters are not available for populating relevant items in the unit processes underlying the LCA model, values are estimated based on the best available information identified through literature review. Values for GHG emissions from the wastewater treatment processes are not provided by CAPDETWorks™ and, therefore, are estimated independently (See Section 4.3.2 and Appendix F). Calculation of inputs and outputs for unit processes not covered in CAPDETWorks™ are also described separately in Appendix E: Sections E.2 through E.7)

4.3.2 Process Air Emissions Estimation Methodologies

For this study it is necessary to separately estimate process-based greenhouse gas (GHG) emissions for the nine wastewater treatment configurations. Emissions are already captured in the background existing unit processes for fuel production and combustion as well as material and chemical production (e.g., unit processes listed in Table 4-1). Estimates of process-based air emissions are made for methane (CH_4) production from biological treatment, anaerobic digestion, landfill disposal of biosolids, and biogas flaring at the anaerobic digester. Estimates of nitrous oxide (N_2O) emissions from biological treatment and receiving waters are also included in the analysis (IPCC, 2006). Separate methodologies have been developed based on the available literature for each of these sources of GHGs. Carbon dioxide (CO_2) emissions from wastewater treatment processes are not included in the calculation of GHG emissions from wastewater treatment processes because they are of biogenic origin and are not included in national total emissions in accordance with IPCC Guidelines for national inventories (IPCC, 2006). The methodology for calculating GHG emissions associated with wastewater treatment is generally based on guidance provided in the IPCC Guidelines for national inventories; however, more specific emission factors for both CH_4 and N_2O are used based on site-specific emissions data from representative systems. A detailed discussion of the process GHG emission values incorporated in the model is provided in Appendix F. Appendix F also provides the GHG emissions methodology developed for biogas flaring at the anaerobic digester (Table F-3) as well as the GHG emissions methodology associated with avoided electricity from landfill CH_4 recovery (Table F-7).

4.4 LCI Limitations

Some of the main limitations that readers should understand when interpreting the LCI data and findings are as follows:

- **Support Personnel Requirements:** Support personnel requirements are included in the cost analysis but excluded from the LCA model. The energy and wastes associated with research and development, sales, and administrative personnel or related activities are not included, as energy requirements and related emissions are assumed to be quite small for support personnel activities.
- **Representativeness of Background Data:** Background processes are representative of either U.S. average data (in the case of data from U.S. EPA ORD or U.S. LCI) or European or Global average (in the case of ecoinvent) data. In some cases, European ecoinvent processes were used to represent U.S. inputs to the model (e.g., for chemical inputs) due to lack of available representative U.S. processes for these

inputs. The background data, however, met the criteria listed in the project QAPP for completeness, representativeness, accuracy, and reliability.

- **Process GHG Estimates:** There is uncertainty in estimating CH_4 and N_2O process emissions from biological treatment and in differentiating the various treatment levels due to the limited measurement data associated with the different wastewater treatment configurations evaluated. Based on current international guidance, many governments ignore CH_4 GHG emissions in their national inventories from centralized aerated treatment plants because they are considered negligible when compared to other sources. The source of emission can be highly variable from facility to facility and is not associated with the type of treatment configuration. Facility-level process GHGs are also highly dependent on the specific operational characteristics of a system used at one plant versus another, including pH, temperature, and level of aeration. Minimum thresholds for determining differences in GHG results between the waste treatment configurations are discussed in Section 4.6.15.
- **Full LCI Model Data Accuracy and Uncertainty:** In a complex study with literally thousands of numeric entries, the accuracy of the data and how it affects conclusions is truly a difficult subject, and one that does not lend itself to standard error analysis techniques. The reader should keep in mind the uncertainty associated with LCI models (and the underlying CAPDETWorks™ model) when interpreting the results. Comparative conclusions should not be drawn based on small differences in impact results. For this study, minimum threshold guidelines to determine differences in impact results are provided by category in Section 4.6.15.
- **Temporal Considerations:** The LCI model does not distinguish based on temporal correlations and treat short-term and long-term impacts similarly. ~~between emissions or discharges that occur immediately and those that are long-term~~. For instance, long-term emissions of COD in landfill leachate from sludge disposal is incorporated in the model. For the first 100 years, it is assumed the leachate is sent to a WWTP. However, after 100 years it is assumed the landfill ceases to operate and there are still some residual leachate emissions.
- **Transferability of Results:** The LCI data presented here relate to a theoretical average U.S. WWTP with a greenfield installation and the conditions specified in Section 1.2. LCI results may vary substantially for case-specific operating conditions and facilities, and for retrofits of existing systems.

4.5 LCA Modeling Procedure

Development of an LCA requires significant input data, an LCA modeling platform, and impact assessment methods. This section provides a brief summary of the LCA modeling procedure. Each unit process in the life cycle inventory was constructed independently of all other unit processes. This allows objective review of individual data sets before their contribution to the overall life cycle results has been determined. Also, because these data are reviewed individually, EPA reviewed assumptions based on their relevance to the process rather than their effect on the overall outcome of the study. In most cases, individual unit processes were parameterized to dynamically represent multiple treatment levels and configurations.

The model was constructed in OpenLCA Version 1.4.2, an open-source LCA software package provided by GreenDelta (GreenDelta, 2015). This open-source format allowed seamless sharing of the LCA model between project team members. For all novel foreground unit processes developed under this work, individual unit process templates were completed into the United States Department of Agriculture (USDA) and U.S. EPA's US Federal LCA Commons Life Cycle Inventory Unit Process Template (USDA and U.S. EPA, 2015). The OpenLCA model was reviewed to ensure that all inputs and outputs, quantities, units, and metadata correctly matched the unit process templates. Associated metadata for each unit process was recorded in the unit process templates along with the model values. This metadata includes detailed data quality indicators (DQI) for each flow within each unit process.

Once all necessary data were input into the OpenLCA software and reviewed, system models were created for each treatment level configuration. The models were reviewed to ensure that each elementary flow (e.g., environmental emissions, consumption of natural resources, and energy demand) was characterized under each impact category for which a characterization factor was available. The draft final system models were also reviewed prior to calculating results to make certain all connections to upstream processes and weight factors were valid. LCIA results were then calculated by generating a contribution analysis for the selected treatment configuration product system based on the defined functional unit of treatment of one cubic meter of wastewater. The subsequent section discusses the detailed LCIA methods used to translate the LCI model in OpenLCA into the impact categories assessed in this study.

4.6 Life Cycle Impact Assessment (LCIA)

LCIA is defined in ISO 14044 section 3.4 as the "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (ISO, 2006b)." Within LCIA, the multitude of environmental LCI flows throughout the entire study boundaries (e.g., raw material extraction through chemical and energy production and through wastewater treatment and effluent release) are classified according to whether they contribute to each of the selected impact categories. Following classification, all of the relevant pollutants are normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance. One well known example is the reporting of all GHG emissions in CO_2-eq. The LCI and LCIA steps together compromise the main components of a full LCA.

ISO 14040 recommends that an LCA be as comprehensive as possible so that "potential trade-offs can be identified and assessed (ISO, 2006a)." Given this recommendation, this study applies a wide selection of impact categories that encompass both environmental and human health indicators. The selected LCIA categories address impacts at global, regional, and local scales.

This study considers 12 impact categories in assessing the environmental burdens of the nine wastewater treatment configurations. The majority of impact categories address air and water environmental impacts, while three of the selected impact categories are human health impact indicators. There are two main methods used to develop LCIA characterization factors: midpoint and endpoint. The impact categories selected for this study are all midpoint indicators.

Midpoint indicators are directly associated with a specific environmental or human health pathway. Specifically, midpoint indicators lie at the point along the impact pathway where the various environmental flows that contribute to these issues can be expressed in a common unit (e.g., CO_2-eq). Units such as CO_2 equivalents express a relevant environmental unit, in this case radiative forcing (W-yr/m^2/kg), in the context of a reference substance. This is mentioned to reinforce the fact that there are physical mechanisms underlying all of the impact assessment methods put forward. Endpoint indicators build off of these midpoint units and translate them into impacts more closely related to the final damage caused by the substance, which include: (1) human health, (2) man-made environment, (3) natural environment, and (4) natural resources (Udo de Haes et al., 1999). It is commonly believed that endpoint indicators are easier for many audiences to understand, but suffer due to the fact that they significantly increase the level of uncertainty associated with the results because the translation to final damage are typically less understood and lack data. To reduce uncertainty of the results, this work generally focuses on indicators at the midpoint level.

The LCIA method provided by the Tool for the Reduction and Assessment of Chemical and Environmental Impacts (TRACI), version 2.1, developed by the U.S. EPA specifically to model environmental and human health impacts in the U.S., is the primary LCIA method applied in this study (Bare, 2012). Additionally, the ReCiPe LCIA method is recommended to characterize fossil fuel depletion and water use (Goedkoop et al., 2009). Energy is tracked based on point of extraction using the cumulative energy demand method developed by ecoinvent (Ecoinvent Centre, 2010a).

Summaries of each of the 12 impact categories evaluated as part of this study are provided in the subsequent sections. Each summary includes a table of the main substances considered in the impact category, associated substance characterization factor, and the compartment (e.g., air, water, soil) the substance is released to or extracted from (in the case of raw materials). These tables highlight key substances but should not be considered comprehensive.

4.6.1 Eutrophication Potential

Eutrophication occurs when excess nutrients (e.g., nitrogen or phosphorus) are introduced to surface and coastal water causing the rapid growth of aquatic plants. This growth (generally referred to as an "algal bloom") reduces the amount of dissolved oxygen in the water, thus decreasing oxygen available for other aquatic species. Eutrophication midpoint indicators, applied in this study, can lead to a number of negative endpoint effects on human and ecosystem health. Oxygen depletion or changing nutrient availability can affect species composition and ecosystem function. Additionally, the proliferation of certain algal species can result in toxic releases that directly impact human health (Henderson, 2015).

Table 4-4 provides a list of common substances that contribute to eutrophication along with their associated characterization factors. As indicated in the table, air emissions can also contribute to eutrophication through the atmospheric deposition of nitrogen compounds. The TRACI 2.1 eutrophication method considers emissions to both fresh and coastal waters. TRACI 2.1 characterization factors for eutrophication are the product of a nutrient factor and a transport factor (Bare et al., 2003). The nutrient factor is based on the amount of algae growth caused by each pollutant. The relative eutrophying effect of a nitrogen or phosphorus species is determined by its stoichiometric relationship to the Redfield ratio (Norris, 2003). The Redfield ratio is the average C:N:P ratio of phytoplankton, and describes the necessary building blocks to facilitate algal growth and reproduction (Redfield, 1934). The transport factor accounts for the likelihood that the pollutant will reach a body of water based on the average hydrology considerations for the U.S. The transport factor is used to account for the fact that a nutrient reaching a body of water where it is not limiting will not contribute to eutrophication. Both air and water emissions have the potential to contribute to eutrophication; however, the fraction of air emissions which make their way into bodies of water is often lower, which is reflected in a smaller transport factor, and the correspondingly lower characterization factors of nitrogen oxide air emissions in Table 4-4.

Both BOD and COD are also shown in Table 4-4 as contributing to eutrophication impacts. Although the mechanism of oxygen consumption differs from that associated with nutrient emissions of nitrogen and phosphorus, the result remains the same. Only COD (and not BOD) values are characterized in this study to avoid double-counting (Norris, 2003).

In this study, U.S. average characterization factors are used, which are created as a composite of all water basins in the U.S. For a discussion of the procedure used to produce composite U.S. characterization factors, see Norris (2003). Using these factors, the results account for regional variation in nutrient and transport factors, although that regional variability is not presented in a disaggregated form. This is appropriate for the scope of this study as our aim is to estimate average U.S. impacts of wastewater treatment. However, it must be recognized that context specific features of an individual WWTP could serve to ameliorate or increase site-specific impacts. In addition, waterbody-specific nutrient limitations and local transport characteristics tend to be the most decisive factors in determining regional differences in eutrophication impacts (Henderson, 2015).

Table 4-4. Main Pollutants Contributing to Eutrophication Potential Impacts (kg N eq/ kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
BOD_5, Biological Oxygen Demand	N/A	Water	0.05
COD, Chemical Oxygen Demand	N/A	Water	0.05
Ammonia	NH_3	Water	0.78
Nitrate	NO_3-	Water	0.24
Nitrogen dioxide	NO_2	Air	0.04
Nitrogen monoxide	NO	Air	0.04
Nitrogen oxides	NO_x	Air	0.04
Nitrogen, organic bound	N/A	Water	0.99
Phosphate	PO_4^{3-}	Water	2.4
Phosphorus [a]	P	Water	7.3
Selected Method—			TRACI 2.1

a – Represents phosphorus content of unspecified phosphorus pollutants (e.g., “total phosphorus” in effluent composition).

4.6.2 Cumulative Energy Demand

The cumulative energy requirements for a system can be categorized by the fuels from which energy is derived. This method is not an impact assessment, but rather is a cumulative inventory of all energy extracted and utilized. Energy sources consist of non-renewable fuels (natural gas, petroleum, nuclear and coal) and renewable fuels. Renewable fuels include hydroelectric energy, wind energy, energy from biomass, and other non-fossil sources. Cumulative energy demand (CED) includes both renewable and non-renewable sources as well as the embodied energy in biomass and petroleum feedstocks. CED is measured in MJ/kg. Energy is tracked based on the higher heating value (HHV) of the fuel at the point of extraction. Table 4-5 includes a few examples of fuels that contribute to CED in this project and their associated characterization factors.

Table 4-5. Main Energy Resources Contributing to Cumulative Energy Demand

Energy Resource	Compartment	Units	Characterization Factor
Energy, gross calorific value, in biomass	Resource (biotic)	MJ/kg	1.0
Coal, hard, unspecified, in ground	Resource (in ground)	MJ/kg	19
Gas, natural, in ground	Resource (in ground)	MJ/kg	47
Oil, crude, in ground	Resource (in ground)	MJ/kg	46
Selected Method—		Ecoinvent	

4.6.3 Global Warming Potential

Global warming refers to an increase in the earth's temperature in relation to long-running averages. In accordance with IPCC recommendations, TRACI's GWP calculations are based on a 100-year time frame and represent the heat-trapping capacity of the gases relative to an equal weight of carbon dioxide. Relative heat-trapping capacity is a function of a molecule's radiative forcing value as well as its atmospheric lifetime. Table 4-6 provides a list of the most common GHGs along with their corresponding GWPs, or CO_2 equivalency factors, used in TRACI 2.1. Contributing elementary flows can be characterized using GWPs reported by the IPCC in either 2007 (Fourth Assessment Report) or in 2013 (Fifth Assessment Report) (IPCC, 2007; IPCC, 2013). While the 2013 GWPs are the most up-to-date, the 2007 GWPs have been officially adopted by the United Nations Framework Convention on Climate Change (UNFCCC) for international greenhouse gas reporting standards and are used by EPA in their annual greenhouse gas emissions report. The baseline results in this study apply the 2007 GWPs, but results with the 2013 GWPs are provided in a sensitivity analysis in Chapter 9.

Table 4-6. Main GHG Emissions Contributing to Global Warming Potential Impacts (kg CO_2 eq/kg GHG)

GHG	Chemical Formula	Compartment	GWP (IPCC 2007)	GWP (IPCC 2013)
Carbon dioxide	CO_2	Air	1.0	1.0
Nitrous oxide	N_2O	Air	3.0E+2	2.7E+2

Table 4-6. Main GHG Emissions Contributing to Global Warming Potential Impacts ($kg\ CO_2$ eq/kg GHG)

GHG	Chemical Formula	Compartment	GWP (IPCC 2007)	GWP (IPCC 2013)
Methane	CH_4	Air	25	28
Sulfur hexafluoride	SF_6	Air	2.3E+4	2.4E+4
Selected Method—			IPCC 2007 or 2013 100a	

4.6.4 Acidification Potential

The deposition of acidifying substances such as those listed in Table 4-7 have an effect on the pH of the terrestrial ecosystem. Each species within these ecosystems has a range of pH tolerance, and the acidification of the environment can lead to shifting species composition over time. Acidification can also cause damage to buildings and other human infrastructure (Bare, 2012). The variable buffering capacity of terrestrial environments yields a correspondingly varied response per equivalent unit of acidification. Due to a lack of data, the variable sensitivity of receiving regions is not captured in TRACI characterization factors (Norris, 2003). The acidification method in TRACI utilizes the results of an atmospheric chemistry and transport model, developed by the US National Acid Precipitation Assessment Program (NAPAP), to estimate total North American terrestrial deposition of expected SO_2 equivalents due to atmospheric emissions of NO_x and SO_2 and other acidic substances such as HCl and HF, as a function of the emissions location (Bare et al., 2003). Emissions location is modeled in this study as average U.S. using TRACI's composite annual North American emissions average of U.S. states.

Table 4-7. Main Pollutants Contributing to Acidification Potential Impacts ($kg\ SO_2$ eq/kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
Sulfur dioxide	SO_2	Air	1.0
Ammonia	NH_3	Air	1.9
Nitrogen dioxide	NO_2	Air	0.70
Nitrogen oxides	NO_x	Air	0.70
Hydrogen chloride	HCl	Air	0.88
Hydrogen fluoride	HF	Air	1.6
Hydrogen sulfide	H_2S	Air	1.9
Selected Method—		TRACI 2.1	

4.6.5 Fossil Depletion

Fossil depletion is a measure of the study systems demand for non-renewable energy resources. As non-renewable resources, the availability of fossil energy will not change (i.e., new fossil energy will not be produced) on relevant human timescales. When these resources are depleted and resource quality declines, the cost and environmental impact of accessing a given quantity of energy increases. Fossil depletion is measured in kg oil equivalent based on each fuel's heating value. Renewable energy systems and uranium are not included in the fossil depletion metric but are assessed within the CED methodology previously discussed. Table 4-8 presents common fossil fuel flows and their associated characterization factors for this impact category.

Table 4-8. Main Fossil Fuel Resource Contributing to Fossil Depletion (kg oil eq/kg Fossil Fuel Resource)

Fossil Fuel Resource	Compartment	Characterization Factor
Oil, crude, 42 MJ per kg	Resource (in ground)	1.0
Coal, 18 MJ per kg	Resource (in ground)	0.43
Coal, 29.3 MJ per kg	Resource (in ground)	0.70
Gas, natural, 30.3 MJ per kg	Resource (in ground)	0.72
Gas, natural, 35 MJ per m3	Resource (in ground)	0.83
Methane	Resource (in ground)	0.86
Selected Method—		ReCiPe

4.6.6 Smog Formation Potential

The smog formation impact category characterizes the potential of airborne emissions to cause photochemical smog. The creation of photochemical smog occurs when sunlight reacts with NO_x and volatile organic compounds (VOCs), resulting in tropospheric (ground-level) ozone (O_3) and particulate matter. Potential endpoints of such smog creation include increased human mortality, asthma, and deleterious effects on plant growth. Smog formation potential impacts are measured in kg of O_3 equivalents. Table 4-9 includes a list of smog forming chemicals expected to be associated with this project along with their characterization factors.

Table 4-9. Main Pollutants Contributing to Smog Formation Impacts (kg O_3 eq/kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
Sulfur monoxide	SO	Air	1.0
Carbon monoxide	CO	Air	0.06
Methane	CH_4	Air	0.01
Nitrogen dioxide	NO_2	Air	17
Nitrogen oxides	NO_x	Air	25
VOC, volatile organic compounds	N/A	Air	3.6

Table 4-9. Main Pollutants Contributing to Smog Formation Impacts (kg O_3 eq/kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
Selected Method—			TRACI 2.1

4.6.7 Human Health—Particulate Matter Formation Potential

Particulate matter (PM) emissions have the potential to negatively impact human health. Respiratory complications are particularly common among children, the elderly, and individuals with asthma (U.S. EPA, 2008a). Respiratory impacts can result from a number of types of emissions including PM10, PM2.5, and precursors to secondary particulates such as sulfur dioxide and nitrogen oxides. Respiratory impacts are a function of the fate of responsible pollutants as well as the exposure of human populations. Table 4-10 provides a list of common pollutants contributing to impacts in this category along with their associated characterization factors. Impacts are measured in relation to PM2.5 emissions.

Table 4-10. Main Pollutants Contributing to Human Health-Particulate Matter Formation Potential (kg PM2.5 eq/kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
Particulates, < 2.5 µm	N/A	Air	1.0
Particulates, > 2.5 µm, and < 10 µm	N/A	Air	0.23
Ammonia	NH_3	Air	0.07
Nitrogen oxides	NO_x	Air	7.2E-3
Sulfur oxides	SO_x	Air	0.06
Selected Method—			TRACI 2.1

4.6.8 Ozone Depletion Potential

Stratospheric ozone depletion is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substance (e.g., CFCs and halons). The ozone depletion impact category characterizes the potential to destroy ozone based on a chemical's reactivity and atmospheric lifetime. Potential impacts related to ozone depletion includes skin cancer, cataracts, immune system suppression, crop damage, other plant and animal effects. Ozone depletion potential is measured in kg CFC-11 equivalents. Table 4-11 lists common ozone depleting chemicals and their associated characterization factors in TRACI 2.1. Nitrous oxide is incorporated in the results based on the ReCiPe hierarchies midpoint method (Goedkoop et al., 2009).

Table 4-11. Main Pollutants Contributing to Ozone Depletion Potential Impacts (kg CFC11 eq/kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	$C_2Cl_3F_3$	Air	1.0
Methane, bromochlorodifluoro-, Halon 1211	$CBrClF_2$	Air	7.1
Methane, bromotrifluoro-, Halon 1301	$CBrF_3$	Air	16
Methane, chlorodifluoro-, HCFC-22	$CHClF_2$	Air	0.05
Methane, trichlorofluoro-, CFC-11	CCl_3F	Air	1.0
Nitrous oxide	N_2O	Air	0.01
Selected Method—			TRACI 2.1, ReCiPe

4.6.9 Water Depletion

Water use results are displayed on a consumptive basis (i.e., depletion). When water is withdrawn from one water source and returned to another watershed this is considered consumption, as there is a net removal of water from the original water source. For instance, it is assumed that deepwell injection of the brine fluid from RO is consumptive water use, since water is being diverted from a watershed making it unavailable for subsequent environmental or human uses. Consumption also includes water that is withdrawn and evaporated or incorporated into the product. Cooling water that is closed-loop circulated, and does not evaporate, is not considered consumptive use. Water consumption is only included as an inventory category in this study, which is a simple summation of water inputs. The analysis does not attempt to assess water-related damage factors. For instance, there is no differentiation between water consumption that occurs in water-scarce or water-abundant regions of the world. Water consumption in this study includes values for upstream fuel and electricity processes. In addition to water consumption associated with thermal generation of electricity from fossil and nuclear fuels, the water consumption for power generation includes evaporative losses due to establishment of dams for hydropower. Table 4-12 shows some of the common flows associated with water use along with their characterization factors. Section 4.6.15 also discusses some of the uncertainty associated with calculating water depletion in LCA.

Table 4-12. Main Water Flows Contributing to Water Depletion

Water Flow	Compartment	Units	Characterization Factor
Water, lake	Resource (in water)	$m^3\ H_2O/m^3$	1.0
Water, river	Resource (in water)	$m^3\ H_2O/m^3$	1.0
Water, unspecified natural origin	Resource (in water)	$m^3\ H_2O/m^3$	1.0
Water, well, in ground	Resource (in water)	$m^3\ H_2O/m^3$	1.0
Water, unspecified natural origin/kg	Resource (in water)	$m^3\ H_2O/kg$	1.0E-3
Selected Method—		ReCiPe	

4.6.10 Human Health—Cancer Potential

Carcinogenic human health results in this study are expressed on the basis of Comparative Toxic Units (CTU_h) based on the USEtox™ method (Huijbregts et al. 2010). Characterization factors within the USEtox™ model are based on fate, exposure, and effect factors. Each chemical included in the method travels multiple pathways through the environment based on its physical and chemical characteristics. The potential for human exposure (e.g., ingestion or inhalation) varies according to these pathways. The effect factor characterizes the probable increase in cancer-related morbidity for the total human population per unit mass of a chemical emitted (i.e., cases per kg) (Rosenbaum et al., 2008). The full USEtox™ model contains over 3,000 chemicals of global relevance and is the product of an international project to harmonize the approach to evaluation of toxicity effects. The USEtox™ model develops characterization factors at the continental and global scale. The exclusion of more localized parameters is justified in that it was found during the harmonization process that site-specific parameters have a far lower impact on results than do the substances themselves.

Global midpoint characterization factors are employed from the most recent version of USEtox™ available in OpenLCA, version 2.02. An updated version of USEtox™, version 2.11, was released in April 2019. Characterization factors for the heavy metals, toxic organics and DBPs were updated in the OpenLCA USEtox™ LCIA method to match version 2.11. All other characterization factors remain at the default value for OpenLCA's USEtox version 2 (recommended+interim) database. Not all heavy metals, toxic organics and DBPs have established characterization factors in the USEtox™ method. Several additional sources were used to identify appropriate characterization factors. When no appropriate characterization factor was identified, the pollutant was assigned a characterization factor equal to the median characterization factor for its trace pollutant group. Table B-5, Table C-8, and Table D-4 list values and sources of characterization factors for all heavy metals, toxic organics, and DBPs. For illustration purposes, Table 4-13 lists five of the primary chemicals contributing to cancer human health impacts in the US and Canada (Ryberg, 2014) along with their associated characterization factors.

The developers of the USEtox™ method are clear to point out that some of the characterization factors associated with human health effects should be considered interim, owing to uncertainty in their precise values ranging across one to three orders of magnitude. Sources of uncertainty are often attributable to the use of one exposure route as a proxy for another (route-to-route extrapolation). For a more detailed discussion of uncertainty present in these models, see the USEtox™ User's Manual (Huijbregts et al., 2010). Appropriate interpretation of results must consider the uncertainty associated with the use of interim characterization factors.

Table 4-13. Main Pollutants Contributing to Human Health - Cancer Potential Impacts (CTU_h/kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
Arsenic	As	Soil	1.8E-4[a]
Formaldehyde	CH_2O	Air	2.5E-5

Table 4-13. Main Pollutants Contributing to Human Health - Cancer Potential Impacts (CTU_h/kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
Chromium VI	Cr	Soil	5.0E-3[a]
Chromium VI	Cr	Air, urban	3.8E-3[a]
Chromium VI	Cr	Water	0.01[a]
Selected Method—			USEtox™ 2.11

a – Designates an interim characterization factor.

4.6.11 Human Health—Noncancer Potential

Non-carcinogenic human health results in this study are expressed on the basis of Comparative Toxic Units (CTU_h) based on the USEtox™ method, which is incorporated in TRACI 2.1. The impact method characterizes the probable increase in noncancer related morbidity for the total human population per unit mass of a chemical emitted (i.e., cases per kg) (Rosenbaum et al., 2008). These impacts are calculated using the same approach as that taken for human health - cancer (Section 4.6.10).

Global midpoint characterization factors are employed from the most recent version of USEtox™ available in OpenLCA, version 2.02. An updated version of USEtox™, version 2.11, was released in April 2019. Characterization factors for the heavy metals, toxic organics and DBPs were updated in the OpenLCA USEtox™ LCIA method to match version 2.11. All other characterization factors remain at the default value for OpenLCA's USEtox version 2 (recommended+interim) database. Not all heavy metals, toxic organics and DBPs have established characterization factors in the USEtox™ method. Several additional sources were used to identify appropriate characterization factors. When no appropriate characterization factor was identified, the pollutant was assigned a characterization factor equal to the median characterization factor for its trace pollutant group. Table B-5, Table C-8, and Table D-4 list values and sources of characterization factors for all heavy metals, toxic organics, and DBPs. For illustration purposes, Table 4-14 lists the main chemicals contributing to noncancer, human health impacts (Ryberg, 2014) along with their associated characterization factors.

As is discussed in Section 4.6.10, uncertainty in USEtox factors can range across one to three orders of magnitude for interim characterization factors, which are identified in Table 4-14. At the current time, all characterization factors for metal compounds are considered interim. Appropriate interpretation of results must consider the uncertainty associated with the use of interim characterization factors.

Table 4-14. Main Pollutants Contributing to Human Health—Noncancer Potential Impacts (CTU_h/kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
Acrolein	C_3H_4O	Soil	3.4E-5
Zinc, ion	Zn^{2+}	Soil	1.4E-4[a]

Table 4-14. Main Pollutants Contributing to Human Health—Noncancer Potential Impacts (CTU_h/kg Pollutant)

Pollutant	Chemical Formula	Compartment	Characterization Factor
Arsenic, ion	As^{3+}	Soil	0.01[a]
Zinc, ion	Zn^{2+}	Air, urban	5.7E-3[a]
Mercury (+II)	Hg(II)	Air, urban	1.24[a]
Selected Method—			USEtox™ 2.11

a – Designates an interim characterization factor.

4.6.12 Ecotoxicity Potential

Ecotoxicity is a measure of the effect of toxic substances on ecosystems. The effects on freshwater ecosystems are used as a proxy for general ecological impact. Characterization factors within the ecotoxicity model are based on fate, exposure, and effect factors. Each chemical included in the method travels multiple pathways through the environment. As a result of these pathways, various compartments (e.g., freshwater, terrestrial) and the species they contain will have differing opportunities to interact with the chemical in question (exposure). The effect factor refers to the potential negative consequences on ecosystem health when exposure does occur (Huijbregts, 2010). The exclusion of more localized parameters is justified in that it was found during the harmonization process that these parameters have a far lower impact on results than do the substances themselves. Ecotoxicity impacts are measured in terms of the Potentially Affected Fraction of species due to a change in concentration of toxic chemicals (PAF m^3 ·day/kg). These units are also known as comparative toxicity units (CTUe).

Global midpoint characterization factors are employed from the most recent version of USEtox™ available in OpenLCA, version 2.02. An updated version of USEtox™, version 2.11, was released in April 2019. Characterization factors for the heavy metals, toxic organics and DBPs were updated in the OpenLCA USEtox™ LCIA method to match version 2.11. All other characterization factors remain at the default value for OpenLCA's USEtox version 2 (recommended+interim) database. Not all heavy metals, toxic organics and DBPs have established characterization factors in the USEtox™ method. Several additional sources were used to identify appropriate characterization factors. When no appropriate characterization factor was identified, the pollutant was assigned a characterization factor equal to the median characterization factor for its trace pollutant group. Table B-5, Table C-8, and Table list values and sources of characterization factors for all heavy metals, toxic organics, and DBPs. For illustration purposes, Table 4-15 lists some of the main chemicals found to contribute to ecotoxicity impacts (Ryberg, 2013) and their USEtox™ global characterization factors.

As is discussed in Section 4.6.10, uncertainty in USEtox factors can range across one to three orders of magnitude for interim characterization factors, which are identified in Table 4-15. At the current time, all characterization factors for metal compounds are considered interim. Appropriate interpretation of results must consider the uncertainty associated with the use of interim characterization factors.

Table 4-15. Main Pollutants Contributing to Ecotoxicity Potential Impacts (CTUe [PAF m^3.day/kg Pollutant])

Pollutant	Chemical Formula	Compartment	Characterization Factor
Zinc, ion	Zn^{2+}	Ground water	1.3E+5[a]
Chromium VI	Cr(VI)	Ground water	1.0E+5[a]
Nickel, ion	Ni^{2+}	Ground water	3.0E+5[a]
Chromium VI	Cr(VI)	River	1.0E+5[a]
Arsenic, ion	As^{3+}	Ground water	1.5E+4[a]
Selected Method—			USEtox™ within TRACI 2.11

a – Designates an interim characterization factor.

4.6.13 Normalization

Normalization is an optional step in LCIA that aids in understanding the significance of the impact assessment results. Normalization is conducted by dividing the impact category results by a normalized value. The normalized value is typically the environmental burdens of the region of interest either on an absolute or per capita basis. The results presented in this study are normalized to reflect person equivalents in the U.S. using TRACI v2.1 normalization factors (Ryberg et al., 2013). Only impacts with TRACI normalization factors are shown. Some categories like water use and CED are excluded due to lack of available normalization factors.

4.6.14 LCIA Limitations

While limitations of the LCI model are specifically discussed in Section 4.4, some of the main limitations that readers should understand when interpreting the life cycle impact assessment findings are as follows:

- **Coverage of Emissions Leading to Toxicity:** ~~The scope for the results for the three USEtox™ categories (human health - cancer, human health - noncancer, and ecotoxicity) excludes toxicity from wastewater effluent and should be considered with low confidence. These category results are largely dependent on toxic pollutants from sludge in a landfill. However, these toxic pollutants may also be present in the effluent release at the WWTP.~~ The toxicity impacts associated with the sludge and the effluent are limited to pollutants selected in Chapter 2. Such toxic pollutants in the effluent were not assessed in the baseline LCA model; therefore, the toxicity impact categories are showing incomplete results.
- **Transferability of Results:** While this study is intended to inform decision-making for a wide range of stakeholders, the impacts presented here relate to a theoretical average U.S. WWTP. For instance, this study does not address geographic differences that could impact WWTP design, cost options, or local variation in environmental impacts. Further work is recommended to understand the variability of key parameters across specific regional and facility-level situations. Also, the study

looked at greenfield installations only so impacts or benefits would vary for retrofitted operations.

- **LCIA Method Uncertainty:** In addition to the uncertainty of the LCI data, there is uncertainty associated with the application of LCIA methodologies and normalization factors to aggregated LCI. For example, two systems may release the same total amount of the same substance, but one quantity may represent a single high-concentration release to a stressed environment while the other quantity may represent the aggregate of many small dilute releases to environments that are well below threshold limits for the released substance. The actual impacts would likely be very different for these two scenarios, but the LCI does not track the temporal and spatial resolution or concentrations of releases in sufficient detail for the LCIA methodology to model the aggregated emission quantities differently. Therefore, it is not possible to state with complete certainty that differences in potential impacts for two systems are significant differences. Although there is uncertainty associated with LCIA methodologies, all LCIA methodologies are applied to different wastewater treatment configurations uniformly. Therefore, comparative results can be determined with a greater confidence than absolute results for one system. Minimum threshold values for determining meaningful impact differences between wastewater treatment configurations by category are provided in the next section.

4.6.15 Interpreting LCIA Results Differences

Interpretation of LCIA results requires interpretation of the uncertainty associated with inventory data (lists of compounds and resources emitted or extracted by the system under study) and the impact models used to characterize inventory data, translating emissions into impacts. Note that there is also uncertainty associated with the definition of system boundaries, and determination of cutoff values for exclusion of data.

The current state of practice in life cycle assessment includes a quantitative analysis of the uncertainty in inventory data. In this study, much of the background process data, which is part of the ecoinvent database, includes such uncertainty analyses. Possible underestimations of uncertainty associated with ecoinvent are known (Weidema et al., 2011); however, ecoinvent and agricultural inventory uncertainties are expected to be lower overall than impact uncertainty.

At the impact level, uncertainty is not yet typically included in LCA studies; indeed, not all LCA software has this ability. A spatially explicit model of aquatic acidification (Roy et al., 2014) analyzed both parameter uncertainty (via a Monte Carlo approach) and spatial uncertainty. At the characterization factor level, parameter uncertainty contributed a factor of 100 uncertainty, whereas spatial variability ranged from 5 to 8 orders of magnitude for different acidifying compounds.

At the analysis level, it is important to consider that uncertainty in inventory or characterization is not purely multiplicative when considering differences between systems (Hong et al., 2010). For many LCA analyses, many background and some foreground processes will be shared between systems. For example, background electricity generation is often shared, while chemical additives or concrete could be shared foreground processes for wastewater treatment. Therefore, analyses of *differences* between systems must account for these shared processes. Within confidence bounds, systems may be different even if the difference between their impact scores is less than the absolute uncertainty on the corresponding characterization factor (e.g., factor 100 for acidification, from above).

In a case study, Humbert et al. (2009) provide guidelines for determining whether differences in LCA impact results are meaningful. In the energy and global warming category, this minimum significant difference is a 10 percent threshold (i.e., in comparing contributions to this category, a difference lower than 10 percent is not considered to be significant). For particulate matter formation, smog formation, acidification, ozone depletion, and eutrophication, the minimum significant difference is 30 percent. For the toxicity categories, an order of magnitude (factor 10) difference is typically required for a difference to be significant, especially if the dominant emissions are different between scenarios or are dominated by long-term emissions from landfills that can be highly uncertain. In the absence of a detailed uncertainty analysis, these threshold guidelines may serve to help interpretation. This study uses the percent difference thresholds defined by the Humbert et al. 2009 case study with the exception of GWP impact results. As discussed in Section 4.4, there are case-specific uncertainties for estimating GHG emissions from biological treatment. Therefore, this study uses a higher threshold of 30 percent to determine whether a notable GWP difference exists between wastewater treatment configurations. There are also specific considerations for uncertainty thresholds for water depletion results as discussed below.

There is currently a lack of water use data on a unit process level for LCIs. In addition, water use data that are available from different sources do not use a consistent method of distinguishing between consumptive use and non-consumptive use of water or clearly identifying the water sources used (freshwater versus saltwater, groundwater versus surface water). A recent article in the International Journal of Life Cycle Assessment summarized the status and deficiencies of water use data for LCA, including the statement, “To date, data availability on freshwater use proves to be a limiting factor for establishing meaningful water footprints of products” (Koehler, 2008). The article goes on to define the need for a standardized reporting format for water use, taking into account water type and quality as well as spatial and temporal level of detail.

Water consumption is modeled using values reported in literature. In some cases, consumptive use data may not be available. The ecoinvent database includes water in the life cycle inventory as an input and does not record water released to the environment (i.e., as an emission) or water consumed. However, ecoinvent is currently one of the most comprehensive LCI sources on water for upstream processes; many other available databases do not report water input/use as an inventory item. Therefore, when case-specific data were not available, ecoinvent data were utilized for the water calculations. When utilizing ecoinvent, the data are adapted to represent consumptive use to the extent possible: fresh water removed from the environment that is not internally recirculated.

Because water consumption values are uncertain, a minimum 30 percent difference is required to consider water consumption results significantly different. Comparative results can be determined with a greater confidence than absolute results for one system.

5. LIFE CYCLE COST BASELINE RESULTS

This section presents the LCCA results for the nine wastewater treatment configurations included in this study. Table 5-1 presents the total capital, total annual, and net present value for each of the wastewater treatment configurations. As discussed in Section 3.3.2, the net present value combines the one-time capital costs and periodic (annual) operating and maintenance costs into one value for direct comparison of costs. The following sections provide additional discussion differences with the results of the total capital and annual costs (Section 5.1) and net present value (Section 5.2). The results are discussed by unit process and aggregated treatment group, as shown in Table 5-2. For treatment groups, the unit processes are generally grouped sequentially; however, preliminary treatment stages are grouped with disinfection, even though these are not sequential unit processes because, in this study, these unit processes do not vary between wastewater treatment configurations. Complete cost results are presented in Appendix H.

Table 5-1. Total Costs by Wastewater Treatment Configuration

Wastewater Treatment Configuration	Total Capital Cost (2014 $)	Total Annual Cost [a] (2014 $/yr)	Net Present Value (2014 $)
Level 1, AS	$55,300,000	$5,140,000	$204,000,000
Level 2-1, A2O	$71,400,000	$5,470,000	$236,000,000
Level 2-2, AS3	$93,100,000	$10,150,000	$378,000,000
Level 3-1, B5	$86,400,000	$5,800,000	$267,000,000
Level 3-2, MUCT	$88,900,000	$5,960,000	$275,000,000
Level 4-1, B5/Denit	$92,800,000	$6,840,000	$301,000,000
Level 4-2, MBR	$90,100,000	$6,340,000	$285,000,000
Level 5-1, B5/RO	$160,000,000	$8,320,000	$439,000,000
Level 5-2, MBR/RO	$144,000,000	$8,070,000	$409,000,000

a – Total annual cost includes operational labor, maintenance labor, materials, chemicals, and energy (see Section 3.3 for details).

Table 5-2. Unit Processes by Treatment Group

Treatment Group	Unit Processes Included in the Stage	
Preliminary/Primary/Disinfection	Screening and Grit Removal	Chlorination
	Primary Clarifier	Dechlorination
Biological Treatment	Activated Sludge	Tertiary Clarification, Nitrification
	Secondary Clarifier	Denitrification, Suspended Growth
	Anaerobic/Anoxic/Oxic (A2O)	Nitrification, Suspended Growth
	4-Stage Bardenpho	Membrane Filter
	5-Stage Bardenpho	Fermentation
	Tertiary Clarification, Denitrification	Modified University of Cape Town
Post-Biological Treatment	Sand Filtration	Ultrafiltration
	Reverse Osmosis	Chemical Phosphorus Removal
	Denitrification, Attached Growth	

Table 5-2. Unit Processes by Treatment Group

Treatment Group	Unit Processes Included in the Stage	
Sludge Processing and Disposal	Centrifuge	Sludge Hauling and Landfill
	Anaerobic Digester	Gravity Thickener
Effluent Release	Effluent Release	
Brine Injection	Brine Injection	

5.1 Total Capital and Total Annual Cost Results

As described in Section 3.3, the total plant costs are presented as the total capital costs along with the total annual costs. This section presents the total capital and total annual costs and describes the differences in cost by process contribution and treatment group.

5.1.1 Total Capital Costs

Total capital costs generally increase from Level 1 to Level 5, as presented in Figure 5-1. For Level 2, the Level 2-1 A2O total capital costs are almost $22 million lower than the Level 2-2 AS3 total capital costs. The total capital costs for Level 2-2 AS3 are also over $4 million higher than both Level 3 wastewater treatment configurations. This is because the Level 2-2 AS3 wastewater treatment configuration includes three separate biological units (plug-flow activated sludge, nitrification, and denitrification) with dedicated clarifiers, while the Level 2-1 A2O, Level 3-1 B5, and Level 3-2 MUCT wastewater treatment configurations only include one biological unit that have three to five chambers with a secondary clarifier. The multiple clarifiers in Level 2-2 AS3 also results in more sludge generation and, as a result, has larger sludge processing and disposal units, which also contribute to the higher total capital cost for Level 2-2 AS3 compared to Level 2-1 A2O and both Level 3 wastewater treatment configurations. The total capital cost for Level 2-2 AS3 is more comparable to both Level 4 wastewater treatment configurations. Increasing effluent quality from Level 4 to Level 5 increases the total capital costs by over $50 million because of the added post-biological treatment units (i.e., ultrafiltration, reverse osmosis, and deep injection well for Level 5-1 B5/RO and reverse osmosis and deep injection well for Level 5-2 MBR/RO). Total capital costs for the preliminary/primary/disinfection treatment group are included but are comparable for all of the wastewater treatment configurations, as there are no significant design differences between these portions of the wastewater treatment configurations.

For this study, the total capital costs for the biological treatment group generally increases with increasing effluent quality because the biological treatment units are designed to achieve increased nitrogen and phosphorus removals; increased nitrogen and phosphorus removals require a larger sized and/or more complex biological treatment unit. Note that there are biological treatment units outside of the study that may not follow this trend. However, the Level 5-1 B5/RO biological treatment group total capital costs are similar to both Level 3 and Level 4-1 B5/Denit biological treatment group costs because they have the same biological unit processes (BNR plus secondary clarifier) and are designed to achieve the same nitrogen and phosphorus removals. The Level 4-2 MBR and Level 5-2 B5/RO have higher biological treatment group costs by more than $5 million. Although they are designed to achieve the same nitrogen and phosphorus removals as Level 3, Level 4-1 B5/Denit, and Level 5-1 B5/RO, the Level 4-2 MBR and Level 5-2 B5/RO have membrane bioreactors instead of secondary clarifiers, which increases cost. For all these wastewater treatment configurations, the nitrogen and phosphorus removed beyond the Level 3 targets is achieved through post-biological treatment units (e.g., denitrification filter, ultrafiltration, reverse osmosis).

The post-biological treatment group is a component of all levels except Level 1 AS and Level 2-1 A2O since these levels do not require chemical phosphorus removal or additional nutrient control unit processes. The lowest post-biological treatment capital costs are for Level 2-2 AS3 and Level 4-2 MBR, which only require chemical phosphorus removal. There is a large jump in post-biological treatment capital costs for the Level 5 wastewater treatment system configurations due to the addition of ultrafiltration and the reverse osmosis unit. The Level 5-1 B5/RO post-biological treatment capital cost is more than double the Level 5-2 MBR/RO because Level 5-1 B5/RO also includes the sand filter, ultrafiltration, and has a larger reverse osmosis unit.

The sludge processing and disposal treatment group capital costs are comparable for all the wastewater treatment configuration except for Level 2-2 AS3, which has a larger anaerobic digester, larger centrifuge, increased number of vehicles (hauling and land filling), and larger onsite sludge storage shed (hauling and land filling) capital costs. As discussed previously, the Level 2-2 AS3 system has three separate clarifiers and a very high alum dose that increases the quantity of sludge generated even beyond that of higher performing wastewater treatment configurations, which are able to achieve their level of phosphorus removal performance through a combination of chemical precipitation and other unit processes.

The Level 5 wastewater treatment configurations both have RO which requires brine disposal capital costs, while the other wastewater treatment configurations do not. The other capital costs include the direct and indirect costs that are calculated as a percentage of the purchased equipment cost component of the total capital cost (see Section 3.3.1 for details). As a result, the other capital costs increase as the other components of the total capital costs increase.

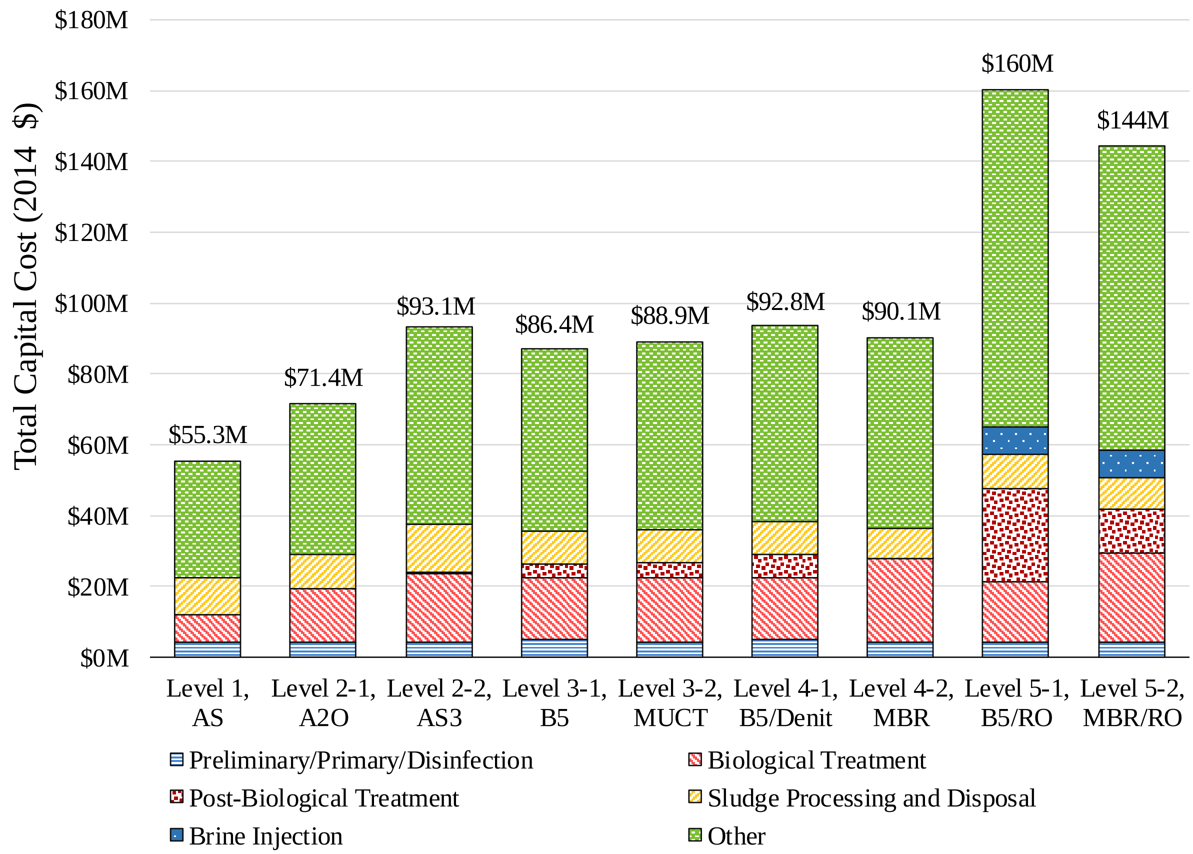


Figure 5-1. Total Capital Costs by Aggregated Treatment Group

5.1.2 Total Annual Costs

Figure 5-2 presents the total annual costs for all the wastewater treatment configurations broken into the annual cost components. The total annual costs are highest for Level 2-2 AS3, followed by Level 5-1 B5/RO and Level 5-2 MBR/RO. The annual costs for operation labor is highest for Level 2-2 AS3 because of the increased sludge processing and disposal from the 3-sludge system. The maintenance labor for Level 1, Level 2-1 A2O, and both Level 3 wastewater treatment configurations is generally comparable, while the maintenance labor for Level 2-2 AS3, both Level 4, and both Level 5 wastewater treatment configurations is generally comparable. The maintenance labor for Level 2-2 AS3, both Level 4, and both Level 5 wastewater treatment configurations is higher because these wastewater treatment configurations have more unit processes. The materials annual costs are highest for Level 2-2 AS3, again due to the increased sludge processing and disposal from the 3-sludge system. Level 2-2 AS3 annual chemical costs are between 3.3 times (Level 5-1 B5/RO) and almost 8.5 times (Level 2-1 A2O) higher than the other wastewater treatment configurations due to the large alum dose for chemical phosphorus removal in Level 2-2 AS3. This large dose is needed compared to other wastewater treatment configurations because Level 2-2 AS3 achieves phosphorus removal solely through chemical phosphorus precipitation while the other wastewater treatment configurations have some level of biological phosphorus removal. The annual costs for Levels 5-1 B5/RO and

5-2 MBR/RO are driven by the annual energy costs, which are between 2 times (Level 4-1 B5/MBR) and almost 4 times (Level 1 AS) higher than the annual energy costs for the other wastewater treatment configurations because both Level 5 configurations include an energy-intensive reverse osmosis unit.

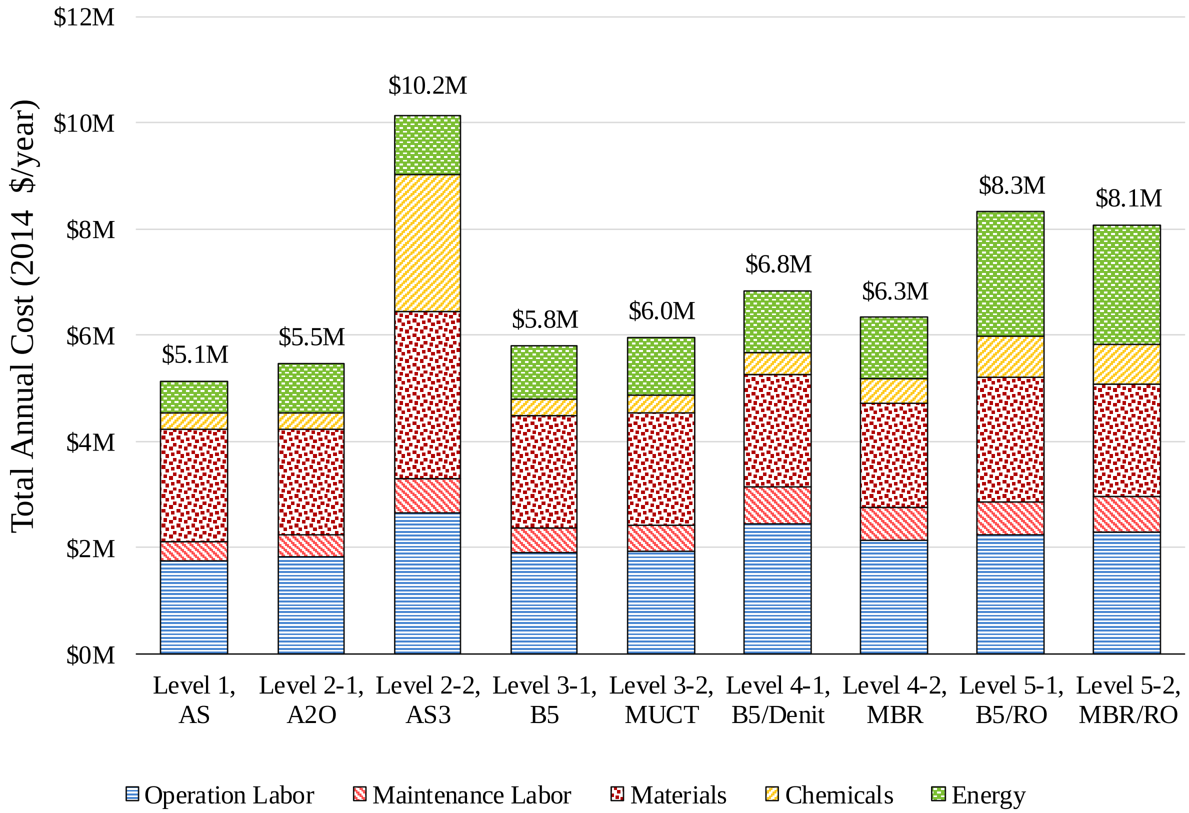


Figure 5-2. Annual Costs by Wastewater Treatment Configuration

Figure 5-3 presents the total annual costs for all the wastewater treatment configurations broken out according to treatment group. The total annual costs for the preliminary/primary/disinfection treatment group are comparable for all of the wastewater treatment configurations, as there are no significant operating differences between the various wastewater treatment configurations.

The biological treatment total annual costs are the highest for Level 2-2 AS3 due to the operational labor, maintenance labor, and chemical costs associated with the three separate biological units. The only chemical addition in the biological treatment portion of Level 2-2 AS3 is for methanol addition in the suspended growth denitrification process unit. The 4-stage and 5-stage Bardenpho and Modified University of Cape Town unit processes in Level 3-1 through Level 5-2 have comparable total annual costs, however the total annual costs for the membrane bioreactors are much higher than the total annual costs for the secondary clarifiers. As a result, the biological treatment total annual costs for the Level 4-2 MBR and Level 5-2 MBR/RO wastewater treatment configurations are high. These wastewater treatment configurations have higher annual operational labor due to the membrane bioreactor and membrane cleaning chemical costs. The Level 4-2 MBR also has supplemental methanol addition immediately preceding the 4-stage Bardenpho reactor, which accounts for the higher chemical costs than Levels 2-1 A2O and both Level 3 wastewater treatment configurations. The Level 4-1 B5/Denit wastewater treatment configuration also has supplemental methanol addition to the denitrification filter, but the methanol dose is lower than the Level 4-2 MBR.

The total annual costs for post-biological treatment are highest for Level 5-1 B5/RO, followed by Levels 2-2 AS3, Level 4-1 B5/Denit, and Level 5-2 MBR/RO, which are all comparable. The Level 5-1 B5/RO annual costs are the highest because of the high energy demand for the ultrafiltration, reverse osmosis unit, and brine injection well, along with having high material replacement costs for the ultrafiltration and reverse osmosis membranes. The Level 2-2 AS3 post-biological treatment annual costs are driven by the alum chemical costs for chemical phosphorus removal. Level 4-1 B5/Denit post-biological treatment annual costs are driven by operational and maintenance labor. The Level 5-1 MBR/RO post-biological treatment annual costs are driven by energy demand for the reverse osmosis and brine injection well, along with the materials replacement cost for the reverse osmosis membranes.

The sludge processing and disposal costs are comparable for all of the wastewater treatment configurations, except for Level 2-2 AS3, which is about $1 million/year more than the other configurations due to the additional sludge generated from the three clarifiers and high alum dose for chemical phosphorus removal.

The Level 5 wastewater treatment configurations both have brine disposal, while the other wastewater treatment configurations do not. The annual costs for the brine disposal are the same for both Level 5 configurations.

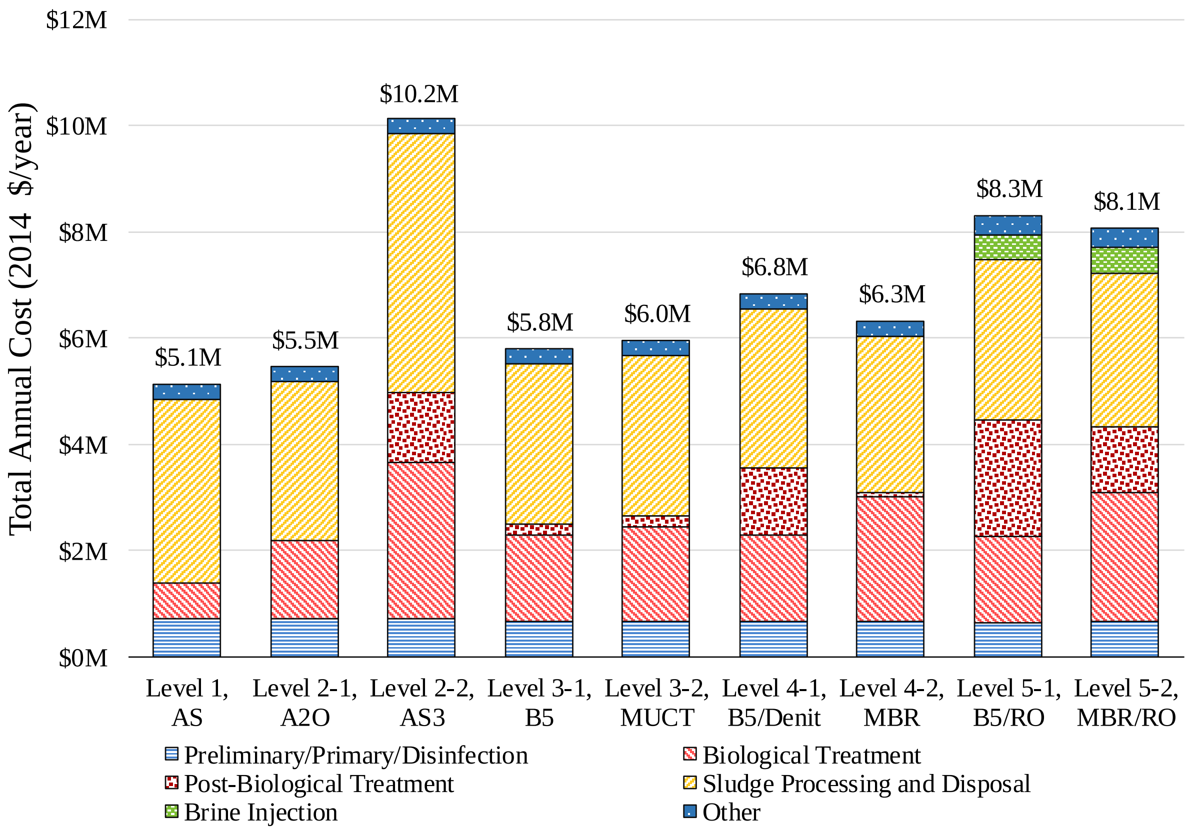


Figure 5-3. Annual Costs by Aggregated Treatment Group

5.2 Net Present Value Cost Results

The net present value, presented in Figure 5-4, trends similarly to the total annual costs discussed in Section 5.2. The net present value for Level 1 AS is the lowest, while the Level 5-1 B5/RO the highest. In general, the net present value increases with increasing nutrient control levels, except for Level 2-2 AS3, which has a net present value almost as high as the Level 5-2 MBR/RO wastewater treatment configuration due to the high annual costs associated with the three separate biological units as discussed in Section 5.1.2. The net present value for both Level 3 wastewater treatment configurations are similar, with only a $8 million difference. The net present value for both Level 4 wastewater treatment configurations are also similar, with only a $2 million difference.

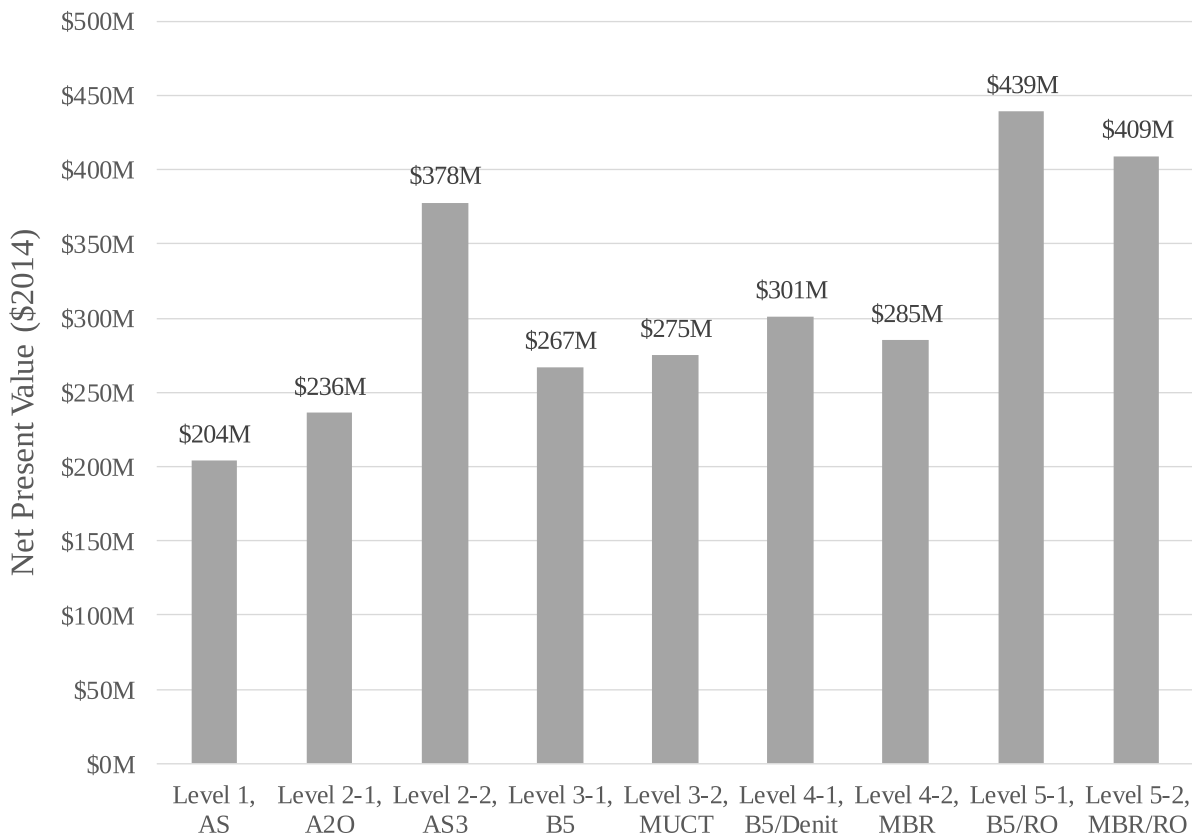


Figure 5-4. Net Present Value by Wastewater Treatment Configuration

5.3 Cost Results Quality Discussion

In accordance with the project's Quality Assurance Project Plan (QAPP) entitled *Quality Assurance Project Plan for Life Cycle and Cost Assessments of Nutrient Removal Technologies in Wastewater Treatment Plants* approved by EPA on March 25, 2015 (ERG, 2015c), ERG subjected the LCCA results to a multi-stage review, verification, and validation process.

The LCCA methodology and results received three levels of technical review, including conceptual review, developmental review, and final product review. ERG developed the planned LCCA approaches and methods; subjected them to internal review by ERG technical reviewers with knowledge relevant to engineering costing, but not directly involved in the approach development; and discussed them with GLEC and EPA during regular project meetings. During development of the LCCA methodologies and results, all CAPDETWorks™ output files and supplemental cost estimation spreadsheets underwent internal technical review to verify the estimates and calculations comported with the planned methods and approaches and confirm the accuracy of the calculations. Finally, ERG conducted an overall assessment of the reasonableness of the final LCCA results. For example, ERG confirmed that differences among the unit-process and configuration-level costs, and other factors such as chemical demand, energy use, and sludge generation, were reasonable based on engineering judgement of the relative size and complexity of the units and systems.

ERG validated the LCCA results by comparing them against available data that were not used in the project to develop the LCCA. For the CAPDETWorks™ costing, ERG compared the total capital and total annual costs and net present value costs for Level 1 AS, Level 2-1 A2O, Level 3-1 B5, Level 4-1 B5/Denit, and Level 5-1 B5/RO to similar treatment systems in Falk et al., 2011, which are presented in Table 5-3. ERG was unable to identify additional literature that included planning-level costs for greenfield wastewater treatment plants with similar wastewater treatment configurations. The other wastewater treatment configurations were not included in Falk et al., and are therefore not included in Table 5-3. In general, Falk et al. included limited detail for a direct comparison with the wastewater treatment configurations included in this study. As an example, Falk et al. did not provide the software used to develop the costs, only included select design parameters for select unit processes, and did not present the unit process-specific costs. The total capital costs in this study are 50-66% of the capital costs presented in Falk et al. Falk (2017) noted that Falk et al. included a raw sewage pump station, more conservative construction assumptions associated with site conditions (e.g., sheeting, shoring, dewatering), and higher concrete unit costs than for this study. The total annual costs for this study are between 1.5 and 5.0 times higher than the total annual costs in Falk et al. This difference is predominately due to the scope of the annual costs; this study included operational labor, maintenance labor, materials, chemicals, and energy, while Falk et al. only included chemicals and energy. For this study, the operational labor, maintenance labor, and materials accounted for 63 to 82% of the total annual costs. Although there are differences between the costs developed for this study and presented in Falk et al., literature sources indicate that CAPDETWorks™ construction estimates are within 20% of actual construction costs (U.S. EPA OWM, 2008b). The net present value for this study are $66 million to $104 million higher than the net present value from Falk et al. This is primarily due to the differences in total annual costs discussed above, but also because Falk et al. used 5% discount rate and 3.5% escalation rate for capital, energy, and non-energy components. This study calculated net present value using 3% discount rate and did not escalate any costs.

Table 5-3. Total Costs Compared to Falk et al., 2011

Wastewater Treatment Configuration	Total Capital Cost (2014 $)	Falk et al. Total Capital Costs (2014 $) [a]	Total Annual Cost (2014 $/yr)	Falk et al. Total Annual Costs (2014 $) [a]	Net Present Value (2014 $)	Falk et al. Net Present Value (2014 $) [a]
Level 1, AS	$55,300,000	$103,000,000	$5,140,000	$1,020,000	$204,000,000	$123,000,000
Level 2-1, A2O	$71,400,000	$142,000,000	$5,470,000	$1,410,000	$236,000,000	$167,000,000
Level 3-1, B5	$93,100,000	$161,000,000	$10,150,000	$2,620,000	$378,000,000	$201,000,000
Level 4-1, B5/Denit	$86,400,000	$171,000,000	$5,800,000	$3,570,000	$267,000,000	$234,000,000
Level 5-1, B5/RO	$88,900,000	$243,000,000	$5,960,000	$5,570,000	$275,000,000	$335,000,000

a – ERG converted Falk et al.'s costs from 2010 dollars to 2014 dollars using the calculations presented in Section 3.2.1.

b – Total annual cost includes operational labor, maintenance labor, materials, chemicals, and energy (see Section 3.3 for details).

Validation of the cost results for ultrafiltration, reverse osmosis, and brine disposal was difficult as these technologies represent the state-of-the-art in the municipal wastewater treatment industry with few or no applications in the U.S. and little or no published data. For ultrafiltration, ERG compared the cost results to Noble et al., 2003. Noble et al. describes a study of the performance of a pilot-scale microfiltration treatment system, and provides detailed capital and O&M cost estimates for a full-scale 5 MGD system. The vendor, US Filter, is a major membrane technology provider. The study regards surface-water treatment, rather than domestic wastewater treatment, and is somewhat dated. ERG found the capital costs for the two data sources differed by approximately 11%, which is well within the range of uncertainty for planning-level costs. ERG did not compare the operating and maintenance costs, as the Noble et al., 2003 costs are specific to treatment of surface water and are not applicable to domestic wastewater treatment.

For reverse osmosis, ERG compared the cost results to costs published by the Orange County Water District, 2010. The Orange County report described the estimated capital costs for a planned 30 MGD expansion of their Groundwater Replenishment System, which includes treatment of domestic wastewater using reverse osmosis and other technologies. We found the reverse osmosis capital costs for the two data sources differed by approximately 9%, which is well within the range of uncertainty for planning-level costs.

Energy usage is a significant component of total operating and maintenance costs for membrane technologies such as ultrafiltration and reverse osmosis. ERG validated the estimated energy usage provided by vendors to a literature source WateReuse Research Foundation, 2014. For ultrafiltration, estimated energy usage by the vendor (ERG, 2015a) and WateReuse Research Foundation, 2014 were 0.5 kWh/kgal and 0.75 to 1.1 kWh/kgal, respectively. Due to concerns regarding the validity of estimated energy usage, for the final ultrafiltration costs estimates, ERG used the average estimated energy usage reported by these two sources (see Appendix E.5). For reverse osmosis, estimated energy usage by the vendor (ERG, 2015b) and WateReuse Research Foundation, 2014 were 1.2 to 2.4 kWh/kgal and 1.9 to 2.3 kWh/kgal, respectively. These two estimates are similar and overlap for much of their range. For consistency with the ultrafiltration cost methodology, for the final reverse osmosis cost estimates, ERG used the average estimated energy usage reported by these two sources (see Appendix E.6).

ERG was unable to validate estimated brine disposal costs as published costs for deep well disposal of domestic wastewater are not available.

6. LIFE CYCLE IMPACT ASSESSMENT BASELINE RESULTS BY TREATMENT GROUP

This section presents the LCA results for the nine wastewater treatment configurations by impact category. Throughout this section, results calculated at the unit process level have been aggregated by treatment group, as shown in Table 5-2. For the treatment groups, the unit processes are generally grouped sequentially; however, preliminary treatment stages are grouped with disinfection, even though these are not sequential unit processes because, in this study, these unit processes do not vary by wastewater treatment configuration. In general, add-on technologies that occur in the treatment train after the main biological treatment unit process are classified as post-biological treatment, regardless of their treatment mechanism. The figures presented in this section include the abbreviated wastewater treatment configuration names. The associated full names with information on the differentiating unit processes were previously provided in Table 1-2. Full LCIA results by unit process are provided separately in Appendix I. For three high priority impact categories, eutrophication potential, CED, and GWP, results are also presented according to the underlying processes that contribute to results regardless of their treatment group. For example, all of the electricity use from each of the wastewater treatment unit processes are combined to show the cumulative contribution of electricity use to each impact category. It is important to note that uncertainties in life cycle data and LCIA are present in all modeled treatment configurations. As discussed in Section 4.6.15, any difference lower than 10 percent is not considered significant for CED. Differences lower than 30 percent are not considered significant for particulate matter formation, acidification, eutrophication, water depletion, smog formation, fossil depletion, and ozone depletion. For the toxicity categories, an order of magnitude (factor 10) difference is typically required to be meaningful. Because of this uncertainty magnitude, the toxicity results are presented and discussed separately in Section 7. Although there is uncertainty associated with LCIA methodologies, all LCIA methodologies are applied to different treatment configurations uniformly. Therefore, comparative results can be determined with a greater confidence than absolute results for one treatment configuration.

6.1 Eutrophication Potential

Given the focus of this project on wastewater treatment nutrient removal capacity, eutrophication is a critical metric for measuring the environmental performance of the nine studied treatment configurations. As discussed in Section 4.6.1, eutrophication occurs when excess nutrients are introduced to surface and coastal water causing the rapid growth of aquatic plants. Table 6-1 presents the nutrient concentrations and annual loads for the influent and effluent from the nine wastewater treatment configurations. Although the modeled concentrations and resulting loads are not identical between the two alternatives for some of the levels, the treatment objectives are the same and would generally result in the same effluent quality, with the possible exception of Level 2. The results associated with the Level 2 treatment configuration is provided in the next paragraph.

For this study, ERG designed the wastewater treatment configuration models in CAPDETWorks™ to achieve specific effluent nutrient concentrations. As such, there is a step-wise decreasing trend in total nitrogen and total phosphorus effluent concentrations and loads with increasing treatment levels. The only exception to this is the total phosphorus effluent concentration for Level 2-1 A2O, which is lower than the Level 2 total phosphorus effluent target of 1 mg/L. This is due to the way CAPDETWorks™ calculates effluent total phosphorus from secondary clarifiers. To achieve total suspended solids of 20 mg/L for Level 2-1 A2O, the total phosphorus effluent concentration is about 0.3 mg/L; revising the clarifier design parameters to achieve total phosphorus effluent concentration of 1 mg/L results in total suspended solids around 70 mg/L, which is over the secondary treatment standards.

Table 6-1. Nutrient Discharges by Wastewater Treatment Configuration

Wastewater Treatment Configuration	Total Nitrogen		Total Phosphorus	
	Long-Term Average Concentration (mg/L)	Annual Load (lb/yr)	Long-Term Average Concentration (mg/L)	Annual Load (lb/yr)
Influent	40	1,220,000	5.0	152,000
Effluent Concentrations				
Level 1, AS	30	908,000	4.9	150,000
Level 2-1, A2O	8.0	244,000	0.29	8,570
Level 2-2, AS3	7.8	237,000	1.0	30,500
Level 3-1, B5	6.0	183,000	0.22	6,770
Level 3-2, MUCT	6.0	183,000	0.22	6,770
Level 4-1, B5/Denit	3.0	91,100	0.10	3,050
Level 4-2, MBR	3.0	91,500	0.10	3,020
Level 5-1, B5/RO	0.78	23,800	0.02	457
Level 5-2, MBR/RO	1.9	58,800	0.02	549

Figure 6-1 presents eutrophication potential results grouped according to treatment group. Eutrophication is the combined effect of direct nutrient discharges in the effluent, landfilled sludge leachate, and the water discharges and air emissions from upstream inputs to the treatment steps such as electricity and chemical production. The green bar represents the eutrophication potential related to effluent release and is directly related to the designed performance of each treatment level. As expected, the potential eutrophication impact from effluent release for the conventional activated sludge configuration (Level 1) are significantly greater compared to the other treatment configurations. The impact of effluent drops off markedly for Level 2 treatment configurations and remain consistently lower throughout the remaining treatment levels. Eutrophication impact potential is very similar for Levels 3 and 4; although the effluent nitrate values for Level 4 are lower than Level 3, they are offset by an increase in COD in the effluent (as shown in the effluent characteristics in Table 1-4).

The release of organic nitrogen, ammonia and phosphorus in the effluent drives the observed potential eutrophication impact for the majority of wastewater treatment configurations evaluated, whereas the contributions to eutrophication of the sludge and biological treatment groups are relatively consistent across Levels 2 through 5. The eutrophication potential impact from sludge disposal are primarily related to the long-term release of COD in landfill leachate described previously in Section 4.4. Sludge processing and disposal eutrophication impact generally does not vary substantially since the wastewater treatment configurations produce a similar quantity of sludge sent to landfill, with the exception of Level 2-2. Level 2-2 has higher eutrophication impact for the sludge processing and disposal treatment group because of the higher sludge generation in this level from the significant use of chemical phosphorus precipitation. The biological treatment step for conventional activated sludge has a noticeably lower impact than the other levels, which is due to the lower energy intensity of the more basic activated sludge treatment process. Overall, it is apparent that the potential cumulative eutrophication impact generally decreases between Level 1 and Level 2 and then again between Level 2 and Level 3 and Level 4. Level 5 results in an increase in eutrophication impact compared to Level 4 due to the high energy intensity of RO and brine injection, which off-set the reduction in impact associated with the effluent release. However, based on the uncertainty thresholds for impact results, the eutrophication potential difference between Level 3, Level 4 and Level 5 wastewater treatment configurations is not considered significant. As discussed in Section 4.6.1, both indirect and direct air and water emissions have the potential to contribute to eutrophication. Eutrophication from these energy intensive unit processes is largely due to the portion of the nitrogen oxide air emissions from upstream fuel combustion for electricity production that is modeled as deposited in water bodies. Nitrogen oxide emissions are largely associated with deposition from the combustion of coal in the average US electrical grid (coal is currently estimated to contribute approximately 45 percent to the average U.S. electrical grid as shown in Table 4-2, Section 4.2, which comes from 2009). For more detail, Table J-1 in Appendix J shows the contribution of each individual unit process to the overall eutrophication potential for each wastewater treatment configuration. To compare electricity consumption across the wastewater treatment configurations refer to Table H-1 through Table H-10 in Appendix H.

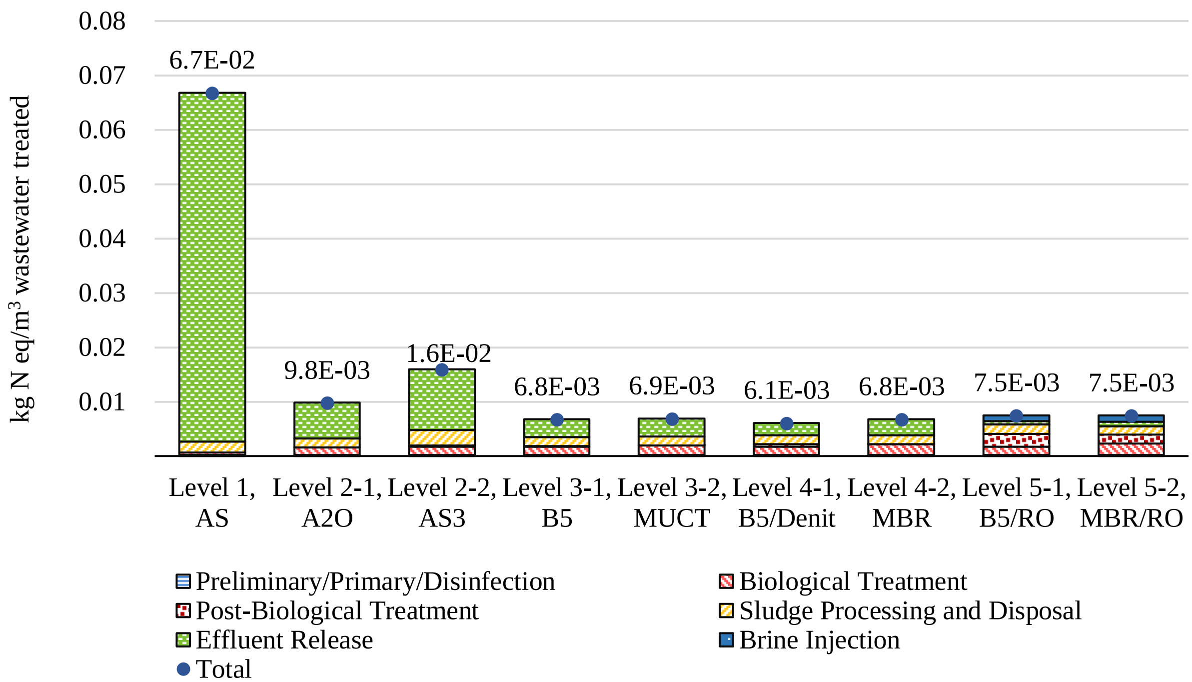


Figure 6-1. Eutrophication Potential Results by Treatment Group

The impact of increased energy use, particularly in Level 5, is visible in Figure 6-2. As previously discussed, disposal of sludge in a municipal solid waste landfill also contributes to eutrophication impact, primarily related to the long-term release of COD in landfill leachate.

Natural gas, infrastructure, chemicals, process emissions, and sludge transport cumulatively contribute between 0.3 and 4 percent of eutrophication impact depending on treatment level.

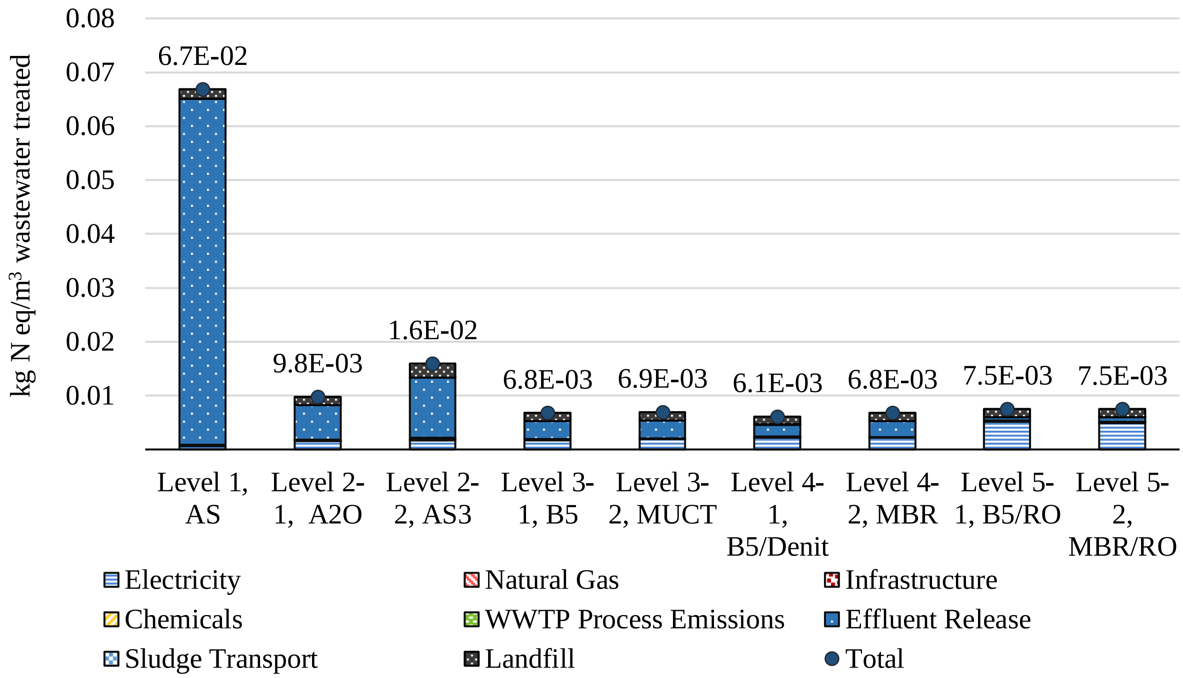


Figure 6-2. Eutrophication Potential Results by Process Contribution

6.2 Cumulative Energy Demand

Figure 6-3 and Figure 6-4 present CED results grouped according to treatment group and by process contribution. The CED results are driven by direct energy use in the form of electricity and natural gas at the WWTP as well as energy consumption associated with upstream chemical and infrastructure production. Fuel inputs for transportation and landfill management are also incorporated in the CED results.

The separation processes selected for use in this study to remove nutrients from wastewater require energy, and this energy requirement generally increases with the level of separation. Between 43 and 88 percent of CED is attributable to electricity use associated with each wastewater treatment configuration, including supply-chain electricity use. Natural gas consumption, primarily to provide heat for anaerobic digestion, is the second largest contributor to CED, accounting for between five and 30 percent of CED.

The biological treatment units and sludge processing and disposal from Level 2 through Level 5 all produce a relatively consistent energy demand. More significant differences in energy demand between treatment systems are associated with the post-biological treatment units, such as denitrification, membrane bioreactors, ultrafiltration, and RO. For Levels 5-1 and 5-2, RO filtration and brine injection cumulatively contribute 48 and 49 percent of CED impact, respectively. For more detail, Table J-2 shows the contribution of each individual unit process to the overall CED for each wastewater treatment configuration. The upstream energy demand of chemical production is visible in Figure 6-4, particularly for Level 2-2. Level 2-2 CED from chemical production is largely associated with the methanol requirement for denitrification and aluminum sulfate used for chemical phosphorus precipitation.

As discussed in Section 1.2.3, it may be possible, depending on the demand, to recycle the effluent from Levels 1 through 5 for a variety of reuse applications ranging from landscape irrigation to indirect potable reuse (U.S. EPA 2012b). While recycled water was not considered in the system boundaries of this study, recycling the water would likely offset some of the increased CED of the higher nutrient removal wastewater treatment configurations by displacing production of potable water elsewhere. The magnitude of the offset would depend upon the current source of water for that reuse application.

The effect of biogas energy recovery on CED is discussed in Section 9.5.

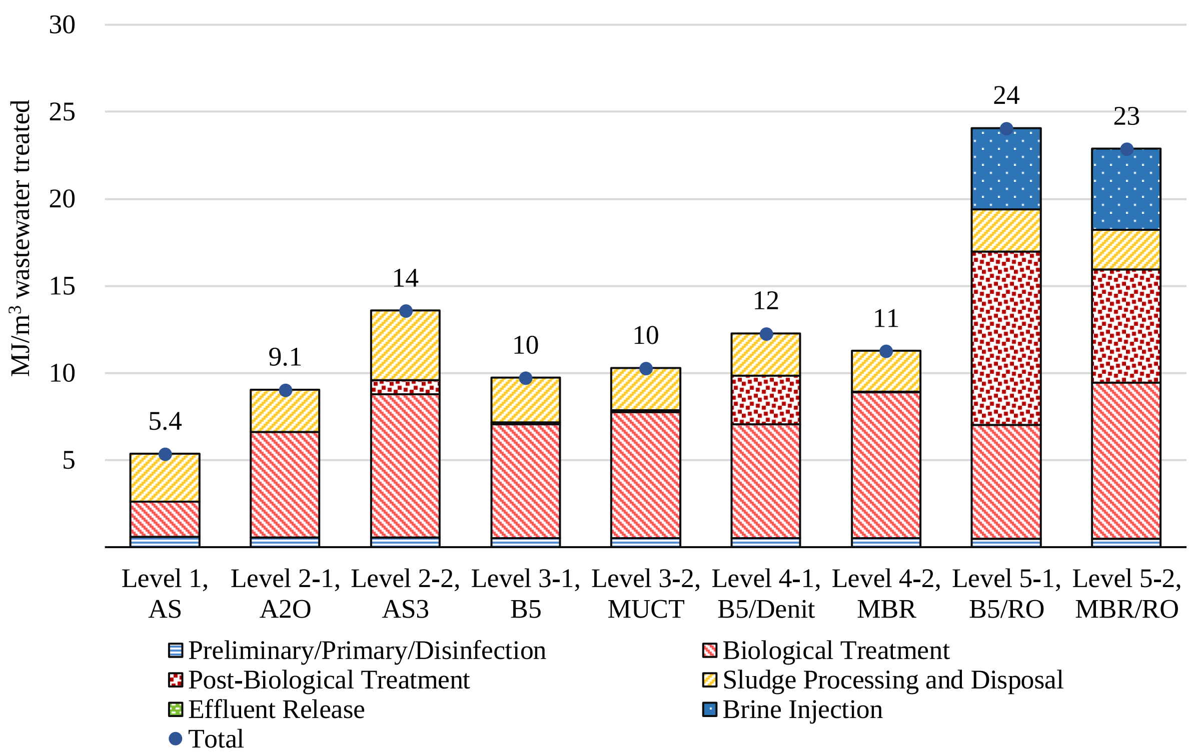


Figure 6-3. Cumulative Energy Demand Results by Treatment Group

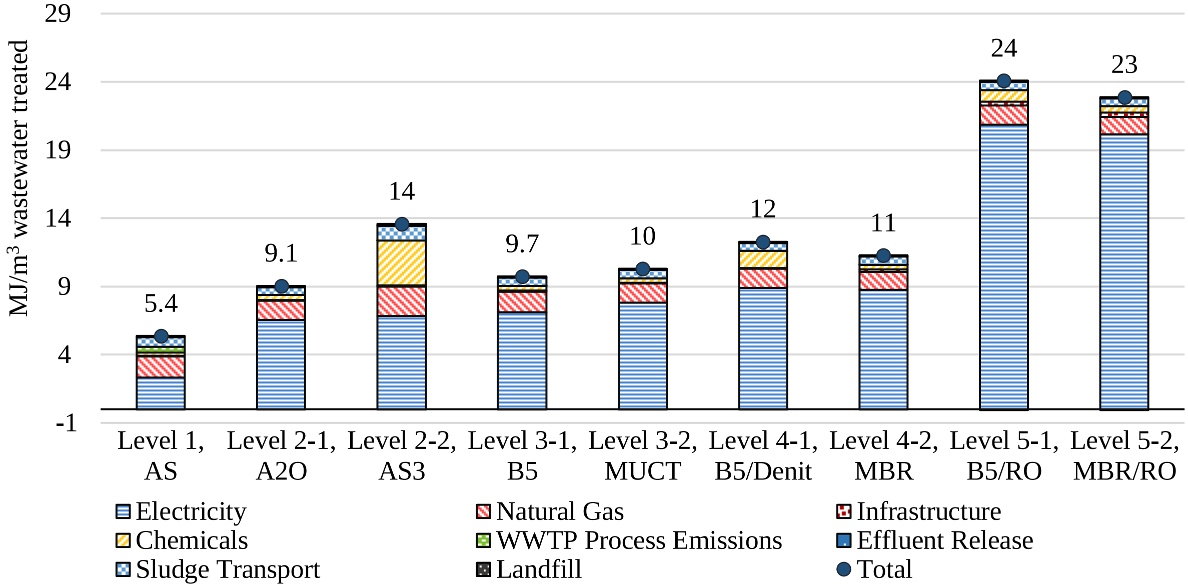


Figure 6-4. Cumulative Energy Demand Results by Process Contribution

6.3 Global Warming Potential

Figure 6-5 presents the GWP results grouped according to treatment group. Overall, the GWP of the treatment configurations increases with the stringency of effluent quality criteria, as additional unit processes are required. The total GWP of Level 5 is over three times greater than that for Level 1. The GWP of the biological treatment subcategory increases by approximately 415 percent as we progress from Level 1 to Level 3. GWP impact associated specifically with biological treatment then remains relatively constant between Levels 3 and 5. The increase between Level 1 and Level 3, is due both to the increasing energy demand of the biological treatment configurations as well as the increased production of process GHG emissions. The advanced biological treatment units contain a combination of aerobic, anoxic, and anaerobic stages, in which both CH_4 and N_2O emissions may be generated and ultimately emitted from the treatment system. Based on available data to characterize these types of treatment configurations, as described in Appendix F, CH_4 emissions from biological treatment are the most impactful process GHGs; however, there is uncertainty associated with estimating these process GHGs and in differentiating the various treatment levels due to the limited measurement data associated with the different treatment configurations evaluated.

RO and brine injection together increase the GWP of Levels 5-1 and 5-2 by approximately 35 percent. The attached growth denitrification filter contributes just over 10 percent of GWP impact to Level 4-1. Sludge processing and disposal, shown in yellow, contributes between 0.22 and 0.27 kg of CO_2 eq. per cubic meter of wastewater for each treatment system. Over half of the sludge processing and disposal impact is attributable to operation of anaerobic digesters. Although the absolute contribution demonstrates consistency between treatment levels, the relative contribution to total impact scores decreases from a high of 53 percent for Level 1 to only 12 percent for Level 5-1. Fugitive release of CH_4 from landfilled biosolids at end-of-life (EOL) is responsible for approximately one-quarter of total sludge processing and disposal GWP emissions. While indirect N_2O emissions from wastewater after discharge of effluent into receiving waters contribute less than three percent of GWP impact for Levels 2 through 5, this source of GHG emissions constitutes nearly 13 percent of Level 1 GWP. These emissions decrease across the treatment levels corresponding to increased removal of nitrogen from the final effluent. Nitrous oxide emissions from wastewater effluent are the result of denitrification processes that occur in the receiving water after wastewater is discharged from the treatment facility. Documentation of the N_2O GHG calculations for receiving waters is provided in Appendix F.

For more detail, please refer to Table J-3 and Table J-4, which shows the contribution of individual unit processes to the overall GWP.

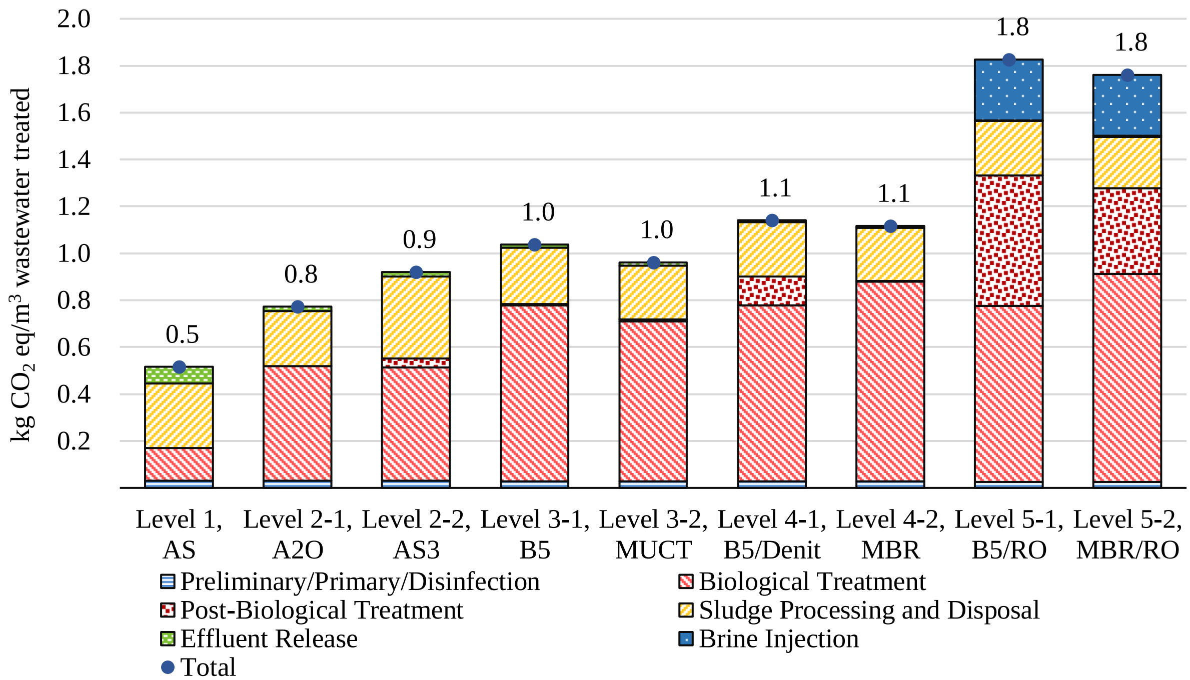


Figure 6-5. Global Warming Potential Results by Treatment Group

Figure 6-6 aggregates GWP impact according to process contribution, highlighting the dominant contribution of electricity use to GWP impact. The relative percentage of GWP impact provided by electricity use increases from a low of 28 percent for Level 1 to a high of 64 percent for Level 5-2. Process GHG emissions from biological treatment units and anaerobic digestion are the second largest source of GWP impact and are similar in magnitude to electricity contributions for several treatment levels. The relative contribution of GHG process emissions is greatest for Levels 3 and 4 due to the unit processes used to attain the high degree of nutrient removal combined with a relatively lower energy footprint as compared to Level 5 configurations. For Level 1, the release of N_2O emissions is shifted to receiving streams.

Natural gas use and landfill disposal of biosolids are both noticeable contributors to GWP impact, remaining consistent across treatment configurations. Natural gas contributes between four and 18 percent of GWP impact. Fugitive landfill methane emissions contribute a further three to 13 percent, depending upon the configuration. It is important to remember that fugitive landfill emissions occur over long periods of time as the anaerobic degradation of sludge proceeds in the landfill environment. Although the fugitive landfill methane releases occur gradually over many years, the approach used here models the impacts of the aggregated emissions using 100-year GWPs. This is consistent with the use of 100-year GWPs used for all other life cycle GHG emissions, as discussed in Section 4.6.3. Future refinements to landfill LCA modeling may include time-scale modeling of landfill methane emissions; however, this is not part of the current study. Such future refinements of time scale modeling of long-term GHGs may lead to exclusion of methane emissions released after 100 years. As discussed in Appendix F Section F.1.5, this study has assumed landfill gas capture and energy recovery is based on average municipal landfill statistics in the U.S. There are a few instances where relative impact associated with these unit process categories can rise above ten percent for a specific treatment level. Effluent release, landfill emissions, and natural gas use contribute 14, 13, and 18 percent of Level 1 impact, respectively. Chemical use in Level 2-2, which relies heavily on chemical phosphorus precipitation, contributes 11 percent of GWP impact.

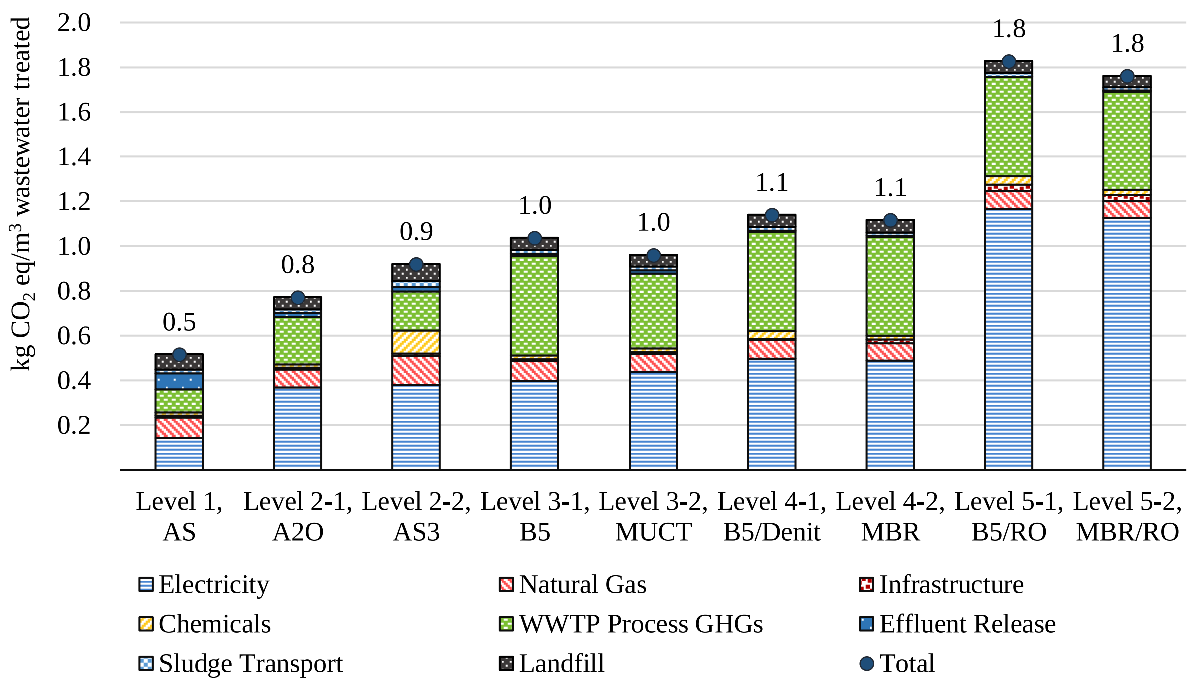


Figure 6-6. Global Warming Potential Results by Process Contribution

6.4 <u>Acidification Potential</u>

Figure 6-7 presents results for acidification potential grouped according to treatment group. Acidification impact associated with biological treatment, post-biological treatment, and brine disposal are the dominant treatment groups contributing to acidification impact. Electricity use attributable to these treatment processes is the primary source of acidifying emissions. Eighty-eight percent of Level 1 impact in this category is associated with electricity use, and the relative contribution rises to over 95 percent for Level 5. Approximately 70 to 80 percent of acidification impact is associated with sulfur dioxide and nitrogen oxide emissions from coal combustion. The contribution of biogas flaring to acidification impact, again from sulfur oxides and nitrogen oxide emissions, varies between 0.1 and 9 percent depending on the treatment level with lower levels having higher relative contributions from biogas flaring. The effect of biogas energy recovery on acidification potential impact is discussed in Section 9.5. For more detail, Table J-4. presents the contribution of individual unit processes to acidification potential impact.

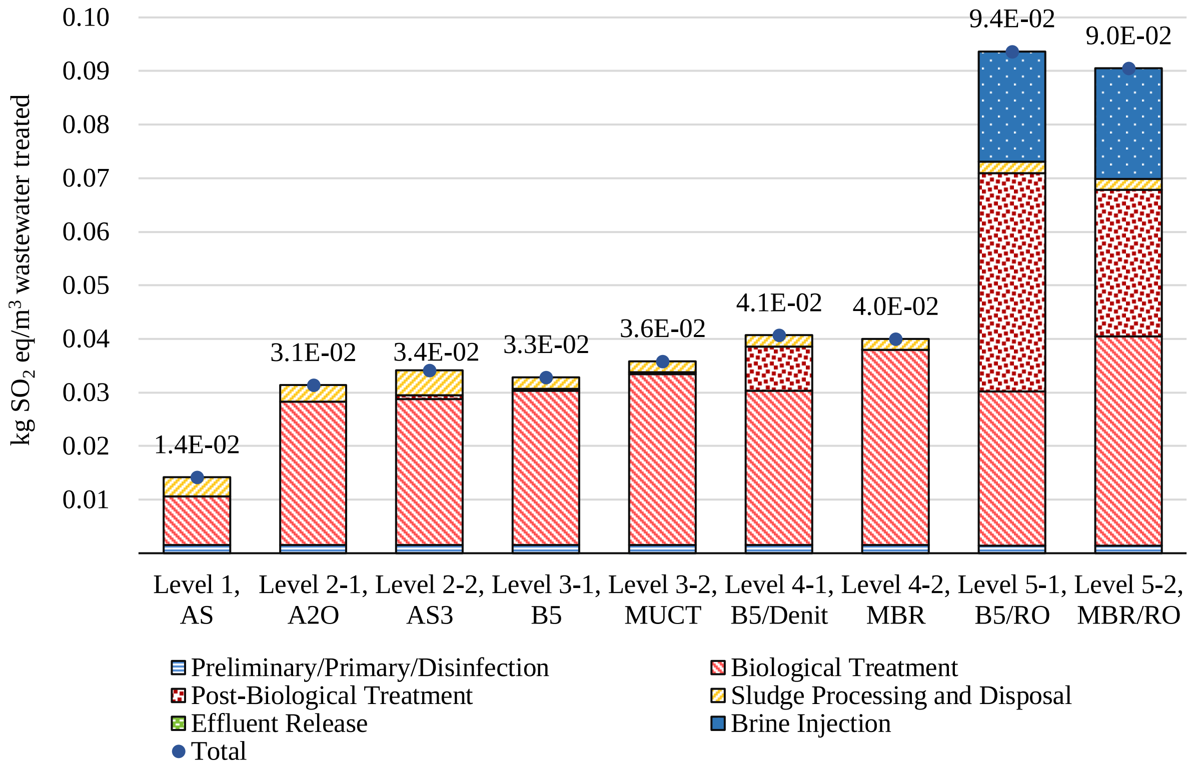


Figure 6-7. Acidification Potential Results by Treatment Group

6.5 Fossil Depletion

Figure 6-8 presents the fossil depletion results according to treatment group. Approximately 50 percent of fossil depletion impact for the Level 1 treatment system are attributable to electricity consumption. Electricity contributes over 90 percent of total fossil depletion impact for Level 5 configurations. Within electricity consumption, the contribution to fossil depletion is associated with coal, natural gas, and crude oil in a static ratio of approximately 2:1:1. An electricity credit, derived from the combustion of landfill gas, is reflected in the figure and serves to reduce relative fossil depletion impact by between one and six percent depending upon the treatment level, with greater relative decreases being associated with lower levels of nutrient removal.

Natural gas combustion used to provide process heat for anaerobic digestion contributes 31 percent of the relative impact for Level 1. The relative contribution of natural gas combustion decreases for higher treatment levels. Truck transport of processed biosolids to the landfill also figures prominently in the results, contributing approximately 13 percent of the impact associated with Level 1. The absolute contribution of sludge hauling to fossil depletion is greatest for Level 2-2 due to the increase in sludge volume associated with chemical precipitation. The contribution of chemical use to fossil depletion amounts to over five percent of impact for Level 1 and over nine percent for Level 4-1. The increase associated with Level 4-1 is due to the use of methanol for denitrification. For more detail, Table J-5 shows the contribution of individual unit processes to fossil depletion potential.

The high energy use in the biological treatment group is due to the biological treatment units (e.g., 3-stage Bardenpho, Modified University of Cape Town) and membrane filtration solids separation in Levels 4-2 and 5-2. For the biological treatment units, energy use is due to aeration, mixing, internal recycle and return activated sludge pumping. Membrane filtration use energy for aeration, permeate pumping, and internal recycle. Energy use for the post-biological treatment group is high for Levels 4-1, 5-1, and 5-2. For Level 4-1, over 95 percent of post-biological energy use is associated with the denitrification filter. For Level 5-1, post-biological energy use is approximately 70 percent for the RO and 25 percent for ultrafiltration. For Level 5-2, close to 100 percent post-biological energy use is for RO.

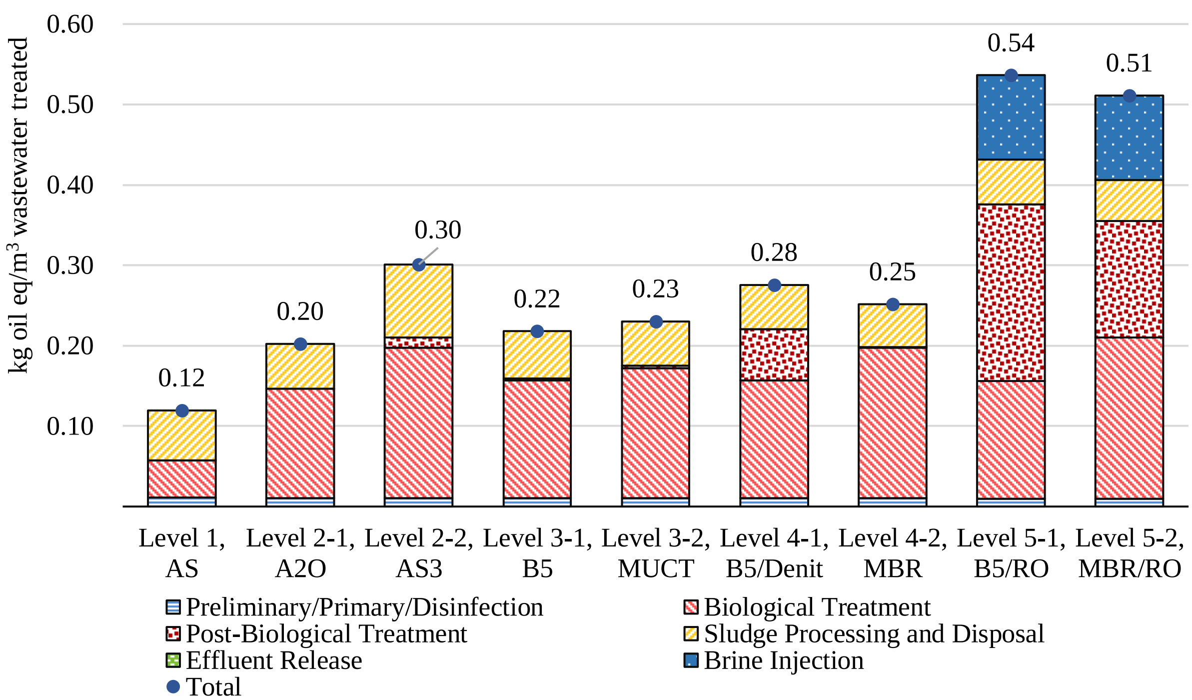


Figure 6-8. Fossil Depletion Results by Treatment Group

6.6 Smog Formation Potential

Figure 6-9 presents the smog formation potential results by treatment group. Greater than 95 percent of smog formation potential is linked to air emissions of nitrogen oxides from fuel combustion processes. Coal combustion, which is primarily associated with electricity generation, produces high nitrogen oxide emissions. For the Level 5 wastewater treatment configurations, coal combustion contributes most of the impact. However, only about half of the smog formation potential is due to coal combustion for the conventional activated sludge system configuration. For Level 1, the relative smog formation impact of biogas flaring is 27 percent, with the absolute impact of biogas flaring consistent across wastewater treatment configuration. Other typical combustion processes such as transport and industrial manufacturing contribute less than one percent of cumulative impact in this category. For more detail, Table J-6 shows the contribution of individual unit processes to smog formation potential.

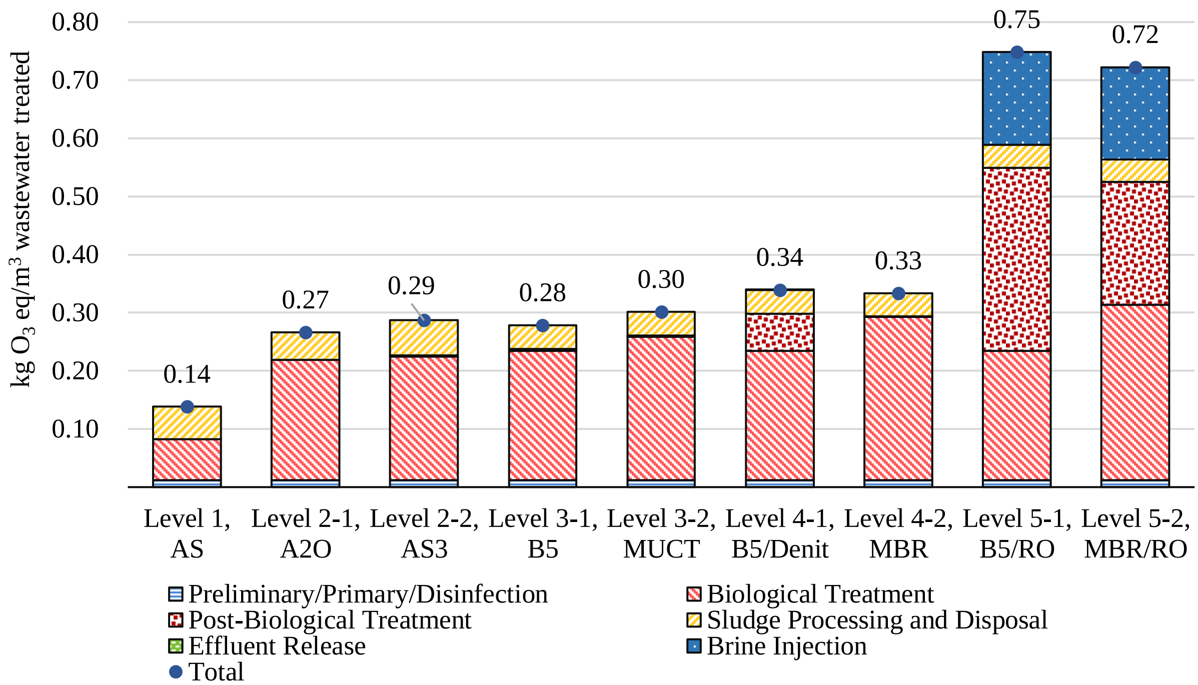


Figure 6-9. Smog Formation Potential Results by Treatment Group

6.7 Human Health-Particulate Matter Formation Potential

Figure 6-10 presents the PM formation potential results by treatment group. PM formation is considered a human health impact category due to its close association with respiratory conditions, leading to increased morbidity (Bare, 2012). Over 92 percent of the impact in this category is attributable to the combustion of fossil fuels for electricity production. Biogas flaring produces a relatively low level of PM-related emissions and does not contribute greater than three percent of total PM impact for any treatment level assessed. Approximately 45 to 50 percent of PM impact is attributable to PM2.5 for all treatment levels. Sulfur dioxide, a precursor to secondary particulates (Bare, 2012), contributes a further 30 to 40 percent of total impact in this category. Recovery of methane energy at the landfill, and the corresponding electricity off-set, provides a credit that reduces impact in this category by just under 12 percent for the Level 1 treatment system. The relative contribution of electricity off-sets to reductions in particulate matter formation potential impact decreases with increasing energy intensity as the level of nutrient removal increase. For more detail, Table J-7 shows the contribution of individual unit processes to particulate matter formation potential.

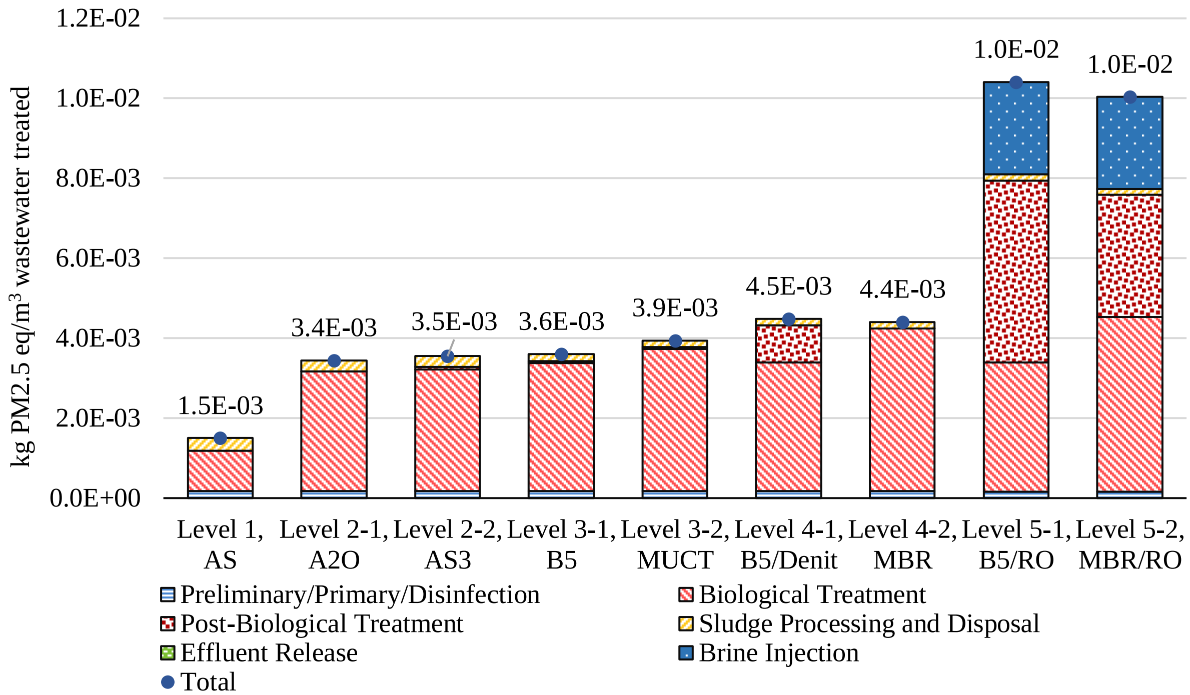


Figure 6-10. Human Health Particulate Matter Formation Potential Results by Treatment Group

6.8 Ozone Depletion Potential

Figure 6-11 presents ozone depletion potential results by treatment group. Results are driven by process and effluent related N_2O emissions. Combustion processes, such as biogas flaring, are also sources of N_2O. Electricity use accounts for most of the remaining ozone depletion potential. Electricity related impact is driven by the assumed use of three refrigerant substances[8] in power generation facilities. These substances were widely used refrigerants, but their incidence is currently decreasing following the implementation of the Montreal Protocol, which legislates the global phase out of the most powerful ozone depleting substances. Overall, the normalized impact from ozone depletion tends to be lower compared to other impacts assessed in this study due to the benefits realized from the Montreal Protocol, see Table 8-3. For more detail, Table J-8 shows the contribution of individual unit processes to ozone depletion potential.

[8] R-40 = monochloromethane, R-10 = tetrachloromethane, and HCFC-140 = 1,1,1 trichloroethane

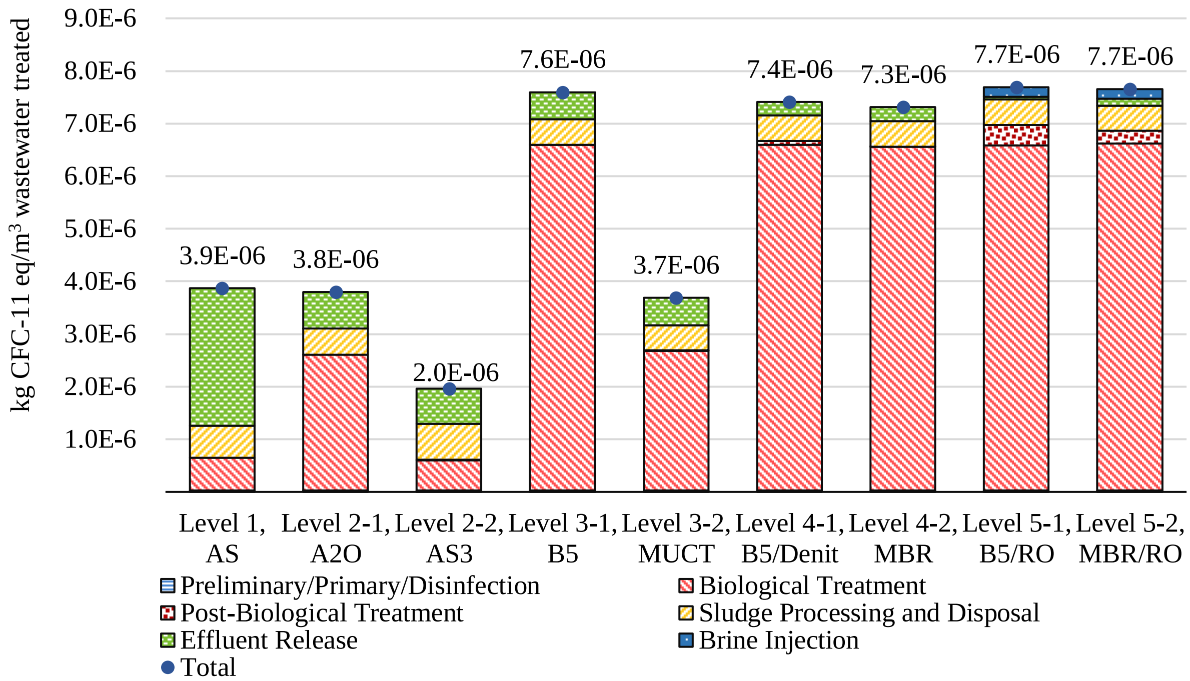


Figure 6-11. Ozone Depletion Potential Results by Treatment Group

6.9 <u>Water Depletion</u>

For Levels 1 through 4 between 55 and 75 percent of water depletion is due to consumptive water use in fuel and electricity production. Chemical manufacturing also contributes strongly to water use. Chlorine production is responsible for 16 percent of the impact for Level 1 treatment. Alum, methanol, and chlorine production contribute 15 percent of impact for Level 4-1, despite the rise in energy intensity. For Level 2-2, the use of alum for chemical phosphorus removal accounts for approximately 55 percent of water depletion impact associated with this wastewater treatment configuration. Level 2-2 relies on chemical precipitation for phosphorus removal, whereas other treatment systems also utilize biological nutrient removal, which lowers their alum requirement. Water use at the landfill facility is responsible for between 4 and 11 percent of impact Level 1 through Level 4 systems. For foreground unit processes, there was no direct water use (e.g., for washing) modeled; however, the loss of water from deepwell injection for Level 5 wastewater treatment configurations was considered in the analysis. As seen in Figure 6-12, the water depletion results are dominated by deepwell injection of brine resulting from Level 5 RO filtration. Approximately 17 percent of influent wastewater is diverted to deepwell injection in these wastewater treatment configurations. This water was originally drawn from surface or groundwater, and diversion to deepwell injection makes it unavailable for subsequent environmental or human uses. Reuse of treated wastewater was not considered in the system boundaries of this study, which is a possibility for all treatment levels, and would serve to reduce water depletion impact. Table J-9 shows the contribution of individual unit processes to water depletion.

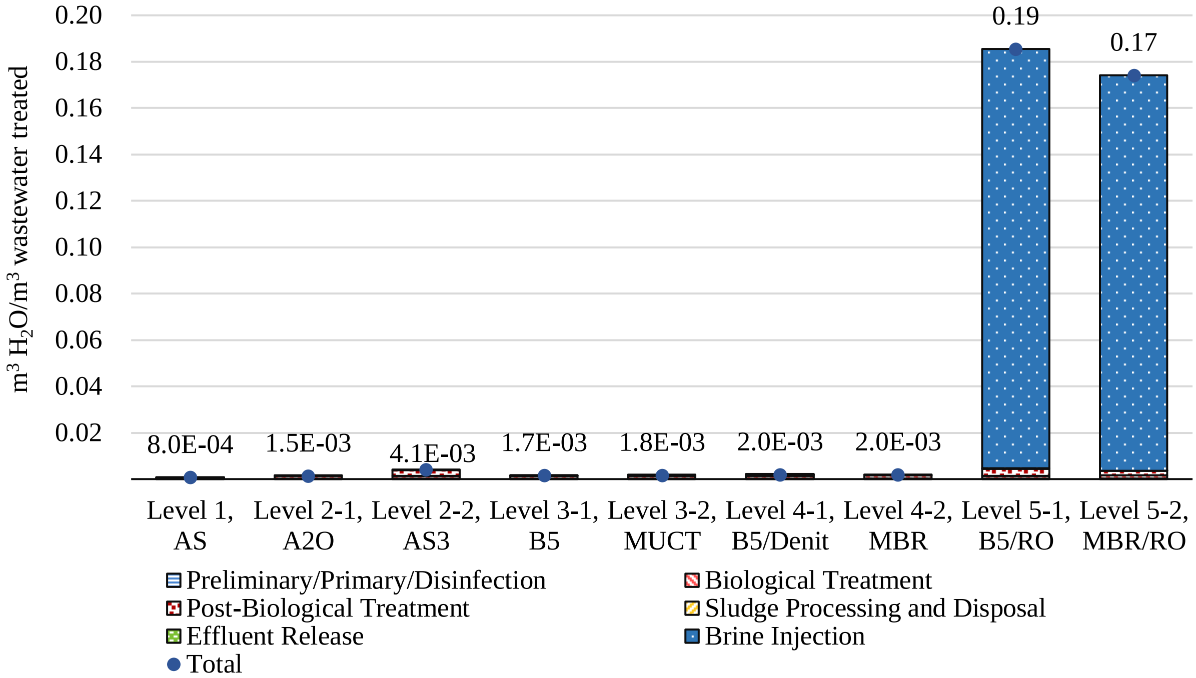


Figure 6-12. Water Depletion Results by Treatment Group

7. TOXICITY LCIA RESULTS

Toxicity results are presented for the three USEtox™ impact categories. Presented results include impacts associated with metals, toxic organics and DBPs in effluent and sludge for each wastewater treatment configuration as well as upstream impacts associated with energy, chemical and material production.

Figure 7-1 presents summary contribution results for all nine treatments systems in the three toxicity impact categories. The figure is intended to highlight the most important aspects of each treatment configuration that contributes to toxicity impacts. All results in Figure 7-1 are standardized such that the total impact of each treatment configuration equals 100%. Contributions to impact are aggregated in the following groups: material and energy inputs, effluent metals, effluent toxic organics, effluent DBPs, metals in sludge, and toxic organics in sludge. Metals in liquid effluent are the dominant contributor among the three trace pollutant categories. For treatment Levels 1 thorough 4-1, metals in liquid effluent are the single largest contributor to ecotoxicity and non-cancer human health impacts. For Levels 4-2 through 5-2, contributions from plant material and energy inputs dominate toxicity impacts. As treatment becomes more rigorous from Level 1 to Level 5, the contributions of trace pollutants to toxicity impact decrease. There is a slight increase in toxicity impacts associated with sludge landfilling along the same continuum, however total toxicity contributions from sludge disposal never exceed 10%. Contributions from toxic organic chemicals, either in sludge or liquid effluent, are only visible for the non-cancer human health impact category amounting to four percent or less of total impact for all treatment configurations. DBPs contribute greater than 10% of total impact for the cancer human health impact category in Levels 1, 2-1, and 4-2.

It is important to consider the uncertainty inherent in the calculation of toxicity related impacts using the USEtox™ method (Huijbregts et al., 2010). Many of the characterization factors used to quantify impacts in these categories are considered interim by USEtox™ developers. All toxicity related characterization factors associated with metals and metal ions, which dominate the results of this study, are considered interim at this time. Moreover, the characterization factors assume impacts result from a specific ionic form of each metal species that is not necessarily the same form in which the metal is emitted from treatment systems. This is a common limitation of the USEtox™ method, and it implies the assumption that once emitted, transformations to a more toxic form may occur within the receiving environment. Overall, the uncertainty associated with interim characterization factors is between one and three orders of magnitude (Huijbregts et al., 2010).

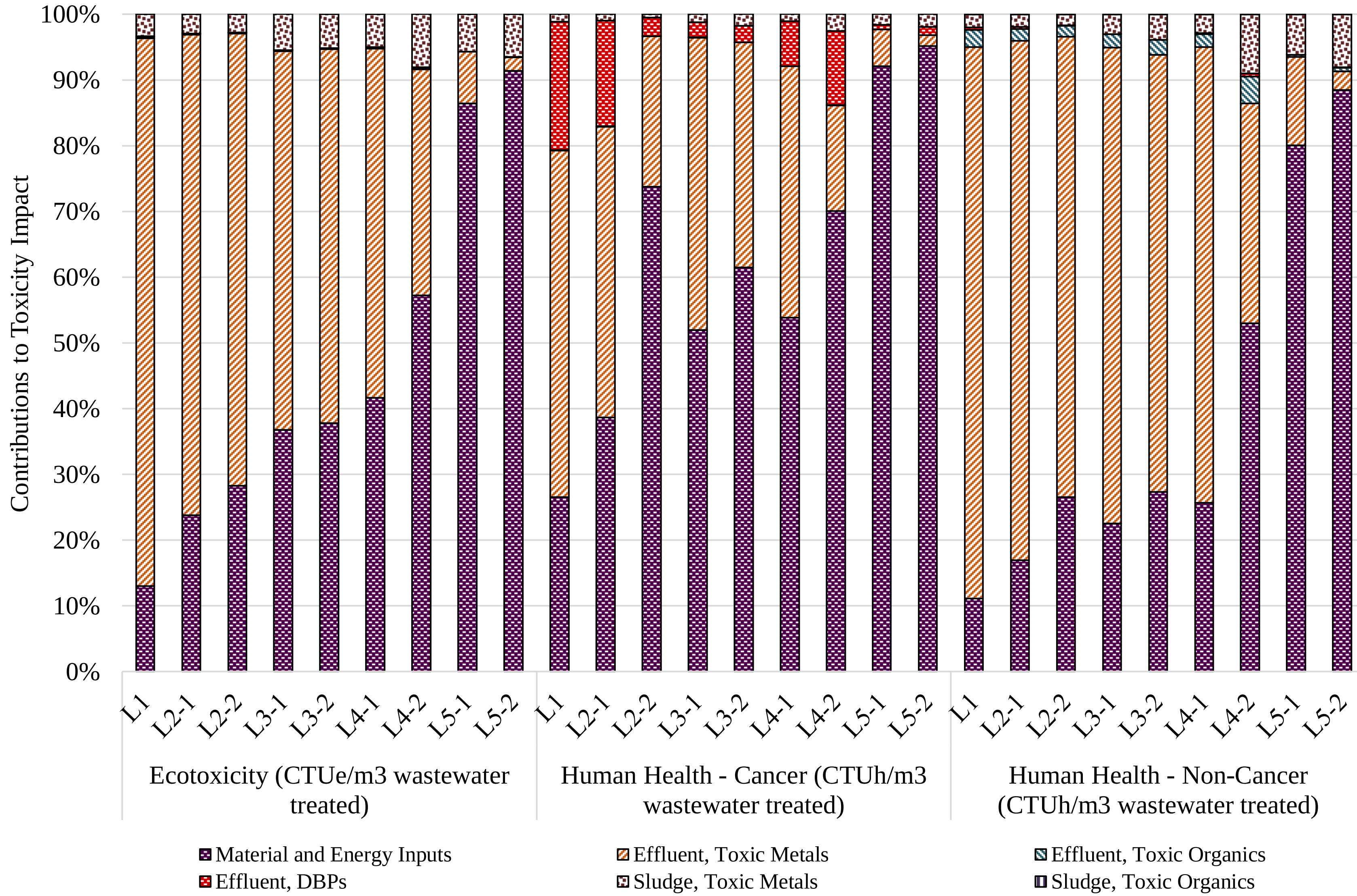


Figure 7-1. Contribution Analysis of Cumulative Toxicity Impacts

7.1 Human Health-Cancer Potential

Figure 7-2 presents the human health-cancer results by treatment group. Error bars in the figure represent the range of results generated by applying minimum and maximum removal efficiency scenario assumptions outlined in Sections 2.1 and 2.2 for metals and toxic organic pollutants, respectively. Contributions to toxicity impact from metals, toxic organics and DBPs summarized in Figure 7-1 are included in this figure within the effluent release and sludge processing and disposal treatment groups.

This figure reinforces the important contribution of metals in treatment plant effluent to cumulative human health-cancer impacts for the lower treatment Levels. The figure also demonstrates that for Level 5 treatment configurations, the increasing contribution of plant material and energy inputs outweighs the benefits of effluent improvements. Electricity consumption of the RO filter and brine injection system is primarily responsible for this increase. The Level 2-2 treatment system is associated with the highest cancer potential impacts attributable largely to aluminum sulphate production for chemical phosphorus precipitation.

When considering the average removal efficiency scenario, Levels 3-2 and 4-2 most effectively balance improvements in effluent quality against the increase in material and energy inputs required to achieve this goal. This is in large part due to the effectiveness of the MUCT unit process (Level 3-2) and the MBR unit process (Level 4-2) in removing metals from the liquid effluent. The MBR unit process, in particular, showed metal removal performance almost on par with RO, though without the detrimentally high energy requirements.

The range of impacts found for Level 1 and 2-1 are also worth noting, as although average metal removal efficiencies of these levels are lower than other configurations (around 40-60% depending on the metal), there is evidence to suggest that removals can be greater than 80% in some cases. Combined with lower process-based impacts, a high efficiency Level 1 or Level 2-1 system may perform best with respect to human health-cancer potential impacts.

Table J-10 documents the contribution of individual unit processes to the human health – cancer potential.

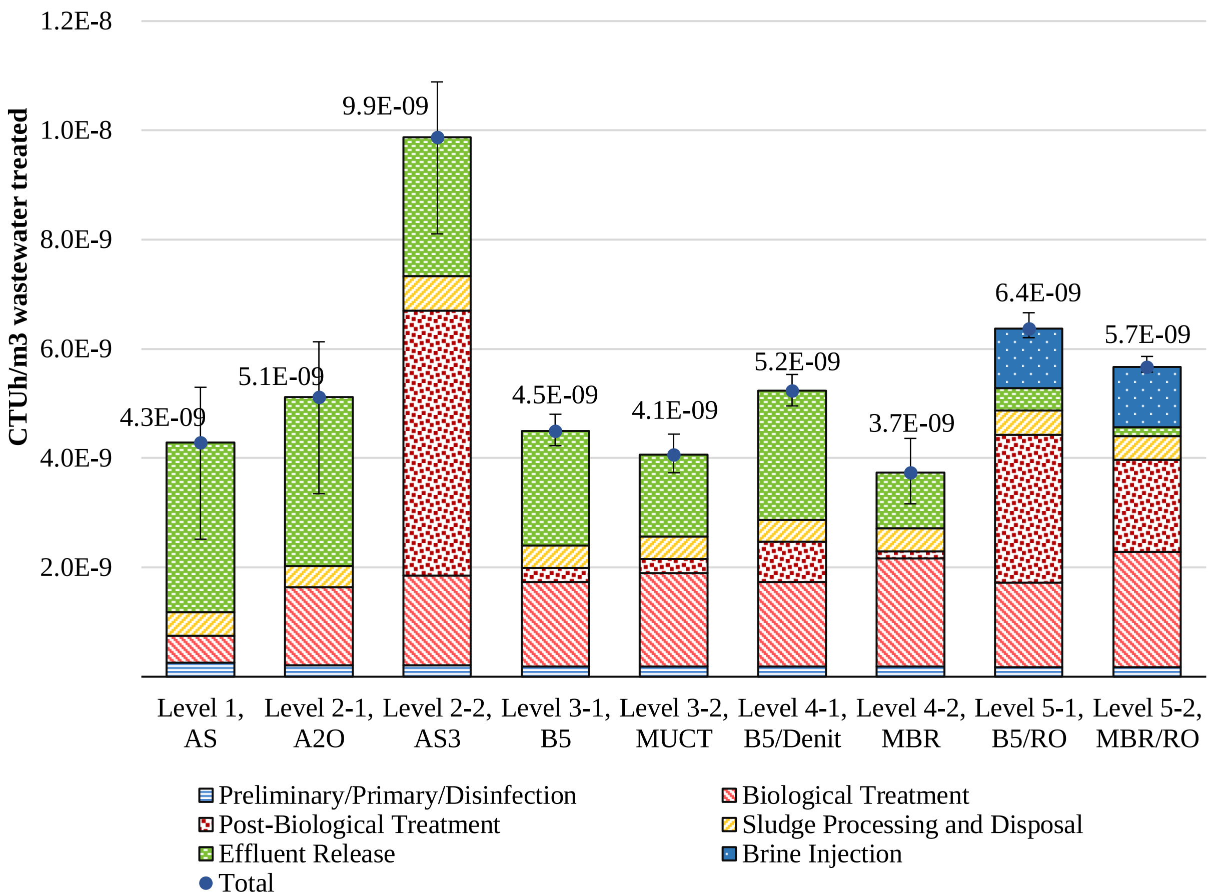


Figure 7-2. Human Health – Cancer Potential Results by Treatment Group (CTUh/m3 wastewater treated)

7.2 Human Health-Noncancer Potential

Figure 7-3 presents the human health-noncancer results by treatment group. Error bars in the figure represent the range of results generated by applying minimum and maximum removal efficiency scenario assumptions outlined in Sections 2.1 and 2.2 for metals and toxic organic pollutants, respectively. Contributions to toxicity impact from metals, toxic organics and DBPs summarized in Figure 7-1 are included in this figure within the effluent release and sludge processing and disposal treatment groups.

The toxicity impact of metals in treatment plant effluent is even more pronounced for the non-cancer human health impact category where it dominates contributions for Level 1 through Level 4-1 treatment configurations. Figure 7-1 shows that DBPs also contribute to non-cancer human health potential especially for Levels 1 and 2-1. When considering the average removal efficiency scenario, total toxicity impacts generally decrease as you move from lower treatment levels to the Level 4-2 treatment system before again increasing for Level 5. The low impacts associated with Level 4-2 are again associated with the high metals removal performance of the MBR unit process without the high energy inputs required of the RO membrane separation process. Also, the removal efficiency range is narrower for the membrane separation processes than for the lower treatment levels that rely more heavily on less precise biological processes for partitioning of metals to sludge. Even considering the high removal efficiency scenario for the lower three treatment levels, total non-cancer potential impacts are greater than or equal to the toxicity impact of Levels 4-2 and 5.

Table J-11 shows the contribution of individual unit processes to human health–noncancer potential.

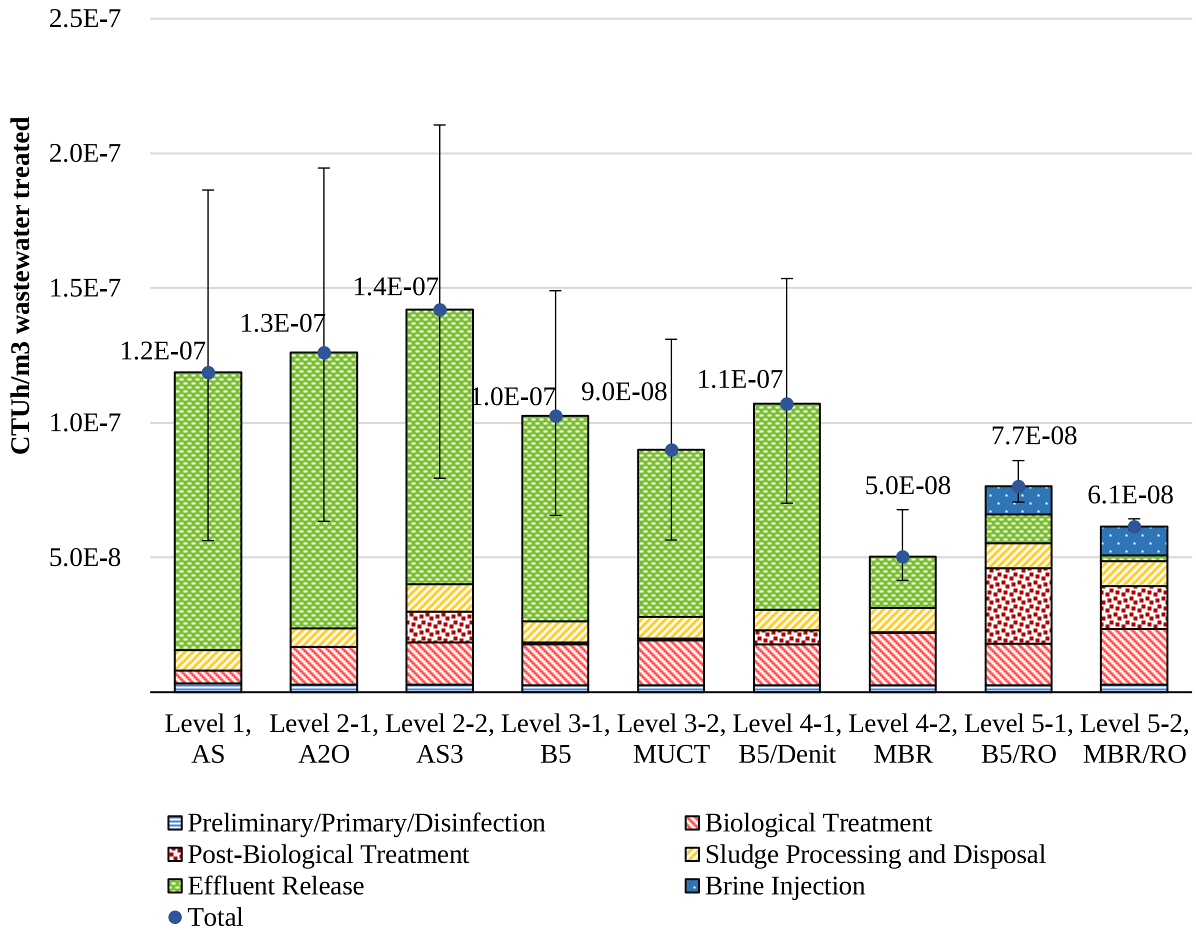


Figure 7-3. Human Health – Noncancer Potential Results by Treatment Group (CTUh/m^3 wastewater treated)

7.3 <u>Ecotoxicity Potential</u>

Figure 7-4 presents ecotoxicity results by treatment group. Error bars in the figure represent the range of results generated by applying minimum and maximum removal efficiency scenario assumptions outlined in Sections 2.1 and 2.2 for metals and toxic organic pollutants, respectively. Contributions to toxicity impact from metals, toxic organics and DBPs summarized in Figure 7-1 are included in this figure within the effluent release and sludge processing and disposal treatment groups.

Ecotoxicity impacts are also strongly linked to metals released with the liquid effluent, especially for Levels 1 and 2. Similar to the previous toxicity impact categories, the average removal efficiency results demonstrate a minimum toxicity impact associated with the Level 4-2 treatment system. However, taking into account the range of potential removal efficiencies, there is considerable overlap in results between Level 4-2 and other configurations. For example, the Level 5 treatment systems perform well compared to the lower treatment levels and provide greater assurances of reaching the average removal efficiency performance due to the greater reliability of their membrane processes. However, when compared against high removal efficiency scenarios for lower treatment levels, Level 5 systems may result in greater potential impact. Likewise, considerable overlap in the estimated removal efficiency performance of Levels 1 through 4-1 make it challenging to draw reliable conclusions regarding their relative performance.

Table J-12 shows the contribution of individual unit processes to ecotoxicity potential.

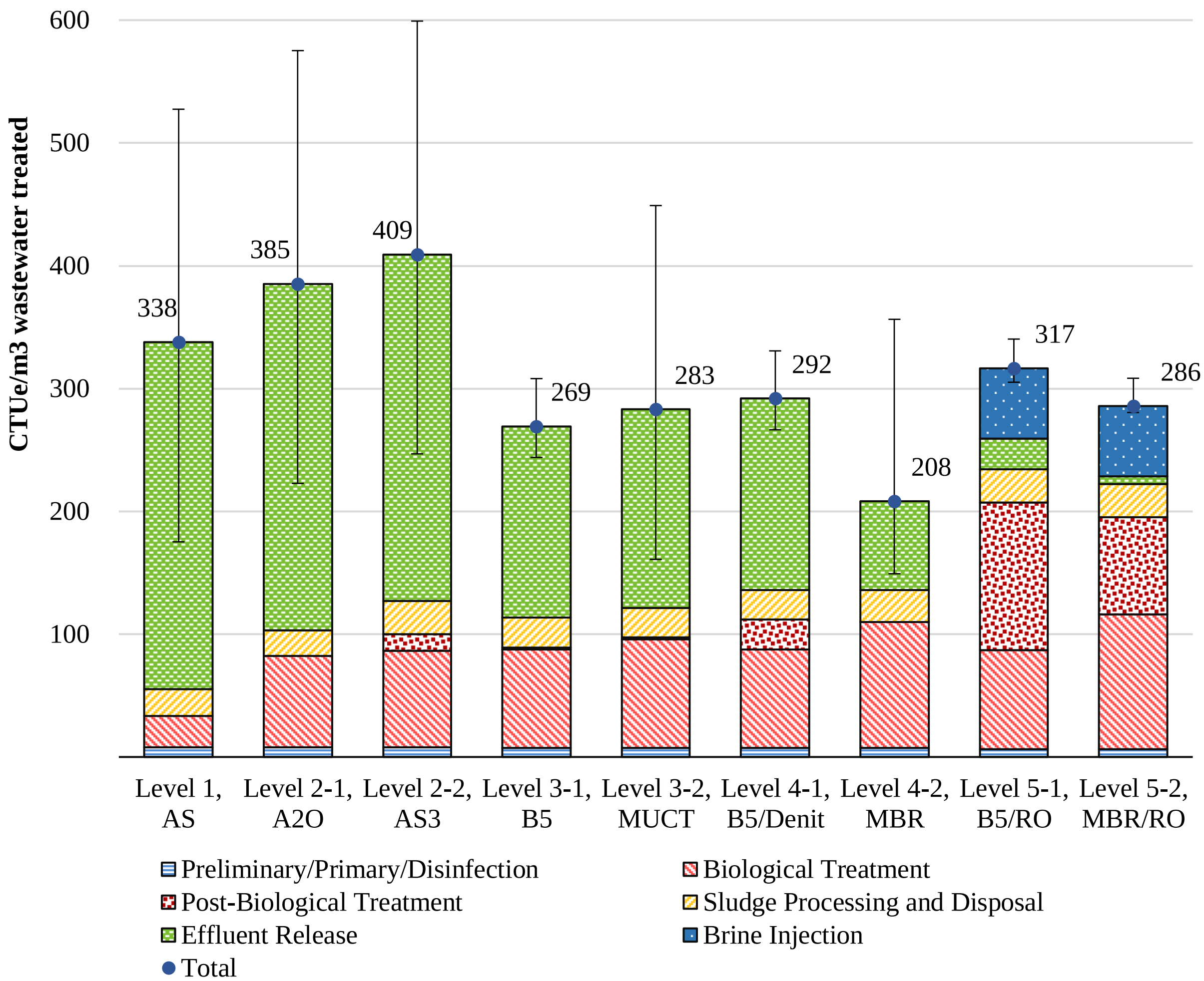


Figure 7-4. Ecotoxicity Potential Results by Treatment Group (CTUe/m^3 wastewater treated)

8. SUMMARY BASELINE RESULTS

This section presents the baseline summary LCIA and cost (as net present value) results to understand the trade-offs in impacts between operation of the different wastewater treatment configurations. Following a presentation of the baseline summary results, a normalization step is applied to the LCIA results to interpret the relative magnitude of the different impact categories assessed.

8.1 Baseline Results Summary

presents a summary of the relative results for the main impact categories. Results have been normalized to the maximum impact within each category. The side-by-side presentation of the results serves to highlight the trade-offs that exist between the various treatment configurations for traditional LCIA categories. Summary results are also displayed in a table format in Table 8-1. **Figure 8-2** presents the results in Table 8-1 for three representative treatment configurations in a graphical format to help visualize the relative impacts and trade-offs. In this graph, seven of the LCIA endpoints and costs are displayed on their own axis in spiral format, with the greatest impact furthest from the center. The shaded areas reflect a "footprint" of impact. Graphical displays of the results in this manner can aid in interpreting results and facilitating associated decision-making when comparing options. The specific information presented in Figure 8-2 is intended to be purely illustrative and is not intended to imply the relative importance of any endpoint or any winnowing of treatment configurations.

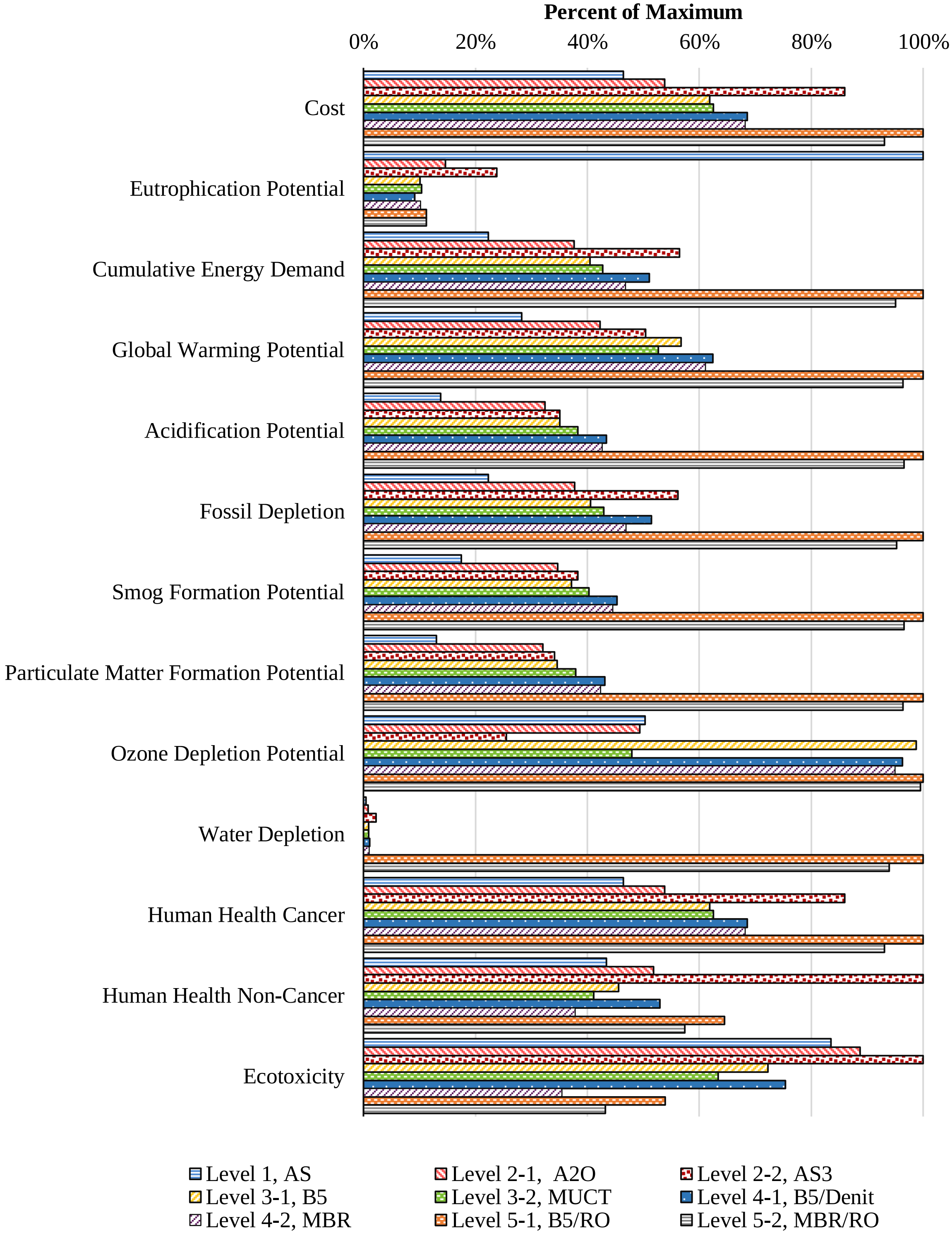


Figure 8-1. Relative LCIA and Cost Results for Nine Wastewater Treatment Configurations

Table 8-1. Summary LCIA and Cost Results for Nine Wastewater Treatment Configurations (per m^3 wastewater treated)

Impact Name	Unit	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Cost	*$ USD*	0.64	0.74	1.2	0.84	0.86	0.94	0.89	1.4	1.3
Eutrophication Potential	*kg N eq*	0.07	9.8E-3	0.02	6.8E-3	6.9E-3	6.1E-3	6.8E-3	7.5E-3	7.5E-3
Cumulative Energy Demand	*MJ*	5.4	9.1	14	9.7	10	12	11	24	23
Global Warming Potential	*kg CO2 eq*	0.52	0.77	0.92	1.0	0.96	1.1	1.1	1.8	1.8
Acidification Potential	*kg SO2 eq*	0.01	0.03	0.03	0.03	0.04	0.04	0.04	0.09	0.09
Fossil Depletion	*kg oil eq*	0.12	0.20	0.30	0.22	0.23	0.28	0.25	0.54	0.51
Smog Formation Potential	*kg O3 eq*	0.13	0.26	0.29	0.28	0.30	0.34	0.33	0.75	0.72
Particulate Matter Formation	*PM2.5 eq*	1.4E-3	3.3E-3	3.5E-3	3.6E-3	3.9E-3	4.5E-3	4.4E-3	0.01	0.01
Ozone Depletion Potential	*kg CFC-11 eq*	3.9E-6	3.8E-6	2.0E-6	7.6E-6	3.7E-6	7.4E-6	7.3E-6	7.7E-6	7.7E-6
Water Depletion	*m3 H2O*	8.0E-4	1.5E-3	4.1E-3	1.7E-3	1.8E-3	2.0E-3	2.0E-3	0.19	0.17
Human Health Cancer Potential	*CTUh*	4.3E-9	5.1E-9	9.9E-9	4.5E-9	4.1E-9	5.2E-9	3.7E-9	6.4E-9	5.7E-9
Human Health Non-Cancer Potential	*CTUh*	1.2E-7	1.3E-7	1.4E-7	1.0E-7	9.0E-8	1.1E-7	5.0E-8	7.7E-8	6.1E-8
Ecotoxicity Potential	*CTUe*	338	385	409	269	283	292	208	317	286

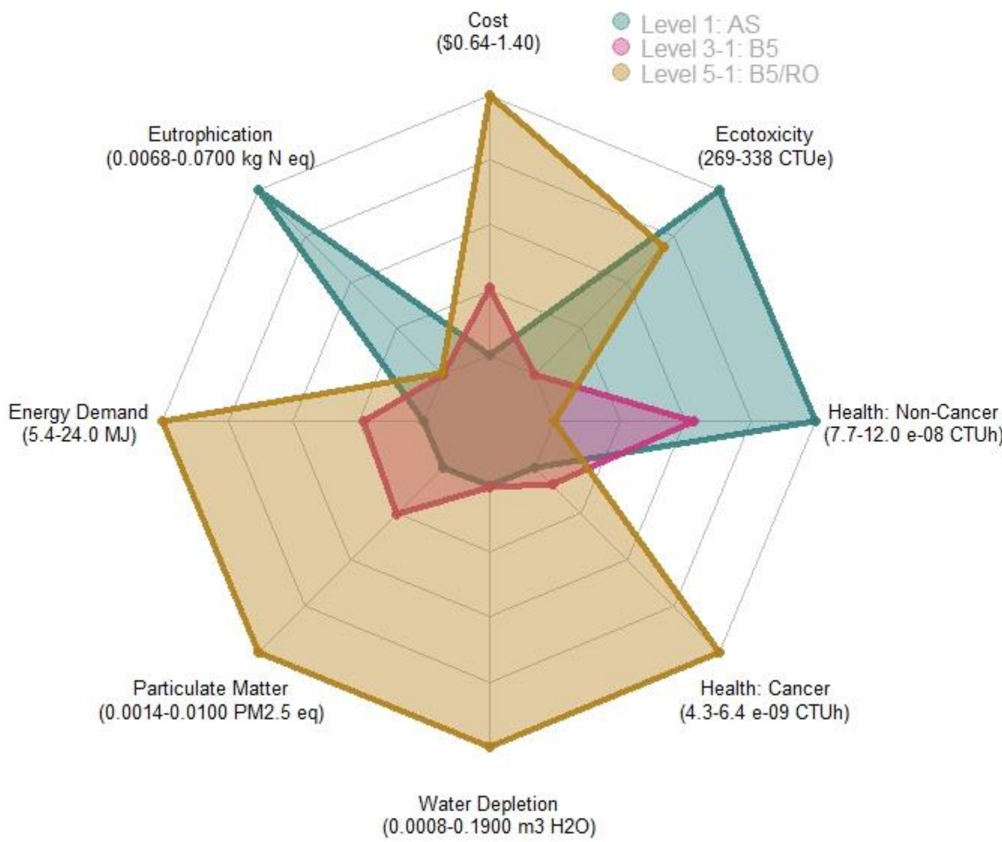


Figure 8-2. Illustrative Comparison of LCIA and Cost Results for Three Wastewater Treatment Configurations

8.2 Normalized Baseline Results

Normalization is a process of standardizing impact results in all categories such that the contribution of impact results associated with the functional unit can be judged relative to total national or global impact for a given category. Table 8-2 shows normalization factors and U.S. national per capita impacts in the year 2008. This is the most recent year normalization factors for LCA are available (Ryberg et al., 2014; Lippiatt et al., 2013). Normalization factors are not available for the impact categories fossil depletion and CED; therefore, these categories are excluded from the normalization step. Toxicity results are also excluded due to the higher magnitude of uncertainty associated with normalization factors for these categories. The normalization factor is the total U.S. impact for the specified category in 2008. Impact per person is estimated by dividing the normalization factor by the U.S. population. The U.S. population in 2008 is estimated as 304,100,000 people (World Bank, 2016). So, for example, the second row of Table 8-2 indicates that average per capita GHG emissions from all U.S. sources was just over 24 metric tons of CO_2 eq in 2008.

Table 8-2. 2008 U.S. Normalization Factors and Per Capita Annual Impacts

Impact Category [a]	Unit	Normalization Factor (US-2008)	Impact per Person [b]	Source
Eutrophication	kg N eq/yr	6.6E+9	22	Ryberg et al., 2014
Global Warming	kg CO2 eq/yr	7.4E+12	2.4E+4	Ryberg et al., 2014
Acidification	kg SO2 eq/yr	2.8E+10	92	Ryberg et al., 2014
Smog	kg O3 eq/yr	4.2E+11	1.4E+3	Ryberg et al., 2014
Particulate Matter Formation	kg PM2.5 eq/yr	7.4E+9	24	Ryberg et al., 2014
Ozone Depletion	kg CFC-11 eq/yr	4.9E+7	0.16	Ryberg et al., 2014
Water Depletion	liter H2O eq/yr	1.7E+14	5.6E+2	Lippiatt et al., 2013

a – Normalization factor not available for cumulative energy demand and fossil depletion, so these categories are excluded from normalization step.

b – Impact per person calculated using 2008 population of 304,100,000.

The process of normalization allows us to better assess the significance of impacts by providing absolute benchmarks at the national level. The functional unit for this study is a cubic meter of wastewater treated. In order to provide a gross, general context to these numbers, this presentation of normalized results calculates values based on the range of per capita municipal wastewater that is generated each year. The average generation of domestic municipal wastewater in the U.S. is estimated to be between 50 and 89 gallons per person per day (Tchobanoglous et al., 2014). This is a large range, reflecting the wide variation in use patterns as determined by factors such as climate, household size, and home and community conservation measures. This level of daily use translates to an annual domestic wastewater generation between 70 and 123 cubic meters per year per person. By multiplying impact results calculated in this study by the annual cubic meters of domestic wastewater treated each year at municipal wastewater facilities and dividing by per capita normalization factors, it is possible to calculate the approximate annual contribution of domestic wastewater treatment to total per capita impact in each of the included impact categories. This calculation excludes wastewater generated by commercial, public, and industrial sources, and therefore overestimates the impact from individuals and does not reflect the full national burden of wastewater treatment. The results of this calculation for the nine treatment systems and environmental impact in seven categories are presented in Table 8-3.

The overall trend in results is the same as that for unnormalized results, with impact in most categories increasing with the level of treatment. However, we can now more easily see the dramatic reduction in normalized contribution to eutrophication between conventional activated sludge treatment and all of the advanced treatment options. Overall per capita eutrophication impact may decrease 12 to 36 percent when shifting from the Level 1 wastewater treatment configuration to the higher nutrient removal wastewater configurations. The results highlight the fact that emissions resulting from wastewater treatment do not contribute equally to all impact categories. Wastewater treatment contributions to GWP and ozone depletion are less than one percent of the average national per capita emissions that contribute to these impact categories across all treatment levels. This implies that more emphasis should be put on eutrophication results compared to GWP or ozone depletion results for the wastewater treatment sector. Emissions associated with impact categories linked strongly with energy consumption such as acidification, smog formation, particulate matter formation, and human health-cancer start out at levels between zero and four percent per capita impacts, but rise to between three and 19 percent per capita impacts by the time Level 5 treatment is reached. These results also demonstrate the significance of impacts associated with a broad range of impact categories not typically thought of in relation to wastewater treatment, particularly at the more advanced levels of nutrient removal, and indicate a possibility for shifting burdens from eutrophication to other categories of environmental impact.

Table 8-3. Estimated Annual Contribution of Municipal Wastewater Treatment Per Capita Impact in Seven Impact Categories

Impact Category [a]	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Eutrophication Potential	21 - 38%	3 - 6%	5 - 9%	2 - 4%	2 - 4%	2 - 3%	2 - 4%	2 - 4%	2 - 4%
Global Warming Potential	0.1 - 0.3%	0.2 - 0.4%	0.3 - 0.5%	0.3 - 0.5%	0.3 - 0.5%	0.3 - 0.6%	0.3 - 0.6%	0.5 - 0.9%	0.5 - 0.9%
Acidification Potential	1 - 2%	2 - 4%	2 - 4%	2 - 4%	3 - 5%	3 - 5%	3 - 5%	7 - 13%	7 - 12%
Smog Formation Potential	1%	1 - 2%	1 - 3%	1 - 2%	2 - 3%	2 - 3%	2 - 3%	4 - 7%	4 - 6%
Particulate Matter Formation Potential	0 - 1%	1 - 2%	1 - 2%	1 - 2%	1 - 2%	1 - 2%	1 - 2%	3 - 5%	3 - 5%
Ozone Depletion Potential	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
Water Depletion	<1%	<1%	<1%	<1%	<1%	<1%	<1%	2 - 4%	2 - 4%

a – Normalization factor not available for cumulative energy demand and fossil depletion, so these categories are excluded from normalization step.

b – Toxicity results are interim.

9. SENSITIVITY ANALYSIS

9.1 Overview

Sensitivity analysis is an important component in the production of robust LCA and LCCA study results. As with any modeling process, the construction and analysis of an LCA and LCCA model and results requires making and documenting many assumptions. Many individual assumptions are known to have only an insignificant effect on the final impact results calculated for a given functional unit, but the effect of other assumptions is uncertain or is known to be significant. In the latter two cases, sensitivity analysis is employed to quantify the effect of modeling choices on LCA results. In this study, a sensitivity analysis was performed on the interest rate used in the LCCA analysis, the choice of GWP factors, the modeled electrical grid fuel mix, and the treatment of anaerobic digestion biogas. A case study is also presented illustrating cost results for a WWTP incorporating nutrient control technology as a retrofit rather than as a greenfield plant. The details of what elements were changed in each of the models and the subsequent effect on results categories are documented in the following subsections.

9.2 Interest and Discount Rates

As discussed in Section 3.3, ERG used the same value for the interest and discount rates. While there are slight differences in the interest and discount rates, it is appropriate to use the same value for the interest and discount rates when developing planning level costs. In this sensitivity analysis, ERG changed the interest rate during construction (see Equation 12), which is part of the total capital costs, and the real discount rate used to calculate the net present value (see Equation 13) from 3% to 5%. The interest and discount rates are not used to calculate the annual costs; as a result, this section focuses on changes to the total construction costs and net present value. The 3% interest rate represents a conservative interest rate for a State Revolving Fund (SRF) loan as the SRF average loan rate was 1.7% in April 2016 (U.S. EPA, 2016a). The 5% interest rate represents a worse-case scenario reflective of rates that WWTPs in poor financial shape, but still able to borrow, would be able to obtain.

Figure 9-1 presents the total construction costs using the 3% and 5% interest and discount rates. On average, the total construction costs increased by approximately 2.6% using the 5% interest rate, due to an increase in the interest paid during construction. **Figure** 9-2 presents the net present value using the 3% and 5% interest and discount rates. The net present value decreased using the 5% interest and discount rates by an average of 18%. The difference in the net present value is primarily because the majority of the costs for the wastewater treatment configurations are annual costs that occur in the future, which become smaller when using the 5% discount rate versus the 3% discount rate.

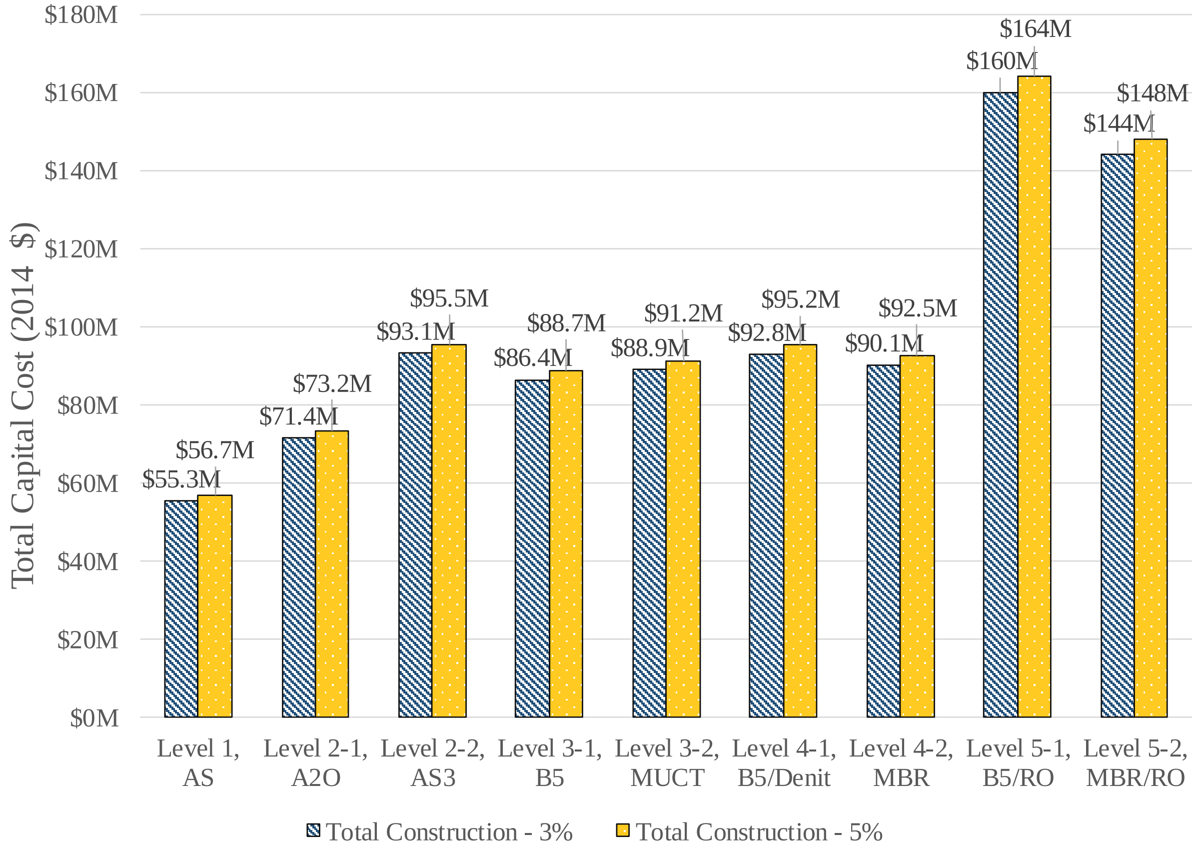


Figure 9-1. 3% versus 5% Interest Rate Total Construction Sensitivity Analysis Results

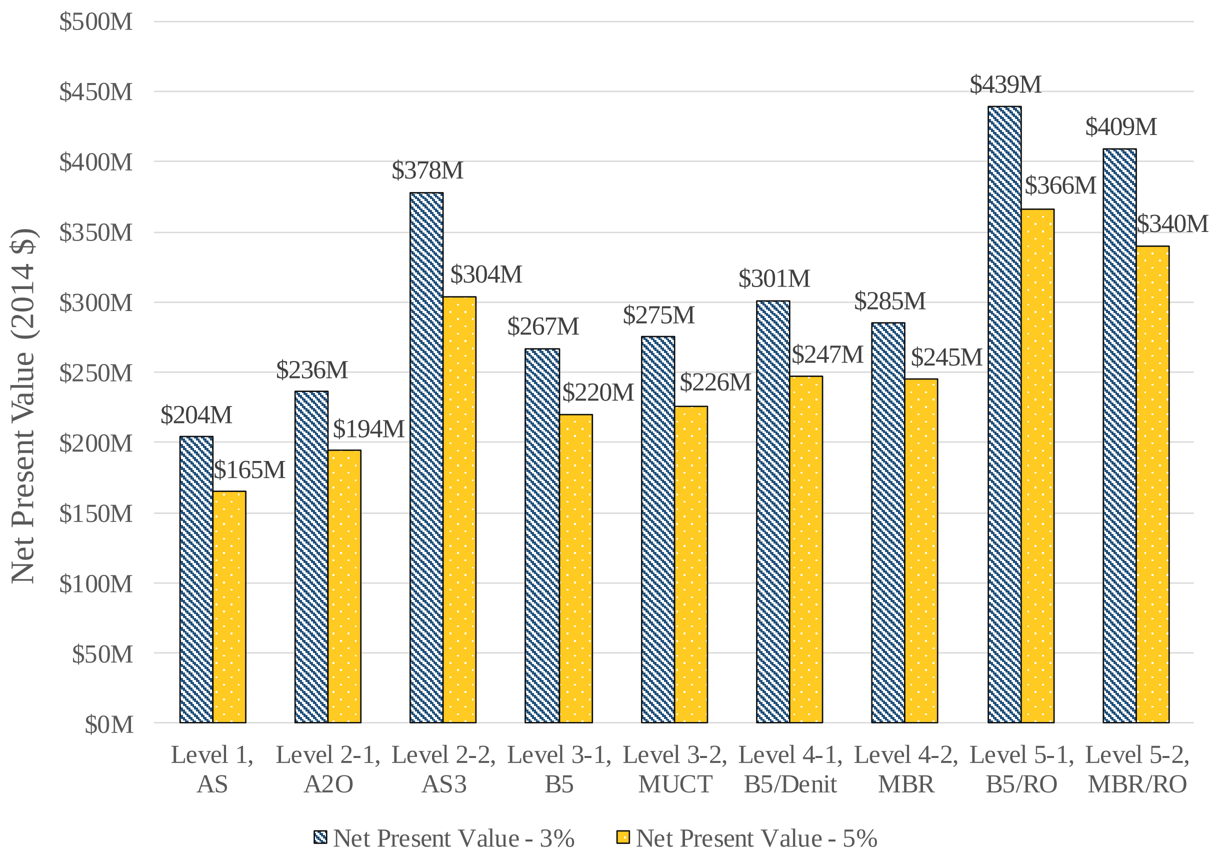


Figure 9-2. 3% versus 5% Interest and Discount Rate Net Present Value Sensitivity Analysis Results

9.3 Global Warming Potential

In this sensitivity analysis, the effect of using IPCC's most recent 2013 GWPs from the Fifth Assessment Report was assessed (IPCC, 2013). The baseline study used 2007 GWP factors from the IPCC Fourth Assessment Report, which have been officially adopted by the UNFCCC for international GHG reporting standards and are used by EPA in their annual greenhouse gas emissions report (IPCC, 2007). GWPs are the values used to transform the emission of all molecules that have heat trapping potential into a standardized unit. The standardization process takes CO_2 as its reference value setting its value to one, with all other factors being set relative to that standard (i.e., kilograms CO_2 eq.). There are many parameters that feed into determination of CO_2 eq. values, and the scientific basis for these values continues to evolve, with the IPCC reviewing and updating factors as the evidence improves. Table 9-1 shows both the 2007 and the updated 2013 IPCC GWP factors for the primary GHGs resulting from the life cycle of wastewater treatment. The last column in the table show the percent change associated with the 2013 update relative to the 2007 values.

Table 9-1. 2007 versus 2013 IPCC GWPs

GHG	GWP IPCC 2007	GWP IPCC 2013	Percent Change
Carbon dioxide	1.0	1.0	0%
Nitrous oxide	3.0E+2	2.7E+2	-12%
Methane	25	28	+11%

The effect of the GWP update on cumulative results depends upon the relative contribution of each GHG to the total GWP impact for each of the wastewater treatment configurations. Across all nine wastewater treatment configurations, the effect of selecting the 2007 versus 2013 GWP factors was shown to alter the GWP impact scores by between 1.8 and 3.8 percent. Figure 9-3 shows the magnitude of these effects per cubic meter of treated wastewater for each of the nine wastewater treatment configurations. The stacked bars correspond to the three main GHGs, which are responsible for the majority of GWP impact. The fact that methane and nitrous oxide are both prevalent GHGs for these systems, and the similarly equal and opposite change in GWP results for these two gases served to mitigate the impact of the update on cumulative results for this study. Table 9-2 lists the percent change in GWP impact that results from the choice between 2007 and 2013 GWP factors. At an aggregate level, the results of this study were not notably affected by GWP factor selection.

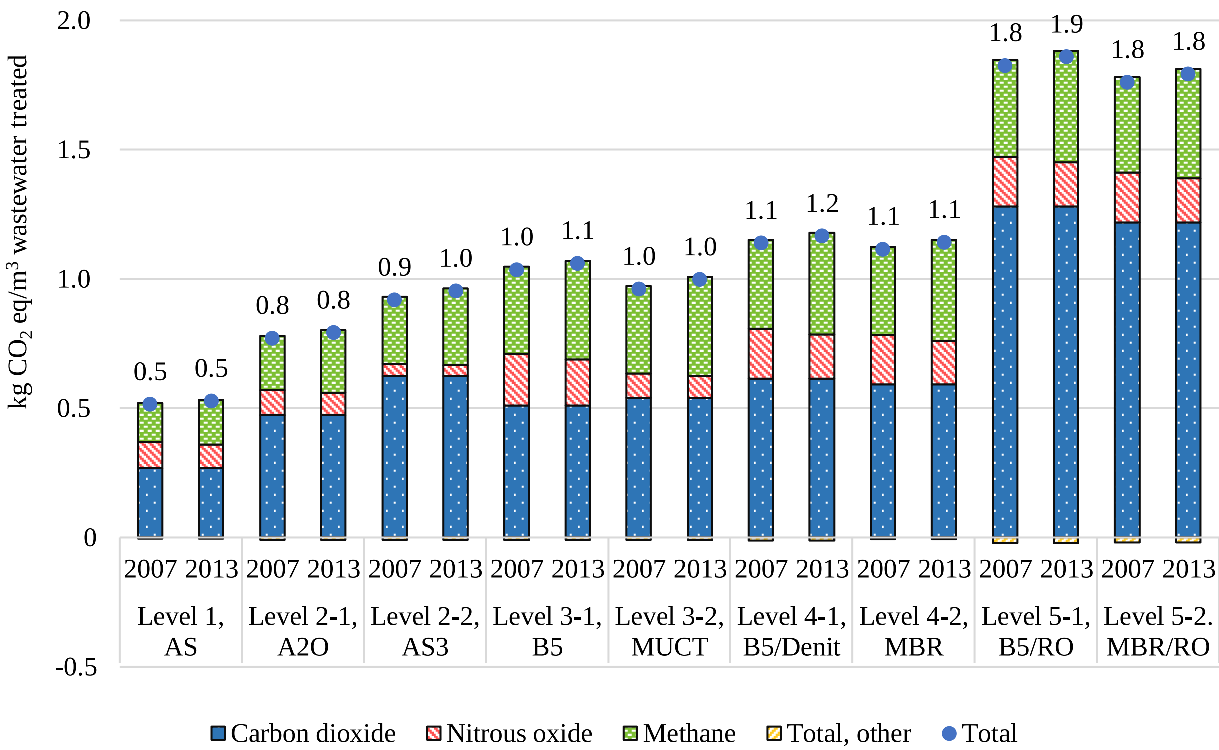


Figure 9-3. 2007 versus 2013 IPCC GWP Sensitivity Analysis Results

Table 9-2. Percent Change in GWP Impact due to GWP Factor Selection

	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2. MBR/RO
Percent Change[a]	2.5%	2.7%	3.7%	2.3%	3.8%	2.3%	2.4%	1.8%	1.8%

a – Percent Change = $(GWP_{2013}-GWP_{2007})/GWP_{2007}$

9.4 <u>Electrical Grid Mix</u>

In this sensitivity analysis, an alternative electrical mix with a "cleaner" grid (e.g., shift away from coal) was applied. Table 9-3 displays the electrical grid mix for the NorthEast Power Coordinating Council (NPCC), in addition to the baseline average mix of fuels used as the basis for this study. This information is based on eGRID data from 2012. NPCC covers states such as New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine. This electrical grid is included in a sensitivity analysis, as it contains a higher portion of electricity from natural gas, nuclear, and hydro and a lower portion of electricity from coal as compared to the U.S. average electrical grid. The last column of Table 9-3 presents the percent change within individual fuel types when shifting from the baseline U.S. average electrical grid mix to the NPCC electrical grid mix.

Table 9-3. NPCC eGRID Regional versus U.S. Average Electrical Grid Mix

Fuel	Baseline U.S. Average Percent of Mix	NPCC Sensitivity Analysis Percent of Mix	Percent Change
Coal	45%	3.1%	-93%
Natural Gas	24%	49%	+100%
Nuclear	20%	30%	+51%
Hydro	6.2%	12%	+94%
Wind	2.3%	1.6%	-28%
Biomass	1.4%	3.6%	+170%
Oil	1.0%	0.38%	-63%
Geothermal	0.37%	0%	-100%
Other Fossil	0.35%	1.1%	+220%
Solar	0.03%	0.03%	0%

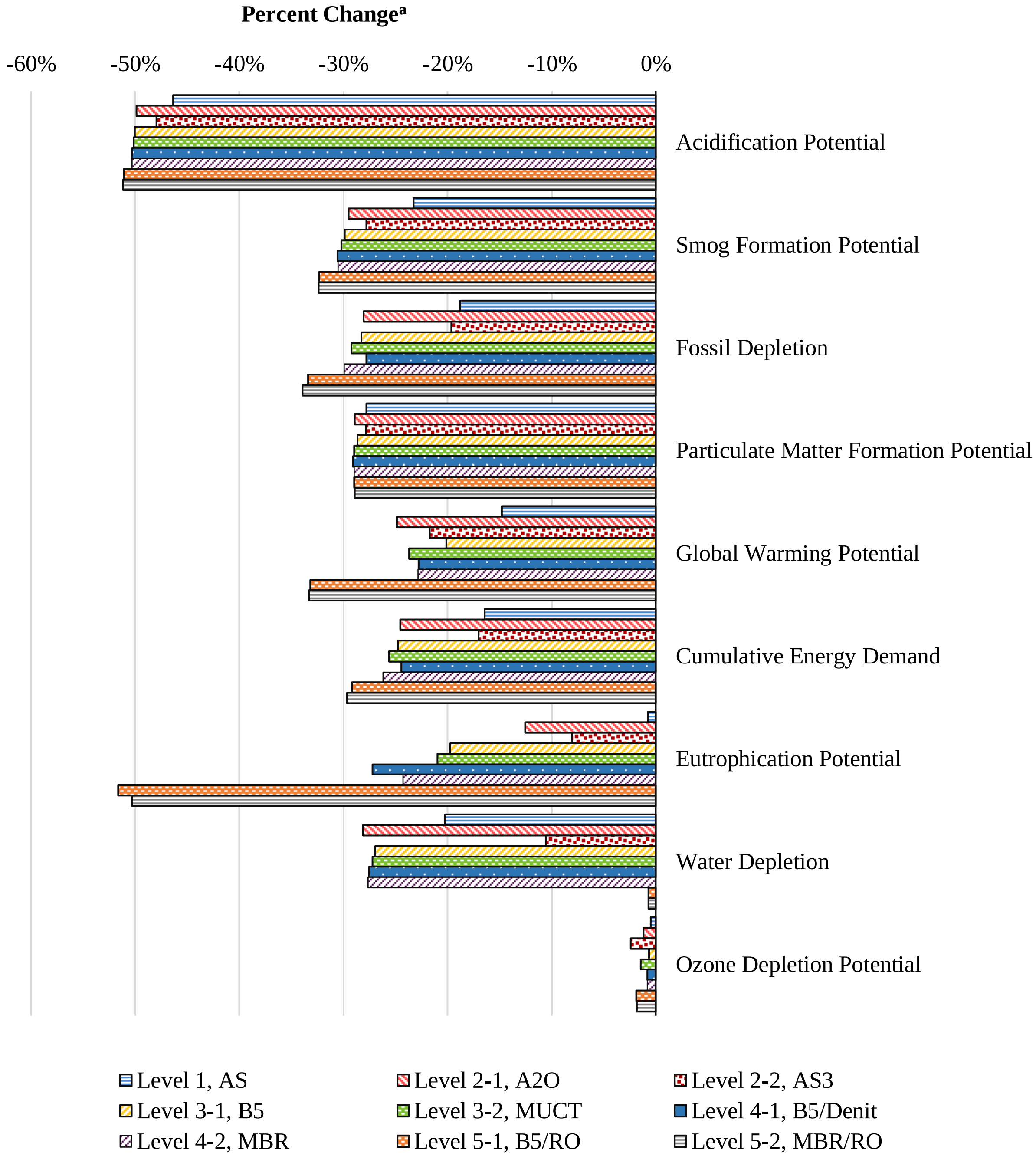
When conducting the sensitivity analysis, the electrical grid mix that serves the wastewater treatment plant is varied for each of the nine wastewater treatment configurations, while the electrical grid mixes associated with background processes remain constant. This is reasonable since it is likely background chemicals and fuels are not produced in the same region of the U.S. that they are utilized. Results for all of the impact categories were rerun and compared to the baseline values. As displayed in Figure 9-4, the relative impact of this substitution depends both upon the wastewater treatment configuration and on the impact category. The impacts in this figure are sorted, with the greatest average reduction across all treatment levels shown at the top and the smallest average reduction across all treatment levels shown at the bottom. The effect of this substitution of electrical grid mix on cumulative impact scores is significant across the majority of impact categories and treatment levels with a few notable exceptions. Ozone depletion potential impact is not shown to be sensitive to the choice of electrical grid with the percent change for all wastewater treatment configurations being less than one percent. The impact on eutrophication potential for Levels 1 and 2 are overshadowed by the predominance of eutrophying emissions associated with effluent release. Similarly, the effect on water depletion impact for Level 5 is reduced due to the predominant impact of brine injection to results in this category.

In general, those wastewater treatment configurations with a higher energy demand per cubic meter of wastewater treated show a greater sensitivity to the source of electricity. A number of interesting patterns are visible in Figure 9-4. The relative effect of this sensitivity analysis between wastewater treatment configurations is most pronounced for eutrophication potential. The percent change associated with eutrophication impacts in Level 1 and Level 5– are approximately -1 and -50 percent, respectively. The large variation in these values can be explained by large differences in the aspects of the LCA model that contribute to impact in each category. As mentioned above, eutrophication impact for Level 1 is predominated by effluent release, so the change in grid energy has little influence on impact. Alternatively, by the time water is cleaned to Level 5 standards, there is so little nutrient content in the effluent itself that electricity impact predominates. Similarly, for other impact categories that show an increasing sensitivity to electricity choice as we move from Level 1 to Level 5, we can attribute this to the increased contribution of electricity to impact results as effluent standards increase.

The consistently high effect on acidification and particulate matter impacts across the treatment systems is demonstrative of the dependence of these impact categories on emissions resulting from electricity production. Toxicity results are excluded from Figure 9-3.

The deviation in general trends associated with Level 2-2 are due to the exceptional reliance of this wastewater treatment configuration on chemical flocculent for phosphorus removal, and the impact associated with these chemical additions. In this way, this wastewater treatment configuration is less sensitive to overall changes in the electrical grid fuel mix.

The findings of this sensitivity analysis indicate that electricity is a primary driver for many of the impact categories assessed in this study. Utilization of “cleaner” fuels for electricity or recovery of resources at the WWTP to produce energy on-site could serve to offset some of the burdens realized when including additional energy intensive unit processes to achieve increased nutrient removal.



[a] Percent Change = [(NPCC$_{impact}$-AvgGrid$_{impact}$)/AvgGrid$_{impact}$]

Figure 9-4. Electrical Grid Mix Sensitivity Analysis Results

Table 9-4. Electrical Grid Sensitivity Analysis, U.S. Average versus NPCC Electrical Grid (per m^3 wastewater treated)

Impact Name	Unit	Level 1, AS		Level 2-1, A2O		Level 2-2, AS3		Level 3-1, B5		Level 3-2, MUCT		Level 4-1, B5/Denit		Level 4-2, MBR		Level 5-1, B5/RO		Level 5-2, MBR/RO	
		U.S. Avg.	NPCC	U.S. Avg.	NPCC	U.S. Avg.	NPCC	U.S. Avg.	NPCC	U.S. Avg.	NPCC	U.S. Avg.	NPCC	U.S. Avg.	NPCC	U.S. Avg.	NPCC	U.S. Avg.	NPCC
Global Warming Potential	**kg CO2 eq**	0.52	0.44	0.77	0.58	0.92	0.72	1.0	0.83	0.96	0.73	1.1	0.88	1.1	0.86	1.8	1.2	1.8	1.2
Eutrophication Potential	**kg N eq**	0.07	0.07	9.8E-3	8.6E-3	0.02	0.01	6.8E-3	5.4E-3	6.9E-3	5.5E-3	6.1E-3	4.5E-3	6.8E-3	5.1E-3	7.5E-3	3.6E-3	7.5E-3	3.7E-3
Acidification Potential	**kg SO2 eq**	0.01	6.9E-3	0.03	0.02	0.03	0.02	0.03	0.02	0.04	0.02	0.04	0.02	0.04	0.02	0.09	0.05	0.09	0.04
Fossil Depletion	**kg oil eq**	0.12	0.10	0.20	0.15	0.30	0.24	0.22	0.16	0.23	0.16	0.28	0.20	0.25	0.18	0.54	0.36	0.51	0.34
Smog Formation Potential	**kg O3 eq**	0.13	0.10	0.26	0.18	0.29	0.21	0.28	0.20	0.30	0.21	0.34	0.24	0.33	0.23	0.75	0.51	0.72	0.49
Particulate Matter Formation	**PM2.5 eq**	1.4E-3	9.8E-4	3.3E-3	2.4E-3	3.5E-3	2.6E-3	3.6E-3	2.6E-3	3.9E-3	2.8E-3	4.5E-3	3.2E-3	4.4E-3	3.1E-3	0.01	7.4E-3	0.01	7.1E-3
Ozone Depletion Potential	**kg CFC-11 eq**	3.9E-6	3.9E-6	3.8E-6	3.8E-6	2.0E-6	1.9E-6	7.6E-6	7.5E-6	3.7E-6	3.6E-6	7.4E-6	7.3E-6	7.3E-6	7.2E-6	7.7E-6	7.6E-6	7.7E-6	7.5E-6
Cumulative Energy Demand	**MJ**	5.4	4.5	9.1	6.8	14	11	9.7	7.3	10	7.7	12	9.3	11	8.3	24	17	23	16
Water Depletion	**m3 H2O**	8.0E-4	6.4E-4	1.5E-3	1.1E-3	4.1E-3	3.7E-3	1.7E-3	1.2E-3	1.8E-3	1.3E-3	2.0E-3	1.5E-3	2.0E-3	1.4E-3	0.19	0.18	0.17	0.17

9.5 Biogas Energy Recovery

The baseline model assumes flaring of biogas produced during anaerobic digestion. This sensitivity analysis investigates the effect on plant level environmental impact and life cycle cost from shifting to energy recovery using a combined heat and power (CHP) engine.

9.5.1 System Description

Biogas system components include the prime mover, which drives the electrical generator, a heat exchanger, gas processing/cleaning equipment, electrical controls and enclosure. An Internal Combustion Engine (ICE) is modeled as the CHP prime mover. ICEs are a common and industry tested technology (Wiser et al. 2010). Biogas exiting the anaerobic digesters is at ambient pressure and is saturated with moisture. Compression, drying and removal of impurities is required before gas can be combusted in a CHP engine. The biogas processing and CHP system boundary is depicted in Figure 9-5. Biogas and CHP system specifications are listed in Table 9-5.

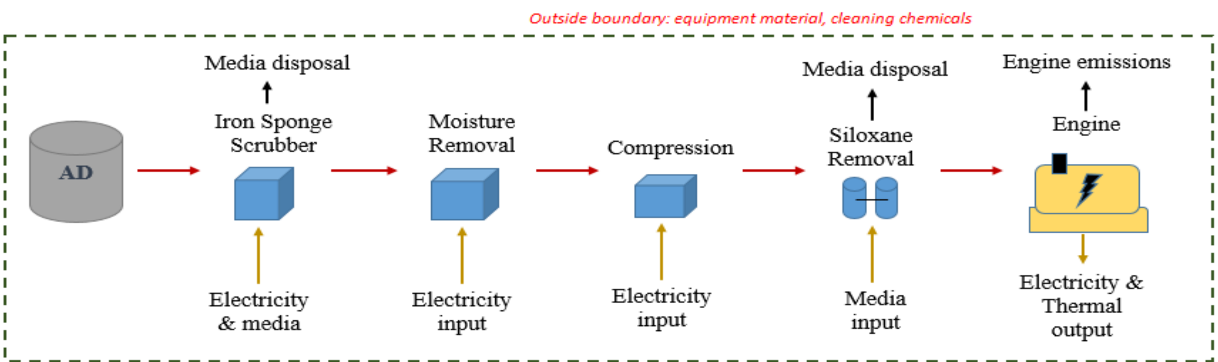


Figure 9-5. System Diagram of Biogas Processing and CHP System

Iron sponge scrubbers are assumed for hydrogen sulfide (H_2S) removal, being a widely used and commercially proven technology. H_2S is corrosive of metallic system components in the presence of water, and can lead to elevated sulfur oxide (SO_x) emissions from the prime mover. H_2S is a common constituent of biogas generated at municipal WWTPs often comprising 200-3500 ppmv of biogas (Wiser et al. 2010). A representative H_2S concentration of 500 ppmv is used to estimate iron sponge requirements (Wiser et al. 2010). The desired temperature range for adsorption via iron sponge is between 25 and 60 °C, which corresponds to the temperature of biogas as it exits the anaerobic digesters. Hydrated iron oxide is usually sold embedded onto wood chips. Iron sponge adsorption requires the presence of moisture in the biogas, so process placement before moisture removal is common. Approximately 20 kg of H_2S can be adsorbed per 100 kg of sorbent material (Ong et al. 2017). The oxide impregnated wood chips can be regenerated by flushing the bed with atmospheric oxygen, which releases H_2S as elemental sulfur. The regeneration process can be repeated approximately 1-2 times before the adsorbent media requires replacement (Abatzoglou and Boivin 2009). This analysis assumes 1 regeneration cycle, achieving 85 percent of original sorbent capacity. The necessary equipment has a modest footprint and is usually located outdoors to mitigate safety concerns.

Table 9-5. Biogas Processing and CHP System Specifications for Nine Treatment System Configurations

System Parameter	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Annual Biogas Production (m^3)	1.6E+6	1.3E+6	1.8E+6	1.3E+6	1.3E+6	1.3E+6	1.3E+6	1.3E+6	1.2E+6
Biogas Production (scfm)	1.1E+2	88	1.2E+2	85	85	85	87	85	82
Available Biogas Energy (MJ)[a]	2.7E+7	2.4E+7	3.2E+7	2.3E+7	2.3E+7	2.3E+7	2.3E+7	2.3E+7	2.2E+7
ICE Availability	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
ICE Power (kw)	3.2E+2	2.8E+2	3.8E+2	2.7E+2	2.7E+2	2.7E+2	2.8E+2	2.7E+2	2.6E+2
Electricity Production (kWh/yr)	2.5E+6	2.2E+6	3.0E+6	2.2E+6	2.2E+6	2.2E+6	2.2E+6	2.2E+6	2.1E+6
Thermal Energy (MJ/yr)	1.2E+7	1.1E+7	1.4E+7	1.0E+7	1.0E+7	1.0E+7	1.0E+7	1.0E+7	9.9E+6
AD Heat Requirement (MJ/yr)[b,c]	1.7E+7	1.6E+7	2.4E+7	1.5E+7	1.5E+7	1.5E+7	1.5E+7	1.5E+7	1.4E+7
WWTP Electricity Requirement (kWh/yr)	2.8E+6	6.7E+6	6.8E+6	8.1E+6	8.6E+6	9.8E+6	8.2E+6	2.2E+7	2.0E+7
Percent of AD Heat Demand Satisfied (%)	70%	68%	59%	67%	67%	67%	70%	67%	71%
Percent of Facility Electricity Demand Satisfied (%)	90%	33%	43%	30%	27%	24%	25%	10%	10%
H_2S removed (kg/day)	1.9	1.6	2.2	1.6	1.6	1.6	1.6	1.6	1.5
Iron Oxide requirement (kg/yr)	1.8E+3	1.6E+3	2.2E+3	1.6E+3	1.6E+3	1.6E+3	1.6E+3	1.6E+3	1.5E+3
Siloxane removed (kg/day)	0.44	0.36	0.48	0.35	0.35	0.35	0.36	0.35	0.33
Activated Carbon requirement (kg/yr)	1.6E+3	1.3E+3	1.8E+3	1.3E+3	1.3E+3	1.3E+3	1.3E+3	1.3E+3	1.2E+3

[a] Accounts for 5 percent fugitive biogas loss and 20 percent flaring rate.

[b] Expressed as CHP thermal energy, accounts for 90 percent efficiency of heat exchanger.

[c] AD – anaerobic digester/digestion

Moisture removal is the next step in biogas processing as it enhances performance of the subsequent siloxane removal step (Wiser et al. 2010). Moisture removal via chilling and condensation is proposed to ensure sufficiently dry biogas. Refrigeration energy demands typically account for less than two percent of the energy content of the processed biogas. A conservative value of two percent is used to estimate electricity demands of the refrigeration process (Ong et al. 2017).

Compression of biogas is necessary prior to combustion in the prime mover. Fuel pressurization to between 3 and 5 psi is sufficient for use in ICEs. Use of a blower is recommended for moderate compression requirements up to 15 psig (Wiser et al. 2010). Compression follows H_2S and moisture removal to ensure longevity of compressor components. Blowers have the benefit of being low cost, require no oil, lack VOC emissions and have minimal maintenance requirements (Wiser et al. 2010). Energy requirements for compression are estimated based on the use of heavy duty rotary blowers that operate at brake horsepowers of between 2.4 and 3.3 depending upon the biogas flowrate in standard cubic feet per minute (scfm), which ranges between 82 and 118 scfm depending upon the system configuration (see Table 9-5).

The final biogas cleaning and processing step involves removal of siloxanes, which are another common contaminant of biogas generated via anaerobic digestion of wastewater sludge. Siloxanes can be removed using refrigeration or sorbents such as activated carbon, alumina, synthetic resins, or liquid sorbents. Siloxane removal via activated carbon adsorption is modeled given its prevalent use, low cost and maintenance requirements. Coal is modeled as the activated carbon feedstock, based on LCI information presented in Bayer et al. (2005).

The ICE is sized based upon the available energy content of biogas produced by each system assuming a 90 percent availability factor (i.e. 10 percent system downtime). The quantity of biogas available for energy consumption equals total biogas production less fugitive emissions (5 percent) and flared biogas (UNFCCC 2012). The analysis assumes that 20 percent of biogas is flared due to system downtime, upsets and lack of available storage capacity required to handle inconsistency in biogas production. ICE power requirements range from approximately 260 to 380 kW depending upon the system configuration, placing it in line with other WWTP CHP installations based on installed kW/MGD (U.S. DOE 2016). Electrical and thermal efficiency values of 34 percent and 45 percent are selected, respectively, representing the average of the reported ICE efficiency range in Wiser et al. (2010). ICE emissions are representative of an ICE engine utilizing selective catalytic reduction for NO_x control, and an oxidation catalyst system for carbon monoxide and VOC emission control.

9.5.2 Biogas Sensitivity LCIA Results

LCIA results by treatment group are presented for GWP in Figure 9-6. The addition of energy recovery yields a decrease in GWP impact for all system configurations due to the avoided environmental burdens of natural gas and grid electricity consumption associated with the electrical and thermal products of the CHP system. The absolute decrease in GWP impact varies between 0.21 and 0.31 kg CO_2-eq. per m^3 wastewater treated according to the quantity of biogas available for energy recovery. The relative effect on system level GWP impact is greatest for treatment Level 1, and decreases as total GWP impact increases for the higher levels of nutrient removal. The addition of energy recovery reduces Level 1 GWP impact by approximately 50 percent, while the reduction in GWP impact for Level 5 treatment configurations is less than 15 percent of base GWP impact. Base and CHP sensitivity LCIA results and corresponding percent reduction values are presented for all impact categories in Table 9-6. Figure 9-6 shows that the benefits of energy recovery are sufficient to offset the GWP impact of the sludge processing and disposal treatment group.

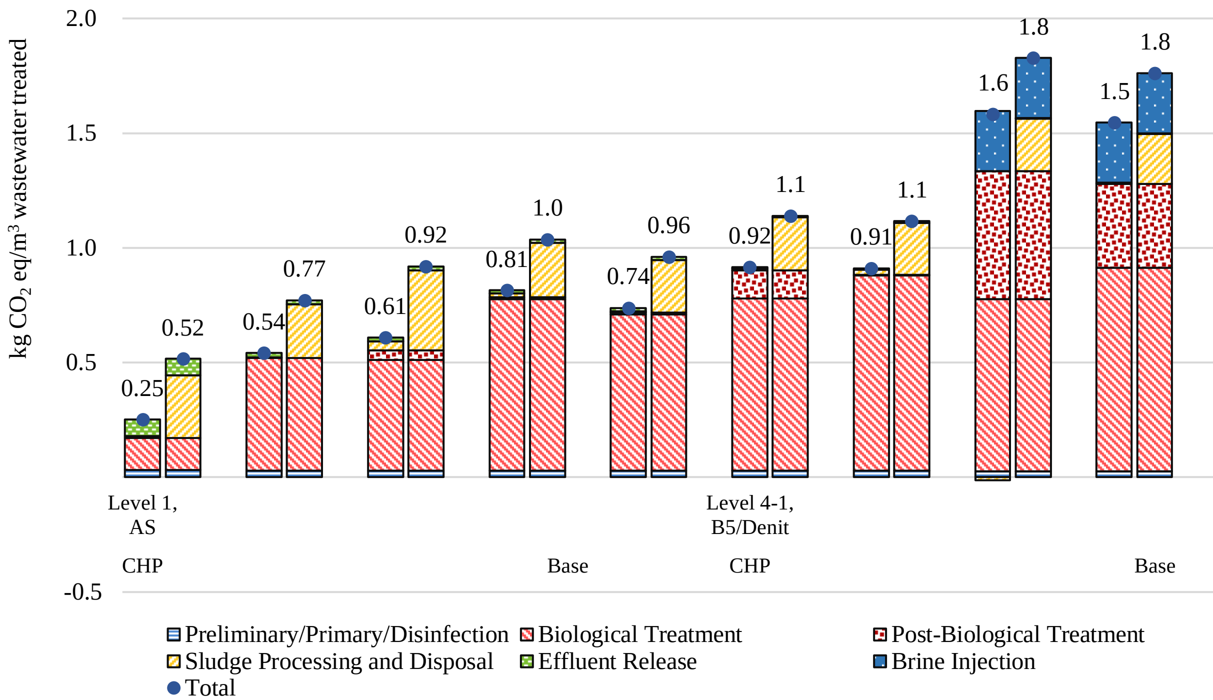


Figure 9-6. Global Warming Potential by Treatment Group for Base Results and the CHP Energy Recovery Sensitivity

Figure 9-7 presents results by treatment group for the CED inventory indicator, and demonstrates reductions in system level energy demand for all treatment configurations. Absolute reduction in CED range from 3.5 to 5.4 MJ/m^3 wastewater treated, according to biogas production associated with each configuration. The relative reduction in CED is greater than that observed for GWP, and varies between 16 and 86 percent for Levels 5-2 and 1, respectively. Figure 9-7 shows that the sludge processing and disposal treatment group now contributes an energy credit to the system, reducing the net CED of each treatment configuration.

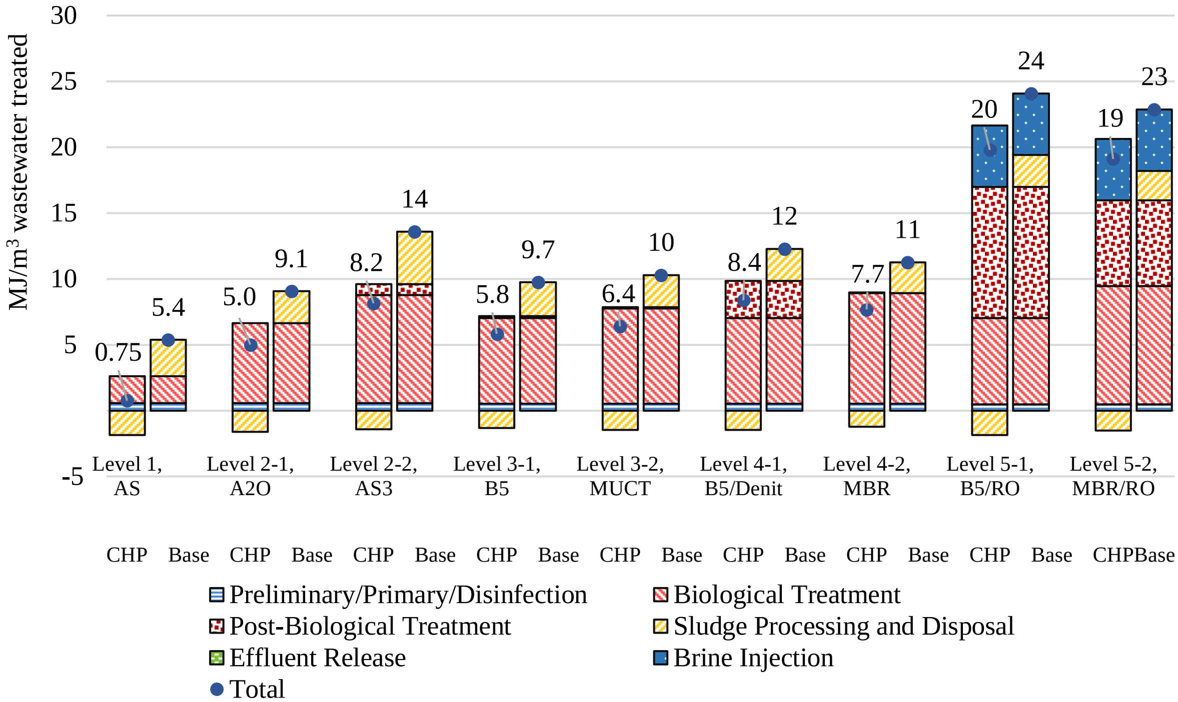


Figure 9-7. Cumulative Energy Demand by Treatment Group for Base Results and the CHP Energy Recovery Sensitivity

Table 9-6 shows that acidification, PM formation, smog formation, and fossil depletion potential all show significant reductions in system level impact in response to biogas energy recovery. Relative reductions in impact for these four impact categories are all greater for the lower treatment levels where absolute impact results are lower owing to lower relative energy and material consumption. Biogas production is also greatest for Level 1 and Level 2-2, leading to greater quantities of recovered energy. Energy recovery has a less dramatic effect on ozone depletion and eutrophication potential impact, with relative reductions in impact potential of between 1 and 26 percent. Eutrophication potential demonstrates a pattern unlike the other impact categories, where percent reductions in eutrophication impact are greatest for the higher treatment levels, which are associated with the lowest absolute eutrophication impact.

Table 9-6. Summary of Comparative Impact Assessment Results for the Base Case and CHP Energy Recovery Sensitivity

Impact Category	Description	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Global Warming Potential	Base Results	0.52	0.77	0.92	1.0	0.96	1.1	1.1	1.8	1.8
	CHP Sensitivity	0.25	0.54	0.61	0.81	0.74	0.92	0.91	1.6	1.5
	Percent Reduction[a]	*51%*	*30%*	*34%*	*21%*	*23%*	*20%*	*18%*	*13%*	*12%*
Cumulative Energy Demand	Base Results	5.4	9.1	14	9.7	10	12	11	24	23
	CHP Sensitivity	0.75	5.0	8.2	5.8	6.4	8.4	7.7	20	19
	Percent Reduction[a]	*86%*	*45%*	*40%*	*40%*	*38%*	*32%*	*32%*	*18%*	*16%*
Eutrophication Potential	Base Results	0.07	9.8E-3	0.02	6.8E-3	6.9E-3	6.1E-3	6.8E-3	7.5E-3	7.5E-3
	CHP Sensitivity	0.07	9.2E-3	0.02	6.2E-3	6.4E-3	5.6E-3	6.3E-3	6.9E-3	7.0E-3
	Percent Reduction[a]	*1%*	*6%*	*5%*	*8%*	*8%*	*9%*	*7%*	*8%*	*7%*
Water Depletion	Base Results	8.0E-4	1.5E-3	4.1E-3	1.7E-3	1.8E-3	2.0E-3	2.0E-3	0.19	0.17
	CHP Sensitivity	3.9E-4	1.1E-3	3.6E-3	1.3E-3	1.4E-3	1.7E-3	1.7E-3	0.19	0.17
	Percent Reduction[a]	*51%*	*25%*	*12%*	*21%*	*20%*	*18%*	*14%*	*0%*	*0%*
Acidification Potential	Base Results	0.01	0.03	0.03	0.03	0.04	0.04	0.04	0.09	0.09
	CHP Sensitivity	1.1E-3	0.02	0.02	0.02	0.03	0.03	0.03	0.08	0.08
	Percent Reduction[a]	*92%*	*36%*	*44%*	*30%*	*28%*	*25%*	*21%*	*12%*	*11%*
Particulate Matter Formation	Base Results	1.5E-3	3.4E-3	3.5E-3	3.6E-3	3.9E-3	4.5E-3	4.4E-3	0.01	1.0E-2
	CHP Sensitivity	1.1E-4	2.2E-3	2.1E-3	2.6E-3	2.9E-3	3.4E-3	3.5E-3	9.2E-3	9.0E-3
	Percent Reduction[a]	*93%*	*35%*	*41%*	*29%*	*27%*	*24%*	*20%*	*12%*	*10%*
Smog Formation Potential	Base Results	0.14	0.27	0.29	0.28	0.30	0.34	0.33	0.75	0.72
	CHP Sensitivity	0.02	0.16	0.15	0.18	0.21	0.24	0.25	0.64	0.63
	Percent Reduction[a]	*88%*	*39%*	*46%*	*34%*	*31%*	*28%*	*25%*	*14%*	*13%*
Ozone Depletion Potential	Base Results	3.9E-6	3.8E-6	2.0E-6	7.6E-6	3.7E-6	7.4E-6	7.3E-6	7.7E-6	7.7E-6
	CHP Sensitivity	3.4E-6	3.4E-6	1.5E-6	7.2E-6	3.3E-6	7.0E-6	7.0E-6	7.3E-6	7.3E-6
	Percent Reduction[a]	*12%*	*10%*	*26%*	*5%*	*10%*	*5%*	*5%*	*5%*	*5%*
Fossil Depletion	Base Results	0.12	0.20	0.30	0.22	0.23	0.28	0.25	0.54	0.51
	CHP Sensitivity	0.01	0.11	0.18	0.13	0.14	0.19	0.17	0.44	0.42
	Percent Reduction[a]	*89%*	*46%*	*42%*	*41%*	*39%*	*33%*	*33%*	*18%*	*17%*

a – Percent Reduction = $(Base_{GWPimpact} - CHP_{GWPimpact}) / Base_{GWPimpact}$

9.5.3 Biogas Sensitivity LCCA

The base case LCCA results were updated to reflect the increased capital and O&M costs associated with the installation and ongoing maintenance of a CHP system. The cost sensitivity includes the avoided cost of reduced natural gas consumption, as well as revenue from the sale of electricity. Equipment costs for ICE CHP generally fall in the range of $465 to $1600 per kW of installed generation capacity (Wiser et al. 2010). The average of this range, $1033/kW, is used in this analysis. Gas processing costs typically add $600/kW of generation capacity (Darrow et al. 2017). The same direct and indirect cost factors are applied to the CHP system as are described in Section 2. Inclusive operation and maintenance costs are estimated per kWh of electricity production. Gas cleaning and processing O&M costs typically range from 0.015 to 0.025 $/kWh, while prime mover maintenance costs typically fall in the range of 0.01 to 0.025 $/kWh (Wiser et al. 2010). The average of these reported ranges is used in this analysis, 0.02 and 0.0175 $/kWh, respectively.

Electricity revenue is estimated using the same cost factor, $0.10/kWh, that is used to estimate system energy cost in the main LCCA analysis. Avoided natural gas costs are based on a natural gas purchase price of $15.50 per 1000 ft^3.

Figure 9-8 summarizes the effect of including CHP and energy recovery on total system cost. The effect on system net present value over a 30-year time horizon is relatively modest, yielding a reduction in system net present value of between six and nine million dollars depending upon the configuration. The relative reduction in system net present value is greatest for level 1, yielding a 3.5 percent reduction in system net present value relative to the base scenario that assumes flaring of biogas. Table 9-7 summarizes base case and biogas case study life cycle costs.

Table 9-7. Summary of Biogas LCCA Costs (million 2014 $s)

Treatment System Configuration	Net Present Value		Annual Labor, Material and Chemical Cost		Annual Energy Cost		Annual Amortization Cost	
	with CHP	Base	with CHP	Base	with CHP	Base	with CHP	Base
Level 1, AS	$197	$204	$4.6	$4.5	$0.11	$0.59	$3.8	$3.7
Level 2-1, A2O	$230	$236	$4.6	$4.5	$0.5	$0.9	$4.8	$4.8
Level 2-2, AS3	$369	$378	$9.1	$9.0	$0.6	$1.1	$6.3	$6.2
Level 3-1, B5	$261	$267	$4.9	$4.8	$0.6	$1.0	$5.8	$5.8
Level 3-2, MUCT	$269	$275	$4.9	$4.9	$0.7	$1.1	$6.0	$5.9
Level 4-1, B5/Denit	$295	$301	$5.8	$5.7	$0.8	$1.2	$6.3	$6.2
Level 4-2, MBR	$294	$285	$5.9	$5.2	$0.7	$1.1	$6.1	$6.0
Level 5-1, B5/RO	$433	$439	$6.1	$6.0	$1.9	$2.3	$11	$11
Level 5-2, MBR/RO	$403	$409	$5.9	$5.8	$1.9	$2.2	$10	$10

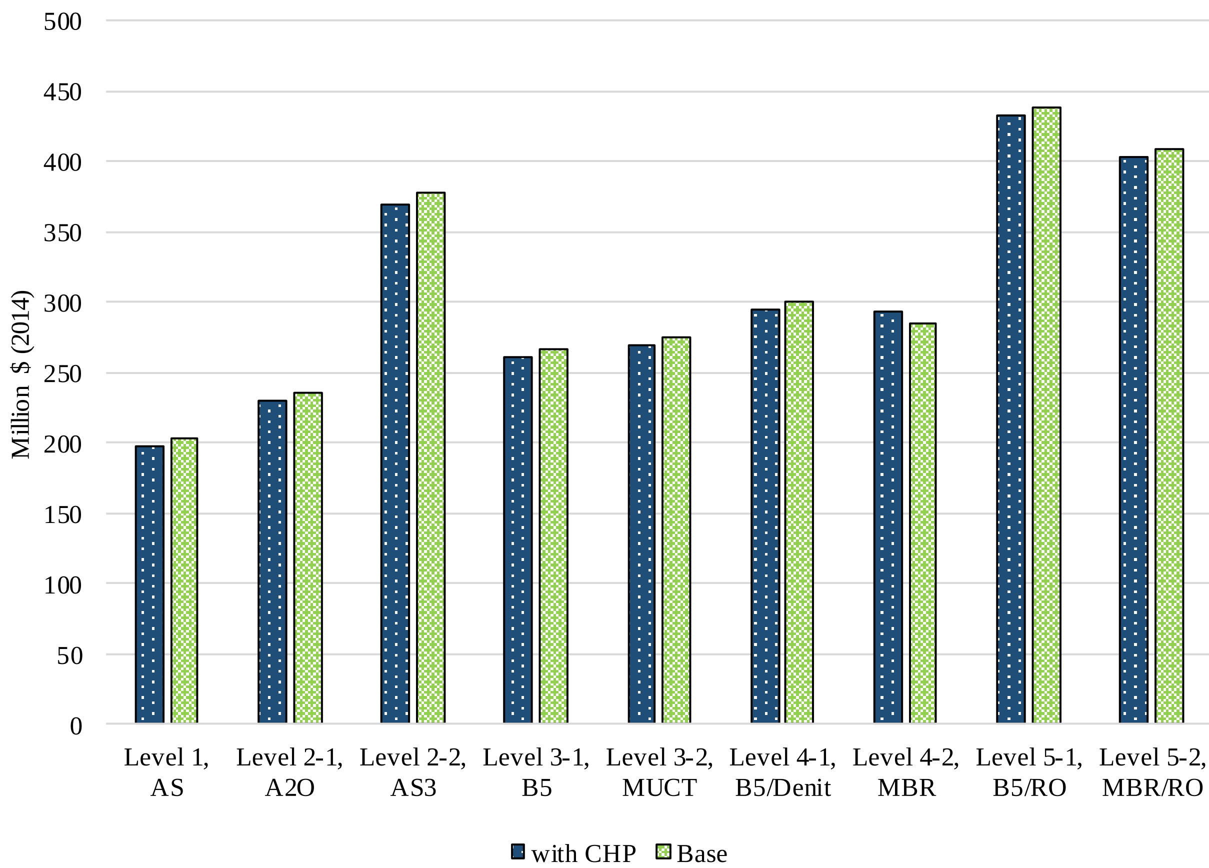


Figure 9-8. Biogas Case Study Net Present Value Comparison

9.6 Retrofit Case Study

While this report displays cost results for greenfield installations, existing plants may incorporate nutrient control technology in a retrofit. In this section, ERG conducted a case study to investigate the potential cost implications of such a retrofit. This case study considers a retrofit of the Level 2-1 A2O wastewater treatment configuration as the baseline (see Figure 9-9) with the addition of chemical phosphorus removal and a denitrification filter to achieve the Level 4 target effluent nutrient concentrations of 3 mg/L total nitrogen and 0.1 mg/L total phosphorus (see Figure 9-10).

Table 9-8 presents the total capital, total annual, and net present value for the nine greenfield wastewater treatment configurations and the Level 2-1 greenfield wastewater treatment configuration plus the cost for the retrofit chemical phosphorus removal and denitrification filter (Level 2-1 to 4 Retrofit) (presented in bold). While the Level 2-1 to 4 Retrofit wastewater treatment configuration achieves the Level 4 effluent nutrient targets, the total capital cost, total annual cost, and net present value are between the greenfield Level 2-1 A2O and both greenfield Level 3 wastewater treatment configurations. As shown in Figure 9-11, the capital cost for the Level 2-1 to 4 Retrofit wastewater treatment configuration is $12M to $15M lower than the greenfield Level 4 wastewater treatment configurations, but is designed to achieve the same effluent nutrient concentrations, due to lower biological treatment and post-biological treatment capital costs. The chemical phosphorus removal and denitrification filter portion of the Level 2-1 to 4 Retrofit capital costs are $6.9M. As shown in Figure 9-12, the total annual costs for Level 2-1 to 4 Retrofit are about $0.6M/yr to $0.8M/yr higher than the greenfield Level 3 wastewater treatment configurations, but $0.3M/yr to $0.4M/yr lower than the greenfield Level 4 wastewater treatment configurations. The annual costs for just the chemical phosphorus removal and denitrification filter portion of the Level 2-1 to 4 Retrofit is $1.11M/yr.

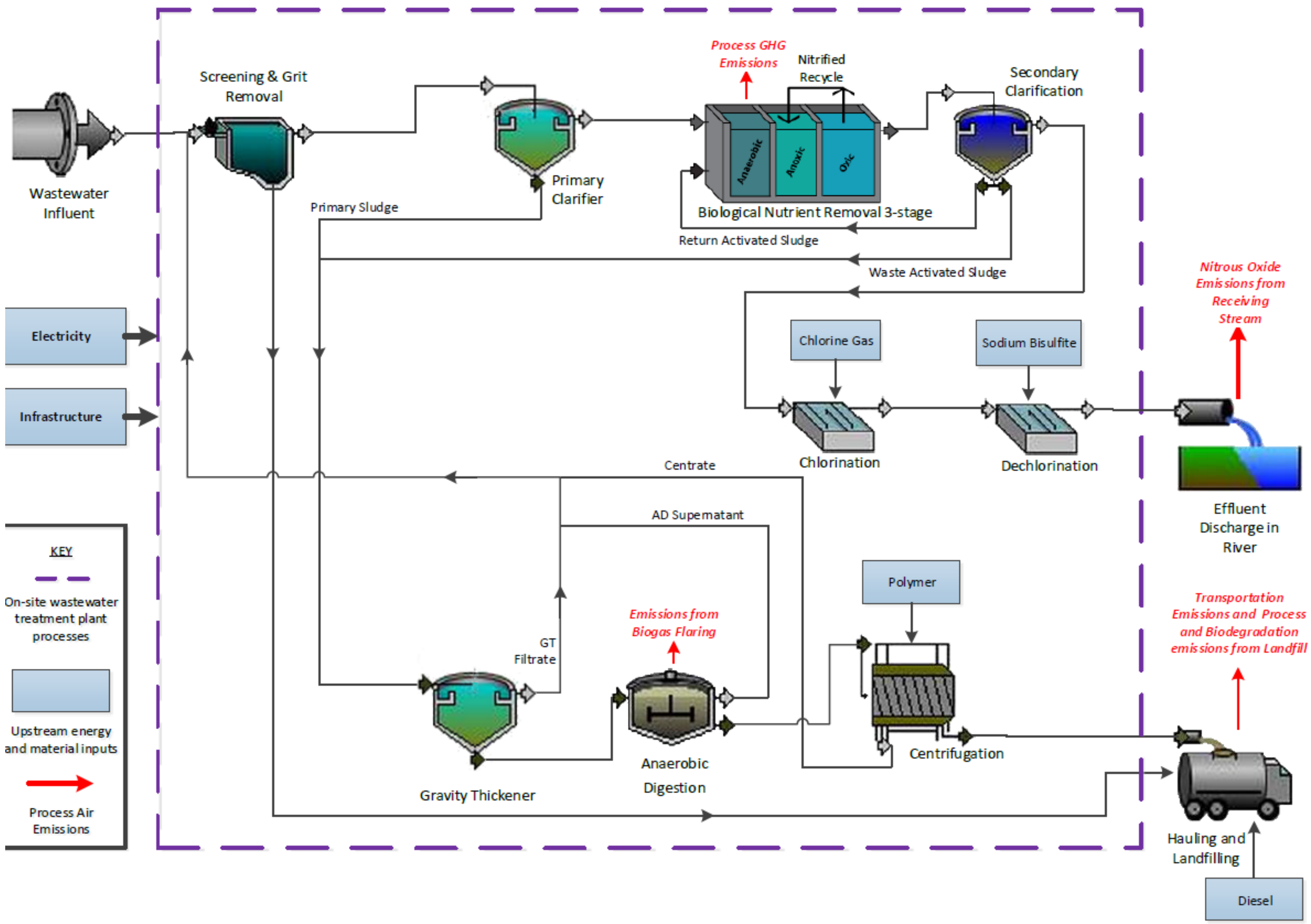


Figure 9-9. Level 2-1: Anaerobic/Anoxic/Oxic Wastewater Treatment Configuration (Baseline for Retrofit)

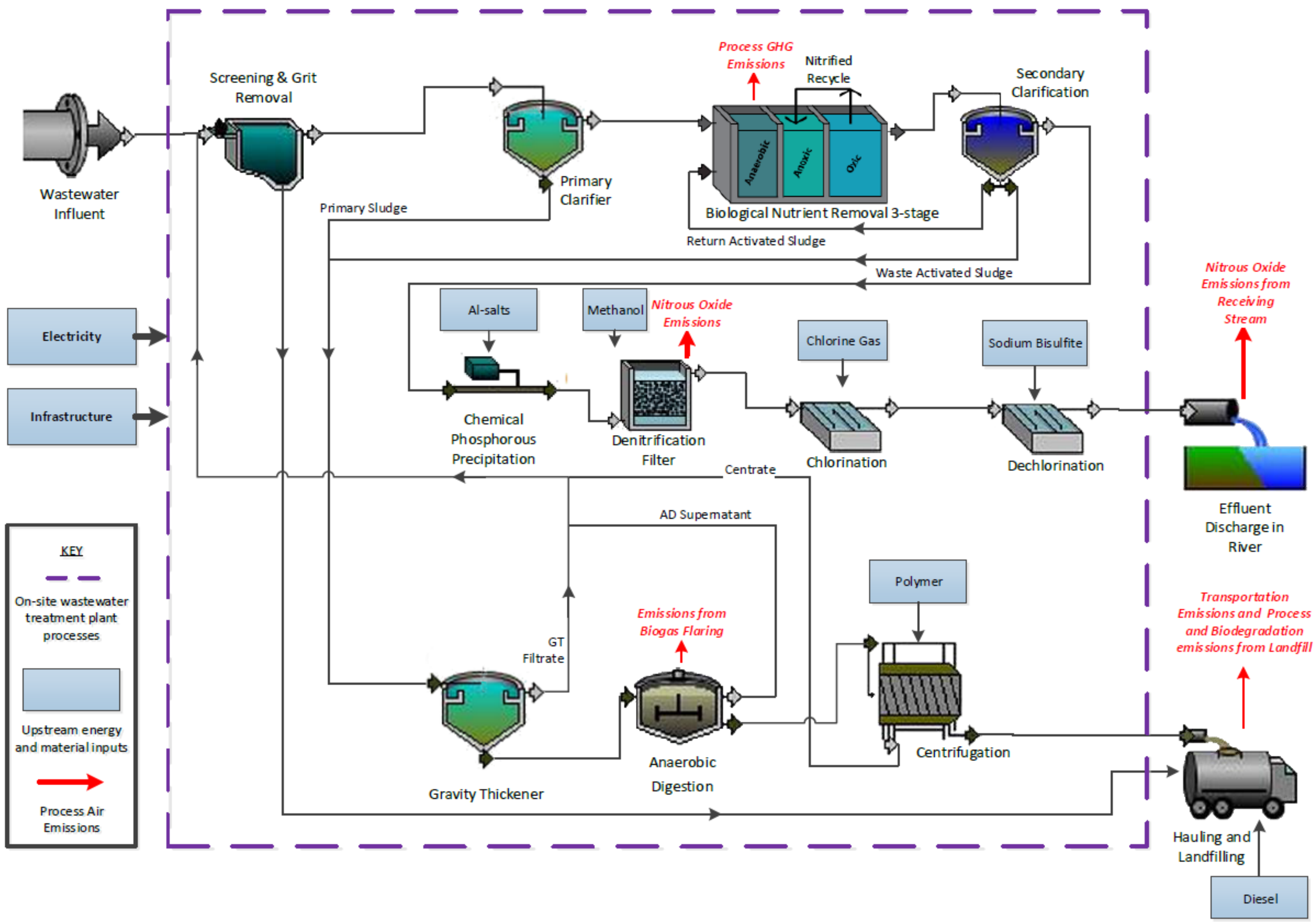


Figure 9-10. Level 2-1 to 4 Retrofit: Anaerobic/Anoxic/Oxic with Chemical Phosphorus Removal and Denitrification Filter Wastewater Treatment Retrofit Configuration

Table 9-8. Greenfield and Level 2-1 to 4 Retrofit Total Costs

Wastewater Treatment Configuration	Total Capital Cost (2014 $)	Total Annual Cost [a] (2014 $/yr)	Net Present Value (2014 $)
Level 1, AS	$55,300,000	$5,140,000	$204,000,000
Level 2-1, A2O	$71,400,000	$5,470,000	$236,000,000
Level 2-2, AS3	$93,100,000	$10,150,000	$378,000,000
Level 3-1, B5	$86,400,000	$5,800,000	$267,000,000
Level 3-2, MUCT	$88,900,000	$5,960,000	$275,000,000
Level 4-1, B5/Denit	$92,800,000	$6,840,000	$301,000,000
Level 4-2, MBR	$90,100,000	$6,330,000	$285,000,000
Level 2-1 to 4, Retrofit [b]	**$78,300,000**	**$6,580,000**	**$273,000,000**
Level 5-1, B5/RO	$160,000,000	$8,320,000	$439,000,000
Level 5-2, MBR/RO	$144,000,000	$8,080,000	$409,000,000

a – Total annual cost includes operational labor, maintenance labor, materials, chemicals, and energy (see Section 3.3 for details).

b – Costs are presented for the greenfield Level 2-1 plus the retrofit chemical phosphorus removal and denitrification filter. The capital cost, annual cost, and net present value for the chemical phosphorus removal and denitrification filter retrofit are $6.9M, $1.11M, and $37M, respectively.

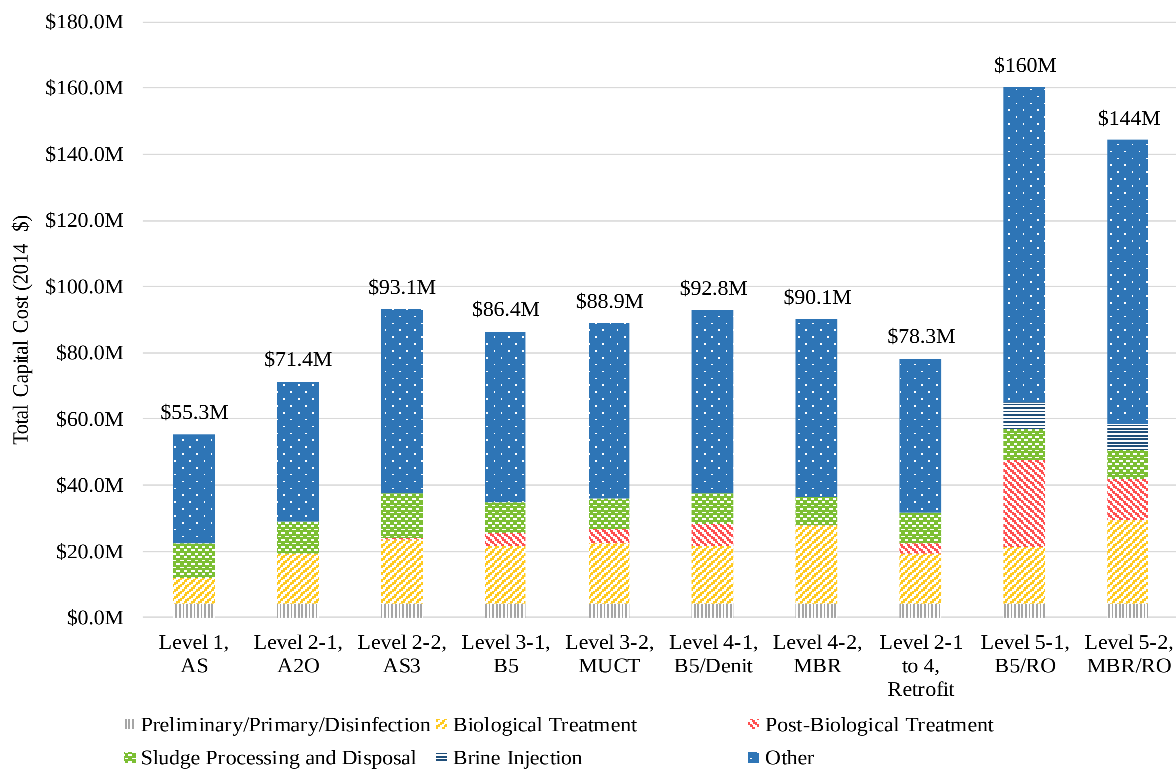


Figure 9-11. Level 2-1 A2O Baseline and Retrofit Total Capital Costs by Aggregated Treatment Group

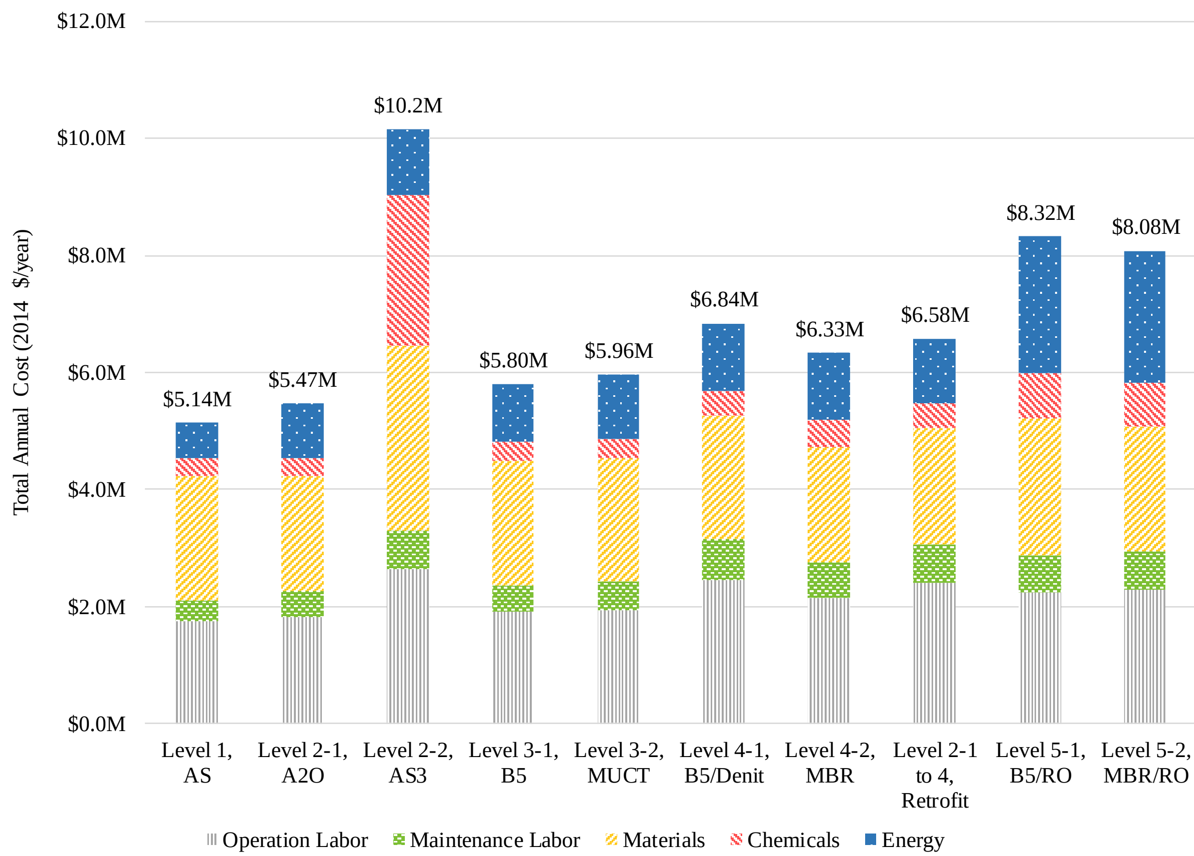


Figure 9-12. Level 2-1 A2O Baseline and Retrofit Total Annual Costs by Annual Cost Category

Figure 9-13 presents relative impact results for all greenfield treatment configurations plus the Level 2 retrofit case study. Retrofit LCIA results are generally in line with those associated with other Level 4 treatment configurations. GWP and ozone depletion potential lower for the retrofit case study, relative to other Level 4 treatment configurations, due to lower estimated N2O emissions. Eutrophication impacts are slightly elevated, compared to Level 4-1 and 4-2. Table 9-9 lists summary LCIA results for all treatment levels plus the Level 2 retrofit case study system. Retrofit results are in bold in Table 9-9.

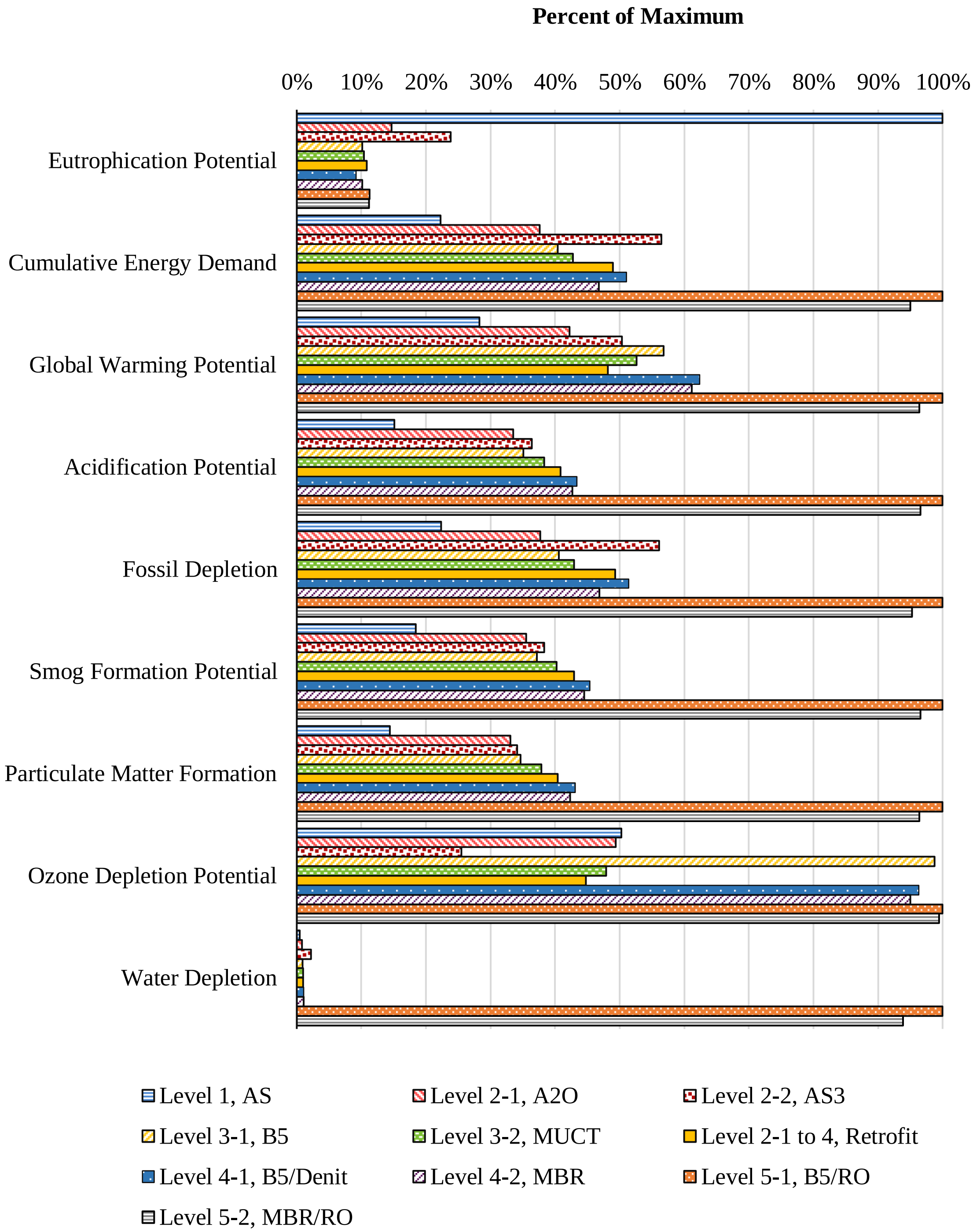


Figure 9-13. Relative LCIA Results for Nine Greenfield Wastewater Treatment Configurations and the Level 2 Retrofit Case Study

Table 9-9. Summary LCIA and Cost Results for Nine Greenfield Wastewater Treatment Configurations and the Level 2 Retrofit Case Study (per m^3 wastewater treated)

Impact Category	Unit	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 2-1 to 4, Retrofit	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Cost	$ USD	$0.64	$0.74	$1.18	$0.84	$0.86	**$0.85**	$0.94	$0.89	$1.37	$1.28
Global Warming Potential	kg CO2 eq	0.52	0.77	0.92	1.0	0.96	**0.88**	1.1	1.1	1.8	1.8
Cumulative Energy Demand	MJ	5.4	9.1	14	9.7	10	**12**	12	11	24	23
Eutrophication Potential	kg N eq	0.07	9.8E-3	0.02	6.8E-3	6.9E-3	**7.3E-3**	6.1E-3	6.8E-3	7.5E-3	7.5E-3
Water Depletion	m3 H2O	8.0E-4	1.5E-3	4.1E-3	1.7E-3	1.8E-3	**1.9E-3**	2.0E-3	2.0E-3	0.19	0.17
Acidification Potential	kg SO2 eq	0.01	0.03	0.03	0.03	0.04	**0.04**	0.04	0.04	0.09	0.09
Particulate Matter Formation	PM2.5 eq	1.5E-3	3.4E-3	3.5E-3	3.6E-3	3.9E-3	**4.2E-3**	4.5E-3	4.4E-3	0.01	0.01
Smog Formation Potential	kg O3 eq	0.14	0.27	0.29	0.28	0.30	**0.32**	0.34	0.33	0.75	0.72
Ozone Depletion Potential	kg CFC-11 eq	3.9E-6	3.8E-6	2.0E-6	7.6E-6	3.7E-6	**3.4E-6**	7.4E-6	7.3E-6	7.7E-6	7.7E-6
Fossil Depletion	kg oil eq	0.12	0.20	0.30	0.22	0.23	**0.26**	0.28	0.25	0.54	0.51

10. CONCLUSIONS

This study met its goal to assess a series of wastewater treatment configurations that reduce the nutrient content of effluent from municipal WWTPs considering treatment costs as well as human health and ecosystem impacts from a life cycle perspective.

The LCA results highlight the trade-offs that exist between the various treatment configurations for cost and traditional LCIA impact categories. The largest normalized impact observed across all combinations of treatment configurations and impact categories was the eutrophication impact for the Level 1 treatment configuration. It is clear that use of a traditional Level 1 treatment configuration results in the lowest costs, but also significantly higher normalized eutrophication impacts compared to all other study treatment system configurations. When considering the impaired state of many of this nation’s water bodies related to nutrients, the use of nutrient removal technologies explored in this study are tools that could be used to improve water quality. This study aims to help communities and businesses consider the environmental and economic costs and benefits of advanced nutrient removal options.

Given the predominant contribution of electricity and energy consumption to impact results in many of the impact categories, it is necessary to think critically about the energy efficiency of treatment processes, particularly in relation to their level of nutrient removal. A series of ratios are presented in Table 10-1 to help in this process. The aggregate level of nutrient removal increases rapidly as nutrient removal standards progress from Level 1 to Level 5. The total electricity demand that coincides with increasing levels of nutrient removal, increases substantially across the treatment configurations, from 0.20 to 1.5 kWh/m^3 wastewater treated. However, when considering the electricity consumption compared to each unit of nutrient removed reveals that the electricity demand does not increase across the majority of the treatment configurations on the basis of nutrient equivalents removed. Electricity per unit of total nitrogen and phosphorus equivalents removed remains consistent from Level 2 through Level 4. However, due to the large electrical demand of the reverse osmosis process, total electricity per nutrient removal is generally two to three times higher for the Level 5 treatment configurations compared to Levels 2 through 4.

Table 10-1. Nutrient Removal Electricity Performance Metrics

Treatment Level	**1**	**2-1**	**2-2**	**3-1**	**3-2**	**4-1**	**4-2**	**5-1**	**5-2**
Total P removed (g/m^3)	0.06	4.7	4.0	4.8	4.8	4.9	4.9	5.0	5.0
Total N removed (g/m^3)	9.7	32	32	34	34	37	37	39	38
Total Electricity Demand (kWh/m^3)	0.20	0.48	0.51	0.52	0.57	0.65	0.64	1.5	1.4
Total Electrical Demand/Total P removed (kWh/g)	N/A[a]	0.10	0.13	0.11	0.12	0.13	0.13	0.30	0.29
Total Electrical Demand/Total N removed (kWh/g)	N/A[a]	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.04

a – Values not shown for Level 1 since this treatment configuration not designed for nutrient removal.

While this work was primarily focused on nutrients, the effect of study treatment configurations on the removal of trace pollutants was also reviewed to determine if additional benefits, not part of the original treatment design, may be realized from the implementation of more advanced treatment processes. This part of the project focused on potential toxicity impacts associated with heavy metals, toxic organics and disinfection byproducts. Results showed that metals were by far the most influential pollutant group in terms of life cycle toxicity impacts. Similar to nutrients, tradeoffs were identified between high effluent-based impacts at low levels of treatment and high process-based impacts at high levels of treatment. Generally, Levels 3 and 4 (and specifically Levels 3-2 and 4-2) resulted in the lowest overall toxicity impacts, owing to their high metal removal efficiencies and moderate material and energy requirements. Relative to Level 4-2 in particular, the higher and more consistent degree of metal removal provided by Level 5 was outweighed by greater process-based impacts, resulting in greater total impacts in all toxicity categories. Results of the analysis reveal that heavy metals contribute more strongly to human health and ecotoxicity impacts than do the toxic organics and DBPs with sufficient data to be evaluated.

The electrical grid sensitivity analysis showed that the importance of electricity and energy use and the trade-offs associated with achieving the key eutrophication reductions could largely be offset if the WWTP were to utilize an electrical grid with reliance on energy sources such as natural gas, hydro, and nuclear or use of recovered resources to generate on-site energy in order to reduce the need for purchased electricity. While an effort to achieve reductions in the environmental burdens associated with electricity production is certainly warranted given the information presented in the results section, Table 10-1 provides an indication of which treatment options may serve communities and businesses attempting to reduce environmental impacts while simultaneously controlling energy costs. The realization of benefits associated with these insights is not dependent on improvements in the electrical grid, which lie outside of the control of many WWTPs. Other strategies within the facilities boundaries, such as energy recovery from biogas, may help to offset environmental impacts from increased nutrient removal.

Generally, the results show the benefits to eutrophication impact associated with more stringent levels of nutrient removal. This benefit is generally increasingly offset by increases in other environmental impacts as the standard of removal progresses from Level 2 to Level 5, with Level 5 showing the most dramatic increase in cost and other impacts due to the exacting standard of treatment required. However, given local and regional environmental and economic considerations, the selection of the most appropriate treatment configuration will vary by location. This work cannot answer the question of how much nutrient removal can be considered sufficient for any specific WWTP or body of water. The question is inherently local or regional in nature, and an individual or institution must consider a number of factors when trying to determine what is appropriate for their situation. This study does indicate that careful consideration should be given to the benefits that are expected to be gained by pursuing the more advanced levels of nutrient removal, and that these benefits should be weighed against the environmental and economic costs discussed in Sections 5, 6 and 7. As discussed earlier, this study focused on the implementation of greenfield treatment configurations, and the economic impacts may vary significantly for retrofitted operations.

Overall, this study built a comprehensive framework to assess the environmental, human health, and cost implications of shifting to higher nutrient removal wastewater treatment configurations. The LCCA and LCA models constructed here can be continually built upon to improve the baseline analysis or investigate additional wastewater treatment configurations or variability with regional conditions. The system boundaries could also be expanded to understand the influence and potential benefit of recycling water from the effluent of the higher nutrient removal wastewater configurations to displace production of potable water elsewhere.

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APPENDIX A
SELECTION OF WASTEWATER TREATMENT CONFIGURATIONS

Appendix A: Selection of Wastewater Treatment Configurations

ERG searched the literature to compile performance information on wastewater treatment configurations which remove both TN and TP from municipal wastewater. ERG recorded the type of biological treatment used and the use or absence of chemical addition for phosphorus precipitation, fermenter, sand filter, and other technology components. ERG assumed preliminary treatment with screens, a grit chamber, and primary clarification. Sludge management was assumed to include gravity thickening, anaerobic digestion, dewatering (centrifugation), and transport of wastewater solids to a landfill. ERG gathered performance data from nine key sources:

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ERG recorded performance data for all wastewater treatment configurations and assigned each a performance level as defined in Falk et al. (2011), Table ES-1:

- Level 1 – No target effluent concentration specified;
- Level 2 – 8 mg N/L, 1 mg P/L;
- Level 3 – 4-8 mg N/L, 0.1-0.3 mg P/L;
- Level 4 – 3 mg N/L, 0.1 mg P/L; and
- Level 5 – 2 mg N/L, <0.02 mg P/L.

In many cases, performance levels for wastewater treatment configurations differ for TN and TP (i.e., a configuration achieves a certain level for TN and a different level for TP).

ERG examined the set of identified wastewater treatment configurations for which TN and TP performance levels match to identify nine which are commonly used and provide contrast. Contrast was defined by differences in terms of performance level, type of biological nutrient reduction, combinations of additional treatment steps, costs (capital and operating), and other contrasting parameters such as energy requirements, chemical usage, and sludge generation. For level 1, ERG recommended one wastewater treatment configuration, and for each of levels 2 to 5 ERG recommended two wastewater treatment configurations. ERG's rationale for these recommendations is described below.

A.1 Results and Recommendations

ERG identified 37 wastewater treatment configurations that achieve the same performance level for both TN and TP (see Table A-1). The technologies used in these wastewater treatment configurations include a variety of biological nutrient removal and enhanced nutrient removal technologies.

The sections below describe the wastewater treatment configurations identified for each performance level and discuss ERG's rationale for selection of specific wastewater treatment configurations to be evaluated in the LCA. Selected configurations generally represent those most commonly used to achieve the desired performance levels, and that also provide contrast in biological processes, capital and/or annual costs, or other factors such as energy requirements and sludge generation. The most common reasons wastewater treatment configurations were not selected include: 1) they are unique retrofits and otherwise not commonly used, 2) they are very similar to another selected technology, or 3) they exhibit a wide range of performance, spanning multiple performance levels, which raises uncertainty as to the reliability with which the process can achieve a specific performance level.

Table A-1. Identified Wastewater Treatment Configurations

Recommended wastewater treatment configuration

All configurations assumed to also include preliminary/primary treatment and sludge management.

No.	Type of Biological Treatment	Phosphorus Precipitation	Fermenter	Sand Filter	Additional Treatment	Long Term Average Effluent TN Concentration (mg/L as N)	TN Level	Long Term Average Effluent TP Concentration (mg/L)	TP Level	Performance Source [1]
1	3-stage Westbank					3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
2	3-stage Westbank	x				3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
3	4-stage Bardenpho	x				3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
4	5-stage Bardenpho (Level 3)	x	x	x		4 to 8	2,3	0.1 to 0.3	3	b, Table 3-1 and 2-b, pages 56, 57, 59.
5	5-stage Bardenpho (Level 4)	x	x	x	Denitrification filter	3	4	0.1	4	b, Table 3-1 and 2-b, pages 56, 57, 60-61; also a, Table 5-d, page 237
6	5-stage Bardenpho	x		x		3	4	0.1	4	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)
7	5-stage Bardenpho (Level 5)	x	Not listed in reference (Falk et al), but may be appropriate	x	Denitrification filter (10% flow) + ultrafiltration and reverse osmosis (90% flow)	<2	5	<0.02	5	b, Table 3-1 and 2-b, pages 56, 57, 61; also a, Table 5-d, page 237
8	Activated sludge + Modified Ludzack-Ettinger				Biological activated filter	4	3	<=0.3	3	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)
9	Activated sludge + Modified Ludzack-Ettinger	x				3	4	0.1	4	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)
10	Activated sludge (Level a, assuming conventional activated sludge treatment)					3 to 9	a,2,3	0.3 to 2	a,2	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)

Table A-1. Identified Wastewater Treatment Configurations

(green) Recommended wastewater treatment configuration

All configurations assumed to also include preliminary/primary treatment and sludge management.

No.	Type of Biological Treatment	Phosphorus Precipitation	Fermenter	Sand Filter	Additional Treatment	Long Term Average Effluent TN Concentration (mg/L as N)	TN Level	Long Term Average Effluent TP Concentration (mg/L)	TP Level	Performance Source [1]
11	Activated sludge, 3-sludge system (Level 2)	x				6 to 8	2	0.43	2	a, pages 2-5 and 3-5/6 (pg 59 and 151/152)
12	Aerobic lagoons					3 to 8	2,3	0.1 to 1	2,3	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)
13	Anaerobic/Anoxic/Oxic (Level 2)					8; 3 to 8	2; 2,3	1; 0.5 to 1	2; 2	b, Table 3-1 and 2-b, pages 56, 57, 58.; a, Table 5-d, page 237
14	Anaerobic/Oxic, Phoredox					3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
15	Cyclic activated sludge	x				3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
16	Integrated fixed-film activated sludge	x				3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
17	Extended aeration					3 to 8	2,3	0.1 to 1 (2)	2,3	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)
18	Facultative lagoon					3 to 8	2,3	0.1 to 1	2,3	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)
19	Membrane bioreactor (Level 4)	x				<3	4	<=0.1	4	a, Table 5-d, page 237
20	Membrane bioreactor (Level 5)	x	Not listed in reference (Falk et al), but may be appropriate		Reverse osmosis (85% flow)	<2; <0.1	5	<0.02; -	5	b, Table 3-1 and 2-b, pages 56, 57, 61; a, Table 5-d, page 237; 8, page 6127; 9, page 1

Table A-1. Identified Wastewater Treatment Configurations

Recommended wastewater treatment configuration

All configurations assumed to also include preliminary/primary treatment and sludge management.

No.	Type of Biological Treatment	Phosphorus Precipitation	Fermenter	Sand Filter	Additional Treatment	Long Term Average Effluent TN Concentration (mg/L as N)	TN Level	Long Term Average Effluent TP Concentration (mg/L)	TP Level	Performance Source [1]
21	Membrane bioreactor		x		Land application/ infiltration bed	<3	4	<=0.1	4	a, Table 5-d, page 237, also land application note on pages 13d, 27, and 39
22	Modified Ludzack-Ettinger	x				3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
23	Modified Ludzack-Ettinger	x	x	x	Denitrification filter	<3	4	<=0.1	4	a, Table 5-d, page 237, page 63
24	Moving-bed biofilm reactor (Level 2)	x				3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
25	Phased isolation ditch					3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
26	PhoStrip II					3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
27	Post-aeration anoxic with methanol (Blue Plains process, a retrofit system)	x				3 to 8; 4 to 8	2,3	0.5 to 1; 0.18	2; 3	a, Table 5-d, page 237; 7, page 3-43 (pg 83)
28	Rotating biological contactor (assume Level 3 performance)					3 to 8	2,3	0.1 to 1	2,3	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)
29	Sequencing batch reactor					3 to 8	2,3	0.1 to 1	2,3	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)
30	Sequencing batch reactor			x		3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
31	Sequencing batch reactor	x				3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
32	Step-feed activated sludge					3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237

Table A-1. Identified Wastewater Treatment Configurations

[green box] Recommended wastewater treatment configuration

All configurations assumed to also include preliminary/primary treatment and sludge management.

No.	Type of Biological Treatment	Phosphorus Precipitation	Fermenter	Sand Filter	Additional Treatment	Long Term Average Effluent TN Concentration (mg/L as N)	TN Level	Long Term Average Effluent TP Concentration (mg/L)	TP Level	Performance Source [1]
33	Step-feed activated sludge (Level 4)	x	x	x	Chemically assisted clarification	<3	4	<=0.1	4	a, Table 5-d, page 237
34	Trickling filter				Submerged biological filter	3	4	0.1	4	c, Figure IV-9, page IV-11 (pg 58), Figure IV-16, page IV-17 (pg 64), page E-1 (pg 97)
35	Suspended growth activated sludge	x	x		Inclined plate settling tanks, deep bed sand filter	3 to 6	3	0.18	3	d, page 3-39 (pg 79-80)
36	University of Cape Town process, modified					3 to 8	2,3	0.5 to 1	2	a, Table 5-d, page 237
37	University of Cape Town process, modified (Level 3)	x	x	x		<3	3	0.1 to 0.5	3	a, Table 5-d, pages 5-5 (pg 237), ES-22 (pg 40), UCTm equivalent to technologies in Table 5-2 on page 5-4 (pg 236)

1 – Sources: a – U.S. EPA OWM, 2008b; b – Falk et al., 2011; c – U.S. EPA OST, 2015a; d – Bott and Parker, 2011.

2 – This phosphorus removal capability is unexpected, but is included as reported in the cited wastewater treatment configuration source document.

A.1.1 Level 1

Level 1 technologies are not designed to specifically remove nutrients, although some removal of nutrients occurs with the wastewater treatment configuration. ERG recommended the conventional plug flow activated sludge system to represent level 1 performance.

A.1.2 Level 2

Twenty-two wastewater treatment configurations performed at level 2 for both TN and TP. These wastewater treatment configurations included the biological and enhanced nutrient reduction technologies listed in Table A-1. ERG selected the anaerobic/anoxic/oxic (A2O) system as a typical level 2 wastewater treatment configuration and then reviewed the remaining level 2 wastewater treatment configurations for contrast, performance, and likelihood of use.

ERG considered and rejected the moving-bed biofilm reactor because it is most frequently used as a retrofit but otherwise is not commonly used. The integrated fixed-film activated sludge and anaerobic/oxic Phoredox systems were rejected as too similar to the selected A2O system. The Modified University of Cape Town process and 4-stage Bardenpho were rejected at level 2 to allow for their selection as contrasting wastewater treatment configurations for other performance levels.

The sequencing batch reactor, 3-stage Westbank, cyclic activated sludge, step-feed activated sludge, phased isolation ditch, modified Ludzack-Ettinger (MLE), and PhoStrip II were rejected due to concerns that their performance ranges were too wide, raising uncertainty regarding their ability to reliably achieve level 2 performance. The extended aeration system was rejected because of concerns about the performance data presented in the reference. The Blue Plains Process was rejected because it is a unique retrofit system. The aerobic and facultative lagoons were rejected because lagoons are not applicable for all publicly owned treatment works (POTWs). A rotating biological contactor (RBC) system was initially considered because it offers the advantages of low energy usage, low solids generation, and good settling. However, the RBC technology was ultimately rejected because its use is predominately restricted to small plants; the technology also exhibited a number of problems in the 1970s and 1980s, some of which remain unresolved today.

After eliminating the other level 2 options for the reasons discussed above, ERG recommended a common alternative level 2 configuration of plug flow activated sludge followed by separate stage nitrification and separate stage denitrification with chemical phosphorus removal. This technology contrasts with the recommended A2O system in its relative ease of operation and control (due to segregated treatment components for BOD, ammonia, and nitrate removal) and relatively higher cost due to multiple biological reactors and associated clarifiers/sludge recycling.

In summary, ERG recommended the following two technologies to represent level 2 performance in the LCA:

- 2-1) A2O with chemical phosphorus precipitation; and
- 2-2) 3-Sludge activated sludge system with chemical phosphorus precipitation.

A.1.3 Level 3

Ten wastewater treatment configurations performed within the level 3 range. Of these, six were rejected from further consideration because their TN/TP performance spans levels two and three (included in the level 2 description above). The remaining four wastewater treatment configurations perform at level 3 for both TN and TP. The first system, which uses activated sludge, MLE, and a biological activated filter, was not recommended because it is a unique retrofit system. The second system, which uses suspended growth in high purity oxygen activated sludge, inclined plate setting tanks, and a deep bed sand filter, was rejected because suspended growth systems are not applicable for all POTWs. The remaining two systems are commonly used systems that ERG recommended to represent level 3 performance in the LCA:

- 3-1) 5-Stage Bardenpho with chemical phosphorus precipitation, fermenter, and sand filter; and
- 3-2) Modified University of Cape Town process with chemical phosphorus precipitation, fermenter, and sand filter.

A.1.4 Level 4

Eight wastewater treatment configurations perform at level 4 for both TN and TP. These processes included a 5-stage Bardenpho activated sludge coupled with a MLE unit, 4- and 5-stage Bardenpho systems coupled with membrane filtration, denitrification filters coupled with a MLE unit or with a 5-stage Bardenpho, a trickling filter coupled with a submerged biological filter, and a step-feed activated sludge process with chemically assisted clarification. Most of these wastewater treatment configurations also include chemical phosphorus precipitation, and half also include either a fermenter or a sand filter.

ERG selected the 5-stage Bardenpho with denitrification filter as a typical level 4 wastewater treatment configuration. For the contrasting level 4 wastewater treatment configuration, ERG considered and rejected the membrane bioreactor with land infiltration and the trickling filter because neither is applicable for all POTWs. The activated sludge coupled with a MLE unit was rejected as a unique retrofit system. The 5-stage Bardenpho without denitrification filter was rejected as too similar to the typical level 4 configuration. Of the remaining three options (step-feed activated sludge, MLE with denitrification filter, and 4-stage Bardenpho with membrane filter), ERG selected the membrane bioreactor (MBR) system as a contrasting alternative because of its increasing popularity.

In summary, ERG recommended the following technologies to represent level 4 performance in the LCA:

- 4-1) 5-Stage Bardenpho with chemical phosphorus precipitation, fermenter, sand filter, and denitrification filter; and
- 4-2) 4-Stage Bardenpho MBR and chemical phosphorus precipitation.

A.1.5 Level 5

Two wastewater treatment configurations performed at level 5 for both TN and TP. The first configuration includes 5-stage Bardenpho, chemical precipitation, and fermentation. The wastestream is then split with a portion of the flow undergoing side stream treatment by reverse osmosis (RO) and the remainder of the flow undergoing side stream treatment by a denitrification filter and sand filter. The second wastewater treatment configuration is a 5-stage Bardenpho MBR with chemical phosphorus precipitation and fermenter followed by a portion of the flow to RO and the remainder of the flow not requiring additional side stream treatment. This second process is a modification of the first, substituting a 5-stage Bardenpho MBR for the 5-stage Bardenpho and clarifier. The MBR allows the wastewater treatment configuration to achieve similar TN and TP performance without a denitrification filter and sand filter.

ERG conducted additional literature reviews and communications with RO vendors to determine RO pretreatment requirements. For the first configuration, RO pretreatment includes solids removal (ultrafiltration, UF), biofouling control (chlorination followed by dechlorination), and scale control (antiscalant addition). RO pretreatment for the second configuration is similar to the first, except that use of the 5-stage Bardenpho MBR precludes the need for solids removal via UF.

ERG performed calculations to determine the percentage of flow requiring side stream treatment for each configuration to achieve the target TN and TP effluent concentrations. For TN, ERG assumed the following effluent quality achieved by nutrient control technologies:

- A 5-stage Bardenpho TN effluent concentration of 4 - 8 mg/L (based on the performance of the level 3 5-stage Bardenpho configuration).
- A denitrification and sand filter TN effluent concentration of 3 mg/L (based on the performance of the level 4 5-stage Bardenpho configuration).
- A 5-stage Bardenpho MBR TN effluent concentration of 3 mg/L (based on the performance of the level 4 5-stage Bardenpho MBR configuration).
- A RO removal of 95 percent (based on information from RO vendors).

Using these assumptions, and a target overall TN effluent concentration of 2 mg/L, approximately 35 to 40 percent of flow would need to undergo side stream treatment by RO.

For TP, ERG assumed the following effluent quality achieved by nutrient control technologies:

- A 5-stage Bardenpho TP effluent concentration of 0.1 to 0.3 mg/L (based on the performance of the level 3 5-stage Bardenpho configuration).
- A denitrification and sand filter TP effluent concentration of 0.1 mg/L (based on the performance of the level 4 5-stage Bardenpho configuration).
- A 5-stage Bardenpho MBR TP effluent concentration of 0.1 mg/L (based on the performance of the level 4 5-stage Bardenpho MBR configuration).
- A RO removal of 95 percent (based on information from RO vendors).

Using these assumptions, and a target overall TP effluent concentration of 0.02 mg/L, approximately 85 to 90 percent of flow (for the second and first configurations, respectively) would need to undergo side stream treatment by RO.[9]

These calculations demonstrate that TP removal, rather than TN removal, drives the percentage of wastewater requiring RO treatment to achieve level 5 performance.

In summary, ERG recommended the following technologies to represent level 5 performance in the LCA:

- 5-1) 5-stage Bardenpho with chemical phosphorus precipitation, fermenter, and sand filter followed by 10 percent of the flow to a denitrification filter and sand and 90 percent of the flow to UF and RO; and
- 5-2) 5-stage Bardenpho MBR with chemical phosphorus precipitation and fermenter followed by 85 percent of the flow to RO.

A summary of these recommendations is found in Table A-2 below.

Table A-2. Recommended Technologies

Performance Level	Type of Biological Treatment	Phosphorus Precipitation	Fermenter	Sand Filter	Other Technical Components	Reference
1	Plug Flow Activated Sludge					OST, 2015
2	Anaerobic/Anoxic/Oxic					Falk, 2011
2	Activated Sludge, 3-Sludge System	X				OWM, 2008
3	5-Stage Bardenpho	X	X	X		Falk, 2011
3	University of Cape Town Process, Modified	X	X	X		OWM, 2008
4	5-stage Bardenpho	X	X	X	Denitrification Filter	Falk, 2011
4	4-stage Bardenpho MBR	X				OWM, 2008
5	5-Stage Bardenpho	X	X	X	10%: Denitrification Filter 90%: UF and RO	Falk, 2011 and OWM, 2008
5	5-stage Bardenpho MBR	X	X		85% RO	Falk, 2011 and OWM, 2008

[9] Note that RO effluent quality expressed as a percentage of TP removal may not be the most appropriate measure of RO performance, but rather an effluent concentration of non-detect (detection limit 0.02 mg/L). Under this scenario, assuming an average effluent concentration equal to the detection limit, ½ the detection limit, and zero, approximately 80 to 100 percent of flow would need to undergo side stream treatment by reverse osmosis.

A.2 Technology Selection Data Quality

In accordance with the project's Quality Assurance Project Plan (QAPP) entitled *Quality Assurance Project Plan for Life Cycle and Cost Assessments of Nutrient Removal Technologies in Wastewater Treatment Plants* (ERG, 2015c) approved by EPA on March 25, 2015, ERG collected existing data[10] via a literature search to determine the performance of identified wastewater treatment configurations. The literature search focused on peer-reviewed literature, EPA projects, and publicly available equipment specifications from and communications with technology vendors. ERG evaluated the collected information for completeness, accuracy, and reasonableness. In addition, ERG considered publication date, accuracy/reliability, and nutrient concentrations (reported as TN and TP) when reviewing data quality. Finally, ERG performed conceptual, developmental, and final product internal technical reviews of the data compilation and this Appendix.

Completeness. The descriptions of wastewater treatment configurations in the literature vary in level of detail. Descriptions used in this analysis were limited to those sufficiently detailed to be classified into one of the performance level categories and to identify the major technology components (e.g., type of biological treatment, chemical treatments, sand filter). ERG reviewed the treatment system descriptions, and did not include data for incomplete treatment systems.

Accuracy. ERG evaluated sources to ensure that the descriptions of each treatment system represent current operations at municipal treatment systems, and that nutrient reductions reflect the performance of the identified control technologies rather than other design or operational factors.

Reasonableness. ERG evaluated sources to ensure that the type of treatment correlates with expected nutrient reduction performance; for example, treatment systems with nutrient control should have lower nutrient concentrations than systems with secondary treatment only.

The criteria ERG used in evaluating the quality of information collected during the literature review are summarized in Table A-3.

Table A-3. Literature Review Data Quality Criteria

Quality Criterion	Description/Definition
Current (up to date)	Report the time period of the data. Year of publication (or presentation, if a paper presented at a conference) is 2005 or after.
Accurate/Reliable	U.S. government publications assumed accurate. For academic researcher: • Publication in peer reviewed journal. • Presentation at professional technical conference. For vendor researcher: • Publication in peer reviewed journal.

[10] *Existing data* means information and measurements that were originally produced for one purpose that are recompiled or reassessed for a different purpose. Existing data are also called secondary data. Sources of existing data may include published reports, journal articles, LCI and government databases, and industry publications.

Table A-3. Literature Review Data Quality Criteria

Quality Criterion	Description/Definition
Analyte Scope	Nutrient concentrations, reported as TN and TP.

In accordance with the QAPP, ERG performed conceptual, developmental, and final product technical reviews of the spreadsheet included as Table A-1. These reviews included the following general steps:

- The spreadsheet developer verified the accuracy of any data that were transcribed into the spreadsheet;
- The team member reviewer also verified the accuracy of any data that were transcribed into the spreadsheet;
- The team member reviewer evaluated the technical soundness of methods and approaches used;
- The ERG spreadsheet developer maintained version control of interim spreadsheets; and
- The ERG spreadsheet developer maintained documentation in the project files.

APPENDIX B
DETAILED CHARACTERIZATION OF HEAVY METALS BEHAVIOR IN STUDY TREATMENT CONFIGURATIONS

Appendix B: Detailed Characterization of Heavy Metals Behavior in Study Treatment Configurations

B.1 Introduction

The discharge of metals to the environment represents an ever-present concern, given their potential toxicity at even trace levels. Wastewater treatment plants (WWTP) receive variable but sometimes high loads of metals depending on the mix of sources in their watershed, which can include industrial activities, domestic sources and stormwater (Yost et al. 1981; Rule et al. 2006; J.-M. Choubert et al. 2011b). Given a WWTP's position as a final barrier between source and environmental discharge, they are an opportunity for smart management of potentially toxic substances like metals.

The direct management of metals in conventional, municipal WWTPs has traditionally not been a focus of WWTP design and operation as measures like the National Pretreatment Program[11] are in place to limit the concentration and load of metals coming from industrial facilities. Rather, most discussion surrounding the treatment of metals by municipal WWTPs has dealt with the ancillary benefits afforded by existing processes that impact metals as well as the organics and nutrients these processes were designed to address (Choubert et al. 2011a; Choubert et al. 2011b; Ziolko et al. 2011; Cantinho et al. 2016). Additionally, little to no attention has been paid to the life cycle impacts of metal emissions associated with upstream processes, especially in conjunction with and relative to direct effluent emissions. To date, the most comprehensive study performed to address the 'co-benefits' of various treatment processes from a life cycle perspective only qualitatively discussed the effects of metals from both upstream and direct discharge impact calculations (Rahman et al. 2018). This study is therefore intended to address these gaps, which will help to both characterize the ability of a variety of commonly used wastewater treatment practices to partition metals from the liquid phase, as well as to help inform the full potential benefits of these treatment trains from a comprehensive life cycle perspective.

The metals reviewed for this study were selected based on two main criteria: the metal's recurrent presence in lists of regulated substances and its prevalence in the literature regarding treatability in the study treatment configurations. Indirectly, these two criteria were assumed to be indicators of demonstrated potential of the metal to cause environmental or human health impacts. The resulting list of metals includes Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), and Zinc (Zn). Each of these metals have been regulated in different countries. Four of them (Cd, Hg, Ni and Pb) were classified by the European Water Framework Directive (EUWFD) as priority substances and two (Hg and Cd) were additionally classified as hazardous substances (EU 2013; Cantinho et al. 2016). In the United States (US), guidance is provided for concentration limits of each of these metals in WWTP effluent through National Recommended Water Quality Criteria (EPA 2009). Table B-1 summarizes relevant regulatory criteria for the metals included in this study. Metal concentrations in land-applied sludge are also regulated in the US through the Part 503 Rule (NRC 2002).

[11] https://www.epa.gov/npdes/national-pretreatment-program

Elevated levels of metals in the environment can result from both natural and anthropogenic sources. In the urban environment, metals are present in mixed municipal wastewater owing to the contribution of commercial and industrial sources, residential sources, contact with piping, and stormwater runoff (Yost et al. 1981; Thornton et al. 2001; Jones et al. 2017). Often, domestic inputs tend to be the largest sources of Cu, Zn and Pb, whereas commercial and industrial sources contribute greater proportions of Hg and Cr (Makepeace et al. 1995; Cantinho et al. 2016). Table B-1 summarizes ranges of influent concentrations established in several literature reviews, along with the ranges that were compiled from the case study data reviewed as part of this effort. These concentrations, as well as concentrations throughout this document, represent total concentrations (as opposed to specific fractions) unless otherwise noted.

Table B-1. Summary of Literature and Case Study Metal Influent Concentrations and Regulatory Effluent Concentrations

Value		Concentrations in µg/L							Notes	Source
		Pb	**Cu**	**Zn**	**Ni**	**Cr**	**Cd**	**Hg**		
Influent Concentrations - Literature Reviews		5.7	63	181	11	10	0.21	0.36	19 Plants, France	1
		25	78	155	14	12.0	0.8	0.5	30 Plants, UK	2
		140-600	--	--	--	--	--	--	Combined WW	3
		232	489	968	455	378	19	--	12+ Cities, US	4
Case Study Ranges	High	68	118	493	77	290	10	7.0	This Study	5
	Medium	21	65	350	24	59	4.9	3.8	This Study	5
	Low	10.8	25	204	11	19	0.94	0.37	This Study	5
US CCC[a]		2.5	9	120	52	74/11[b]	0.25	0.77	Effluent Limits	6
US CMC[a]		65	13	120	470	570/16[b]	2	1.4	Effluent Limits	6

a - Criterion Continuous Concentration/Criteria Maximum Concentration, hardness dependent except for Cr (VI) and Hg. Values shown assume a hardness of 100 mg/L.

b - Chromium (III/VI)

1 - Choubert et al., 2011b; Ruel et al., 2012

2 - Rule et al., 2006

3 - Metcalf and Eddy, 2014

4 – Yost et al., 1981

5 - Linstedt et al., 1971; Brown et al., 1973; Chen et al., 1974; Oliver and Cosgrove, 1974; Aulenbach and Chan, 1988; Huang et al., 2000; Innocenti et al., 2002; Chipasa, 2003; Karvelas et al., 2003; Qdais and Moussa, 2004; Buzier et al., 2006; da Dilva Oliveira et al., 2007; Mohsen et al., 2007; Obarska-Pempkowiak and Gajewska, 2007; Carletti et al, 2008; Johnson et al., 2008; Dialynas and Diamadopoulos, 2009; Renman et al., 2009; Malamis et al., 2012; Arevalo et al., 2013; Garcia et al., 2013; Salihoglu, 2013; Inna et al., 2014; Reddy et al., 2014

6 - U.S. EPA, 2019b

B.2 Metal Chemistry

With the exception of Cr, the metals selected in this study are commonly found in the 2+ oxidation state (Huang et al. 2000). Chromium mainly occurs in the Cr(III) and Cr(VI) oxidation states. While the Cr(VI) form is more labile and toxic to a number of organisms, it is generally associated with industrial effluent and is therefore less prevalent in both raw municipal wastewater and WWTP effluent (Jan and Young 1978; Stasinakis et al. 2003; Stasinakis and Thomaidis 2010). Moreover, Cr(VI) can be reduced to Cr(III) in the presence of suitable electron donors (e.g., organic substrates), whereas experimental results have shown that Cr(III) is not oxidized to Cr(VI) under the aerobic conditions found in AS plants (Stasinakis et al. 2003). A possible explanation is that oxidation of Cr(III) may be so slow that biosorption occurs before any oxidation can occur (Schroeder and Lee 1975).

With respect to treatability, the fraction in which the metal exists (solid or dissolved) is more important than its oxidation state which, under average municipal wastewater conditions, tends not to vary. Throughout the wastewater treatment process, metals generally exist in precipitated (strong complex), organically complexed (weak complex) or soluble forms (Nelson et al. 1981; Huang et al. 2000; Buzier et al. 2006). The type and fraction of precipitates present, which are considered insoluble and often the strongest of the complexes, depend on pH, solubility of the metal species, and the availability of complexing reagents including hydroxides, carbonates, and phosphates (Stoveland and Lester 1980; Huang et al. 2000; Wang et al. 2006). However, the solubility coefficients and products of metals reported in the literature vary markedly (Cheng et al. 1975) and direct application to study systems may not be appropriate as site-specific calculated solubilities can be up to two orders of magnitude different than experimental determinations (Nelson et al. 1981; Parker et al. 1994).

The unprecipitated fraction of metals tend to form weak organic complexes, which can be both settleable or dissolved (distinguished by the fraction passing through a 0.45 μm filter). The process of metal ion sorption to organic material is typically referred to as biosorption, and its effectiveness varies with the type of metal, ambient water quality, and the source of the organic material (Cheng et al. 1975; Huang et al. 2000; Arican et al. 2002; Chang et al. 2007). With the exception of Ni and Cd, which show an intermediate and variable affinity to solids partitioning (Cheng et al. 1975; Wang et al. 2006), the study metals tend to readily adsorb to particulate matter in raw, mixed municipal wastewater (mean dissolved fractions below 30%) (Goldstone et al. 1990a; Goldstone et al. 1990b; Goldstone et al. 1990c; Buzier et al. 2006; Choubert et al. 2011b). Accordingly, processes that remove solids or metal-organic complexes are often effective at removing metals as well.

Extracellular polymers (ECPs) have been found to play a key role in biosorption (Brown and Lester 1979; Hunter et al. 1983; Lawson et al. 1984; Norberg and Persson 1984; Rudd et al. 1984) as they contain negatively charged functional groups such as phosphoryl, carboxyl, sulphydryl, and hydroxyl groups which can serve as adsorption sites (Kelly et al. 1979; Nelson et al. 1981). Additionally, the metal affinity of ECPs has been shown to depend on the microorganism (MO) or MO consortium that produced them. In general, slower growing MOs produce more ECPs (Nelson et al. 1981; Hunter et al. 1983; Ghosh and Bupp 1992). Operationally, solids retention time (SRT) is typically used (along with ambient redox and nutrient conditions) to hold the bacterial growth rate constant, which in turn maintains consistent sorption characteristics of the biosolids. Conversely, increasing the SRT tends to select for slower-growing MOs, which in turn can increase the metal sorption capacity of the biosolids (Stensel and Shell 1974; Chao and Keinath 1979; Nelson et al. 1981). For example, the floc produced by slow-growing phosphate accumulating organisms (PAOs) and denitrifying organisms (DNOs) that are selected for in biological nutrient removal (BNR) processes with high SRTs have been found to have greater affinity towards Cd and Ni than conventional activated sludge floc (Chang et al. 2007). Notably, biosorption is a passive process taking place on the order of minutes to hours and does not depend on the viability of biological floc (Cheng et al. 1975; Neufeld and Hermann 1975; Nelson et al. 1981); the influence of active metabolic processes can therefore be considered unimportant (Huang et al. 2000). Moreover, for this study, hydraulic retention time (HRT) is maintained on the order of hours rather than minutes and will likely have little effect on the removal of metals by the different treatment levels.

Dissolved organic matter (DOM), for which COD can be considered a surrogate, also has a significant effect on metal sorption by biosolids (Sterritt and Lester 1983; Rudd et al. 1984; Tien and Huang 1991). High DOM can prevent both metal precipitation and metal uptake by sludge particulates by lowering ambient pH and competing for sorption sites, respectively (Cheng et al. 1975; Lo et al. 1989). In a detailed study of the factors influencing metals removal in four full-scale conventional activated sludge (AS) wastewater treatment (WWT) systems, Huang et al. (2000) found COD and SS concentrations to be the most important as indicators of effective biosorption of the dissolved fraction to biosolids, and biosolids removal, respectively.

B.3 Fate of Metals During Wastewater Treatment

The fate of metals during wastewater treatment depends on a number of chemical, physical, and operational parameters of the treatment process. Many processes commonly found in municipal wastewater treatment plants result in the effective removal of certain metals from the liquid fraction, thus limiting emissions to receiving waters. Depending on the type of unit processes present, the metals removed from the liquid fraction are partitioned to either the solids (sludge) fraction or in the case of this study where reverse osmosis is used, the brine solution. Although volatilization was proposed as a loss pathway for Hg in the early wastewater treatment literature (Yamada et al. 1969), results from full-scale systems indicate that this is likely an artifact of startup conditions. In continuously operating full scale WWTPs, adsorption to biomass is the dominant partitioning mechanism and volatilization is negligible (Goldstone et al. 1990c; Pomiès et al. 2013).

In general, metal concentrations tend to decrease during primary treatment. Metals present as precipitated species or adsorbed to settleable solids (i.e. the non-dissolved fraction) are the main fractions that are removed. As such, many authors have found a correlation between primary treatment solids removal and metal removal, with reported metal removals ranging from 40-70% when solids removal is high (Rossin et al. 1982; Lester 1983; Kempton et al. 1987). However, where primary solids removal is lower or concentrated supernatant is recirculated to the headworks (in effect increasing internal, dissolved metal loadings), reported total metal removals can be on the order of 1-10% (Oliver and Cosgrove 1974) and can even be negative depending on the strength of recirculated supernatant (Huang et al. 2000; Inna et al. 2014). Due to the variability of this documented performance, the similarity of primary treatment unit processes and the incorporation of internal circulation within most study configurations, it was conservatively assumed that no metals removal was directly attributed to primary treatment. Primary treatment performance was instead aggregated with secondary biological processes, both because proper functioning of secondary processes implicitly assumes proper primary treatment or pretreatment, and because most performance data obtained for secondary processes implicitly accounted for the presence of standard primary treatment.

In secondary biological unit processes, SRT, COD, and TSS tend to be important indicators of metals partitioning (Lo et al. 1989; Huang et al. 2000). Systems that provide better COD removal tend to allow for greater sorption potential between metals and biological flocs, which can then be removed through efficient suspended solids removal. The sorption process varies by metal type as well, depending on the affinity of metal species to sludge and the stability of the sludge metal complexes. Results from batch equilibrium adsorption experiments using solids from conventional activated sludge (CAS) systems indicate that the stability constants of the sludge-metal complexes follow the order of Hg(II)≈Pb(II)≈Cu(II)≈Cr(II)>Zn(II)> Cd(II)>Ni(II) (Wang 1997). This is supported by results from full scale case studies as well, with removals of Hg, Pb, Cu, Cr, Cd, and Zn often in the range of 40-60% and the removal of Ni often less than 40% for sorption-based processes like CAS (Lester 1983; Cantinho et al. 2016). For more advanced biological treatment processes like Bardenpho or Modified University Cape Town (MUCT) systems, much less work has been done to characterize the biosorption and metals partitioning dynamics, however the limited case studies available suggest that due to the greater SRT, COD removal and diversity of microbial consortiums (and by extension variety of metal-binding ECPs), overall metal removal performances are marginally better than CAS, ranging from approximately 60-80% for all metals except Cd and Ni, which are around 30-40% (Chipasa 2003; Obarska-Pempkowiak and Gajewska 2007; Salihoglu 2013; Emara et al. 2014). Aside from potential detection limit influences on full removal potentials, no mechanistic explanations of the lower Cd and Ni removal efficiencies were given (Chipasa 2003; Salihoglu 2013)

Following biological treatment, advanced filtration in the form of sand filters, MBR, and RO can be effective in physically removing the remaining soluble or colloidal fractions, as well as what remains of the insoluble fraction. Of the three, sand filters tend to be the least effective, owing to the larger pore spaces through which water can travel. Still, as a tertiary treatment process, removals of remaining organics can be on the order of 10-50%, and metals 0-35% (Linstedt et al. 1971; Aulenbach and Chan 1988; Renman et al. 2009). Next, MBRs have proven very effective as a tertiary polishing step, with removals of most metals on the order of 50% to greater than 95% (Innocenti et al. 2002; Carletti et al. 2008; Dialynas and Diamadopoulos 2009; Malamis et al. 2012; Arévalo et al. 2013). Last, with the smallest effective pore size, RO is the most effective unit process for metals removal with the case study literature indicating consistent removal efficiencies of 90% or greater (Dialynas and Diamadopoulos 2009; Malamis et al. 2012; Arévalo et al. 2013; Garcia et al. 2013).

For this study there are also several unit processes that through either limited, contradictory or inconclusive evidence, were not assigned any removal credit. Chemical phosphorus precipitation is a unit process that can be effective at removing metals, however it is dependent upon the chemicals used for precipitation and the conditions of the plant. In a study of three WWTPs using only alum or sodium aluminate for enhanced phosphorus removal, Aulenbach et al. (1984) found statistically insignificant effects for Pb and Cr removal and only a minor benefit to Cu removal (less than a 10% difference), noting that Cd, Hg, and Zn were removed to undetectable levels prior to alum dosing. Accordingly, chemical phosphorus precipitation using alum salts alone (U9, Table B-2) was not considered to provide an additional metals removal benefit.

The metals removal performance of tertiary biological nutrient removal processes, including nitrification reactors, denitrification reactors and tertiary clarification, has also not been extensively researched. Conceptually, the additional contact time between remaining soluble metal species and a new, distinct biological consortium (compared to upstream secondary unit processes) could reasonably be thought to provide for additional metals removal. However, in a study using copper as an indicator of the comparative metal removing performance of tertiary vs. secondary WWTPs, Inna et al. (2014) found that while tertiary processes like biological aerated flooded filters and nitrifying trickling filters provided some degree of additional copper removal, the tertiary return flows tended to have adverse and somewhat unpredictable effects on the performance of upstream unit processes. While they found total removal efficiencies of 57% for the three secondary plants and 78% for the two tertiary plants with nitrifying filters, the removal attributed directly to the nitrifying trickling filters was just 11% (-15% to 37%). Given the lack of information obtained for other metals, the marginal performance documented by Inna et al. (2014) and the potential for adverse effects from concentrated return flows, tertiary biological nutrient removal processes (U11-U14) were assumed to have no net effect on metals.

Table B-2. Unit Process Composition of Study Treatment Configurations

Unit Process		Wastewater Treatment Configuration								
		Level 1, AS	**Level 2-1, A2O**	**Level 2-2, AS3**	**Level 3-1, B5**	**Level 3-2, MUCT**	**Level 4-1, B5/Denit**	**Level 4-2, MBR**	**Level 5-1, B5/RO**	**Level 5-2, MBR/RO**
U1	Preliminary Treatment – Screening and grit removal	✓	✓	✓	✓	✓	✓	✓	✓	✓
U2	Primary Clarification	✓	✓	✓	✓	✓	✓	✓	✓	✓
U3	Fermenter				✓	✓	✓		✓	✓
U4	Plug Flow Activated Sludge	✓		✓						
U5	Biological Nutrient Removal – 3-Stage		✓							
U6	Biological Nutrient Removal – 5-Stage				✓		✓		✓	✓
U7	Biological Nutrient Removal – 4-Stage (Bardenpho)							✓		
U8	Biological Nutrient Removal – 4-Stage (MUCT)					✓				
U9	Chemical Phosphorus Removal			✓	✓	✓	✓	✓	✓	✓
U10	Secondary Clarifier	✓	✓	✓	✓	✓	✓		✓	
U11	Nitrification – Suspended Growth			✓						
U12	Tertiary Clarification			✓ [c]						
U13	Denitrification – Suspended Growth			✓						
U14	Denitrification – Attached Growth						✓		✓	
U15	Membrane Filtration [a, b]							✓		✓
U16	Final Clarification									
U17	Filtration – Sand Filter				✓	✓	✓		✓	
U18	Reverse Osmosis [a, d]								✓	✓
U19	Ultrafiltration [a]								✓	
U20	Chlorination	✓	✓	✓	✓	✓	✓	✓	✓	✓
U21	Dechlorination	✓	✓	✓	✓	✓	✓	✓	✓	✓
U22	WWTP Effluent Discharge	✓	✓	✓	✓	✓	✓	✓	✓	✓
U23	Sludge – Gravity Thickening	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table B-2. Unit Process Composition of Study Treatment Configurations

Unit Process		Wastewater Treatment Configuration								
		Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
U24	Sludge – Anaerobic Digestion	✓	✓	✓	✓	✓	✓	✓	✓	✓
U25	Sludge – Centrifugation	✓	✓	✓	✓	✓	✓	✓	✓	✓
U26	Sludge – Haul and Landfill	✓	✓	✓	✓	✓	✓	✓	✓	✓
U27	Brine – Underground Inject								✓	✓

✓ Indicates unit process is relevant for select wastewater treatment configuration.

a – Periodic chemical cleaning is included for all membranes.

b – Membrane bioreactor wastewater treatment configurations use a membrane filter for the solid-liquid separation process instead of a traditional secondary clarifier.

c – This configuration includes two instances of tertiary clarification.

d – Includes chlorination and dechlorination pretreatment.

B.4 Metals Removal Performance Estimation Methods

Metal removal efficiencies for study system configurations were estimated based on a detailed literature review of performance results from similar systems. Sources reviewed include peer-reviewed literature, government reports and book chapters, covering a range of bench-scale experiments to performance characterization of full-scale treatment systems. Given the complexity of conditions and partitioning processes that can occur within WWTPs, empirical results were prioritized where the demonstrated metals removal performance of comparable treatment configurations or unit processes could be used to estimate performance of the study configurations. Where possible, mechanistic discussion was provided, though it is qualitative in nature as the factors affecting metal partitioning and removal are highly site specific (Cheng et al. 1975; Nelson et al. 1981; Huang et al. 2000) and mechanistic modelling is beyond the capability of the existing CAPDETWorks models used to develop the LCA and cost analysis.

For system levels where no representative equivalent was identified but the important components were characterized, a composite removal efficiency was calculated based upon case study performance data of its major unit processes. For example, Level 3-1 includes a 5-stage Bardenpho process with subsequent sand filtration. However, results of the literature review only identified 5-stage Bardenpho WWTPs without sand filtration. Therefore, Equation B-1 below represents a two-step linear process and was used to combine these results with removal efficiencies identified for sand filtration as a standalone process.

$$R_{total} = f_1 R_1 + f_2 (1 - R_1) R_2$$

Equation B-1

where

R_{total} = composite metal removal efficiency

f_1 = fraction of flow diverted to process 1

R_1 = removal efficiency of process 1

f_2 = fraction of flow diverted to process 2

R_2 = removal efficiency of process 2

In this example, R_1 would be representative of the combined effects of U1, U2, U6, and U10 (pretreatment + 5-stage Bardenpho + secondary clarification), while R_2 would be representative of U17 (sand filter). The functional form has also been adapted to account for more than two stepwise processes (e.g. Level 5-2) or parallel streams (e.g. Level 5-1), as demonstrated below. Note that the unit code descriptions are provided in Table B-2.

B.5 Metals Removal Performance Estimation Results

Following the approach outlined in Section B.4, Table B-3 shows how removal efficiencies for each study configuration were calculated based on major unit process combinations and supporting literature. Final composite removal efficiencies for each metal, by treatment configuration, are provided in Table B-4 and illustrated in Figure B-1. A more detailed discussion of each treatment configuration follows.

Table B-3. Summary of Composite Removal Calculations used in Equation 1

Level	Level Unit Processes[a]	Case Study Unit Process(es)[b]	R[c]	f[d]	Description
Level 1, AS	**U1**+**U2**+**U4**+**U10**	**U1**+**U2**+**U4**+**U10**	N/A	100%	Conventional Activated Sludge[e]
Level 2-1, A2O	**U1**+**U2**+**U5**+**U10**	**U5**	q	100%	Anaerobic/Anoxic/ Oxic[f]
Level 2-2, AS3	**U1**+**U2**+**U4**+*U9*+**U10**+*U11*+*U12*+*U13*	**U1**+**U2**+**U4**+**U10**	q	100%	3-Sludge System[g]
Level 3-1, B5	**U1**+**U2**+*U3*+**U6**+*U9*+**U10**+**U17**	**U1**+**U2**+**U6**+**U10**	R1	100%	5-stage Bardenpho[h]
		U17	R2	100%	Sand filter[i]
Level 3-2, MUCT	**U1**+**U2**+*U3*+**U8**+*U9*+**U10**+**U17**	**U1**+**U2**+**U8**+**U10**	R1	100%	Modified University Cape Town process[j]
		U17	R2	100%	Sand filter[i]
Level 4-1, B5/Denit	**U1**+**U2**+*U3*+**U6**+*U9*+**U10**+*U14*+**U17**	**U1**+**U2**+**U6**+**U10**	R1	100%	5-stage Bardenpho[h]
		U17	R2	100%	Sand filter[i]
Level 4-2, MBR	**U1**+**U2**+**U7**+*U9*+**U15**	**U7**	q	100%	4-stage Bardenpho[k]
		U15	R2	100%	Membrane bioreactor[l]
Level 5-1, B5/RO	**U1**+**U2**+*U3*+**U6**+*U9*+**U10**+*U14*+**U17**+**U18** +*U19*	**U1**+**U2**+**U6**+**U10**	R1	100%	5-stage Bardenpho[h]
		U17	R2a	10%	Sand filter[i]
		U18	R2b	90%	Reverse osmosis[m]
Level 5-2, MBR/RO	**U1**+**U2**+*U3*+**U6**+*U9*+**U15**+**U18**	**U1**+**U2**+**U6**+**U10**	R1	100%	5-stage Bardenpho[h]
		U15	R2	100%	Membrane bioreactor[l]
		U18	R3	85%	Reverse osmosis[m]

a - Bold unit processes affect metals removal, italicized unit processes were determined to have no significant effect.

b - Unit process or unit process configurations represented in the case study literature.

c - Removal efficiency determined from the literature and used in stepwise removal calculations (see Equation B-1. 'NA' indicates that Equation B-1 was not used, as documented removal efficiencies could be used directly to represent the entire treatment system. 'q' indicates that only qualitative conclusions can be drawn from the applicable literature.

d - Proportion of flow directed to unit process(es), see Equation B-1.

e - Brown et al., 1973; Oliver and Cosgrove, 1974; da Silva Oliveira et al., 2007; Carletti et al., 2008; Karvelas et al., 2003

f - Chang et al., 2007

g - Metal-affecting unit processes same as Level 1, use Level 1 for conservative estimation

h - Salihoglu et al., 2013

i - Linstedt et al., 1971; Aulenbach and Chan, 1988; Renman et al., 2009; Reddy et al., 2014

j - Chipasa, 2003; Obarska-Pempkowiak and Gajewska, 2007. Data describe the metals removal performance of membrane bioreactors. Data were assumed to be representative of membrane filtration as well, as the physical filtration is the dominant partitioning mechanism of metals sorbed to dissolved organic complexes.

k - Emara et al., 2014

l - Innocenti et al., 2002; Carletti et al., 2008; Dialynas and Diamadopoulos, 2009; Malamis et al., 2012; Arevalo et al., 2013

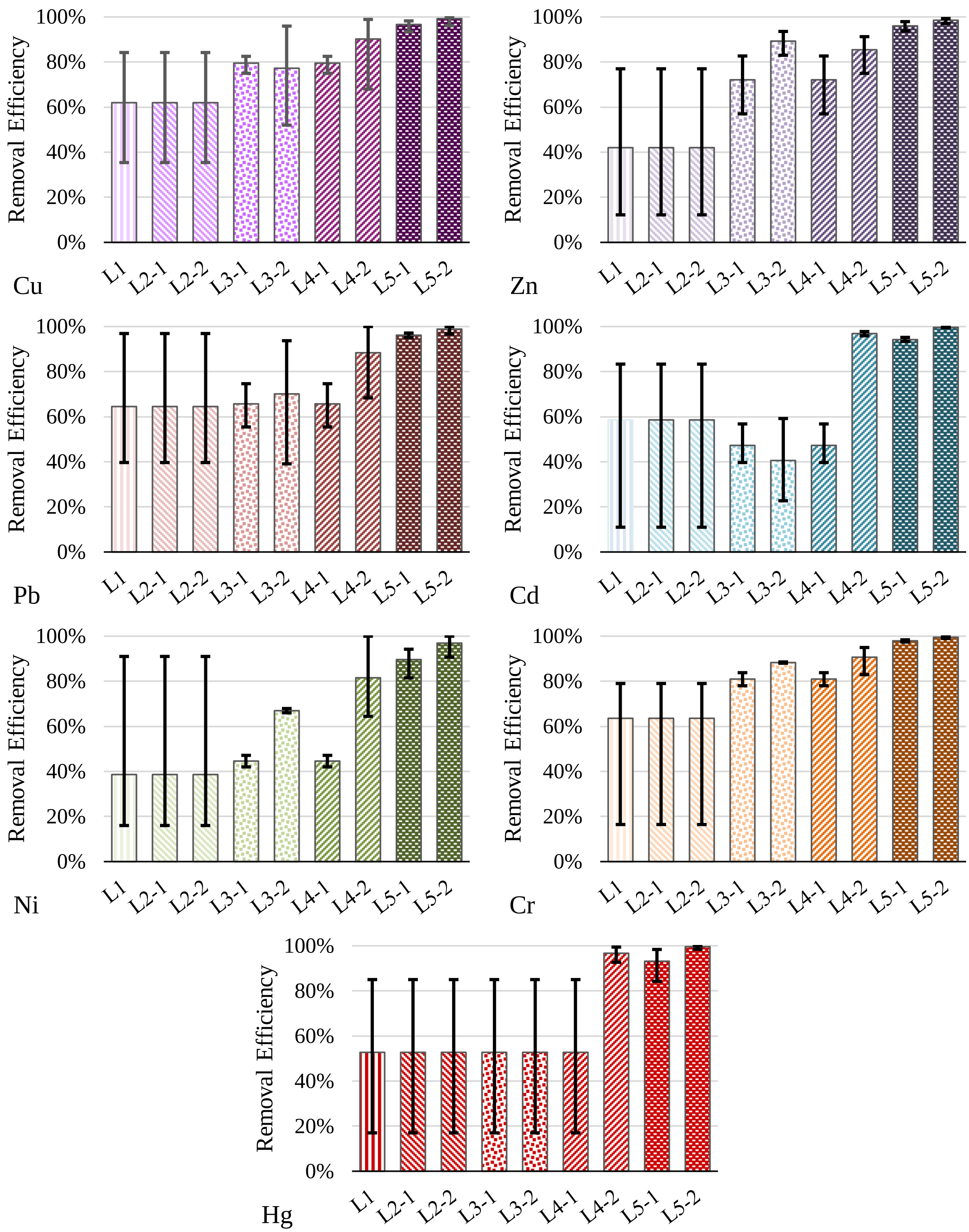
m - Dialynas and Diamadopoulos, 2009; Malamis et al., 2012; Garcia et al., 2013; Arévalo et al. 2013

Table B-4. Summary of Estimated Metal Removal Efficiencies[a]

Metal		Level 1 AS	Level 2-1 A2O	Level 2-2 AS3	Level 3-1 B5	Level 3-2 MUCT	Level 4-1 B5/Denit	Level 4-2 MBR	Level 5-1 B5/RO	Level 5-2 MBR/RO
Cu	Min	35%	35%	35%	75%	52%	75%	68%	93%	96%
	Mean	62%	62%	62%	80%	77%	80%	90%	97%	99%
	Max	84%	84%	84%	83%	96%	83%	99%	98%	100%
Pb	Min	40%	40%	40%	55%	39%	55%	68%	95%	97%
	Mean	65%	65%	65%	66%	70%	66%	88%	96%	99%
	Max	97%	97%	97%	75%	94%	75%	100%	97%	100%
Ni	Min	16%	16%	16%	42%	66%	42%	64%	82%	91%
	Mean	39%	39%	39%	45%	67%	45%	82%	90%	97%
	Max	91%	91%	91%	47%	68%	47%	100%	94%	100%
Zn	Min	12%	12%	12%	57%	83%	57%	75%	94%	97%
	Mean	42%	42%	42%	72%	89%	72%	85%	96%	99%
	Max	77%	77%	77%	83%	94%	83%	91%	98%	99%
Cd	Min	11%	11%	11%	40%	23%	40%	96%	93%	99%
	Mean	59%	59%	59%	47%	41%	47%	97%	94%	100%
	Max	83%	83%	83%	57%	59%	57%	98%	95%	100%
Cr	Min	16%	16%	16%	78%	88%	78%	83%	97%	99%
	Mean	64%	64%	64%	81%	88%	81%	91%	98%	100%
	Max	79%	79%	79%	84%	89%	84%	95%	98%	100%
Hg[1]	Min	17%	17%	17%	17%	17%	17%	93%	84%	98%
	Mean	53%	53%	53%	53%	53%	53%	97%	93%	100%
	Max	85%	85%	85%	85%	85%	85%	99%	98%	100%

a – "Removal Efficiency" used loosely; data more explicitly represents partitioning to sludge. Min and max represent minimum and maximum removal efficiencies reported in the literature. Where removal efficiencies are composites of multiple processes, minimum represents the composite of both contributing minimums, likewise for maximum.

b – No data for Hg removal found for 4-stage Bardenpho, 5-stage Bardenpho or MUCT. Therefore, conservatively assumed same removal for these biological treatment processes as documented for CAS (Level1). Data for Levels 4-2, 5-1 and 5-2 represent the effect of tertiary polishing step alone, i.e. MBR and RO.



a – Distinct bar patterns are used to distinguish treatment systems in each of the five nutrient removal levels.
b - Error bars represent the minimum and maximum removal efficiencies reported in the literature.

Figure B-1. Summary of Estimated Metal Treatment Performance[a, b]

B.5.1 Level 1: Conventional Plug Flow Activated Sludge (AS)

Level 1 is the most commonly represented treatment configuration within the case study literature. Overall, seven conventional activated sludge (CAS) systems were reviewed providing a range of performance results. Metals with the highest mean removals were Pb, Cr and Cu, each with a mean removal >60%. Intermediate mean removals of 40-60% were determined for Cd, Hg and Zn, while Ni returned the lowest mean removal of 39%. This pattern is to be expected, with previous reviews showing good (>50%) removals of Cd, Cr, Cu and Pb, and lower removals (<30%) for Ni (Stephenson and Lester 1987). For all metals, variability in results was high, with ranges from less than half to more than double the mean for most metals.

B.5.2 Level 2-1: Anaerobic/Anoxic/Oxic (A2O)

Level 2-1 is differentiated from Level 1 by its three-stage biological nutrient removal system which consists of sequential anaerobic, anoxic, and oxic basins. No performance data for A2O systems were found in the literature review, however a study conducted to determine the metal affinity of A2O sludge was reviewed (Chang et al. 2007). While data were not provided that could provide an input/output removal performance, results indicated that A2O sludge exhibited higher biosorption affinities than CAS sludge for Cd and Ni, and similar affinity for Zn (only three metals were evaluated). Based on these relative conclusions and in combination with the slightly longer SRT (Table 1-5) and better removal performance of COD (Table 1-4), it was conservatively assumed that the metal removal performance of Level 2-1 was equivalent to Level 1.

B.5.3 Level 2-2: Activated Sludge, 3-Sludge System (A3S)

Level 2-2 is similar to Level 1, with the addition of post-secondary suspended growth nitrification and denitrification reactors, as well as chemical phosphorus precipitation. No performance data for A3S systems were found in the literature review. Despite the greater SRT (Table 1-5) and better removal performance of COD (Table 1-4), in the absence of literature specifically documenting effects of this process on metal concentrations, it was conservatively assumed that the metal performance of Level 2-2 was equivalent to Level 1.

B.5.4 Level 3-1: 5-Stage Bardenpho System (B5)

Level 3-1 is characterized by a combination of case studies that are representative of its major metal-affecting unit processes, including the 5-stage Bardenpho process and sand filtration. Salihoglu (2013) reviewed the metals removal performance of two WWTPs that utilized the 5-stage Bardenpho process in the Turkish city of Bursa. The treatment plants, which serve populations of 170,000 and 85,000 in mixed urban areas, consist of pretreatment (screening and grit removal) followed by an equalization tank, 5-stage Bardenpho process and a clarifier. In terms of applicability to Level 3-1, the plants describe the beginning of the treatment train including pretreatment (U1), 5-stage Bardenpho process (U6) and secondary clarification (U10). Although primary sedimentation (U2) is not included, it is assumed that the level of treatment conferred by the particular combination of unit processes (U1+U6+U10) allows for sufficient settleable solids removal such that the absence of U2 can be considered negligible.

Data for sand filtration came from a range of studies, including pilot- or bench-scale tests of sand filtration as a tertiary treatment unit process (Linstedt et al. 1971; Aulenbach and Chan

1988), as a polishing step for septic effluent (Renman et al. 2009) and for the treatment of stormwater (Reddy et al. 2014). Although stormwater is compositionally different than wastewater, it is arguably closer to secondary effluent than raw wastewater and the inclusion of these results helped fill data gaps left by the wastewater-specific studies.

Reported removal efficiencies for the 5-stage Bardenpho system for all metals except Cd and Pb (data were not given for Hg) tended to be similar to those reported for CAS, while the removal efficiency for Cd was lower than CAS and Pb was higher (Salihoglu 2013). No mechanistic explanations were provided for these deviations by Salihoglu (2013), though possible reasons may have to do with the relatively high affinity of Pb and relatively low affinity of Cd to organic matter, respectively (e.g., Wang, 1997) Mean removal efficiencies for sand filtration case studies ranged from 2% to 29%, bounded by Cr (2%) and Ni (3%) at the low end and Pb (22%) and Zn (29%) at the high end. Composite removal efficiencies for L3-1 were greater than Level 1 for all metals except Cd (and Hg, as no data were reported for U6 or U17 unit processes), owing to low removals of Cd in both 5-stage Bardenpho (41%) and sand filtration (11%).

B.5.5 Level 3-2: Modified University of Cape Town (MUCT)

Level 3-2 is characterized by a combination of case studies that are representative of its major metal-affecting unit processes, including the Modified University of Cape Town process and sand filtration. Metals performance data for MUCT systems come from a pair of case studies conducted in Poland (Chipasa 2003; Obarska-Pempkowiak and Gajewska 2007). The first system, reviewed by Chipasa (2003), includes screening and grit removal (U1), primary sedimentation (U2), MUCT reactors (U8), and secondary clarification (U10). The second system, reviewed in Obarska-Pempkowiak and Gajewska (2007), refers to a 23 MGD plant receiving mixed municipal wastewater with roughly 10% coming from industrial sources. Primary treatment consists of screening, an aerated sand trap and primary sedimentation, which was assumed equivalent to screening and grit removal (U1) and primary sedimentation (U2). Biological treatment consists of six sequential reactors that make up the MUCT process (U8) followed by secondary sedimentation (U10).

Data for sand filtration come from a range of studies, including pilot- or bench-scale tests of sand filtration as a tertiary treatment unit process (Linstedt et al. 1971; Aulenbach and Chan 1988), as a polishing step for septic effluent (Renman et al. 2009) and for the treatment of stormwater (Reddy et al. 2014). Although stormwater is compositionally different than wastewater, it is arguably closer to secondary effluent than raw wastewater and the inclusion of these results helped fill data gaps left by the wastewater-specific studies.

Mean removal efficiencies for the MUCT systems ranged from 66% to 88% with the exception of Cd, which had a mean removal of 34%. Mean removal efficiencies for sand filtration case studies ranged from 2% to 29%, bounded by Cr (2%) and Ni (3%) at the low end and Pb (22%) and Zn (29%) at the high end. Composite removal efficiencies for Level 3-2 were slightly better than Level 3-1 for Pb, Zn, Ni and Cr and slightly worse for Cu and Cd. No data were reported for Hg.

B.5.6 Level 4-1: 5-Stage Bardenpho System with Denitrification Filter (B5/Denit)

The unit process configuration of Level 4-1 is identical to Level 3-1, with the exception of an attached growth denitrification reactor. Although no data were identified to directly characterize the metals removal performance of this unit process, it is likely that it provides some degree of metals removal as it allows for additional contact time between secondary effluent and a new, biologically distinct consortium. However, in the absence of literature specifically documenting effects of an attached growth denitrification reactor on metal concentrations, it was conservatively assumed that the performance of Level 4-1 was equivalent to that of Level 3-1.

B.5.7 Level 4-2: 4-Stage Bardenpho Membrane Bioreactor System (MBR)

Level 4-2 is characterized by a 4-stage Bardenpho system followed by a membrane bioreactor. The 4-stage Bardenpho system of Level 4-2 differs from the 5-stage Bardenpho system of Level 4-1, lacking the first anaerobic stage and having a total SRT of 19 days as opposed to 15 days for the 5-stage system. No data were found characterizing the metals performance of a 4-stage Bardenpho system, rather performance was estimated based on the comparative design and operation of the study configurations as well as results from a bench-scale study performed to directly compare the performance of 4-stage and 5-stage Bardenpho systems using Ni and Fe as indicators of metal removal (Emara et al. 2014). The study showed that after incorporation of the upstream anaerobic tank, thus modifying the 4-stage to a 5-stage system, Ni removal increased from 68% to 86% and Fe removal increased from 82% to 92%. This is to be expected, as the incorporation of the anaerobic stage is done to improve phosphorus removal through the promotion of phosphorus accumulating organisms, which produce floc that provides for an additional degree of biosorption. As such, it was conservatively assumed that the metal removal efficiency of the 4-stage system was 50% of the 5-stage system described by Salihoglu (2013). The greater SRT of the Level 4-2, 4-stage system compared to the Level 4-1, 5-stage system, adds a further degree of conservatism as it would suggest better performance than what is being assumed.

The metals removal performance of MBRs has been well characterized, with five applicable studies identified representing six different systems (Innocenti et al. 2002; Carletti et al. 2008; Dialynas and Diamadopoulos 2009; Malamis et al. 2012; Arévalo et al. 2013). The systems all treated mixed municipal primary effluent, ranged in size from a 100 gpd pilot plant to a 5.3 MGD full-scale plant, and had membrane pore sizes of either 0.020 µm or 0.040 µm. Average removal efficiencies across all studies were high, ranging from 76% (Ni) to 96% (Cd and Hg). That the removals are high relative to other unit processes discussed thus far is reasonable when considering the pore size of MBRs (0.020 to 0.040 µm) relative to the filter pore size generally used to delineate between dissolved and non-dissolved fractions (0.45 µm). This comparison suggests an ability to remove smaller dissolved organic complexes in the 0.04-0.45 µm range that may be missed by processes that rely on settling or clarification.

Although a conservative assumption was made regarding the treatment performance of the 4-stage Bardenpho system, composite removal efficiencies for the Level 4-2 configuration are greater than those of Level 4-1 for all metals reviewed, owing to the high removal efficiency of the MBR unit process. Moreover, although Hg was not included in any Bardenpho study, the two MBR studies that did evaluate Hg found an average removal of 96%, which could reasonably be interpreted as a total Hg removal efficiency for Level 4-2.

B.5.8 Level 5-1: 5-Stage Bardenpho with Sidestream Reverse Osmosis (B5/RO)

Level 5-1 is characterized by a 5-stage Bardenpho system followed by two parallel processes. The first, treating 90% of the 5-stage Bardenpho effluent, consists of an ultrafilter followed by a reverse osmosis (RO) system. The remaining 10% is treated by a sand filter, similar to Level 3-1.

For the 5-stage Bardenpho system, Salihoglu (2013) reviewed the metals removal performance of two WWTPs that utilize this process in the Turkish city of Bursa. The treatment plants, which serve populations of 170,000 and 85,000 in mixed urban areas, consist of pretreatment (screening and grit removal) followed by a selector tank, 5-stage Bardenpho process and a clarifier. In terms of applicability to Level 5-1, the plants describe the beginning of the treatment train including pretreatment (U1), 5-stage Bardenpho process (U6) and secondary clarification (U10). Although primary sedimentation (U2) is not included, it is assumed that the level of treatment conferred by the particular combination of unit processes (U1+U6+U10) allows for sufficient settleable solids removal that the absence of U2 can be considered negligible.

For the first parallel process, consisting of an ultrafilter followed by an RO system, four studies were found evaluating the performance of five distinct RO systems (Qdais and Moussa 2004; Dialynas and Diamadopoulos 2009; Malamis et al. 2012; Garcia et al. 2013). The systems reviewed were mostly pilot scale treating mixed municipal primary effluent, with the exception of a 0.3 MGD full scale system (Garcia et al. 2013) and a pilot scale study evaluating synthetic industrial wastewater (Qdais and Moussa 2004). Ultrafiltration was not explicitly included as, in the case of most case study systems and study configurations, this step serves as a pretreatment step allowing for proper RO functioning and its performance was generally not characterized. Mean removal of each metal across all systems for which data were available were greater than 90%. The lowest removal efficiencies reported for any single system, and the only rates less than 90%, were those for the pilot plant treating pretreated, mixed municipal wastewater evaluated by Malamis et al. (2012) at 82% for Cu and 76% for Ni.

Data for sand filtration come from a range of studies, including pilot- or bench-scale tests of sand filtration as a tertiary treatment unit process (Linstedt et al. 1971; Aulenbach and Chan 1988), as a polishing step for septic effluent (Renman et al. 2009) and for the treatment of stormwater (Reddy et al. 2014). Although stormwater is compositionally different than wastewater, it is arguably closer to secondary effluent than raw wastewater and the inclusion of these results helped fill data gaps left by the wastewater-specific studies.

Composite removal efficiencies for Level 5-1 are 90-98% for all metals reviewed. Also, although sufficient data were not obtained for the full characterization of Hg removal in 5-stage Bardenpho or RO systems, Ruel et al. (2011) measured effluent concentrations in two full-scale municipal WWTPs that incorporated RO for advanced nutrient removal and found Hg to be below the level of detection in both cases.

B.5.9 Level 5-2: 5-Stage Bardenpho Membrane Bioreactor with Sidestream Reverse Osmosis (MBR/RO)

Level 5-2, the most advanced study configuration, consists of a 5-stage Bardenpho system followed by an MBR, then treatment of 85% of MBR effluent by an RO system with the remaining 15% discharged with no further treatment.

For the 5-stage Bardenpho system, Salihoglu (2013) reviewed the metals removal performance of two WWTPs that utilized this process in the Turkish city of Bursa. The treatment plants, which serve populations of 170,000 and 85,000 in mixed urban areas, consist of pretreatment (screening and grit removal) followed by a selector tank, 5-stage Bardenpho process and a clarifier. In terms of applicability to Level 5-2, the plants describe the beginning of the treatment train including pretreatment (U1), 5-stage Bardenpho process (U6) and secondary clarification (U10). Although primary sedimentation (U2) is not included, it is assumed that the level of treatment conferred by the particular combination of unit processes (U1+U6+U10) allows for sufficient settleable solids removal that the absence of U2 can be considered negligible.

The metals removal performance of MBRs has been well characterized, with 5 applicable studies identified representing 6 different systems (Innocenti et al. 2002; Carletti et al. 2008; Dialynas and Diamadopoulos 2009; Malamis et al. 2012; Arévalo et al. 2013). The systems all treated mixed municipal primary effluent, ranged from a 100 gpd pilot plant to a 5.3 MGD full-scale plant and had membrane pore sizes of either 0.020 µm or 0.040 µm. Average removal efficiencies across all studies were high, ranging from 76% (Ni) to 96% (Cd and Hg). That the removals are high relative to other unit processes discussed thus far is reasonable when considering the pore size of MBRs (0.020 to 0.040 µm) relative to the filter pore size generally used to delineate between dissolved and non-dissolved fractions (0.45 µm). This comparison suggests an ability to remove much smaller, dissolved organic complexes missed by processes that rely on settling or clarification.

For the characterization of RO systems, four studies were found evaluating the performance of 5 distinct RO systems (Qdais and Moussa 2004; Dialynas and Diamadopoulos 2009; Malamis et al. 2012; Garcia et al. 2013). The systems reviewed were mostly pilot scale treating pretreated mixed municipal wastewater, with the exception of a 0.3 MGD full scale system (Garcia et al. 2013) and a pilot scale evaluating synthetic industrial wastewater (Qdais and Moussa 2004). Ultrafiltration was not explicitly included as, in the case of most case study systems and study configurations, this step serves as a pretreatment step allowing for proper RO functioning and its performance was generally not characterized. Mean removal of each metal across all systems for which data were available were greater than 90%. The lowest removal efficiencies reported for any single system, and the only rates less than 90%, were those for the pilot plant treating pretreated, mixed municipal wastewater evaluated by Malamis et al. (2012) at 82% for Cu and 76% for Ni.

Composite removal efficiencies for Level 5-2 are 97% to >99% for all metals reviewed. Also, although sufficient data were not obtained for the full characterization of Hg removal in 5-stage Bardenpho or RO systems, Ruel et al. (2011) measured effluent concentrations in two full-scale municipal WWTPs that incorporated RO for advanced nutrient removal and found Hg to be below the level of detection in both cases.

B.6 Heavy Metals Toxicity Characterization Factors

Table B-5 presents the characterization factors used to estimate toxicity impacts associated with heavy metals in treatment plant effluent and sludge. Not all heavy metals included in this study have associated characterization factors listed in the most recent versions of USEtox™, versions 2.02 and 2.11. Characterization factors that were not otherwise available were estimated using the median value of all other heavy metals for which data was available. Sources for individual characterization factors are listed in Table C-8.

Table B-5. Heavy Metals Toxicity Characterization Factors, USEtox™ version 2.11

Chemical Name	USETox Chemical Name	Freshwater Ecotoxicity, (CTUe, PAF m3.day/kg emitted)		Human Health cancer, freshwater (CTUh, cases/kg emitted)		Human Health noncancer, freshwater (CTUh, cases/kg emitted)	
		Emissions to Freshwater	Emissions to Natural Soil	Emissions to Freshwater	Emissions to Natural Soil	Emissions to Freshwater	Emissions to Natural Soil
Lead	Pb(II)	6.9E+2	4.1E+2	1.4E-7	8.5E-8	5.0E-5	3.0E-5
Copper	Cu(II)	9.9E+6	5.2E+6	8.8E-6[a]	4.5E-6[a]	1.4E-7	7.2E-8
Zinc	Zn(II)	1.3E+5	7.3E+4	-	-	2.6E-4	1.4E-4
Nickel	Ni(II)	3.0E+5	1.5E+5	1.2E-4	6.1E-5	6.7E-6	3.4E-6
Chromium	Cr(III)	8.1E+3	4.1E+3	-	-	2.1E-11	1.0E-11
Cadmium	Cd(II)	2.3E+6	1.2E+6	1.7E-5	8.9E-6	4.7E-3	2.4E-3
Mercury	Hg(II)	2.2E+4	1.6E+4	1.5E-4	1.1E-4	0.02	0.01

a - Estimated using the median of heavy metals with available characterization factors.

APPENDIX C
DETAILED CHARACTERIZATION OF TOXIC ORGANICS BEHAVIOR IN STUDY TREATMENT CONFIGURATIONS

Appendix C: Detailed Characterization of Toxic Organics Behavior in Study Treatment Configurations

C.1 Toxic Organics: Introduction

This section presents background information and methods used to estimate the environmental impact associated with select trace organic chemical releases in the Level 1 through 5 treatment systems.

Toxic organics are a diverse and growing category of chemical substances that includes other commonly referred to pollutant groups such as contaminants of emerging concern (CECs), pharmaceuticals and personal care products (PPCPs), and endocrine disrupting chemicals (EDCs). The pollutant category includes medications, fragrances, insect repellents and other household items that can be harmful to environmental and human health at even trace levels (U.S. EPA 2015c; Montes-Grajales et al. 2017).

Many toxic organics have a documented presence in surface waters, groundwater, wastewater and WWTP effluent, both in the U.S. and globally (Ellis 2008; Ebele et al. 2017; Montes-Grajales et al. 2017). No comprehensive list exists, though based on the diverse literature the number of contaminants is at least in the hundreds (if not thousands) and is continually being expanded upon as analytical techniques for measuring both presence and toxicity are continually refined. In order to provide a targeted analysis of their behavior in WWTPs, a restricted group of 43 pollutants (Table C-1) has been selected for specific treatment in this analysis. The selected pollutant group uses the chemical list from Rahman et al. (2018) as a starting point. Rahman et al. (2018) performed a comparative LCA that examines the effect of toxic organics removal on life cycle human health and ecotoxicity impacts for treatment systems that correspond to three levels of nutrient removal, focusing on the use of advanced tertiary processes for toxic organics removal. Their selection of toxic organics was based on frequency of presence in WWTPs and availability of information regarding concentration, chemical degradation, transformation and removal. Several additional common chemicals, including triclocarban, tonalide, celestolide, phantolide and musk ketone, were added based on the assessment of Montes-Grajales et al. (2017), which looked at the presence of PPCPs in global water resources and found these compounds to be the most widely reported. Per- and Polyfluoroalkyl Substances (PFAS) are not included in this toxic organics' assessment.

The concentration of trace pollutants can vary considerably on a daily and seasonal basis and between WWTPs (Martin Ruel et al. 2012). Urban WWTPs have also been shown to receive higher influent concentrations of some toxic organics that are less common in rural water systems. As such, the median influent concentrations from Table C-1 were used as input to subsequent calculations as the averages had a tendency to be strongly influenced by a small number of very high influent concentration records. Figure C-1 and Figure C-2 present boxplots of the influent concentration of toxic organics. The figures divide the pollutants into two subgroups to allow better visualization across pollutants with considerably different influent concentrations. Acetaminophen is excluded from these figures due to its notably greater median influent concentration, 97 µg/L, as compared to the other included pollutants. The figures show the tendency for some pollutant distributions to skew towards large outlier values, causing a disparity between the median and average values.

Table C-1. Occurrence of the Selected Toxic Organic Compounds in WWTP Influent

Chemical Name	Chemical Type/Use	Influent Concentration (µg/L)				Sample Size
		Average	Median	Minimum	Maximum	
acetaminophen[a]	pain reliever, anti-inflammatory	97	19	0.02	400	12
androstendione[a]	steroid hormone	0.29	0.10	0.02	1.3	7
atenolol	beta blocker	4.3	1.1	0.03	26	10
atorvastatin	lipid regulator	0.49	0.22	0.07	1.6	6
atrazine[b]	pesticide	0.02	0.02	1.0E-3	0.06	5
benzophenone	PCP, sunscreen	0.24	0.27	7.0E-3	0.42	4
bisphenol A	EDC, plasticizer	4.6	0.84	0.01	44	16
butylated hydroxyanisole[c]	beta blocker	1.3	0.16	0.13	3.5	3
butylated hydroxytoluene	beta blocker, cosmetic	0.93	0.41	0.05	3.5	5
butylbenzyl phthalate[d]	plasticizer	0.11	0.11	0.08	0.14	2
carbamazepine[a]	Anti-convulsant	0.92	0.69	0.04	3.8	28
N,N-diethyl-meta-toluamide (DEET)	insect repellent	1.4	0.40	0.02	6.9	6
diclofenac	Analgesics, anti-inflammatory	2.1	0.96	1.0E-3	17	20
dilantin	anti-seizure medication	0.16	0.17	0.05	0.24	4
dioctyl phthalate[b]	plasticizer, industry	23	1.4	1.1	67	3
estradiol[a,c]	EDC, steroid hormone	0.59	0.03	8.0E-3	5.0	11
estrone[a,c]	EDC, steroid hormone	0.17	0.05	0.01	1.0	9
galaxolide	beta blocker, PCP, fragrance	4.3	2.3	1.4E-3	25	16
gemfibrozil[a]	lipid regulator	3.1	1.6	0.02	22	15
hydrocodone	analgesic, opioid	0.08	0.11	0.02	0.12	5
ibuprofen[a]	Analgesics, anti-inflammatory	7.8	2.4	1.0E-3	39	27
iopromide	contrast agent	7.4	0.05	0.01	38	6
meprobamate	tranquilizer, medication	0.40	0.35	0.01	0.97	5
naproxen[a]	Analgesics, anti-inflammatory	8.5	2.5	2.0E-3	53	20
nonylphenol[b,c]	EDC, disinfectant, surfactant, solvent	3.4	2.3	0.02	9.7	14

Table C-1. Occurrence of the Selected Toxic Organic Compounds in WWTP Influent

Chemical Name	Chemical Type/Use	Influent Concentration (μg/L)				Sample Size
		Average	Median	Minimum	Maximum	
octylphenol[b]	EDC, surfactant, solvent	1.9	0.41	0.12	8.7	12
o-hydroxy atorvastatin	lipid regulator	0.12	0.12	0.10	0.14	2
oxybenzone	PCP	1.2	0.39	0.03	3.8	4
p-hydroxy atorvastatin	lipid regulator	0.12	0.12	0.10	0.14	2
progesterone[a]	EDC	0.02	0.01	3.1E-3	0.06	4
sulfamethoxazole[a]	antibiotic	1.1	0.43	0.04	4.5	14
tris(2-chloroethyl) phosphate (TCEP)	flame retardant, plasticizer	0.35	0.24	0.17	0.65	3
tris(2-chloroisopropyl) phosphate (TCPP)	flame retardant	1.2	1.2	1.1	1.3	2
testosterone[a]	EDC	0.06	0.05	0.01	0.14	5
triclosan[a]	pesticide, disinfectant	2.7	0.80	2.3E-3	24	17
trimethoprim[a]	antibiotic	0.52	0.53	0.10	1.4	8
triclocarban[a]	disinfectant	0.42	0.42	0.29	0.54	2
tonalide	beta blocker, PCP, fragrance	1.5	0.80	5.0E-5	7.6	13
celestolide	PCP, fragrance	5.1	0.07	0.04	15	3
phantolide	fragrance	0.10	0.10	0.04	0.15	2
clofibric acid	lipid regulator	0.46	0.29	0.03	1.1	3
musk ketone	fragrance	0.12	0.12	0.10	0.15	3
diuron[b,c]	fragrance	0.14	0.11	0.05	0.25	3

a - Identifies substances with EPA developed analytical methods for detection of contaminants of emerging concern per (U.S. EPA, 2017).

b - Identifies substances with a European Quality Standard per (EP 2008).

c - Identifies substances identified in EPA's Candidate Contaminant List (CCL), version 4 (U.S. EPA, 2016). The CCL identifies chemicals that are currently unregulated but may pose a risk to drinking water.

d - Identifies substances identified as human health criteria in Section 304(a) of the Clean Water Act (U.S. EPA, 2019c).

Table Acronyms: EDC – endocrine disrupting chemical, PCP – personal care product.

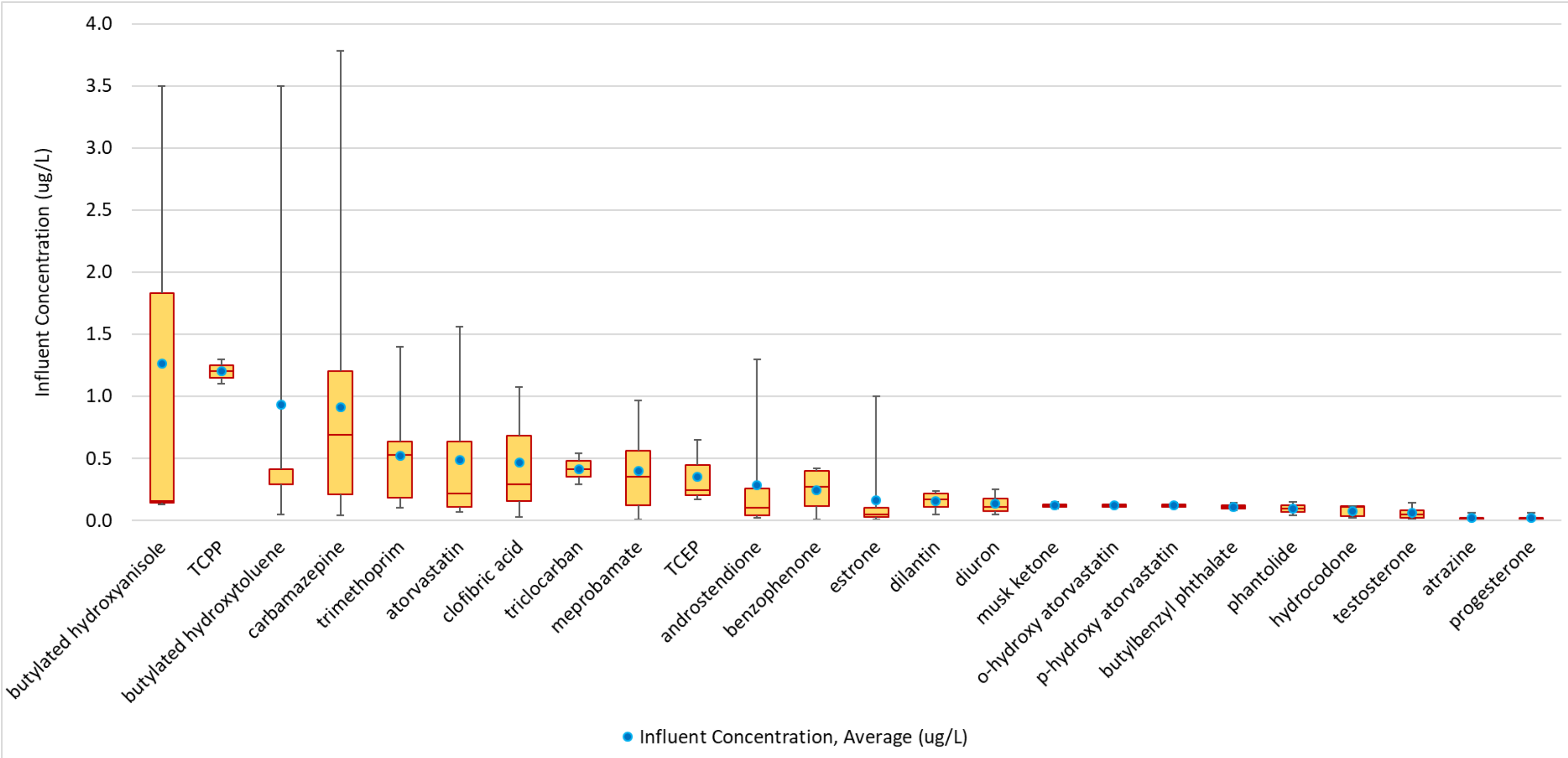


Figure C-1. Boxplot of the Influent Concentration of Toxic Organics with Maximum Concentration Less than 4 µg/L.

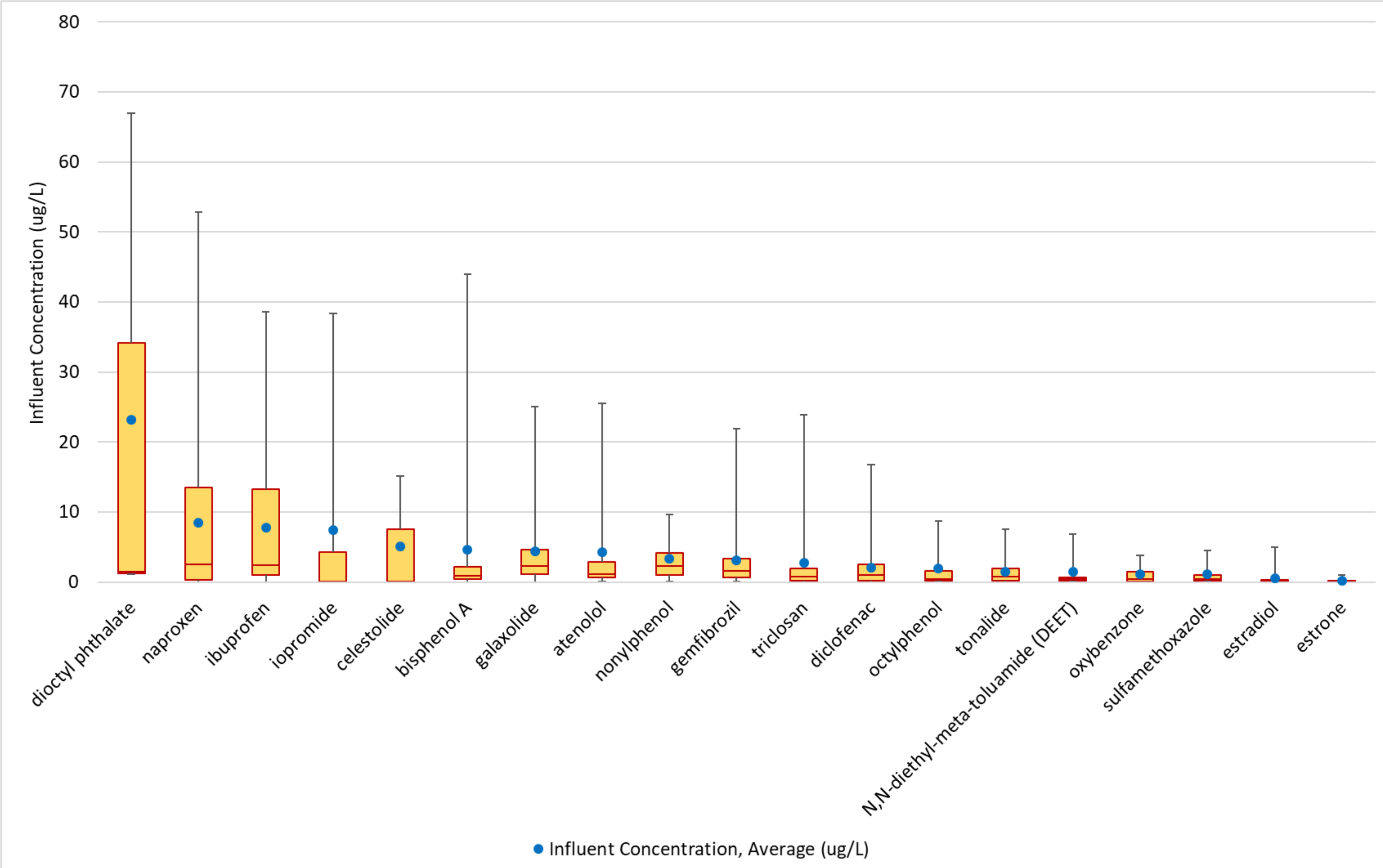


Figure C-2. Boxplot of the Influent Concentration of Toxic Organics with Maximum Concentration Greater than 4 µg/L.

C.2 Fate of Toxic Organics during Wastewater Treatment

A great deal of work has been done regarding the degradation and partitioning of toxic organics within municipal WWTPs. The extent of degradation as well as the mechanisms of removal can vary widely, reflecting the underlying diversity in the pollutants themselves and conditions and operational procedures practiced at WWTPs. For example, some chemicals such as acetaminophen and bisphenol A are highly degradable and exhibit excellent removal, often greater than 90 percent, in conventional (Level 1) treatment works (Liwarska-Bizukojc et al. 2018). Conversely, chemicals such as diclofenac and trimethoprim are more recalcitrant, exhibiting removal efficiencies of less than 80 percent in conventional treatment systems (Ahmed et al. 2017, Ogunlaja et al. 2013). The term removal efficiency is used to refer to the combined effect of biodegradation and partitioning to solids, unless otherwise specified.

As a general rule-of-thumb, Level 1 treatment systems remove approximately 80 percent of the toxic organic load from the liquid stream (Martin Ruel et al. 2012). Removal that is attributable to solids partitioning versus biodegradation varies according to pollutant. The reason for this variation is not well agreed upon within the literature. Martin Ruel et al. (2012) states that roughly two-thirds of pollutant removal can be accounted for by partitioning to sludge, while Jelic et al. (2011) found that this pathway was considerably less important. Biodegradation is a second important removal pathway, especially for chemicals that remain dissolved in the liquid fraction of wastewater. Volatilization of organic pollutants is expected to contribute negligibly to removal of most pollutants. Of the reviewed pollutants only celestolide is known to count volatilization as a significant loss pathway, accounting for up to 16% of total pollutant removal (Luo et al. 2014). Generally, volatilization is only expected to be relevant for treatment systems that have a large surface area (Liwarska-Bizukojc et al. 2018), which is not the case for any of the studied treatment configurations.

Several chemical properties of trace organics including the octanol-water coefficient (K_{ow}) and acid dissociation constant (pKa) affect the partitioning of individual organic pollutants between the solid and liquid phase in a WWTP (Alvarino et al. 2018). Pollutants with a high log K_{ow} should preferentially adsorb to the solid fraction of wastewater (Alvarino et al. 2018). Luo et al. (2014) identified a log K_{ow} threshold of 4, above which pollutants have a high sorption potential. Trace pollutants with a log K_{ow} of less than 2.5 (hydrophilic) have a low sorption potential and will tend to remain in the dissolved phase. For example, many pesticides have a log K_{ow} of less than three, are hydrophilic and predominantly exist in the dissolved phase (Martin Ruel et al. 2012). The solid-water distribution coefficient (K_d) is defined as the ratio between the concentration in the liquid and solid phases of a solution under equilibrium conditions and has been used to determine the fraction of trace pollutants that partition to sludge (Alvarino et al. 2018). For pollutants with a log K_d value of less than 2.5, sorption onto sludge can be considered negligible (Luo et al. 2014). Other authors indicate that K_{ow} alone does not provide a consistent indicator of removal performance (Oppenheimer et al. 2007), indicating that generalized approaches should be used with caution and interpreted appropriately. For example, Alvarino et al. (2018) state that hormones with high K_{ow} will tend to partition to sludge, however Martin Ruel et al. (2012) found that the majority of hormones are generally found in the dissolved phase, highlighting the complexity of these interactions.

Within the literature, there are three unit-process parameters most commonly found to affect pollutant degradation rates: (1) solids retention time (SRT), (2) hydraulic retention time (HRT), and (3) redox condition. Biomass conformation (i.e., size and type), use of adsorbents, pH, and temperature are additional unit process parameters that may vary between treatment configurations and affect pollutant degradation or removal (Alvarino et al. 2018). The pH of wastewater can affect removal of some micropollutants, particularly acidic pharmaceuticals for which the affinity to biosolids was pH affected (Luo et al. 2014). These additional factors were excluded from the current study as they are not expected to vary considerably between the nine treatment configurations, or are unknown, as in the case of biomass conformation.

Solids retention time is a measure of sludge age in secondary biological treatment processes. Longer SRT, in general, allows the growth and proliferation of slower growing microbial partners, and is thought to increase the diversity of organisms present in mixed liquor suspended solids (Luo et al. 2014). Biodegradation of organic pollutants has been shown to exhibit a variable dependence on SRT according to specific chemical characteristics. Oppenheimer et al. (2007) calculated the minimum SRT value required for 80 percent CEC removal (SRT80) for several common CECs. Easily degradable compounds such as ibuprofen and oxybenzone had an SRT80 of less than 5 days, while poorly degradable substances such as galaxolide had SRT80 values of greater than 15 days. Results showed a pronounced plateau in removal performance for SRTs greater than the SRT80 value for each respective chemical.

Hydraulic retention time measures the average period that water is retained in a given treatment unit. Longer HRT allows more time for biodegradation and partitioning to solids. HRT often correlates with SRT and it can therefore be difficult to determine the predominant factor contributing to variations in pollutant removal. The literature shows variable pollutant removal responses to HRT, which in some cases can be marginal (Oppenheimer et al. 2007).

Redox conditions are defined as the tendency of a given redox reaction to occur. In wastewater treatment, redox conditions are categorized into the three broad conditions of aerobic, anoxic, and anaerobic. Aerobic is the presence of free oxygen and indicates positive redox values. Anoxic indicates the presence of bound oxygen (e.g., nitrate) and redox values around zero. Negative redox conditions indicate the absence of free and/or bound oxygen. Redox values are indicators of what types of microbial communities may be active and which chemical reactions may occur in a given wastewater. Research has shown that the removal rate of specific organic pollutants varies according to the redox environment. Overall, aerobic conditions have been shown to more effectively degrade the broadest range of substances. Anaerobic environments had greater removal performance for a small number of compounds, some of which were not degraded in aerobic environments (Alvarino et al. 2018). Anoxic conditions were in many cases found to be a less effective environment for removal of toxic organics, however some chemicals such as diclofenac, clofibric acid, and contrast agents exhibited improved removal under anoxic conditions (Luo et al. 2014). It is suspected that anoxic conditions often found in advanced biological treatment systems, intended for nitrogen removal, are not particularly effective in the degradation of organic micropollutants (Alvarino et al. 2018). The effect of variable redox conditions, such as those present in the level 2 through 5 treatment systems assessed in this study, on toxic organics removal are still understudied (Alvarino et al. 2018).

The preceding unit process and chemical characteristics are some of the primary determinants of the fate of toxic organics within wastewater treatment systems. Those chemicals that partition readily to solids will tend to settle out with the sludge, be subject to anaerobic digestion and exit the plant heading to landfills or land application. Un-degraded dissolved chemicals will exit with the WWTP effluent and enter receiving surface waters.

C.3 Toxic Organics Removal Performance Estimation Methodology

This section describes the data and methods used to quantify a range of estimated removal efficiencies for individual unit processes that compose the 9 WWTP configurations of this study and to combine unit level removal efficiency data to estimate cumulative removal efficiency for each of the 9 WWTP configurations. Low, medium and high estimates of removal efficiency were developed for each unit process and are used to define corresponding estimates of cumulative removal efficiency for each configuration. Limited data were found to define chemical specific removal efficiencies for the advanced biological treatment units of Levels 2 through 5. Therefore, sensitivity approaches were used to assess the importance of biodegradation and solids partitioning in advanced biological treatment units to the overall environmental impact of each respective system described below.

C.3.1 Biological Treatment

Biological treatment processes contribute to both the degradation of toxic organic compounds and additional partitioning to solids by creating biological flocculants that provide adsorption sites and allow time for metabolic degradation and adsorption to take place. Owing to these processes, Miege et al. (2009) note that removal of toxic organics from the liquid portion of biological wastewater treatment is typically in the range of 50-90%, and that nitrogen removal improves the removal efficiency of many pharmaceutical compounds. Additionally, the work of Alvarino et al. (2018) concludes that hybrid biological reactors offer a "good alternative to enhance the removal of organic micropollutants." This is expected to be especially true for pollutants that are not readily degraded in aerobic conditions such as sulfamethoxazole and trimethoprim.

Table C-2 presents a summary of the Level 1, activated sludge removal efficiency of the toxic organics considered in this study. To facilitate discussion of diverse and sometimes divergent treatment performances, this study adopts a classification system for biological treatment systems developed by Oppenheimer et al. (2007) that characterizes overall treatment performance as "good", "moderate" or "low". Good removal efficiency is defined as 80% or greater. Moderate removal efficiency is classified as being in the range of 50-80% removal, while less than 50% removal efficiency is considered poor.

Based on Table C-2, Level 1 treatment systems promote "Good" removal efficiency of at least 30% of the toxic organics examined. The table also includes low, medium and high estimates of removal efficiency for the Level 1 treatment system, which includes the combined effect of primary and secondary treatment processes. Removal efficiency includes both biodegradation and the fraction of toxic organics that partition to solids and are removed in primary and waste activated sludge. Low, medium and high estimates in the table were defined as the 25th percentile, median and 75th percentile of the documented removal efficiencies. In instances where removal efficiencies are negative (i.e. formation), a value of zero has been substituted for use in this study (e.g. carbamazepine).

No removal efficiency data were found for eight of the 43 chemicals including: butylated hydroxyanisole, butylated hydroxytoluene, dilantin, hydrocodone, o-hydroxy atorvastatin, p-hydroxy atorvastatin, TCPP and triclocarban (marked with italics in Table C-2). Proxy values that bracket the extreme values for removal efficiency were used to determine if the removal of these chemicals is significant in the LCA results. Proxy removal efficiency values of 0%, 50%, and 100% were applied in the low, medium and high removal efficiency scenarios, respectively. The selection of 0% and 100% in the low and high removal efficiency scenarios was based on the minimum and maximum removal across the 35 pollutants with reported level 1 removal efficiency data. The removal efficiency estimate in the medium removal efficiency scenario is halfway between the minimum and maximum values.

Preliminary screening and grit removal were assumed to have no effect on partitioning and degradation of toxic organics. Reported removal performance of biological treatment units was assumed to include operation of the secondary clarifier, which is not assessed separately. It is important to note that within the literature it is often not clear whether pollutant removal is the result of solids partitioning or biodegradation.

Studies have shown that expected changes in toxic organic influent concentrations do not produce a noticeable effect on removal efficiency (Oppenheimer et al. 2007). One study looking at estradiol, diclofenac, and nonylphenol showed indistinguishable removal rates at influent concentrations of 1 and 10 µg/L (Liwarska-Bizukojc et al. 2018). Based on this observation, we utilized all available removal data for a given unit process, regardless of reported influent concentration.

Table C-2. Degradation and Removal of Toxic Organics within the Level 1 Biological Treatment System

Chemical Name	Removal – Class[a]	Removal Efficiency - Level 1		
		Low	Medium	High
acetaminophen	Good	92%	100%	100%
androstendione	Good	96%	98%	99%
atenolol	Medium	30%	70%	81%
atorvastatin	Good	88%	90%	92%
atrazine	Poor	26%	28%	29%
benzophenone	Good	79%	80%	80%
bisphenol A	Good	77%	85%	98%
*butylated hydroxyanisole**	N/A	*0%*	*50%*	*100%*
*butylated hydroxytoluene**	N/A	*0%*	*50%*	*100%*
butylbenzyl phthalate	Good	80%	80%	80%
carbamazepine	Poor	0%	0%	22%
N,N-diethyl-meta-toluamide (DEET)	Medium	50%	50%	50%
diclofenac	Poor	22%	49%	68%

Table C-2. Degradation and Removal of Toxic Organics within the Level 1 Biological Treatment System

Chemical Name	Removal – Class[a]	Removal Efficiency - Level 1		
		Low	Medium	High
*dilantin**	N/A	*0%*	*50%*	*100%*
dioctyl phthalate	Medium	70%	70%	70%
estradiol	Good	73%	96%	98%
estrone	Good	14%	81%	95%
galaxolide	Medium	47%	77%	87%
gemfibrozil	Medium	67%	70%	75%
*hydrocodone**	N/A	*0%*	*50%*	*100%*
ibuprofen	Good	80%	96%	99%
iopromide	Poor	0%	0%	8%
meprobamate	Poor	0%	0%	0%
naproxen	Medium	56%	73%	94%
nonylphenol	Medium	62%	78%	89%
octylphenol	Good	63%	80%	95%
*o-hydroxy atorvastatin**	N/A	*0%*	*50%*	*100%*
oxybenzone	Good	72%	80%	89%
*p-hydroxy atorvastatin**	N/A	*0%*	*50%*	*100%*
progesterone	Good	92%	93%	95%
sulfamethoxazole	Poor	31%	50%	66%
tris(2-chloroethyl)phosphate (TCEP)	Medium	50%	50%	50%
*tris(2-chloroisopropyl) phosphate (TCPP)**	N/A	*0%*	*50%*	*100%*
testosterone	Good	86%	90%	95%
triclosan	Medium	58%	71%	76%
trimethoprim	Poor	18%	20%	29%
*triclocarban**	N/A	*0%*	*50%*	*100%*
tonalide	Good	61%	84%	86%
celestolide	Medium	0%	60%	68%
phantolide	Poor	0%	9%	34%
clofibric acid	Medium	50%	52%	53%
musk ketone	Poor	0%	25%	38%
diuron	Poor	30%	30%	30%

a - Removal class refers to the qualitative removal efficiency classification thresholds defined by (Oppenheimer et al. 2007). Poor = <50% removal, Medium = 50-80% removal, Good = >80% removal. Classifications were assigned based on the median removal efficiency.

* Marked and italicized chemicals lack data on removal efficiency and use 0%, 50%, and 100% as proxy removal efficiency values to determine significance in LCA results.

C.3.2 Advanced Biological Treatment

The majority of literature related to degradation and removal of toxic organics considers the removal efficiency of entire WWTPs or advanced tertiary processes (e.g. RO, ozonation). Because of this limitation it was not possible to determine individualized removal efficiencies that correspond to each of the advanced biological treatment units. Therefore, a more generalized approach was used to define low, medium and high estimates of removal efficiency for advanced biological treatment works.

As a conservative estimate, the low removal efficiency of the advanced treatment systems was set equal to the low removal efficiency of the Level 1 treatment system, which was based on the 25th percentile of documented values. The medium removal efficiency scenario value for Levels 2 through 5 was established assuming an increase in removal performance that is 25% ($EF_{inc.y}$) beyond the Level 1 median removal efficiency. The high removal efficiency scenario value assumes a removal performance that is 50% ($EF_{inc.y}$) above the Level 1 median removal efficiency as calculated in Equation C-1. For example, assuming a median removal efficiency for Level 1 treatment of 50%, the removal efficiency of advanced biological treatment units would be 62.5% and 75% (EF_x) in the medium and high removal efficiency scenarios. The proposed increases in removal efficiency attributed to Levels 2 through 5 are indicative of increased HRT, SRT and variable redox conditions that are known to increase removal efficiency of many toxic organics as discussed in Section C.2 and document in the removal notes of Table C-3.

$$EF_x = EF_{med} + [(1 - EF_{med}) \times EF_{\mathrm{inc.y}}]$$

Equation C-1

Where:

EF_x = Adjusted removal efficiency of scenario x

EF_{med} = Level 1 median removal efficiency

$EF_{inc.y}$ = Removal efficiency increase factor y (varies by scenario)

Table C-3 summarizes the calculated advanced biological process removal efficiency values for individual organic pollutants used in the sensitivity analysis. The notes in Table C-3 describe additional information that sheds light on how the studied compounds may respond to alternate redox conditions and longer HRTs and SRTs that characterize the advanced biological treatment units of Levels 2 through 5. As noted above, several authors state that current evidence indicates that comparable or improved removal efficiencies can be expected in advanced biological treatment works. Examination of removal notes in Table C-3 often confirms this perspective, however, there are also numerous instances where the findings of authors contradict one another. For example, Lakshminarasimman et al. (2018) identified improved removal of bisphenol A at high SRTs, whereas (Luo et al. 2014) identified no significant effect of SRT on removal efficiency. What is clear from Table C-2 and Table C-3 is the conclusion that individual toxic organics respond differently to the range of conditions that characterize both activated sludge and advance nutrient removal WWTPs. The sensitivity approach described in this section will allow the analysis to judge the importance of removal efficiency estimates on final LCA results.

Table C-3. Toxic Organic Removal Efficiency of Advanced Biological Treatment Process

Chemical Name	Level 1	Removal Efficiency - Advanced Biological Processes (Levels 2-5)			Removal Notes
	Median	Low	Medium	High	
acetaminophen	100%	92%	100%	100%	
androstendione	98%	96%	98%	99%	
atenolol	70%	30%	78%	90%	Biodegrades in all three redox conditions. Degradation was greatest under aerobic conditions (Lakshminarasimman et al. 2018) Better removal at high SRT (Lakshminarasimman et al. 2018) Less than 20% removal under aerobic conditions (Miege et al. 2009) Poor to moderate removal in activated sludge, 45-80% (Martin Ruel et al. 2012)
atorvastatin	90%	88%	93%	96%	
atrazine	28%	26%	46%	64%	
benzophenone	80%	79%	85%	90%	
bisphenol A	85%	77%	89%	99%	Biotransformation is catalyzed by nitrifying conditions (Lakshminarasimman et al. 2018) Not affected by SRT (Luo et al. 2014) Better removal at high SRT (Lakshminarasimman et al. 2018)
*butylated hydroxyanisole**	*50%*	*0%*	*63%*	*100%*	
*butylated hydroxytoluene**	*50%*	*0%*	*63%*	*100%*	
butylbenzyl phthalate	80%	80%	85%	90%	
carbamazepine	0%	0%	25%	61%	Poor removal (Miege et al. 2009; Martin Ruel et al. 2012) Removal less than 20% under all redox conditions (Alvarino et al. 2018; Lakshminarasimman et al. 2018) Removal less than 25% under aerobic conditions (Jelic, (Miege et al. 2009; Jelic et al. 2011)
N,N-diethyl-meta-toluamide (DEET)	50%	50%	63%	75%	Degradation is primarily aerobic (Lakshminarasimman et al. 2018) Poor removal in anaerobic conditions

Table C-3. Toxic Organic Removal Efficiency of Advanced Biological Treatment Process

Chemical Name	Level 1	Removal Efficiency - Advanced Biological Processes (Levels 2-5)			Removal Notes
	Median	Low	Medium	High	
					(Lakshminarasimman et al. 2018) Better removal at high SRT (Lakshminarasimman et al. 2018)
diclofenac	49%	22%	62%	84%	Removal <20% under all redox conditions (Alvarino et al. 2018) Anoxic conditions have a positive influence on removal (Luo et al. 2014) Exhibited inconsistent overall removal. (Jelic et al. 2011) Poor to moderate removal in activated sludge, less than 60% (Miege et al. 2009) Poor removal in activated sludge, <50% (Martin Ruel et al. 2012)
*dilantin**	*50%*	*0%*	*63%*	*100%*	
dioctyl phthalate	70%	70%	78%	85%	Poor to moderate removal in all three redox conditions (Luo et al. 2014) High HRT increases removal to sludge (Luo et al. 2014)
estradiol	96%	73%	97%	99%	Biotransformation is catalyzed by nitrifying conditions (Lakshminarasimman et al. 2018) Better removal at high SRT (Lakshminarasimman et al. 2018) Moderate to good removal in activated sludge, 65-100% (Miege et al. 2009) Good degradation in aerobic conditions (Alvarino et al. 2018) Moderate degradation in anaerobic conditions (Alvarino et al. 2018)

Table C-3. Toxic Organic Removal Efficiency of Advanced Biological Treatment Process

Chemical Name	Level 1	Removal Efficiency - Advanced Biological Processes (Levels 2-5)			Removal Notes
	Median	Low	Medium	High	
estrone	81%	14%	85%	98%	Biotransformation is catalyzed by nitrifying conditions (Lakshminarasimman et al. 2018) Better removal at high SRT (Lakshminarasimman et al. 2018) Moderate to good removal in activated sludge, 45-100% (Miege et al. 2009) Good degradation in aerobic conditions (Alvarino et al. 2018) Moderate degradation in anaerobic conditions (Alvarino et al. 2018)
galaxolide	77%	47%	83%	93%	Poor degradation (Oppenheimer et al. 2007) Good aerobic degradation (Alvarino et al. 2018) Moderate anoxic degradation (Alvarino et al. 2018) Poor anaerobic degradation (Alvarino et al. 2018) Poor to moderate removal in activated sludge, 25-75% (Miege et al. 2009)
gemfibrozil	70%	67%	78%	87%	Moderate removal in activated sludge (Miege et al. 2009)
*hydrocodone**	*50%*	*0%*	*63%*	*100%*	
ibuprofen	96%	80%	97%	100%	Good degradation (Oppenheimer et al. 2007) Good aerobic degradation (Alvarino et al. 2018) Poor anaerobic and anoxic degradation (Alvarino et al. 2018) Biotransformation is catalyzed by nitrifying conditions (Lakshminarasimman et al. 2018) Better removal at high SRT (Lakshminarasimman et al. 2018) Moderate to good removal in activated sludge, 50-100% (Miege et al. 2009)

Table C-3. Toxic Organic Removal Efficiency of Advanced Biological Treatment Process

Chemical Name	Level 1	Removal Efficiency - Advanced Biological Processes (Levels 2-5)			Removal Notes
	Median	Low	Medium	High	
iopromide	0%	0%	25%	54%	Anoxic conditions have a positive influence on removal (Luo et al. 2014) Biotransformation is catalyzed by nitrifying conditions (Lakshminarasimman et al. 2018) Demonstrated no removal in activated sludge (Miege et al. 2009)
meprobamate	0%	0%	25%	50%	
naproxen	73%	56%	79%	97%	Good degradation in aerobic and anaerobic conditions (Alvarino et al. 2018) Poor degradation in anoxic conditions (Alvarino et al. 2018) Biotransformation is catalyzed by nitrifying conditions (Lakshminarasimman et al. 2018) Better removal at high SRT (Lakshminarasimman et al. 2018) Good degradation. Does not accumulate in sludge (Jelic et al. 2011) Moderate to good removal in activated sludge, 65-95% (Miege et al. 2009)
nonylphenol	78%	62%	83%	94%	SRT greater than 20 hours improves removal (Luo et al. 2014)
octylphenol	80%	63%	85%	98%	
*o-hydroxy atorvastatin**	*50%*	*0%*	*63%*	*100%*	
oxybenzone	80%	72%	85%	95%	Good degradation (Oppenheimer et al. 2007)
*p-hydroxy atorvastatin**	*50%*	*0%*	*63%*	*100%*	
progesterone	93%	92%	95%	97%	

Table C-3. Toxic Organic Removal Efficiency of Advanced Biological Treatment Process

Chemical Name	Level 1	Removal Efficiency - Advanced Biological Processes (Levels 2-5)			Removal Notes
	Median	Low	Medium	High	
sulfamethoxazole	50%	31%	62%	83%	Good degradation in anaerobic conditions (Alvarino et al. 2018) Poor degradation in anoxic and aerobic conditions (Alvarino et al. 2018) Comparable degradation under varying redox conditions (Lakshminarasimman et al. 2018) Mixed results on the effect of SRT (Lakshminarasimman et al. 2018) Poor to good removal in activated sludge, 35-80% (Miege et al. 2009)
tris(2-chloroethyl)phosphate (TCEP)	50%	50%	63%	75%	
*tris(2-chlorisopropyl) phosphate (TCPP)**	*50%*	*0%*	*63%*	*100%*	
testosterone	90%	86%	93%	97%	
triclosan	71%	58%	78%	88%	Better degradation under aerobic conditions (Lakshminarasimman et al. 2018) SRT greater than 20 hours improves removal (Luo et al. 2014) Removal rates do not vary with increasing SRT (Lakshminarasimman et al. 2018)
trimethoprim	20%	18%	40%	65%	Good degradation anaerobic conditions (Alvarino et al. 2018) Poor degradation under aerobic and anoxic conditions (Alvarino et al. 2018) Poor degradation under aerobic conditions, <40% (Miege et al. 2009) Demonstrated degradation under anaerobic and anoxic conditions (Lakshminarasimman et al. 2018) Mixed results on the effect of SRT (Lakshminarasimman et al. 2018)

Table C-3. Toxic Organic Removal Efficiency of Advanced Biological Treatment Process

Chemical Name	Level 1	Removal Efficiency - Advanced Biological Processes (Levels 2-5)			Removal Notes
	Median	Low	Medium	High	
					No significant removal under aerobic conditions (Jelic et al. 2011)
*triclocarban**	*50%*	*0%*	*63%*	*100%*	
tonalide	84%	61%	88%	93%	Good degradation under aerobic conditions (Alvarino et al. 2018) Moderate degradation under anaerobic and anoxic conditions (Alvarino et al. 2018) Poor to good degradation in activated sludge, 35-85% (Miege et al. 2009)
celestolide	60%	0%	70%	84%	Good degradation under aerobic conditions (Alvarino et al. 2018) Moderate degradation under anaerobic and anoxic conditions (Alvarino et al. 2018) Poor to moderate removal in activated sludge, less than 60% (Miege et al. 2009) Volatilization is a significant loss pathway, approximately 16% (Luo et al. 2014)
phantolide	9%	0%	32%	67%	
clofibric acid	52%	50%	64%	76%	Anoxic conditions have a positive influence on removal (Luo et al. 2014) Poor removal in activated sludge, less than 50% (Miege et al. 2009)
musk ketone	25%	0%	44%	69%	Poor degradation under aerobic conditions (Miege et al. 2009)
diuron	30%	30%	48%	65%	Poor degradation in activated sludge (Martin Ruel et al. 2012)

* Marked and italicized chemicals lack data on removal efficiency and use 0%, 50%, and 100% as proxy removal efficiency values to determine significance in LCA results.

It was also necessary to estimate the fraction of pollutant removal that is attributable to solids partitioning as opposed to biological degradation. Miege et al. (2009) performed an in-depth review of studies looking at the fate of PPCPs in WWTPs and noted that the vast majority (87%) of studies focus on the aqueous phase. None of the reviewed studies looked at both aqueous and solid phases of PPCPs simultaneously. As noted earlier, (Martin Ruel et al. 2012) proposed that up to two-thirds of pollutant removal can be attributed to solids partitioning. Other authors disagree with this conclusion, proposing that the majority of removal efficiency is due to biodegradation (Liu et al. 2009). It is beyond the scope of this analysis to attempt to resolve this discrepancy.

In the low efficiency scenario, it was assumed that two-thirds of removal efficiency is due to solids partitioning (one-third biodegradation). The analysis does not specify if this removal occurs during primary or secondary clarification. The medium removal efficiency estimates assume a 50-50 split between solids partitioning and biodegradation, while the high removal efficiency estimates assume that one-third of removal is attributable to solids partitioning (two-thirds biodegradation). All assumptions related to solids partitioning were applied to the corresponding removal efficiency as documented in Table C-2.

C.3.3 Anaerobic Digestion

All 9 treatment systems include anaerobic digestion as a sludge processing step, and a low, medium and high estimate of removal efficiency was established for each of the 43 pollutants using the 25th percentile, median and 75th percentile degradation values. The reviewed research on anaerobic digestion deals more consistently with pollutants in both the liquid and solid phase. Removal efficiency measurements for anaerobic digestion tend to refer to biodegradation explicitly. Pollutant specific data were identified for 20 of the 43 pollutants and are summarized in Table C-4. Removal efficiency was set as zero for pollutants reporting negative values. Proxy values that bracket the extreme values for removal efficiency were used to determine if the removal of the 23 remaining chemicals is significant in the LCA results. Proxy removal efficiency values of 0%, 50%, and 100% were applied in the low, medium and high removal efficiency scenarios, respectively. The selection of 0% and 100% in the low and high removal efficiency scenarios was based on the minimum and maximum removal across the 20 pollutants with reported AD removal efficiency data. The removal efficiency estimate in the medium removal efficiency scenario is halfway between the minimum and maximum values.

A study by Malmborg and Magnér (2015) looked at several sludge treatment steps including pasteurization, thermal hydrolysis, advanced oxidation and ammonia treatment, concluding that anaerobic digestion was the most effective at removing organic substances. Toxic organics pollutants not degraded in anaerobic digestion remain with the solids for disposal in landfills.

Table C-4. Toxic Organic Removal Efficiency of Anaerobic Digestion

Chemical Name	Removal Efficiency (%)			
	Low	Medium	High	Range (min-max)
acetaminophen	89%	89%	96%	85-100
*androstendione**	*0%*	*50%*	*100%*	*N/A*
atenolol	61%	77%	89%	39-96

Table C-4. Toxic Organic Removal Efficiency of Anaerobic Digestion

Chemical Name	Removal Efficiency (%)			
	Low	Medium	High	Range (min-max)
*atorvastatin**	*0%*	*50%*	*100%*	*N/A*
*atrazine**	*0%*	*50%*	*100%*	*N/A*
*benzophenone**	*0%*	*50%*	*100%*	*N/A*
bisphenol A	12%	30%	84%	0-100
*butylated hydroxyanisole**	*0%*	*50%*	*100%*	*N/A*
*butylated hydroxytoluene**	*0%*	*50%*	*100%*	*N/A*
butylbenzyl phthalate	93%	93%	93%	93-93
carbamazepine	0%	0%	7%	0-15
N,N-diethyl-meta-toluamide (DEET)	0%	0%	0%	0-0
diclofenac	21%	34%	55%	0-78
*dilantin**	*0%*	*50%*	*100%*	*N/A*
*dioctyl phthalate**	*0%*	*50%*	*100%*	*N/A*
estradiol	85%	93%	96%	75-100
estrone	75%	79%	85%	70-95
galaxolide	58%	65%	73%	50-80
gemfibrozil	0%	0%	0%	0-0
*hydrocodone**	*0%*	*50%*	*100%*	*N/A*
ibuprofen	21%	27%	44%	0-70
iopromide	16%	23%	31%	8-38
*meprobamate**	*0%*	*50%*	*100%*	*N/A*
naproxen	86%	89%	93%	76-96
nonylphenol	43%	86%	100%	0-100
*octylphenol**	*0%*	*50%*	*100%*	*N/A*
*o-hydroxy atorvastatin**	*0%*	*50%*	*100%*	*N/A*
*oxybenzone**	*0%*	*50%*	*100%*	*N/A*
*p-hydroxy atorvastatin**	*0%*	*50%*	*100%*	*N/A*
*progesterone**	*0%*	*50%*	*100%*	*N/A*
sulfamethoxazole	79%	99%	100%	23-100
*tris(2-chloroethyl)phosphate (TCEP)**	*0%*	*50%*	*100%*	*N/A*
*tris(2-chloroisopropyl) phosphate (TCPP)**	*0%*	*50%*	*100%*	*N/A*
*testosterone**	*0%*	*50%*	*100%*	*N/A*
triclosan	45%	53%	55%	30-55
trimethoprim	90%	96%	99%	80-100
triclocarban	20%	40%	53%	0-65
tonalide	59%	65%	67%	52-68
*celestolide**	*0%*	*50%*	*100%*	*N/A*
*phantolide**	*0%*	*50%*	*100%*	*N/A*
*clofibric acid**	*0%*	*50%*	*100%*	*N/A*
*musk ketone**	*0%*	*50%*	*100%*	*N/A*
*diuron**	*0%*	*50%*	*100%*	*N/A*

* Marked and italicized chemicals lack data on removal efficiency and use 0%, 50%, and 100% as proxy removal efficiency values to determine significance in LCA results.

C.3.4 Chemical Phosphorus Removal

The effect of chemical phosphorus removal was considered to the extent that it is expected to enhance partitioning and settling of toxic organics. Alexander et al. (2012) reviewed the available literature on the effect of chemical coagulation on trace organic pollutant removal. They found that chemical phosphorus removal (i.e. chemical coagulation) has been demonstrated to be an inefficient means of removing trace organics from the liquid phase of wastewater. Across different categories of organic chemicals, average removal efficiency of chemical coagulation varies between six and 77%.

Table C-5 lists low, medium and high removal efficiency scenario values used in this study. Pollutant specific data was identified for 9 of the 43 toxic organic compounds. Twenty-eight of the 43 chemicals were assigned removal efficiency data based on their assigned chemical class, as listed in Table C-5. No data was identified for 15 of the toxic organic chemicals, and they were assigned the median removal efficiency across all chemical classes of 34% (Alexander et al. 2012).

Six of the nine treatment systems included in this study utilize chemically enhanced secondary clarification. The low removal efficiency scenario assumes no increase in removal efficiency relative to secondary clarification without a preceding alum addition. The medium and high removal efficiency scenarios assume that 50% and 100% of the identified chemical coagulation removal efficiencies are in addition to the removal realized by the combined biological process and secondary clarification (without alum addition). The range of these assumptions is wide to accommodate the fact that Alexander et al. (2012) presents chemical coagulation as a stand-alone unit process. The precise relationship between the removal efficiency of stand-alone chemical coagulation and chemically enhanced secondary clarification is not known.

Table C-5. Toxic Organic Removal Efficiency of Chemical Coagulation

Chemical Name	Chemical Class[a]	Removal Efficiency - Chemical Coagulation[b]		
		Low	Medium	High
acetaminophen[3]	N/A	-	24%	48%
androstendione	hormone	-	9.5%	19%
atenolol[3]	beta-blocker	-	9.5%	19%
atorvastatin	hypolipidemic agent	-	13%	26%
atrazine	pesticide	-	15%	30%
*benzophenone**	*N/A*	-	*17%*	*34%*
*bisphenol A**	*N/A*	-	*17%*	*34%*
butylated hydroxyanisole	beta-blocker	-	17%	34%
butylated hydroxytoluene	beta-blocker	-	17%	34%
butylbenzyl phthalate	phthalate	-	25%	49%
carbamazepine[c]	N/A	-	15%	30%
N,N-diethyl-meta-toluamide (DEET)	pesticide	-	15%	30%
diclofenac[c]	anti-inflammatory	-	25%	50.0%
*dilantin**	*N/A*	-	*17%*	*34%*
dioctyl phthalate	phthalate	-	25%	49%
estradiol[c]	hormone	-	1.0%	2.0%

Table C-5. Toxic Organic Removal Efficiency of Chemical Coagulation

Chemical Name	Chemical Class[a]	Removal Efficiency - Chemical Coagulation[b]		
		Low	Medium	High
estrone[c]	hormone	-	6.0%	12%
galaxolide	beta-blocker	-	39%	77%
gemfibrozil	musk fragrance	-	13%	26%
hydrocodone[c]	N/A	-	12%	24%
ibuprofen	anti-inflammatory	-	18%	35%
*iopromide**	*N/A*	-	*17%*	*34%*
*meprobamate**	*N/A*	-	*17%*	*34%*
naproxen[c]	anti-inflammatory	-	11%	23%
*nonylphenol**	*N/A*	-	*17%*	*34%*
*octylphenol**	*N/A*	-	*17%*	*34%*
o-hydroxy atorvastatin	hypolipidemic agent	-	13%	26%
*oxybenzone**	*N/A*	-	*17%*	*34%*
p-hydroxy atorvastatin	hypolipidemic agent	-	13%	26%
progesterone[c]	hormone	-	6.3%	13%
sulfamethoxazole	antibiotic	-	20%	39%
*tris(2-chloroethyl)phosphate (TCEP)**	*N/A*	-	*17%*	*34%*
*tris(2-chloroisopropyl) phosphate (TCPP)**	*N/A*	-	*17%*	*34%*
testosterone	hormone	-	9.5%	19%
triclosan	pesticide	-	15%	30%
trimethoprim	antibiotic	-	20%	39%
*triclocarban**	*N/A*	-	*17%*	*34%*
tonalide	musk fragrance	-	28%	56%
celestolide	musk fragrance	-	39%	77%
phantolide	musk fragrance	-	39%	77%
clofibric acid	hypolipidemic agent	-	13%	26%
musk ketone	musk fragrance	-	39%	77%
*diuron**	*N/A*	-	*17%*	*34%*

a - Chemical classes are based on trace organic compound classes defined in Table 4 of (Alexander et al. 2012).

b - Removal efficiency of chemical coagulation is in addition to the removal efficiencies for combined biological treatment and secondary clarification listed in Table 1-3 and Table 1-4.

c - Chemical specific removal efficiency data was drawn from (Alexander et al. 2012).

* Marked values use median removal efficiency of all chemical classes defined in Alexander et al. (2012) as the proxy removal efficiency value.

C.3.5 Membrane Filtration

For the fraction of toxic organics that remain in the dissolved phase there are subsequent unit processes to consider following biological treatment. Media filters and ultrafiltration membranes do not physically screen toxic organic compounds as the molecules are often two orders of magnitude smaller than the membrane pores (Oppenheimer et al. 2007; Alvarino et al. 2018), or more in the case of sand filters. Ultrafiltration membranes replace traditional secondary clarifiers in Levels 4-2 and 5-2. In this capacity they increase total suspended solids removal by approximately 0.5%, which was considered negligible from the perspective of increasing the fraction of toxic organics exiting the WWTP with the sludge fraction. There is however evidence that certain toxic organics can be sorbed onto hydrophobic filtration membranes via electrostatic interactions and within the cake layer (Alvarino et al. 2018). Retention of toxic organics on filtration membranes was not able to be assessed in this study.

Reverse osmosis has been shown to be effective at removing residual toxic organics in secondary effluent to less-than-detectable levels (Oppenheimer et al. 2007). Reverse osmosis removal efficiency measurement data was found for 37 of the 43 toxic organic chemicals considered. Table C-6 lists the low, medium and high removal efficiency estimates calculated using the 25th percentile, median and 75th percentile of documented values. Data on the removal efficiency of reverse osmosis was not found for six chemicals. Proxy values that bracket the extreme values for removal efficiency were used to determine if the removal of these chemicals is significant in the LCA results. Proxy removal efficiency values of 0%, 49.9%, and 99.9% were applied in the low, medium and high removal efficiency scenarios, respectively. The selection of 0% and 99.9% in the low and high removal efficiency scenarios was based on the minimum and maximum removal across the 37 pollutants with reported RO removal efficiency data. The removal efficiency estimate in the medium removal efficiency scenario is halfway between the minimum and maximum values.

Table C-6. Toxic Organic Removal Efficiency of Reverse Osmosis

Chemical Name	Removal Efficiency - Reverse Osmosis		
	Low	Medium	High
acetaminophen	89%	90%	91%
androstendione	31%	62%	71%
atenolol	98%	98%	99%
atorvastatin	98%	98%	99%
atrazine	49%	97%	98%
benzophenone	40%	69%	98%
bisphenol A	98%	99%	99%
butylated hydroxyanisole	98%	98%	99%
butylated hydroxytoluene	98%	98%	99%
butylbenzyl phthalate	98%	98%	99%
carbamazepine	99%	99%	99%
N,N-diethyl-meta-toluamide (DEET)	94%	95%	99%
diclofenac	95%	97%	97%
dilantin	99%	99%	100%
dioctyl phthalate	98%	98%	99%
estradiol	-	80%	92%
estrone	90%	91%	95%
galaxolide	54%	88%	99%
gemfibrozil	98%	99%	100%
hydrocodone	98%	98%	99%
ibuprofen	97%	99%	99%
iopromide	98%	99%	99%
meprobamate	99%	100%	100%
naproxen	94%	96%	99%
nonylphenol	98%	98%	99%

Table C-6. Toxic Organic Removal Efficiency of Reverse Osmosis

Chemical Name	Removal Efficiency - Reverse Osmosis		
	Low	Medium	High
octylphenol	98%	98%	99%
o-hydroxy atorvastatin	98%	98%	99%
oxybenzone	85%	93%	95%
p-hydroxy atorvastatin	98%	98%	99%
progesterone	-	80%	97%
sulfamethoxazole	98%	99%	100%
TCEP	93%	95%	96%
TCPP	98%	98%	99%
testosterone	49%	97%	98%
triclosan	89%	92%	95%
trimethoprim	99%	99%	100%
*triclocarban**	*98%*	*98%*	*100%*
*tonalide**	*98%*	*98%*	*100%*
*celestolide**	*98%*	*98%*	*100%*
*phantolide**	*98%*	*98%*	*100%*
*clofibric acid**	*98%*	*98%*	*100%*
musk ketone	56%	68%	79%
*diuron**	*98%*	*98%*	*100%*

* Marked and italicized chemicals lack data on removal efficiency and use 0%, 50%, and 100% as proxy removal efficiency values to determine significance in LCA results.

C.3.6 Other Processes

Media filtration has not been shown to provide considerable removal beyond that provided by preceding secondary treatment processes, less than 15 percent (Oppenheimer et al. 2007). Removal efficiency data of standalone sand filters were identified for eight of the 43 pollutants. The low and medium removal efficiency scenarios both assume zero percent removal based on the 25th percentile and median of the eight identified values. The high removal efficiency scenarios assume 11% removal, based on the 75th percentile. The described values were applied to all 43 pollutants and were assumed to constitute additional biodegradation.

Chlorination, dechlorination and the sludge thickening processes were assumed not to affect the fate of toxic organics within the WWTP.

C.3.7 Total System Level Performance

Removal efficiency estimates for individual unit processes listed in Table C-2 through Table C-6 were used as inputs to Equation C-2 to calculate cumulative removal from the liquid effluent. The fraction of influent toxic organics that accumulate in sludge was estimated by adding the fraction of removal efficiency attributable to solids partitioning from the combined primary and secondary biological unit processes ($r_b \times r_s$) to the additional sludge removal that results from chemically enhanced secondary clarification (r_c) less the fraction of each compound that is degraded during anaerobic digestion ($1-r_{AD}$) as summarized in Equation C-2.

$$\boldsymbol{R_{s-total}} = [(\boldsymbol{r_b} \times \boldsymbol{r_s}) + \boldsymbol{r_c}] \times (\mathbf{1} - \boldsymbol{r_{AD}})]$$

Equation C-2

where

$R_{s\text{-}total}$ = total fraction of pollutant (in influent) that accumulates in sludge

r_b = fraction of pollutant removed in primary and secondary treatment, includes degradation and partitioning to solids.

r_s = fraction of primary and secondary removal efficiency attributable to solids partitioning and sludge removal (percentage of r_b).

r_c = additional fraction of pollutant removed by chemically enhanced secondary clarification.

r_{AD} = fraction of pollutant degraded during anaerobic digestion.

Table C-7 summarizes the cumulative fate of toxic organics across the nine system configurations. The presented values represent weighted average degradation and removal efficiencies across the 43 included chemicals and include the estimated effect of the listed unit processes. The median influent concentration of the 43 toxic organic chemicals was used as the weighting factor.

- Primary clarification, biological treatment and secondary/tertiary clarification - combined removal efficiency. Median values for the Level 1 low, medium and high removal efficiency scenarios range from 47 to 87% removal. Median values for the Level 2 through 5 low, medium and high removal efficiency scenarios range from 47 to 93%. Removal efficiency includes partitioning to solids and biodegradation.
- Chemical phosphorus removal – contributes additional partitioning to solids. Median values for the low, medium and high removal efficiency scenarios range from zero to 34% additional partitioning to solids.
- Sand filtration – assumed to increase biodegradation (minor). Low, medium and high removal efficiency scenario values range from 0 to 11% removal.
- Anaerobic digestion – biodegrades a fraction of toxic organics that partition to sludge. Median values for the low, medium and high removal efficiency scenarios range from 0 to 100% biodegradation.
- Reverse Osmosis – physically separates toxic organics from the liquid stream of wastewater, concentrating these substances in the brine solution for underground injection. Median values for the low, medium and high removal efficiency scenarios range from 98 to 99% removal from the liquid fraction of wastewater.

Table C-7. Summary of Total Toxic Organics Fate in the Nine Treatment Systems[a]

Treatment Level	Fraction Degraded			Fraction Removed (includes solids)		
	Low	Mid	High	Low	Mid	High
L1	51.7%	69.9%	84.8%	67.1%	81.1%	89.1%

Table C-7. Summary of Total Toxic Organics Fate in the Nine Treatment Systems[a]

Treatment Level	Fraction Degraded			Fraction Removed (includes solids)		
	Low	Mid	High	Low	Mid	High
L2-1	51.7%	73.5%	89.7%	67.1%	85.8%	94.6%
L2-2	51.7%	73.5%	89.7%	67.1%	85.8%	94.6%
L3-1	51.7%	74.9%	91.6%	67.1%	88.5%	97.0%
L3-2	51.7%	74.9%	91.6%	67.1%	88.5%	97.0%
L4-1	51.7%	74.9%	91.6%	67.1%	88.5%	97.0%
L4-2	51.7%	74.9%	91.2%	67.1%	88.5%	96.7%
L5-1	51.7%	74.9%	91.2%	94.2%	98.5%	99.7%
L5-2	51.7%	74.9%	91.2%	92.7%	98.0%	99.5%

a - Table values represent the cumulative effect of all the described treatment processes, calculated as a weighted average of the 43 toxic organics using influent concentration as the weighting factor.

C.3.8 Toxicity Characterization Factors

Table C-8 presents the characterization factors used to estimate toxicity impacts associated with toxic organics in treatment plant effluent and sludge. Not all toxic organics included in this study have associated characterization factors listed in the most recent versions of USEtox™, versions 2.02 and 2.11. Characterization factors for several of the pollutants were previously calculated by other authors (Rahman et al. 2018, Alfonsín et al. 2014). Characterization factors that were not otherwise available were estimated using the median value of all other toxic organic pollutants for which data was available. Sources for individual characterization factors are listed in Table C-8.

Table C-8. Toxic Organics Toxicity Characterization Factors, USEtox™ version 2.11

Chemical Name	USETox Chemical Name	Freshwater Ecotoxicity, (CTUe, PAF m^3.day/kg emitted)		Human health cancer, freshwater (CTUh, cases/kg emitted)		Human Health noncancer, freshwater (CTUh, cases/kg emitted)	
		Emissions to Freshwater	Emissions to Natural Soil	Emissions to Freshwater	Emissions to Natural Soil	Emissions to Freshwater	Emissions to Natural Soil
acetaminophen	acetamide	2.6	0.88	2.5E-7	8.5E-8	3.5E-6[d]	1.4E-7[d]
androstendione	androstenedione	5.1E+3	5.7E+2	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
atenolol	N/A[c]	1.2E+2[a]	57	-[d]	-[d]	8.0E-3[a]	4.0E-3[a]
atorvastatin	N/A[c]	8.4E+3[a]	4.2E+3[a]	-[d]	-[d]	9.6E-8[a]	4.8E-8[a]
atrazine	atrazine	8.7E+4	3.4E+3	3.7E-6	1.5E-7	4.3E-6	1.7E-7
benzophenone	benzophenone	5.2E+3	94	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
bisphenol A	bisphenol A	8.dE+3	2.0E+2	-	-	1.1E-6[d]	2.6E-8[d]
butylated hydroxyanisole	butylated hydroxyanisole	8.8E+3	1.6E+2	3.4E-7	1.0E-8	3.5E-6[d]	1.4E-7[d]
butylated hydroxytoluene	2,6-DI-T-BUTYL-4-METHYLPHENOL (BHT)	1.8E+3	3.6	3.4E-7	3.6E-9	3.5E-6[d]	1.4E-7[d]
butylbenzyl phthalate	phthalate, butyl-benzyl-	5.7E+3	9.1	5.0E-8	1.0E-9	7.3E-8	1.5E-9
carbamazepine	carbamazepine	7.8E+2	93	-	-	2.3E-6	2.8E-7
N,N-diethyl-meta-toluamide (DEET)	DEET [N,N,-DIET-3-ME BENZAMIDE]	2.2E+2	11	-	-	3.5E-6[d]	1.4E-7[d]
diclofenac	diclofenac	1.9E+3	1.5E+2	-	-	1.6E-4	1.2E-5
dilantin	phenytoin	1.0E+5[a]	5.0E+4[a]	2.9E-6	1.8E-7	5.3E-4[a]	2.7E-4[a]
dioctyl phthalate	phthalate, dioctyl-	30	0.01	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
estradiol	estradiol	2.2E+8	2.3E+6	-	-	1.0E-3[b]	1.4E-6[b]
estrone	estrone	2.4E+4	5.7E+2	-[d]	-[d]	3.2E-4[b]	5.4E-7[b]
galaxolide	N/A[3]	3.3E+5[b]	17[b]	-[d]	-[d]	5.0E-7[b]	4.7E-9[b]
gemfibrozil	gemfibrozil	7.0E+3[d]	1.6E+2[d]	3.1E-6	1.3E-7	3.5E-6[d]	1.4E-7[d]
hydrocodone	N/A	1.4E+4[a]	7.0E+3[a]	-[d]	-[d]	2.1E-5[a]	1.1E-4[a]
ibuprofen	ibuprofen	2.3E+2	7.3	-	-	3.7E-7[2]	1.7E-8[2]

Table C-8. Toxic Organics Toxicity Characterization Factors, USEtox™ version 2.11

		Freshwater Ecotoxicity, (CTUe, PAF m^3.day/kg emitted)		Human health cancer, freshwater (CTUh, cases/kg emitted)		Human Health noncancer, freshwater (CTUh, cases/kg emitted)	
Chemical Name	**USETox Chemical Name**	**Emissions to Freshwater**	**Emissions to Natural Soil**	**Emissions to Freshwater**	**Emissions to Natural Soil**	**Emissions to Freshwater**	**Emissions to Natural Soil**
iopromide	iopromide	24	10	-	-	2.4E-7	1.0E-7
meprobamate	N/A[c]	9.2E+2[a]	4.6E+2[a]	-[d]	-[d]	1.0E-c[a]	5.2E-4[a]
naproxen	N/A[c]	9.6E+2[b]	4.9[b]	-[d]	-[d]	3.0E-7[b]	6.6E-9[b]
nonylphenol	nonylphenol	1.6E+4	8.8	-[d]	-[d]	5.6E-6[b]	7.1E-10[b]
octylphenol	N/A[c]	3.3E+5[b]	1.4E+2[b]	-[d]	-[d]	4.3E-6[b]	3.3E-9[b]
o-hydroxy atorvastatin	N/A[c]	7.0E+3[d]	1.6E+2[d]	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
oxybenzone	N/A[c]	4.4E+4[a]	2.2E+4[a]	-[d]	-[d]	2.4E-6[a]	1.3E-6[a]
p-hydroxy atorvastatin	N/A[c]	7.0E+3[d]	1.6E+2[d]	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
progesterone	N/A[c]	1.6E+4[a]	7.7E+3[a]	-[d]	-[d]	1.3E-5[a]	6.1E-6[a]
sulfamethoxazole	sulfamethoxazole	4.7E+3	1.2E+3	-	-	4.7E-7	1.2E-7
tris(2-chloroethyl)phosphate (TCEP)	tris(2-carboxyethyl)phosphine	7.0E+3[d]	1.6E+2[d]	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
tris(2-chloroisopropyl) phosphate (TCPP)	TRI-2-CHLOROETHYL PHOSPHATE	4.4E+2	1.1E+2	1.1E-6	2.8E-7	3.5E-6[d]	1.4E-7[d]
testosterone	testosterone	1.3E+4	4.0E+2	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
triclosan	5-CHLORO-2-(2,4-DICHLOROPHENOXY)PHENOL	1.3E+5	8.9E+2	-[d]	-[d]	2.2E-7[b]	5.0E-10[b]
trimethoprim	trimethoprim	1.0E+3	13	-	-	2.8E-6	3.7E-8
triclocarban	triclocarban	1.4E+6	7.7E+3	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
tonalide	N/A[c]	7.0E+3[d]	1.6E+2[d]	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
celestolide	N/A[c]	7.0E+3[d]	1.6E+2[d]	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
phantolide	N/A[c]	7.0E+3[d]	1.6E+2[d]	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]

Table C-8. Toxic Organics Toxicity Characterization Factors, USEtox™ version 2.11

Chemical Name	USETox Chemical Name	Freshwater Ecotoxicity, (CTUe, PAF m^3.day/kg emitted)		Human health cancer, freshwater (CTUh, cases/kg emitted)		Human Health noncancer, freshwater (CTUh, cases/kg emitted)	
		Emissions to Freshwater	Emissions to Natural Soil	Emissions to Freshwater	Emissions to Natural Soil	Emissions to Freshwater	Emissions to Natural Soil
clofibric acid	N/A[c]	7.0E+3[d]	1.6E+2[d]	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
musk ketone	N/A[c]	7.0E+3[d]	1.6E+2[d]	-[d]	-[d]	3.5E-6[d]	1.4E-7[d]
diuron	diuron	6.0E+4	4.6E+3	-	-	6.6E-6	5.1E-7

a – Characterizations factors sourced from Rahman et al. 2018.

b – Characterization factors sourced from Alfonsín et al. 2014.

c – Chemical is not present in the current USEtox™ LCIA method.

d - Estimated using the median of toxic organics with available characterization factors.

APPENDIX D
DETAILED CHARACTERIZATION OF DISINFECTION BYPRODUCT FORMATION POTENTIAL IN STUDY TREATMENT CONFIGURATIONS

Appendix D: Detailed Characterization of Disinfection Byproduct Formation Potential in Study Treatment Configurations

D.1 Disinfection Byproducts

Disinfection of wastewater treatment plant (WWTP) effluent is a necessary practice to minimize the acute risk associated with exposure to microbial pathogens, however it must be balanced with the chronic risk posed by the creation of disinfection byproducts (DBPs). DBPs are a class of chemical compounds that can be harmful to both aquatic and human health (Boorman G A 1999; Nieuwenhuijsen et al. 2000; Mizgireuv et al. 2004; Villanueva et al. 2004; Muellner et al. 2007; Richardson et al. 2007; Watson et al. 2012). Similar to other emerging contaminants, the understanding of the occurrence and variety of this class of chemicals is continually expanding as new analytical techniques enable finer characterization of individual compounds, though even by 2007 over 600 DBPs had been reported in the literature (Richardson et al. 2007).

DBPs are formed when DBP precursors, generally organic carbonaceous or nitrogenous compounds, are oxidized during chlorination or chloramination (Christman et al. 1983). By regulation, DBPs are managed at drinking water treatment plants, as their presence in water supplies poses a direct threat to human health (Sedlak and Gunten 2011; U.S. EPA 2015d). However, as water recycling and reclamation programs expand (and as indirect potable reuse continues), management of DBPs and DBP precursors has become increasingly important at the WWTP as well (Krasner et al. 2008; L. Tang et al. 2012).

In the U.S., DBPs are mainly regulated by the U.S. EPA through the Stage 1 and 2 Disinfectants/DBP Rules (U.S. EPA 2015e), which include maximum contaminant levels for the sum of four trihalomethanes (THM4) and the sum of five haloacetic acids (HAA5) (Table D-1).

Regulation focuses on these two groups, in part, as they generally have the highest occurrence in drinking water. More importantly however, they serve as indicators for the presence of other less common, though potentially more toxic, DBPs (Muellner et al. 2007; Richardson et al. 2007; Krasner et al. 2008). More recently, the US EPA has begun to focus on these emerging, high priority DBPs (Richardson et al. 2002). Additionally, the California Department of Health Services established notification levels for several highly toxic nitrosamines, including *N*-Nitrosodimethylamine (NDMA) (Table D-1).

The importance of DBP and DBP precursor control at WWTPs has been growing in recent years for several reasons. First, the type of precursors formed through biological wastewater treatment are complex and, although overlapping with, are in many ways dissimilar from the natural organic matter (NOM)-derived precursors of drinking water-based DBPs. For example, effluent organic matter (EfOM) is generally composed of NOM, synthetic organic compounds and soluble microbial products (SMP) (Doederer et al. 2014), the latter of which can be further decomposed into organic compounds generated during biological treatment processes including (but not limited to) humic and fulvic acids, polysaccharides, proteins, nucleic acids, organic acids, amino acids, structural components of cells and products of energy metabolism (Barker and Stuckey 1999). Given this potential chemical diversity, lessons learned in drinking water DBP formation prediction and control are not directly translatable (Drewes and Croue 2002; L. Tang et al. 2012).

In addition to precursor complexity, there has been increasing concern over emerging and more toxic nitrogenous DBPs such as nitrosamines, halonitroalkanes, haloacetonitriles (HANs) and haloacetamides (Westerhoff and Mash 2002; Joo and Mitch 2007; Lee et al. 2007). Haloacetamides and HANs in particular are approximately two orders of magnitude more cytotoxic and genotoxic than the regulated THMs and HAAs (Muellner et al. 2007; Plewa and Wagner 2009). The precursors for these nitrogenous DBPs are mostly dissolved organic nitrogen (DON) compounds, which are removed to varying degrees depending on the type of treatment process utilized. Secondary effluents are particularly rich in DON (Huang et al. 2016), which can be removed to varying degrees through the addition of nitrification and denitrification biological nutrient removal (BNR) processes (Huo et al. 2013). However, in a study of an A2O (anaerobic, anoxic, oxic), AO (anaerobic, oxic) and MBR treatment, it was found that approximately half of wastewater-derived DON was of low molecular weight (capable of passing through a 1 kDa ultrafilter) which is not effectively removed by BNR processes (Huo et al. 2013). Moreover, the low molecular weight fraction that remains after biological treatment also tends to be hydrophilic, which is challenging for even chemical and physical methods to remove (Pehlivanoglu-Mantas and Sedlak 2008; Huo et al. 2013).

A further complication is the effect of nitrogen, ammonia in particular, on the reaction kinetics of chlorination and chloramination. For example, formation of halogenated DBPs like THMs and HAAs can be greatly reduced if free chlorine is minimized in the disinfection process (Krasner et al. 2009b). This is done by either using chloramines directly or maintaining the Cl_2/N (mass/mass) ratio below 10 so that any free chlorine is quenched by ammonia. Ironically however, this effective control of halogenated DBPs favors the formation of more toxic nitrogenous DBPs like NDMA, especially when applied to poorly nitrified (high DON) effluent (Krasner et al. 2008; Sedlak and Gunten 2011). Thus, the presence of precursors does not necessarily entail DBP formation, which further depends on site-specific operational characteristics like disinfection practices.

Last, DBP precursors formed in biological treatment processes can potentially be recalcitrant, as they are generally composed of cellular debris leftover from substrate metabolism and biomass decay (Barker and Stuckey 1999). Owing to this potential recalcitrance, there is evidence of persistence at least on the order of days, which is of relevance for a typical river indirect potable reuse scenario. In a multi-season survey of a river determined to be effluent dominated (determined through use of primidone, a conservative wastewater tracer), Krasner et al. (2008) documented the presence of EfOM-derived nitrogenous DBP precursors at downstream locations, including the intake of a water treatment plant, with concentrations that suggested dilution, not degradation, to be the primary attenuation mechanism. Results for carbonaceous precursors, which tend to be humic compounds, were masked by the naturally high humic content of the river water.

Given that the formation potential of DBPs is dependent upon numerous variables which can change daily, for purposes of this study, it was decided to use the formation potential (FP) of DBPs (DBPFP) as a more conservative indicator of the concentration of DBPs that could be formed by the various treatment configurations used in this study. Moreover, FP is determined using a standardized procedure, eliminating variability that may arise owing to different disinfection practices, allowing for a clearer distinction between the effects of different treatment approaches on precursor control. Accordingly, to characterize the effects of the nine Study configurations on DBP formation, a comprehensive dataset linking effluent water quality to DBPFP was used for this analysis (Krasner et al. 2008). The DBP and DBP groups included in the study included the regulated carbonaceous DBPs (THMs and HAAs) along with emerging and more toxic carbonaceous and nitrogenous DBPs and are outlined in Table D-1. The general approach is discussed further below.

Table D-1. Summary of Regulated Disinfection Byproducts

DBP (group/compound)	Characteristics	Precursors	Limit	Regulatory Authority
Trihalomethanes (THM)[1,2]				
Chloroform	carbonaceous, halogenated	influent refractory NOM, EfOM, nitrified effluent, humic compounds	80 µg/L (TTHM)	U.S. EPA, Stage 1/2 DBP Rule
Bromodichloromethane (BDCM)				
Chlorodibromomethane (DBCM)				
Bromoform				
Haloacetic Acids (HAA)[2,3]				
Monochloroacetic acid	carbonaceous, halogenated	influent refractory NOM, EfOM, nitrified effluent, humic compounds	60 µg/L (HAA5)	U.S. EPA, Stage 1/2 DBP Rule
Dichloroacetic acid (DXAA)				
Trichloroacetic acid (TXAA)				
Bromoacetic acid				
Dibromoacetic acid				
Nitrosamines[4]				
N-nitrosodimethylamine (NDMA)	nitrogenous, unhalogenated	DON, dimethylamine	10 ng/L	CA (action level)
Aldehydes				
Formaldehyde	carbonaceous, halogenated	DON, amino acids	NA	NA
Acetaldehyde				
Chloroacetaldehyde				
Dichloroacetaldehyde				
Trichloroacetaldehyde (chloral hydrate)				
Haloacetonitriles (HANs)				
Chloroacetonitrile	nitrogenous, halogenated	DON, amino acids	NA	NA
Bromoacetonitrile				
Iodoacetonitrile				
Trichloroacetonitrile				
Bromodichloroacetonitrile				
Dibromochloroacetonitrile				
Tribromoacetonitrile				

1 The four compounds together comprise the four primary trihalomethanes, sometimes referred to as TTHM or THM4

2 (U.S. EPA 2015d)

3 These five compounds together comprise the five primary haloacetic acids, sometimes referred to as HAA5

4 California Department of Health Services, action level

D.2 Methods

The results of a comprehensive survey of the effluent DBPFP of 23 U.S. WWTPs (Survey) were used to construct multiple linear regression models (Models) for the prediction of DBPFP based on effluent water quality (Krasner et al. 2008; Krasner et al. 2009a). The Survey was conducted at WWTPs that utilize a range of common treatment technologies with differing abilities to control DBP precursors, including humic substances, amino acids and other organic nitrogen compounds. The treatment processes included oxidation ditch, aerated lagoon, trickling filter, activated sludge, nitrification/denitrification, soil aquifer treatment (SAT), powdered activated carbon (PAC) and granular activated carbon (GAC), MBR, RO and various combinations. A primary objective of the Survey was to establish a database of water quality and operational parameters that could be used to evaluate global and site-specific correlations between water quality and DBPFP.

In order to draw meaningful conclusions from the Survey, the authors divided the 23 WWTPs into nine general categories according to the dominant biological or physical treatment process. Figure D-1 shows the resulting water quality ranges of Survey categories (25^{th}, 50^{th} and 75^{th} percentiles), along with effluent quality of the nine Study configurations plotted against their most similar Survey category. Although additional water quality parameters were measured in the Survey, only those relevant parameters (i.e. carbonaceous or nitrogenous) that were also defined for Study configurations (Table 1-4) were used in this analysis.

As can be seen from Figure D-1, although many Study configurations fit within the ~~second~~ first and third quartiles (between the 25^{th} and 75^{th} percentile of results) of at least one Survey category, some parameters fall outside of any range. This is especially true for COD, which is particularly important as a surrogate for carbonaceous DBP precursors. Accordingly, a direct translation of Survey categories to Study configurations is not fully appropriate. Therefore, a multiple linear regression modelling approach was used to estimate which water quality parameters were most appropriate for predicting DBPFP, and their approximate effect.

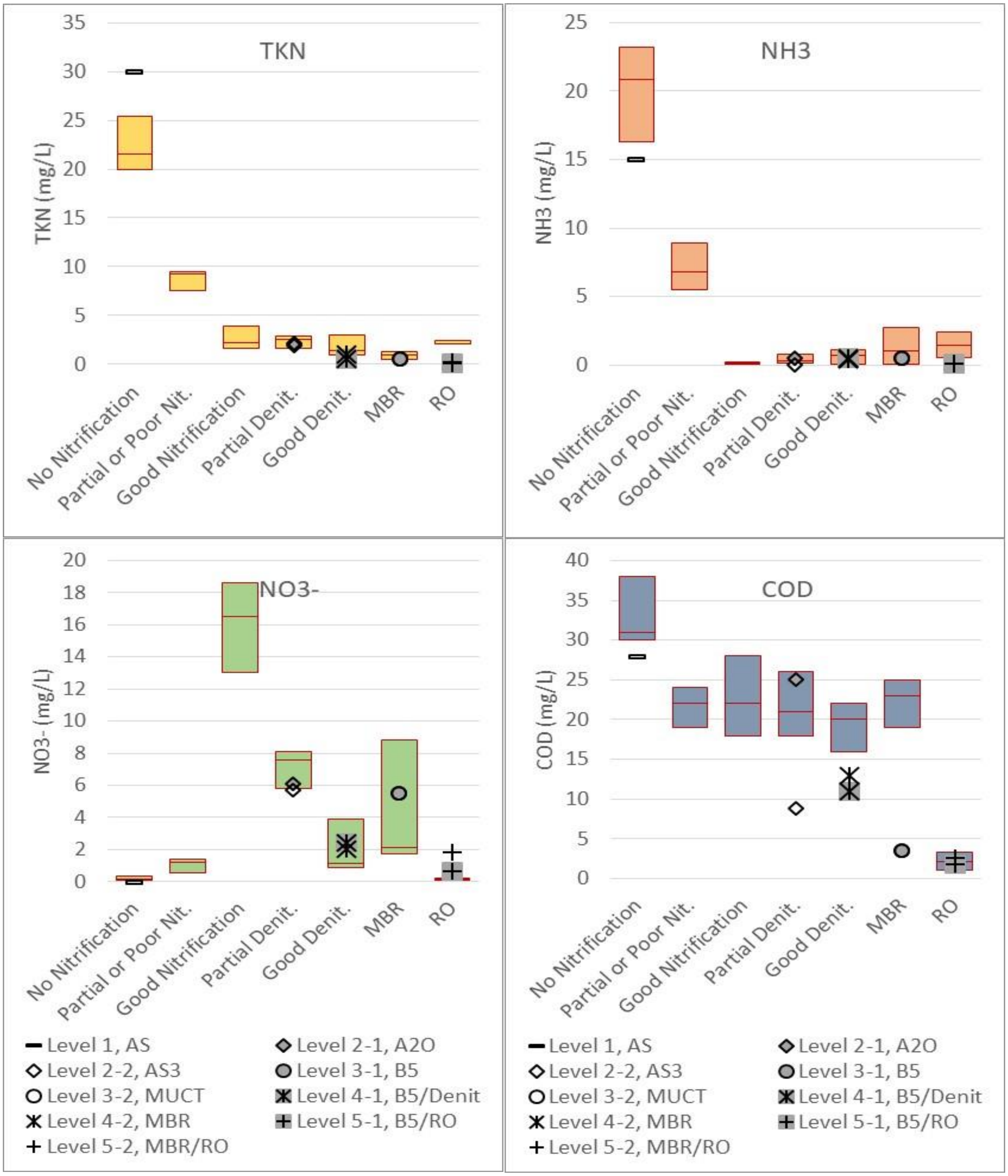


Figure D-1. Statistical summary of Survey category water quality, along with Study configuration water quality plotted within the most applicable Survey category. Ranges represent second and third quartiles, or 25th/50th/75th percentiles (Krasner et al. 2008; Krasner et al. 2009).

First, a linear correlation analysis was performed between relevant water quality parameters and DBPFP, using median values from each Survey category as input. Table D-2 shows the resulting correlations, in terms of the coefficient of determination (R^2). As shown, COD is the largest predictor of DBPFP for each DBP group, followed in most cases by TKN.

Table D-2. Linear Correlation Analysis between Median Water Quality Parameters and Median DBPFP for Survey Categories

DBPFP	Coefficient of Determination (R^2)			
	COD	TKN	NH_3	$NO3^-$
THMs	0.86	0.09	0.07	0.05
HANs	0.79	0.72	0.68	0.01
DXAAs	0.99	0.29	0.26	0.03
TXAAs	0.86	0.24	0.20	0.05
dihaloacetaldehydes	0.88	0.59	0.57	0.00
trihaloacetaldehydes	0.85	0.55	0.50	0.01
NDMA	0.73	0.18	0.20	0.00

Given the predictive ability of both COD and TKN especially, multiple linear regression models were constructed for each DBP group. Models were constructed in a stepwise fashion. Starting with COD as a single predictor, additional predictors were incorporated following the order of their coefficient of determination (Table D-2). Final Models reflect the combination of predictors that resulted in the greatest adjusted R^2. Although NH_3 was in many cases nearly as predictive as TKN, its contribution to overall model fit was generally less than TKN (i.e. the adjusted R^2 of models with COD and TKN were generally greater than that of models with COD and NH_3). Resulting Model coefficients, adjusted R^2 and overall significance (F) are provided in Table D-3. For DXAAs and TXAAs, COD alone provided the greatest predictive power (adjusted R^2). To illustrate the Models' predictive capabilities, Figure D-2 shows Model results using median water quality values for each Survey category as input, plotted against their actual DBPFP ranges (~~second~~ first and third quartiles). As shown, the Models are capable of predicting DBPFP within the 25^{th} to 75^{th} percentile ranges for most DBP categories, with the main exception of the Partial or Poor Nitrification and Good Nitrification categories for NDMA. Importantly however, the Models capture the low DBPFP provided by RO, which ultimately will provide for greater predictive capability in the water quality ranges not represented by Survey categories but occupied by many of the Study configurations (recall Figure D-1).

Table D-3. Multiple Linear Regression Model Parameters, Fit and Significance

DBP	Coefficient			Adjusted R^2	F (Signif.)
	COD	TKN	Intercept		
THMs	11.09	-3.68	3.66	0.89	0.005
HANs	0.59	0.58	-1.58	0.96	0.001
DXAAs	5.31		-4.15	0.99	0.000
TXAAs	4.57		-0.87	0.83	0.003
dihaloacetaldehydes	0.21	0.12	-0.63	0.95	0.001

Table D-3. Multiple Linear Regression Model Parameters, Fit and Significance

DBP	Coefficient			Adjusted R^2	F (Signif.)
	COD	TKN	Intercept		
trihaloacetaldehydes	2.30	1.19	-5.34	0.89	0.006
NDMA	27.92	-2.52	-13.65	0.60	0.072

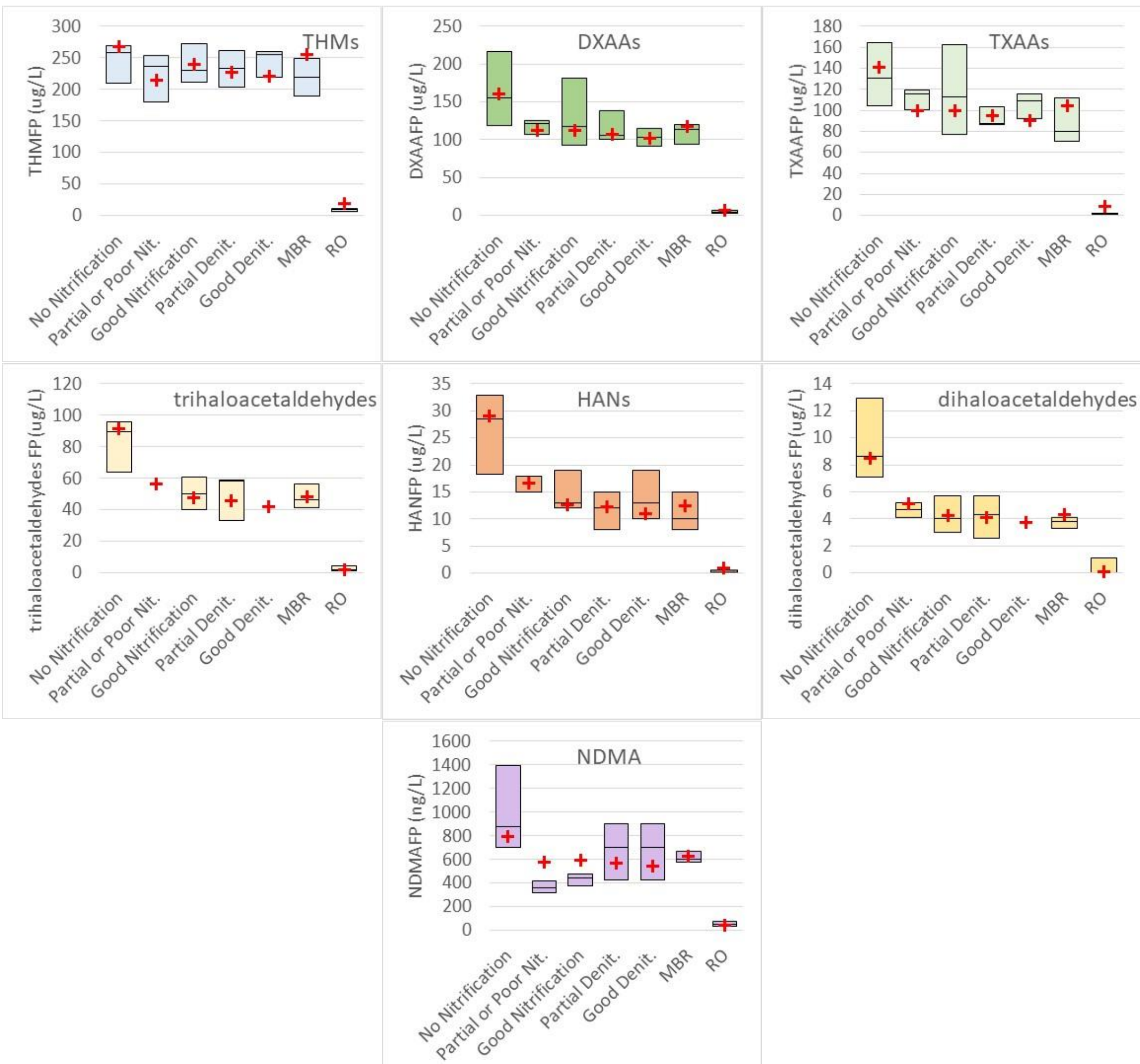


Figure D-2. Multiple linear regression model verification. Red crosses represent model results using median water quality values for each Survey category. DBPFP ranges represent second and third quartiles, or 25th/50th/75th percentiles (Krasner et al. 2008; Krasner et al. 2009a).

Table D-4 presents the characterization factors used to estimate toxicity impacts associated with DBPs in treatment plant effluent. Not all DBPs included in this study have associated characterization factors listed in the most recent versions of USEtox™, versions 2.02 and 2.11. Characterization factors that were not otherwise available were estimated using the median value of all other DBPs for which data was available. Sources for individual characterization factors are listed in Table D-4.

Table D-4. DBP Toxicity Characterization Factors, USEtox™ version 2.11

Chemical Name/Class	USEtox Chemical Name	Freshwater Ecotoxicity, (CTUe, PAF m^3.day/kg emitted)	Human Health cancer, freshwater (CTUh, cases/kg emitted)	Human Health noncancer, freshwater (CTUh, cases/kg emitted)
		Emissions to Freshwater		
trihalomethanes[a]	N/A[c]	90	5.2E-7	8.0E-7
haloacetonitriles	chloroacetonitrile	7.6E+3	3.6E-7[b]	4.5E-7[b]
dichloroacetic Acid	dichloroacetic acid	52	6.7E-7	1.1E-6
trichloroacetic acid	trichloroacetic acid	34	2.9E-7	4.5E-7[b]
dihaloacet-aldehydes	N/A[c]	1.9E+2[b]	3.6E-7[b]	4.5E-7[b]
trihaloacet-aldehydes	chloral hydrate	2.5E+2	3.6E-7[b]	4.5E-7[b]
nitrosamines	N-nitrosodimethylamine	25	7.9E-4	N/A

a – Average of trichloromethane/chloroform, bromodichloromethane, dibromochloromethane, and tribromomethane.

b – Estimated using the median of DBPs with available characterization factors.

c – Chemical is not present in the current USEtox™ LCIA method.

D.3 Results and Discussion

Table D-5 and Figure D-3 give Model results for the nine Study treatment configurations. Effluent COD and TKN values (Table 1-4) were used as input, along with coefficients and intercepts given in Table D-3.

Table D-5. DBPFP Model Results for Study Treatment Configurations

Study Configuration	THMs	HANs	DXAAs	TXAAs	dihaloacet-aldehydes	trihaloacet-aldehydes	NDMA
	µg/L						ng/L
Level 1, AS	204	32	145	127	8.8	95	692
Level 2-1, A2O	274	14	129	113	4.9	54	680
Level 2-2, AS3	95	4.9	43	40	1.5	18	230
Level 3-1, B5	41	0.78	14	15	0.16	3.3	83
Level 3-2, MUCT	41	0.78	14	15	0.16	3.3	83
Level 4-1, B5/Denit	124	5.2	54	49	1.7	21	292
Level 4-2, MBR	144	6.6	65	59	2.2	26	347
Level 5-1, B5/RO	23	0.01	5.4	7.4	0.01	0.01	36
Level 5-2, MBR/RO	32	0.07	10	11	0.01	0.87	58

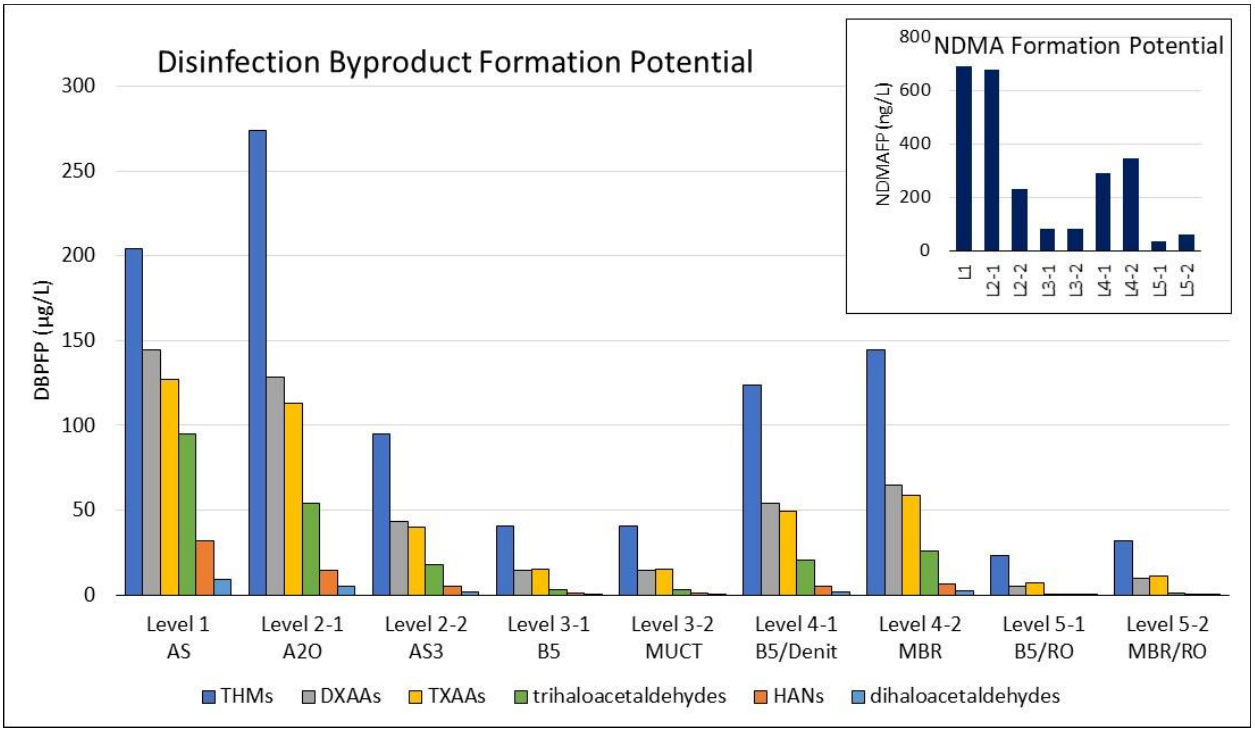


Figure D-3. DBPFP Model results for Study treatment configurations.

The formation potentials presented above are an upper bound to what could be formed at the WWTP. Using THMs as an example, ranges of THMs that actually formed at the surveyed WWTPs were also a function of chlorine dose and the Cl_2/N ratio. When the Cl_2/N ratio was above 10, allowing for the creation of free chlorine and enhanced THM formation, the 10th and 90th percentile concentrations of THMs were 20 µg/L and 80 µg/L, respectively (Krasner et al. 2009b). Compared to the formation potentials determined for each of the Survey groups (illustrated in Figure D-2) with medians largely in the range of 200-250 µg/L, this implies that upon discharge, there remains considerable additional formation potential in the form of unreacted precursors. Similarly, when the Cl_2/N ratio was less than 10, favoring chloramine creation and NDMA formation, the 10th and 90th percentile of observed concentrations of NDMA were 4 and 122 ng/L, compared to formation potentials that were sometimes an order of magnitude greater (also illustrated in Figure D-2). Thus, depending on factors like chlorination, temperature and pH (Doederer et al. 2014), which are assumed constant in Study configurations, formation of DBPs prior to discharge may be on the order of 10-50% of the formation potentials indicated above in Table D-5 and Figure D-3.

APPENDIX E
DETAILED COST METHODOLOGY

Appendix E: Detailed Cost Methodology

Appendix E includes supporting details for the methodology used to estimate costs associated with the nine wastewater treatment configurations. Appendix E.1 presents the unit design values for the unit processes included in CAPDETWorks^{TM}. Appendices E.2, E.4, B.4, E.6, and E.7 present the detailed cost methodologies for the dechlorination, ultrafiltration, reverse osmosis, and deep well injection, respectively. Appendix E.8 presents the CAPDETWorks™ file used to develop the direct cost factors discussed in Section 3.3.1.

E.1 <u>CAPDETWorks™ Process Unit Design Values</u>

This appendix includes the initial CAPDETWorks™ design values for the unit processes included in the nine wastewater treatment configurations. As discussed in Section 3.2.2, ERG revised some of the design values during development of the CAPDETWorks™ models to achieve the effluent wastewater objectives for each treatment level and/or address warnings in the CAPDETWorks^{TM}. For example, CAPDETWorks™ calculates the number of mixers for the Biological Nutrient Removal 3/5 Stage and provides a warning if the horsepower (HP) per mixer exceeds the CAPDETWorks™ recommended 5 HP/mixer. In this instance, ERG increased the number of mixers to eliminate the warning so the design reflected all of the equipment necessary. The final design values used for each wastewater treatment configuration are included in the final CAPDETWorks™ cost output discussed in Section 5. The following unit processes are not in CAPDETWorks^{TM}: modified University of Cape Town, 4-stage Bardenpho, fermentation, ultrafiltration, reverse osmosis (including pretreatment), deep well injection for brine disposal, and dechlorination. Costs for these unit processes were developed outside of CAPDETWorks™ and are documented in Sections 3.2.3.1 through 3.2.3.7 of this report.

ERG reviewed *EPA's Municipal Nutrient Removal Technologies Reference Document (U.S. EPA OWM, 2008b), WERF's Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability* (Falk, 2011), EPA/ORD's Nutrient Control Design Manual (U.S. EPA ORD, 2010), and additional EPA wastewater treatment process fact sheets to confirm that the CAPDETWorks™ default design values (Hydromantis, 2014) are appropriate for use for this study. Based on our review, ERG used the CAPDETWorks™ default design values for the unit processes below that are included in one or more of the wastewater treatment configurations. Appendix E.1.14 includes key parameters and the default design values for these unit processes (Hydromantis, 2014).

- Membrane Bioreactor
- Sand Filter
- Centrifugation – Sludge

The remainder of Section E.1 provides the initial design values used for each of the remaining CAPDETWorks™ unit processes included in the nine wastewater treatment configurations.

E.1.1 Preliminary Treatment – Screening and Grit Removal

The default Preliminary Treatment design values were used. Key parameters and default design values for Preliminary Treatment – Screening include:

- Cleaning Method: Mechanically Cleaned

Key parameters and default design values for Preliminary Treatment – Grit Removal include:

- Type of Grit Removal: Horizontal
- Number of Units: 2
- Volume of Grit: 4.0 ft^3/MGal
- Detention Time: 2.5 min

However, the resulting purchased equipment costs were about half the construction costs presented in *Wastewater Technology Fact Sheet – Screening and Grit Removal* (U.S. EPA, 2003b). As a result, ERG doubled the CAPDETWorks™ Preliminary Treatment purchased equipment costs for all nine wastewater treatment configurations.

E.1.2 Primary Clarifier

The default Primary Clarifier design values were modified as follows, as recommended in *Wastewater Engineering: Treatment and Resource Recovery* (Tchobanoglous et al., 2014):

- Sidewater depth: 12.0 ft (instead of 9.0 ft)
- Underflow concentration: 3.5% (instead of 4.0%)

Note that this sidewater depth and underflow concentration are within CAPDETWorks™'s recommended ranges (7-12 ft and 3-6%, respectively) (Hydromantis, 2014).

Additional key parameters and default design values for Primary Clarifier include:

- Type of Clarifier: Circular
- Surface Overflow Rate: 1,000 gal/ft2-d
- Weir Overflow Rate: 15,000 gal/ft-d
- Suspended Solids Removal: 58%
- BOD Removal: 32%
- COD Removal: 40%
- TKN Removal: 5%
- Phosphorous Removal: 5%

E.1.3 Plug Flow Activated Sludge

Because the Level 1 wastewater treatment configuration represents a system that is not designed for nitrogen removal, and Level 2-2 requires higher effluent ammonia levels for the subsequent nitrification/denitrification processes, the default Plug Flow Activated Sludge design values was modified as follows:

- Process Design: Carbon Removal Only (instead of default Carbon Plus Nitrification)

Additional key parameters and default design values for Plug Flow Activated Sludge include:

- Aeration Type: Diffused Aeration
- Bubble Size: Fine Bubble
- Solids Retention Time (SRT): 10 days
- Mixed Liquor Suspended Solids (MLSS): 2,500 mg/L

E.1.4 Biological Nutrient Removal 3/5 Stage

When used for the Anaerobic/Anoxic/Oxic (A2O) unit process in Level 2-1, the default Biological Nutrient Removal 3/5 Stage design values were modified as follows:

- Number of Stages: 3-Stage (instead of 5-Stage)
- Internal Recycle from Anoxic to Anaerobic Zone: No (the A2O process does not include this recycle)
- Internal Recycle from the Oxic to Anoxic Zone: Yes
- Assume sufficient carbon in the wastewater to denitrify without an additional carbon source
- Effluent Total Kjeldahl Nitrogen (TKN): modified to achieve the 8 mg/L target effluent total nitrogen (TN) concentration
- Effluent Total Phosphorous (TP): modified to achieve the 1 mg/L target effluent TP concentration

When used for the 5-Stage Bardenpho unit process in Levels 3-1, 4-1, 5-1, and 5-2, the default Biological Nutrient Removal 3/5 Stage design values were modified as follows:

- Number of Stages: 5-Stage (instead of 3-Stage)
- Internal Recycle from Anoxic to Anaerobic Zone: No
- Internal Recycle from the Oxic to Anoxic Zone: Yes
- Effluent TKN: modified to achieve the target effluent total nitrogen concentrations of:
    - — Level 3-1: 4–8 mg/L TN
    - — Level 4-1: 3 mg/L TN

— Levels 5-1 and 5-2: 2 mg/L TN

- Effluent TP: modified to achieve the target effluent total phosphorous concentrations of:
  - Level 3-1: 0.1–0.3 mg/L TP
  - Level 4-1: 0.1 mg/L TP
  - Levels 5-1 and 5-2: <0.2 mg/L TP

In addition to the specific modifications proposed above, for instances when CAPDETWorks™ provided a warning that the number of mixers was insufficient for each mixer to be less than 5 HP/mixer, the CAPDETWorks™ default number of mixers per tank was increased until the mixers were less than 5 HP/mixer.

Additional key parameters and default design values for Biological Nutrient Removal 3/5 Stage include:

- Aeration Type: Diffused Aeration
- Bubble Size: Fine Bubble
- Total Reactor SRT: 15 days

E.1.5 Denitrification – Suspended Growth

The default Denitrification – Suspended Growth design values were modified for effluent nitrate to achieve the effluent total nitrogen concentration target for Level 2-2 of 8 mg/L TN.

In addition to the specific modifications proposed above, for instances when CAPDETWorks™ provided a warning that the number of mixers was insufficient for each mixer to be less than 5 HP/mixer, the CAPDETWorks™ default number of mixers per tank was increased until the mixers were less than 5 HP/mixer.

Additional key parameters and default design values for Denitrification – Suspended Growth include:

- Design SRT: 10 d
- MLSS: 2,500 mg/L

E.1.6 Denitrification – Attached Growth

The default Denitrification – Attached Growth design values were modified as follows:

- Allowable Effluent Nitrate:
  - Level 4-1: 3 mg/L TN
  - Levels 5-1 and 5-2: <0.02 mg/L TN (taking into consideration the RO TN removal)
- Application Rate: 1.5 gal/ft^2-min (instead of 1.0 gal/ft^2-min)

The recommended application rate matches that used in the analysis in WERF's *Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability* (Falk, 2011) and is more aligned with actual plant application rates of 2.2 and 3.0 gal/ft^2-min, as presented for two plants in the *Municipal Nutrient Removal Technologies Reference Document* (U.S. EPA OWM, 2008b). Note that this application rate is outside of CAPDETWorks™' recommended range (0.5 to 1.0 gal/ft^2-min). ERG reviewed the underlying cost curves for CAPDETWorks™' construction and O&M costs and considers the outputs to be reasonable at the 1.5 gal/ft^2-min application rate.

Additional key parameters and default design values for Denitrification – Attached Growth include:

- Methanol Requirement: 3 lb/lb NO_3
- Backwash Rate: 12 gal/ft^2-min

E.1.7 Nitrification – Suspended Growth

Because SRT is a key factor for achieving nitrification, the default Nitrification – Suspended Growth design values were modified as follows for the reasons described below:

- Design Basis: Specify Design SRT (instead of default Temperature Specific Growth Rates or pH Ammonia Sensitive Rates)
- Design SRT: 50 d (instead of 10 d)

Note that using a design basis that specifies the default Temperature Specific Growth Rates returned a unit design with a SRT of 5.89 hrs and hydraulic residence time (HRT) of 1.27 hrs, well below recommended SRT and HRT values[12]. Using a SRT of 24 d and the default MLSS of 2,500 mg/L returns a unit design with a HRT of 3.11 hrs, which is still below CAPDETWorks™ recommended minimum. A SRT of 50 d and the default MLSS of 2,500 mg/L returns a unit design with a HRT of 6.31 hours. These values are similar to those of the Western Branch WWTP with a 3-sludge system designed to achieve 1.0 mg/L effluent TP and 3.0 mg/L effluent TN. The Western Branch WWTP has nitrifying activated sludge system SRT ranging from 21.4 days (June) to 84.6 days (September), with an average of 47.6 days (U.S. EPA OWM, 2008b). As a result, ERG's recommended 50 d design SRT is reasonable.

Additional key parameters and default design values for Nitrification – Suspended Growth include:

- Aeration Type: Diffused Aeration
- Bubble Type: Fine Bubble
- MLSS: 2,500 mg/L

[12] A SRT of 24 days is recommended for general nitrification systems from *Municipal Nutrient Removal Technologies Reference Document* (U.S. EPA OWM, 2008b) and a minimum HRT of 6 hrs from CAPDETWorks™ (Hydromantis, 2014).

E.1.8 Chemical Phosphorus Removal

The default effluent phosphorus concentration target for each level that includes chemical phosphorous removal was adjusted to achieve the following effluent total phosphorous concentration targets:

- Level 2-2: 1 mg/L TP
- Levels 3-1 and 3-2: 0.3 mg/L TP
- Levels 4-1, 4-2, 5-1, and 5-2: 0.1 mg/L TP (remaining TP to achieve <0.02 mg/L effluent target for Level 5 configurations will be achieved with RO)

In addition, ERG revised the default chemical dosage to two times the stoichiometric alum dose, as recommended by the *Municipal Nutrient Removal Technologies Reference Document* (U.S. EPA OWM, 2008b).

Additional key parameters and default design values for Chemical Phosphorous Removal include:

- Metal Precipitant: Equivalent Aluminum

E.1.9 Secondary Clarifier

The default Secondary Clarifier design values were modified as followed:

- Surface overflow rate: 600 gal/ft^2-d (instead of 500 gal/ft^2-d)
- Sidewater depth: 14.5 ft (instead of 9.0 ft)

The surface overflow rate was modified to match WERF's *Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability* (Falk et al, 2011). Note that this surface overflow rate is within CAPDETWorks^{TM}' recommended range (200 to 800 gal/ft^2-day) (Hydromantis, 2014). CAPDETWorks^{TM}' background documentation generally describes that lower overflow rates are more appropriate for smaller plants and higher overflow rates are more appropriate for larger plants (Hydromantis, 2014). The sidewater depth and underflow concentrations were modified to within ranges recommended in *Wastewater Engineering: Treatment and Resource Recovery* (Tchobanoglous et al., 2014). Note that the sidewater depth is within CAPDETWorks^{TM}'s recommended ranges (7-15 ft) (Hydromantis, 2014).

Additional key parameters and default design values for Secondary Clarifier include:

- Underflow concentration: 1%
- Weir Overflow Rate – Maximum 15,000 gal/ft-d
- Effluent Suspended Solids: 20 mg/L

E.1.10 Chlorination

Chlorination using liquid hypochlorite is more common that gaseous chlorine due to safety concern and regulations on the handling and storage of pressurized liquid chlorine (Tchobanoglous et al., 2014). However, this analysis assumes use of gaseous chlorine because that is the only disinfection alternative used by CAPDETWorks™ (Hydromantis, 2014).

When used for wastewater treatment configurations where solids removal is completed with clarifiers (Level 1, Level 2-1, and Level 2-2), the default Chlorination design values were modified as follows:

- Contact Time at Peak Flow: 30 min
- Chlorine Dose: 10 mg/L

When used for wastewater treatment configurations where solids removal is completed with a sand filter or membrane bioreactor (Level 3-1, Level 3-2, Level 4-1, and Level 4-2), the default Chlorination design values were modified as follows:

- Contact Time at Peak Flow: 30 min
- Chlorine Dose: 8 mg/L

When used for wastewater treatment configurations with the majority of the flow going through reverse osmosis (Level 5-1 and Level 5-2), the default Chlorination design values were modified as follows:

- Contact Time at Peak Flow: 30 min
- Chlorine Dose: 5 mg/L

ERG developed these design input value recommendations based on consideration of CAPDETWorks™ default design values (Hydromantis, 2014) and assumptions provided in *Striking the Balance Between Nutrient Removal in Wastewater Treatment and Sustainability* (Falk et al, 2011), which were further supported based on an evaluation of design information provided in EPA's *Onsite Wastewater Treatment Systems Manual* (EPA, 2002).

E.1.11 Gravity Thickener

The default Gravity Thickener design values were modified as follows:

- Based On: Mass Loading (instead of Settling)
- Mass Loading: 30 lb/ft^2-d (instead of 10 lb/ft^2-d)
- Underflow Concentration: 4.0% (instead of 5.0%)
- Depth: 11.5 ft (instead of 9 ft)
- Standard 90 ft Diameter Thickener: $1,000,000 (instead of $154,000)

Note that using the default Settling design basis returned a unit design with a HRT of 20.3 hr, well above recommended HRT values (maximum HRT of 6 hrs from CAPDETWorks™ (Hydromantis, 2014)). As a result, ERG used CAPDETWorks™ maximum recommended mass loading rate rather than the default design value of 10 lb/ft^2-d to reduce the gravity thickener HRT and the risk of creating anaerobic conditions that can lead to phosphorous release from the sludge. Using the recommended mass loading results in a HRT of 6.78 hrs, which is reasonable compared to CAPDETWorks™ recommended 6 hr maximum (Hydromantis, 2014).

The underflow concentration was modified to within the range in *Wastewater Engineering: Treatment and Resource Recovery* (Tchobanoglous et al., 2014). The depth was modified to within the range recommended in *Biosolids Technology Fact Sheet – Gravity Thickening* (U.S. EPA, 2003a). The standard 90 ft diameter thickener cost was modified to $1,000,000 so the gravity thickener purchased equipment cost was comparable to the costs in *Biosolids Technology Fact Sheet – Gravity Thickening* (U.S. EPA, 2003a).

E.1.12 Anaerobic Digestion

The default Anaerobic Digestion design values were modified to match the Gravity Thickener underflow concentration (see Section E.1.11) as follows:

- Concentration in Digester: 4.0% (instead of 5.0%)

Note that this concentration in digester is within CAPDETWorks™' recommended range (3 to 7%) (Hydromantis, 2014).

Additional key parameters and default design values for Anaerobic Digestion include:

- Percent Volatile Solids Destroyed: 50%
- Minimum Detention Time in Digester: 15 d
- Fraction of Influent Flow Returned as Supernatant: 2%
- Supernatant Concentrations:
  - Suspended Solids: 6,250 mg/L
  - BOD: 1,000 mg/L
  - COD: 2,150 mg/L
  - TKN: 950 mg/L
  - Ammonia: 650 mg/L

E.1.13 Haul and Landfill - Sludge

ERG modified the following default design values as follows to correspond with the 25 mi one-way distance used in the ORCR CCR rule (ERG, 2013):

- Distance to Disposal Site: 25 mi one way

- Disposal Cost Based On: Sludge Disposal per Ton

E.1.14 Key Default Design Parameters for Select Unit Processes

Membrane Bioreactor

Key parameters and default design values for Membrane Bioreactor include:

- Average Net Flux: 20 L/m2-hr
- Effluent Suspended Solids: 1.0 mg/L
- Underflow Concentration: 1.2%
- Scour Air Cycle Time: 20 s
- Scour Air On Time: 10 s
- Physical Cleaning Interval: 9 min
- Physical Cleaning Duration: 1 min
- Chemical Cleaning Interval: 7 days
- Backflush Flow Factor: 1.25

Sand Filter

Key parameters and default design values for Sand Filter include:

- Number of Layers: 4
- Layer 1: Anthracite
- Layers 2, 3, and 4: Sand
- Loading Rate: 6 gpm/ft^2
- Backwash Time: 10 min

Centrifugation – Sludge

Key parameters and default design values for Centrifugation – Sludge include:

- Cake Solids Content: 9%
- Solids Capture: 90%
- Number of Units: 2
- Operation: 8 hr/d for 5 d/wk

E.2 Dechlorination

Listed below are the capital cost elements included for dechlorination using sodium bisulfite ($NaHSO_3$), with a general description of the basis of estimate, followed by the O&M cost elements and the basis of estimate.

Capital Costs

1. Dechlorination Contact Tank, Dechlorination Building, Chemical Storage Building, and Miscellaneous Items (e.g., grass seeding, site cleanup, piping).

   Costed in 2014 $ using the CAPDETWorks™ chlorination unit process and selecting unit process input values to simulate dechlorination rather than chlorination.

   - Revised the CAPDETWorks™ input contact time at peak flow to 5 minutes to reflect the dechlorination unit contact time:
     - — CAPDETWorks™ uses the contact time at peak flow to calculate the contact tank volume (Hydromantis, 2014).
     - — EPA's Wastewater Technology Fact Sheet – Dechlorination recommends dechlorination contact times of one to five minutes to react with free chlorine and inorganic chloramines (U.S. EPA, 2000). ERG selected five minutes to ensure adequate dechlorination prior to discharge.
   - Revised the CAPDETWorks™ input chemical dose to 3.75 mg/L to reflect the sodium bisulfite solution dose:
     - — CAPDETWorks™ uses the chemical dose to size the chemical feed storage building (Hydromantis, 2014).
     - — ERG selected the input chlorine dose for each wastewater treatment configuration to achieve approximately 1 mg/L residual chlorine. Specifically, for the chlorination unit process, ERG used 10 mg/L for Levels 1, 2-1, and 2-2; 8 mg/L for levels 3-1, 3-2, 4-1, and 4-2; and 5 mg/L for Levels 5-1 and 5-2 (see Appendix E.1.8).
     - — EPA's Wastewater Technology Fact Sheet – Dechlorination indicates that, on a mass basis, 1.46 parts of sodium bisulfite is required to dechlorinate 1.0 parts of residual chlorine (U.S. EPA, 2000), which ERG rounded to 1.5 parts of sodium bisulfite. Assuming a 40% by weight sodium bisulfide in solution results in a sodium bisulfite dose of 3.75 mg/L, as presented in Equation E-1.

$$3.75 \text{ NaHSO}_3 \text{ 40\% Solution } \left(\frac{\text{mg}}{\text{L}}\right) = 1.5 \text{ NaHSO}_3 \text{ 100\% Solution } \left(\frac{\text{mg}}{\text{L}}\right) \times \frac{\text{100\% NaHSO}_3\text{ Solution}}{\text{40\% NaHSO}_3\text{ Solution}}$$

Equation E-1

2. Sodium Bisulfite Liquid Feed System
   - See Table E-1 for calculation of sodium bisulfite liquid feed rates for each wastewater treatment configuration.
   - For sodium bisulfite liquid feed rates less than 100 gph, purchase cost of $5,000, plus $300 for transport, in 2011 $, based on telephone contact with EnPro Technologies (ERG, 2011b). Escalated to 2014 $ using RSMeans Construction Cost Index and the calculation presented in Section 3.2.1 (RSMeans, 2017).
   - Used the installation factor of 0.3 from CAPDETWorks™ for the installation of the dechlorination system to account for installation and other costs such as electrical, piping, painting, etc. associated with the sodium bisulfite system (Hydromatis, 2014).
3. Total capital costs were estimated by applying the CAPDETWorks™ direct and indirect cost factors to the purchase costs, using the factors and methodology described in Section 3.3 of this report.

Table E-1. Sodium Bisulfite Liquid Feed Rate Calculation

Level	$NaHSO_3$Rate (gph) =	Sodium Bisulfite Dose (mg/L)	× Gram to Milligram Factor (g/mg)	× $NaHSO_3$ Dose Factor (calculated in Table E-2)	× Estimated Wastewater Treatment Flow (MGD)	× 1,000,000 gal/Mgal	× Day to Hour Factor (day/hr)
Level 1	2.6	3.8	1.0E-3	1.7E-3	10	1.0E+6	0.04
Level 2-1	2.6	3.8	1.0E-3	1.7E-3	10	1.0E+6	0.04
Level 2-2	2.6	3.8	1.0E-3	1.7E-3	10	1.0E+6	0.04
Level 3-1	2.6	3.8	1.0E-3	1.7E-3	10	1.0E+6	0.04
Level 3-2	2.6	3.8	1.0E-3	1.7E-3	10	1.0E+6	0.04
Level 4-1	2.6	3.8	1.0E-3	1.7E-3	10	1.0E+6	0.04
Level 4-2	2.6	3.8	1.0E-3	1.7E-3	10	1.0E+6	0.04
Level 5-1	4.3	7.5	1.0E-3	1.7E-3	8.2	1.0E+6	0.04
Level 5-2	4.4	7.5	1.0E-3	1.7E-3	8.3	1.0E+6	0.04

Table E-2. Sodium Bisulfite Dose Factor Calculation

$NaHSO_3$ Dose Factor =	1	/ (NaHSO3 Concentration (%)	× NaHSO3 Density (kg/L)	× 1,000 g/kg)
0.00168919	1	0.4	1.48	1000

E.3 Annual Costs

1. Operating Labor, Maintenance Labor, Materials and Supplies[13]
   - Costed in 2014 $ using the CAPDETWorks™ chlorination unit process to simulate dechlorination rather than chlorination.
   - Revised the CAPDETWorks™ input contact time at peak flow to 5 minutes and chemical dose to 3.75 mg/L to reflect the dechlorination unit contact time and dose (see justification in the Capital Cost section item #1).

2. Energy
   - One 0.5 HP feed system pump operated continuously for a calculated annual electrical requirement of approximately 6,500 kWh/yr (ERG, 2011b).
   - Using the CAPDETWorks™ energy rate of $0.10/kWh (2014 $) (Hydromantis, 2014), total energy costs are approximately $650/yr.

3. Sodium Bisulfite
   - Calculated using:
     - Dosage rate of:
       - 1.5 mg/L for Levels 1, 2-1, 2-2, 3-1, 3-2, 4-1, and 4-2 (see justification in the Capital Cost section #1)
       - 3.0 mg/L for Levels 5-1 and 5-2 to also account for the chemicals required for RO pretreatment.[14]
     - Effluent flow rate from the chlorination unit process for each wastewater treatment configuration modeled in CAPDETWorks™.
   - Assumed a 40% by weight sodium bisulfide in solution.
   - Chemical cost of $344/ton of 40% sodium bisulfide solution in 2010 $ (ERG, 2014). This cost includes freight and assumes the chemical will be delivered in drums or totes. Escalated to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017.

E.4 Methanol Addition

Listed below are the capital cost elements included for dechlorination using sodium bisulfite ($NaHSO_3$), with a general description of the basis of estimate, followed by the O&M cost elements and the basis of estimate.

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[13] Materials and supplies include materials and replacement parts required to keep the facilities in proper operating conditions.

[14] The RO system requires 1 mg/L chlorine pretreatment and a corresponding sodium bisulfite dechlorination. ERG assumed the majority of the 1 mg/L chlorine would remain as chlorine residual. Therefore, the dechlorination sodium bisulfite dose is 1.5 mg/L neat. Capital costs for the RO pretreatment sodium bisulfite system are included in Appendix E.5.

Capital Costs

1. Methanol Storage Tank, Feed Pump, Control System, and Miscellaneous Items (e.g., piping).

   Costed in 2014 $ using the CAPDETWorks™ denitrification – attached growth (i.e., denitrification filter) unit process that includes methanol addition. Selected unit process input values to match the required nitrate reduction and used only the output associated with the methanol system.

   - Revised the CAPDETWorks™ influent wastewater average and minimum flow rates to 10.1 MGD and maximum flow rate to 20.1 MGD to match the influent flow rates for the 4-stage Bardenpho. CAPDETWorks™ uses the influent wastewater flow rates to calculate the methanol system capital cost (Hydromantis, 2014).
   - Revised the CAPDETWorks™ influent nitrate concentration to 8.24 mg/L to match the effluent from the 4-stage Bardenpho and the denitrification – attached growth input allowable effluent nitrate to 1.95 mg/L to match the necessary effluent nitrate concentration to achieve 3 mg/L total nitrogen (TKN effluent is 1.05 mg/L) for Level 4-2, MBR. CAPDETWorks™ uses the difference between the influent and allowable effluent nitrate concentration to calculate the methanol feed rate, which is used to calculate the methanol system capital cost (Hydromantis, 2014).

2. Methanol feed system cost (2014 $) from the CAPDETWorks™ output were added to the 4-stage Bardenpho capital costs for the Level 4-2, MBR.

3. Total capital costs for the 4-stage Bardenpho were estimated by applying the CAPDETWorks™ direct and indirect cost factors to the purchase costs, using the factors and methodology described in Section 3.3 of this report.

Annual Costs

1. Operating Labor, Maintenance Labor, Materials and Supplies[15], and Energy
   - CAPDETWorks™ does not calculate costs for operating labor, maintenance labor, materials and supplies, and energy for the methanol feed system separately from the denitrification – attached growth unit process. As a result, assumed the 4-stage Bardenpho operating labor, maintenance labor, materials and supplies, and energy include costs for the methanol feed system.
2. Methanol
   - CAPDETWorks™ calculates the methanol cost based on the influent nitrate and allowable effluent nitrate concentrations, as discussed in the

[15] Materials and supplies include materials and replacement parts required to keep the facilities in proper operating conditions.

Capital Costs section above. Used the default methanol cost of $0.60/lb from CAPDETWorks™.

E.5 Ultrafiltration

Listed below are the capital cost elements included for ultrafiltration, with a general description of the basis of estimate, followed by the O&M cost elements and the basis of estimate. Table E-3 and Table E-4 summarize the capital and O&M cost calculations, respectively.

Capital Costs

1. Membrane Filtration System – cost basis obtained from email contacts with Evoqua Water Technologies LLC, 2015 (ERG, 2015a). Escalated to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017). For a 9 MGD system for this project[16], purchase costs for membrane equipment and appurtenances are approximately $3.7 million. Total capital costs were estimated by applying the CAPDETWorks™ installation factor, and direct and indirect cost factors, to the purchase costs, after incorporating the purchase costs into the CAPDETWorks™ outputs.
2. Membrane Filtration Building – using equipment dimensions provided by Evoqua (ERG, 2015a), calculated a required building footprint of 8,040 square feet to house the system. Using the CAPDETWorks™ building unit cost of $110/square foot, calculated a total capital building cost of approximately $880,000.

Operating and Maintenance Costs

1. Operating Labor – transferred the operating labor costs from reverse osmosis (RO) (see Appendix E.6).
2. Maintenance Labor – transferred the operating labor costs from RO (see Appendix E.6).
3. Materials – membrane replacement cost of $1,650 per membrane times an estimated 768 membranes for a 9 MGD system based on Evoqua (ERG, 2015a). Assumed membranes have a 7-year life based on Evoqua (ERG, 2015a). Escalated to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017). Calculated materials costs of approximately $240,000/yr.
4. Chemicals – membrane cleaning chemical costs estimated using chemical usage rates and costs per Evoqua (ERG, 2015a) and a $0.03/lb freight cost from FreightCenter.com (ERG, 2011a), which were escalated to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017), resulting in a total annual chemicals cost of approximately $91,000/yr. Cleaning chemicals include citric acid, sodium hypochlorite, sulfuric acid, sodium hydroxide, and sodium bisulfite.

[16] Based on side stream treatment of 90 percent of the 10 MGD flow for Level 5-1 5-Stage Bardenpho with Sidestream Reverse Osmosis.

5. Energy – energy usage equal to the average of estimates provided by two sources:

   - Evoqua (ERG, 2015a) estimated energy usage of 0.5 kWh/kgal
   - WateReuse Research Foundation, 2014 estimated energy usage ranging from 0.75 to 1.1 kWh/kgal (average of 0.925 kWh/kgal)

   Used the average of the average estimated energy usage from these two sources, 0.7125kWh/kgal (average of 0.5 kWh/kgal and 0.925 kWh/kgal). For a 9 MGD system, and using the CAPDETWorks™ energy rate of $0.10/kWh (2014 $), total annual energy costs are approximately $230,000.

Table E-3. Ultrafiltration Capital Costs

Equipment Cost Item	Size or Number	Units	Unit Cost	Total Cost	Year	2014 Purchased Cost	Total Capital Cost	Source
Ultrafiltration	9	MGD		$3,750,000	2015	$3,717,344		Evoqua (ERG, 2015a).
Ultrafiltration Building	8,040	sq. foot	$110	$884,400	2014		$884,400	Evoqua, 2015; building unit cost from CAPDETWorks™.

Table E-4. Ultrafiltration Operating and Maintenance Costs

Operating Labor	Labor (hrs/day)	Labor Rate ($/hr)	Days/yr	Annual Operating Labor Cost ($/yr)	Source
Ultrafiltration	1	$51.50	365	$18,798	Evoqua (ERG, 2015a); transferred 1 hour/day operating labor from RO (see Table B.4-3); labor rate from CAPDETWorks™ for Operator.
Maintenance Labor	**Labor (hrs/day)**	**Labor Rate ($/hr)**	**Days/yr**	**Annual Maintenance Labor Cost ($/yr)**	**Source**
Ultrafiltration	1	$51.50	365	$18,798	Evoqua (ERG, 2015a); transferred 1 hour/day maintenance labor from RO (see Table B.4.3); labor rate from CAPDETWorks™ for Operator.
Material	**Annual Materials Cost ($/yr)**				**Source**
Membrane Replacement	$124,473				Evoqua (ERG, 2015a).

Table E-5. Ultrafiltration Operating and Maintenance Costs

Membrane Cleaning Chemicals	Usage (gal/yr)	Cost ($/gal)	Annual Chemicals Cost ($/yr)	Source
50% Citric Acid	4,551	$10.41	$47,369	Evoqua (ERG, 2015a); freight per FreightCenter.com (ERG, 2011a).
50% Sulfuric Acid	2,891	$4.56	$13,183	Evoqua (ERG, 2015a); freight per FreightCenter.com (ERG, 2011a).
12.5% Sodium Hypochlorite	2,997	$0.89	$2,674	Evoqua (ERG, 2015a); freight per FreightCenter.com (ERG, 2011a).
25% Sodium Hydroxide	10,366	$2.43	$25,176	Evoqua (ERG, 2015a) (multiplied usage by 2 as usage data based on 50% solution and cost data based on 25% solution); freight per FreightCenter.com (ERG, 2011a).
12.5% Sodium Bisulfite	1,223	$2.43	$2,970	Evoqua (ERG, 2015a); freight per FreightCenter.com (ERG, 2011a).

Table E-6. Ultrafiltration Operating and Maintenance Costs

Energy	Rate (kWh/day)	Annual Energy (kWh/yr)	Energy Rate ($/kWh)	Annual Energy Cost ($/yr)	Source
Ultrafiltration	6,413	2,340,563	$0.10	$234,056	Evoqua (ERG, 2015a); WateReuse, 2014; and CAPDETWorks™.

E.6 Reverse Osmosis (RO)

Listed below are the capital cost elements included for RO, with a general description of the basis of estimate, followed by the O&M cost elements and the basis of estimate. Table E-7 and Table E-8 summarize the capital cost calculations for the 90 and 85 percent flow options, respectively (Levels 5-1 and 5-2), while Table E-9 and Table E-12 summarize the O&M cost calculations for the 90 and 85 percent flow options, respectively (Levels 5-1 and 5-2).

Capital Costs

1. RO System – cost basis obtained from telephone contacts with Wigen Water Technologies, 2015 (ERG, 2015b). Prepared a cost curve based on purchase costs provided for 2.5, 5, and 10 MGD systems (see Figure E-1).

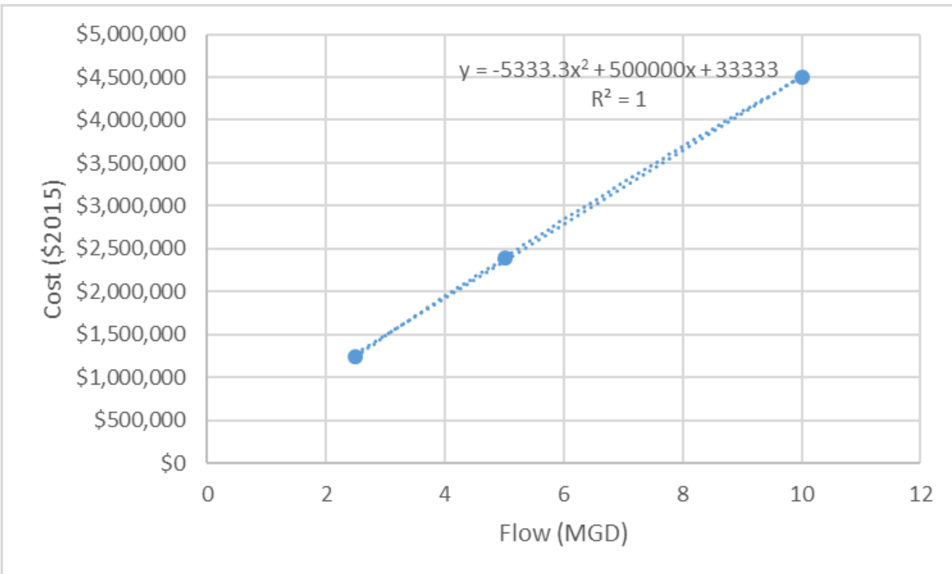

Figure E-1. RO Purchase Cost Curve

Escalated to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017). For a 9 MGD and 8.5 MGD system for this project[17], purchase costs for membrane equipment and appurtenances are approximately $4.4 million and $4.2 million, respectively. Total capital costs were estimated by applying the CAPDETWorks™ installation factor, and direct and indirect cost factors, to the purchase costs, after incorporating the purchase costs into the CAPDETWorks™ outputs.

2. RO Building – using equipment dimensions provided by Wigen (ERG, 2015b), calculated a required building footprint of 4,960 square feet to house the system.

[17] Based on side stream treatment of 85% and 90% of the 10 MGD flow for Level 5-1 5-Stage Bardenpho with Sidestream Reverse Osmosis and Level 5-2 5-Stage Bardenpho Membrane Bioreactor with Sidestream Reverse Osmosis, respectively.

Using the CAPDETWorks™ building unit cost of $110/square foot, calculated a total capital building cost of approximately $550,000.

3. Chlorine Feed System – assumed a single, shared chlorine feed system for the RO biofouling control pretreatment and final wastewater disinfection. Costs for the shared chlorine feed system were estimated as part of the CAPDETWorks™ chlorine wastewater disinfection module.

4. Dechlorination and Antiscalant Feed Systems – purchase cost of $5,000, plus $300 for transport, for each feed system based on telephone contact with EnProTechnologies (ERG, 2011b). Escalated to 2014 $ Using RSMeans Construction Cost Index (RSMeans, 2017), resulting in a 2014 purchase cost of approximately $5,900 for each of these two systems. Total capital costs were estimated by applying the CAPDETWorks™ installation factor, and direct and indirect cost factors, to the purchase costs, after incorporating the purchase costs into the CAPDETWorks™ outputs.

5. Brine Surge Sump – estimated an in-ground concrete brine collection sump volume based on an assumed 60-minute residence time (best professional judgement) and a RO rejection rate of 20 percent based on telephone contacts with Wigen (ERG, 2015b). Calculated a total capital cost of approximately $190,000 for the 90% side stream treatment option, and approximately $180,000 for the 85% side stream treatment option, using a concrete basin cost curve developed using *RSMeans Building Construction Cost Data* (see Figure E-2). Escalated from $2010 to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017).

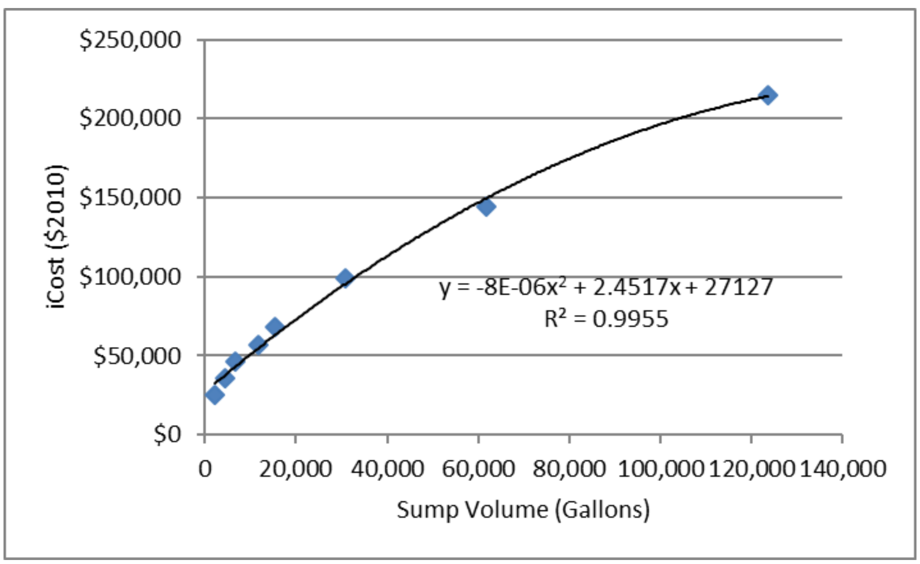

Figure E-2. Brine Surge Sump Total Capital Cost Curve

Operating and Maintenance Costs

1. Operating Labor – One labor hour per day based on Wigen (ERG, 2015b) and CAPDETWorks™ operator labor rate of $51.50/hour (2014 $) for a total operating labor cost of approximately $19,000/yr.
2. Maintenance Labor – One labor hour per day based on best professional judgement that maintenance labor requirements would be similar to, and not greater than, operating labor requirements, and sufficient for maintenance activities such as lubrication, troubleshooting, and installing replacement parts. Used the CAPDETWorks™ operator labor rate of $51.50/hour (2014 $), for a total annual maintenance labor cost of approximately $19,000/yr.
3. Materials – membrane replacement cost of $450 per membrane times an estimated 2,000 membranes for a 10 MGD system based on Wigen (ERG, 2015b), scaled to 9 MGD and 8.5 MGD systems for this project. Assumed membranes has a 4-year life based on Wigen (ERG, 2015b). Escalated to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017). Calculated materials costs of approximately $162,000/yr for the 90% side stream treatment option, and approximately $150,000/yr for the 85% side stream treatment option.
4. Antiscalant Chemicals – calculated using dosage rate of 3 mg/L of Vitec 3000 per Wigen (ERG, 2015b). Vitec 3000 chemical cost of approximately $1,300/500 lb provided by Water Surplus, 2015 and a $0.03/lb freight cost from FreightCenter.com (ERG, 2011a), for a total antiscalant chemicals cost of approximately $220,000/yr and $200,000/yr for the 90% and 85% side stream treatment options, respectively.
5. Membrane Cleaning Chemicals – per Wigen (ERG, 2015b), two cleaning chemicals are each 4,000 lb/yr for a 2.5 MGD system at a cost of $5/lb. Scaled to 9 MGD and 8.5 MGD for this project and added a $0.03/lb freight cost from FreightCenter.com (ERG, 2011a), for a total membrane cleaning chemicals cost of approximately $145,000/yr and $137,000/yr for the 90% and 85% side stream treatment options, respectively.
6. Chlorine and Sodium Bisulfite Pretreatment Chemicals – modified the CAPDETWorks™ chlorine wastewater disinfection module, and the supplemental dechlorination module developed for this project, to incorporate the additional chemical requirements associated with RO pretreatment. Assumed a 1 mg/L chlorine dosage rate per Wigen (ERG, 2015b) and a corresponding dechlorination dosage rate.
7. RO System Energy – energy usage equal to the average of estimates provided by two sources:
   - Wigen (ERG, 2015b) estimated energy usage ranging from 3,000 to 6,000 kWh/day for a 2.5 MGD system (average of 4,500 kWh for a 2.5 MGD system, or 1.8 kWh/kgal)
   - WateReuse Research Foundation, 2014 estimated energy usage ranging from 1.9 to 2.3 kWh/kgal (average of 2.1 kWh/kgal)

Used the average of the average estimated energy usage from these two sources, 1.95kWh/kgal (average of 1.8 kWh/kgal and 2.1 kWh/kgal). For a 9 MGD system, and using the CAPDETWorks™ energy rate of $0.10/kWh (2014 $), total annual energy costs are approximately $640,000/yr and $600,000/yr for the 90% and 85% side stream treatment options, respectively.

8. Dechlorination and Antiscalant Feed System Energy – Two 0.5 HP feed system pumps operated continuously for a calculated annual electrical requirement of approximately 6,500 kWh/yr. Using the CAPDETWorks™ energy rate of $0.10/kWh (2014 $), total energy costs are approximately $650/yr.

Table E-7. RO Capital Costs, 90 Percent of Flow

Equipment Cost Item	Size or number	Units	Unit Cost	Total Cost	Year	2014 Purchased Cost	Total Capital Cost	Source
RO System	9	MGD		$4,460,136	2015	$4,421,296		Wigen (ERG, 2015b).
RO System Building	4,960	sq. foot	$110	$545,600	2014		$545,600	Wigen (ERG, 2015b); building unit cost from CAPDETWorks™.
Chlorination Feed System						$0	$0	
Dechlorination Feed System	1	Each	$5,300	$5,300	2010	$5,918		EnPro (ERG, 2011b).
Anti-Scale Feed System	1	Each	$5,300	$5,300	2010	$5,918		EnPro (ERG, 2011b).
Brine Surge Sump	75,000	gallons		$166,005	2010		$185,364	RSMeans Building Construction Cost Data; RO rejection rate from Wigen (ERG, 2015b).

Table E-8. RO Capital Costs, 85 Percent of Flow

Equipment Cost Item	Size or number	Units	Unit Cost	Total Cost	Year	2014 Purchased Cost	Total Capital Cost	Source
RO System	8.5	MGD		$4,214,802	2015	$4,178,098		Wigen (ERG, 2015b).
RO System Building	4,960	sq. foot	$110	$545,600	2014		$545,600	Wigen (ERG, 2015b); building unit cost from CAPDETWorks™.
Chlorination Feed System						$0	$0	
Dechlorination Feed System	1	Each	$5,300	$5,300	2010	$5,918		EnPro (ERG, 2011b).
Anti-Scale Feed System	1	Each	$5,300	$5,300	2010	$5,918		EnPro (ERG, 2011b).
Brine Surge Sump	70,833	gallons		$160,650	2010		$179,385	RSMeans Building Construction Cost Data; RO rejection rate from Wigen (ERG, 2015b).

Table E-9. RO Operating and Maintenance Costs, 90 Percent of Flow

Operating Labor	**Labor (hrs/day)**	**Labor Rate ($/hr)**	**Days/yr**	**Annual Operating Labor Cost ($/yr)**	**Source**
RO System	1	$51.50	365	$18,798	Wigen (ERG, 2015b).
Maintenance Labor	**Labor (hrs/day)**	**Labor Rate ($/hr)**	**Days/yr**	**Annual Maintenance Labor Cost ($/yr)**	**Source**
RO System	1	$51.50	365	$18,798	Best Professional Judgement and CAPDETWorks™
Materials	**Annual Materials Cost ($/yr)**				**Source**
RO System	$162,044				Wigen (ERG, 2015b).

Table E-10. RO Operating and Maintenance Costs, 90 Percent of Flow

Chemicals	**Dose Rate (lbs/gal)**	**Total Flow (gal/yr)**	**Annual Anti-Scale Chemicals (lbs/yr)**	**Cost ($/lb)**	**Annual Chemicals Cost ($/yr)**	**Source**	**Chemical Consumption**
Pretreatment Anti-Scale	0.00002	3,285,000,000	82,063	$2.64	$216,317	Dose per Wigen (ERG, 2015b); cost per Water Surplus, 2015; freight per FreightCenter.com (ERG, 2011a).	Annual Vitec 3000 Consumption: 91,181 lb/yr Annual Citric Acid Consumption: 16,000 lb/yr Annual Sodium Hypochlorite Consumption: 16,000 lb/yr
Membrane Cleaning	0.00001	3,285,000,000	28,800	$5.03	$144,864	Wigen (ERG, 2015b); freight per FreightCenter.com (ERG, 2011a).	
Pretreatment Chlorine					$0.00	Incorporated into wastewater disinfection module.	
Pretreatment Sodium Bisulfite					$0.00	Incorporated into wastewater dechlorination module.	

Table E-11. RO Operating and Maintenance Costs, 90 Percent of Flow

Energy	Rate (kWh/day)	Annual Electrical (kWh/yr)	Energy Rate ($/kWh)	Annual Energy Cost ($/yr)	Source
RO System	17,550	6,405,750	$0.10	$640,575	Wigen (ERG, 2015b); WateReuse, 2014; CAPDETWorks™.
Chemical Feed Systems	18	6,531	$0.10	$653	EnPro (ERG, 2011b); CAPDETWorks™.

Table E-12. RO Operating and Maintenance Costs, 85 Percent of Flow

Operating Labor	Labor (hrs/day)	Labor Rate ($/hr)	Days/yr	Annual Operating Labor Cost ($/yr)	Source
RO System	1	$51.50	365	$18,798	Wigen (ERG, 2015b).
Maintenance Labor	**Labor (hrs/day)**	**Labor Rate ($/hr)**	**Days/yr**	**Annual Maintenance Labor Cost ($/yr)**	**Source**
RO System	1	$51.50	365	$18,798	Best Professional Judgement and CAPDETWorks™
Materials	**Annual Materials Cost ($/yr)**				**Source**
RO System	$153,041				Wigen (ERG, 2015b).

Table E-13. RO Operating and Maintenance Costs, 85 Percent of Flow

Chemicals	Dose Rate (lbs/gal)	Total Flow (gal/yr)	Annual Anti-Scale Chemicals (lbs/yr)	Cost ($/lb)	Annual Chemicals Cost ($/yr)	Source	Chemical Consumption
Pretreatment Anti-Scale	0.00002	3,102,500,000	77,504	$2.64	$204,299	Dose per Wigen (ERG, 2015b); cost per Water Surplus, 2015; freight per FreightCenter.com (ERG, 2011a).	Annual Vitec 3000 Consumption: 91,181 lb/yr Annual Citric Acid Consumption: 16,000 lb/yr Annual Sodium Hypochlorite Consumption: 16,000 lb/yr
Membrane Cleaning	0.00001	3,102,500,000	27,200	$5.03	$136,816	Wigen (ERG, 2015b); freight per FreightCenter.com (ERG, 2011a).	
Pretreatment Chlorine					$0.00	Incorporated into wastewater disinfection module.	
Pretreatment Sodium Bisulfite					$0.00	Incorporated into wastewater dechlorination module.	

Table E-14. RO Operating and Maintenance Costs, 85 Percent of Flow

Energy	Rate (kWh/day)	Annual Electrical (kWh/yr)	Energy Rate ($/kWh)	Annual Energy Cost ($/yr)	Source
RO System	16,575	6,049,875	$0.10	$604,988	Wigen (ERG, 2015b); WateReuse, 2014; CAPDETWorks™.
Chemical Feed Systems	18	6,531	$0.10	$653	EnPro (ERG, 2011b) and CAPDETWorks™.

E.7 Deep Well Injection

Listed below are the capital cost elements included for deep well injection, with a general description of the basis of estimate, followed by the O&M cost elements and the basis of estimate. Table E-15 and Table E-16 summarize the capital and O&M cost calculations, respectively.

Capital Costs

1. Deep Injection Well – cost basis obtained from telephone contact with North Star Disposal, Inc (U.S. EPA, 2012a). Drilling a new underground injection well costs $3.5 million for a deep well, which was escalated to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017), resulting in a 2014 total capital cost of approximately $3.7 million.
2. Injection Pump/Electrical Building – estimated pump house dimensions (12'x14') based on best professional judgement to house the 3 pumps and control panel, as informed by domestic wastewater deep well injection proposal prepared by the Santa Clarita Valley Sanitation District, 2015[18]. Using the CAPDETWorks™ building unit cost of $110/square foot, calculated a total capital building cost of approximately $18,000.
3. Injection Well Pumps – cost basis of approximately $49,000 for a 786 gpm multistate pump obtained from Water Surplus, 2015, which was escalated to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017). Assumed 2 pumps in operation and 1 spare for a total purchase cost of approximately $140,000. Total capital costs were estimated by applying the CAPDETWorks™ installation factor, and direct and indirect cost factors, to the purchase costs, after incorporating the purchase costs into the CAPDETWorks™ outputs.
4. Injection Well Pumps Freight – cost basis of approximately $1,750 per flatbed truckload to transport all three pumps (total of 10 tons) obtained from Siemens (ERG, 2011c), which we escalated to 2014 $ using RSMeans Construction Cost Index (RSMeans, 2017). Total capital costs were estimated by applying the CAPDETWorks™ installation factor, and direct and indirect cost factors, to the purchase costs, after incorporating the purchase costs into the CAPDETWorks™ outputs.

Operating and Maintenance Costs

1. Operating Labor – 0.5 labor hour per day based on best professional judgement to inspect the pump motors and to record data, and CAPDETWorks™ operator labor rate of $51.50/hour (2014 $), for a total annual operating labor cost of approximately $9,400.

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[18] Santa Clarity Valley Sanitation District. 2015. *Information Sheet – Deep Well Injection Site for Brine Disposal*. DOC #2970311. Accessed from http://www.lacsd.org/civicax/filebank/blobdload.aspx?blobid=9556.

2. Maintenance Labor – 0.5 labor hour per day based on best professional judgement that maintenance labor requirements would be similar to, and not greater than, operating labor requirements, and sufficient for maintenance activities such as lubrication, troubleshooting, and installing replacement parts. Used the CAPDETWorks™ operator labor rate of $51.50/hour (2014 $), for a total annual maintenance labor cost of approximately $9,400/yr.
3. Materials – calculated total annual maintenance materials cost as 2 percent of injection well pump purchase cost based on CAPDETWorks™ methodology. Calculated a maintenance materials cost of approximately $3,000/yr.
4. Energy – Two 350 HP injection well pumps operated continuously for a calculated annual electrical requirement of approximately 4.5 million kWh/yr. Using the CAPDETWorks™ energy rate of $0.10/kWh (2014 $), total energy costs are approximately $460,000/yr.

Table E-15. Deep Well Injection Capital Costs

Equipment Cost Item	Number	Units	Unit Cost	Total Cost	Year	2014 Cost	Total Capital Cost	Data Source
Deep Injection Well	1	Each	$3,500,000	$3,500,000	2012		$3,685,252	North Star Disposal (U.S. EPA, 2012a).
Injection pump building to house pumps and electrical	168	square feet	$110	$18,480	2014		$18,480	Best professional judgement; building unit cost from CAPDETWorks™.
Injection Well Pumps	3	Each	$48,730	$146,190	2015	$144,917		Water Surplus, 2015.
Injection Well Pumps Freight	1	Flatbed Truck	$1,750	$1,750	2011	$1,875		Siemens (ERG, 2011c).

Table E-16. Deep Well Injection Operating and Maintenance Costs

Operating Labor	Labor (hrs/day)	Labor Rate ($/hr)	Days/yr	Annual Operating Labor Cost ($/yr)	Source
	0.5	$51.50	365	$9,399	Best Professional Judgement and CAPDETWorks™.
Maintenance Labor	**Labor (hrs/day)**	**Labor Rate ($/hr)**	**Days/yr**	**Annual Operating Labor Cost ($/yr)**	**Source**
	0.5	$51.50	365	$9,399	Best Professional Judgement and CAPDETWorks™.
Material	**Purchased Pump Cost**	**Rate (% of Purchase)**	**Annual Materials Cost ($/yr)**		**Source**
	$144,917	2	$2,898		CAPDETWorks™.
Chemicals	**Dose Rate (lbs/gal)**	**Total Flow (gallons/yr)**	**Annual Anti-Scale Chemicals (lbs/yr)**	**Cost ($/lb)**	**Annual Chemicals Cost ($/yr)**
No chemical requirements					
Energy	**Rate (kWh/day)**	**Annual Electrical (kWh/yr)**	**Energy Rate ($/kWh)**	**Annual Energy Cost ($/yr)**	**Source**
	12,526	4,572,019	$0.10	$457,202	Water Surplus, 2015 and CAPDETWorks™.

E.8 CAPDETWorks™ Direct Cost Factor Development

See Companion PDF File.

APPENDIX F
DETAILED AIR EMISSIONS METHODOLOGY

Appendix F: Detailed Air Emissions Methodology

F.1 Greenhouse Gas Analysis

This section details the calculations used to determine the process-level GHG emissions from the wastewater treatment and sludge handling stages, from the effluent, and from landfilled sludge. GHG emissions from background and upstream fuel and material processes already exist within the LCI databases used, and while incorporated in the study results, are not discussed here.

F.1.1 Methane Emissions from Biological Treatment

The methodology for calculating CH_4 emissions associated with the wastewater treatment configurations evaluated as part of this study is generally based on the guidance provided in the IPCC Guidelines for national inventories. CH_4 emissions are estimated based on the amount of organic material (i.e., BOD) entering the unit operations that may exhibit anaerobic activity, an estimate of the theoretical maximum amount of methane that can be generated from the organic material (B_o), and a methane correction factor that reflects the ability of the treatment system to achieve that theoretical maximum. In general, the IPCC does not estimate CH_4 emissions from well managed centralized aerobic treatment systems. However, there is acknowledgement that some CH_4 can be emitted from pockets of anaerobic activity, and more recent research suggests that dissolved CH_4 in the influent wastewater to the treatment system is emitted when the wastewater is aerated.

For this analysis, some of the wastewater treatment configurations include anaerobic zones within the treatment system. For these configurations, a methane correction factor (MCF) was used. The methodological equation is:

$$CH_{4\ PROCESS} = BOD\ (mg/L) \times Flow\ (MGD) \times 3.785\ L/gal \times 365.25\ days/yr \times 1x10^{-6}\ kg/mg \times B_o \times MCF$$

Equation F-1

where:

$CH_{4\ PROCESS}$	=	CH_4 emissions from wastewater treatment process (kg CH_4 /yr)
BOD	=	Concentration of BOD entering biological treatment process (mg/L)
Flow	=	Wastewater treatment flow entering biological treatment process (MGD)
B_o	=	maximum CH_4 producing capacity, kg CH_4/kg BOD
MCF	=	methane correction factor (fraction)

For this analysis, there was no relevant MCF provided in the IPCC guidance for centralized aerobic treatment with the wastewater treatment configurations included in this study. Instead, MCFs were developed based on GHG emission studies that were conducted at two U.S. WWTPs. The first study (Czepiel, 1995) evaluated emissions associated with a conventional activated sludge treatment plant, resulting in an MCF of 0.005, which was used for Level 1. The second study (Daelman et al., 2013) evaluated emissions associated with a municipal treatment plant with biological nutrient removal (specifically nitrification and denitrification), resulting in an MCF of 0.05, which was used for all other levels of treatment. No other studies were available and acceptable for use to allow differentiating CH_4 emissions between Levels 2 through 5.

The annual emissions per system were than translated to emissions per m^3 of wastewater treated, using the following calculation and displayed in Table F-1.

$$CH_4 \text{ Process Emissions (kg } CH_4 /m^3 \text{ wastewater)} = CH_{4\,PROCESS} \div [10 \text{ MGD x 365 days/yr x } 0.00378541 \text{ m}^3\text{/gal}]$$

Equation F-2

Table F-1. Methane Emissions from Biological Treatment

System Configuration Level	Influent BOD to biotreatment, mg/L	Flow, MGD	MCF	CH_4 Emitted by Process, kg CH_4/yr	CH_4 Process Emissions, kg CH_4/m^3 wastewater
1	1.6E+2	10	5.0E-3	6.8E+3	5.0E-4
2-1	1.6E+2	10	0.05	6.6E+4	4.8E-3
2-2	1.6E+2	10	0.05	6.8E+4	4.9E-3
3-1	1.7E+2	10	0.05	7.1E+4	5.1E-3
3-2	1.7E+2	10	0.05	7.1E+4	5.1E-3
4-1	1.7E+2	10	0.05	7.1E+4	5.1E-3
4-2	1.6E+2	10	0.05	6.6E+4	4.8E-3
5-1	1.7E+2	10	0.05	7.1E+4	5.1E-3
5-2	1.7E+2	10	0.05	7.0E+4	5.1E-3

F.1.2 Nitrous Oxide Emissions from Biological Treatment

The methodology for calculating N_2O emissions associated with wastewater treatment is based on estimates of emissions reported in the literature. The guidance provided in the IPCC Guidelines for national inventories does not provide a sufficient basis to distinguish N_2O emissions from varying types of wastewater treatment configurations, particularly related to biological nutrient reduction. More recent research has highlighted the fact that emissions from these systems can be highly variable based on operational conditions, specific treatment configurations, and other factors (Chandran, 2012).

For this analysis, data collected from 12 WWTPs were reviewed to identify which wastewater treatment configuration they may best represent (Chandran, 2012). Using the emissions measured from these systems, an average emission factor (EF) was calculated and applied to the modeled data for the nine system configurations. The methodological equation is:

$$N_2O_{\,PROCESS} = \text{TKN (mg/L)} \times \text{Flow (MGD)} \times 3.785 \text{ L/gal} \times 365.25 \text{ days/yr} \times 1\text{x}10^{-6} \text{ kg/mg} \times \text{EF\%} \times 44/14$$

Equation F-3

where:

$N_2O_{PROCESS}$ = N_2O emissions from wastewater treatment process (kg N_2O/yr)

TKN = Concentration of TKN entering biological treatment process (mg/L)

Flow = Wastewater treatment flow entering biological treatment process (MGD)

EF% = average measured % of TKN emitted as N_2O, %

44/14 = molecular weight conversion of N to N_2O

As displayed in Table F-2, the annual emissions per system were translated to emissions per m^3 of wastewater treated, using the following calculation.

$$N_2O \text{ Process Emissions (kg } N_2O/m^3 \text{ wastewater)} = N_2O_{PROCESS} \div [10 \text{ MGD x } 365 \text{ days/yr x } 0.00378541 \text{ } m^3\text{/gal}]$$

Equation F-4

Table F-2. Nitrous Oxide Emissions from Biological Treatment

System Configuration Level	Influent TKN to biotreatment, mg/L[a]	Flow, MGD[a]	EF%, % Emitted as N_2O	Source of EF	Unit Operation Basis	N_2O Emitted by Process, kg N_2O/yr	N_2O Process Emissions, kg N_2O/m^3 wastewater
1	43	10	0.035%	Czepiel (1995)	conventional activated sludge	6.6E+2	4.8E-5
2-1	41	10	0.160%	Chandran (2012)	MLE	2.9E+3	2.1E-4
2-2	43	10	0.020%	Chandran (2012)	separate stage BNR	3.9E+2	2.8E-5
3-1	42	10	0.425%	Chandran (2012)	4-stage Bardenpho	7.8E+3	5.7E-4
3-2	42	10	0.160%	Chandran (2012)	MLE	3.0E+3	2.1E-4
4-1	43	10	0.425%	Chandran (2012)	4-stage Bardenpho	8.2E+3	5.9E-4
4-2	41	10	0.425%	Chandran (2012)	4-stage Bardenpho	7.7E+3	5.6E-4
5-1	42	10	0.425%	Chandran (2012)	4-stage Bardenpho	7.8E+3	5.7E-4
5-2	42	10	0.425%	Chandran (2012)	4-stage Bardenpho	7.7E+3	5.6E-4

a – Flow and influent TKN to biotreatment is based on CAPDETWorks™ modeling

F.1.3 Methane Emissions due to Anaerobic Digestion

The methodology for calculating CH_4 emissions associated with anaerobic sludge digestion is based on the guidance provided in the IPCC Guidelines for national inventories. CH_4 emissions from anaerobic digestion of sludge were estimated based on the amount of biogas generated by the digester, an estimation of the biogas composition, and an estimation of the amount of CH_4 destroyed through flaring.

CH_4 emissions from anaerobic digesters were estimated by multiplying the amount of biogas generated by wastewater sludge treated in anaerobic digesters by the proportion of CH_4 in digester biogas (0.65), the density of CH_4 (662 g CH_4/m^3 CH_4), and the destruction efficiency associated with burning the biogas in an energy/thermal device (0.99). For this analysis, ERG is assuming the biogas is flared, and not recovered for energy use. The methodological equation is:

$$CH_{4\ DIGESTER} = \text{Biogas Flow} \times \text{conversion to } m^3 \times (525960\ \text{min/year}) \times (FRAC\_CH_4) \times (\text{density of } CH_4) \times (1-DE) \times 1/10^3$$

Equation F-5

where:

$CH_{4\ DIGESTER}$	=	CH_4 emissions from anaerobic digestion (kg CH_4 /yr)
Biogas Flow	=	Cubic feet of digester gas produced by digester (ft^3/min)
conversion to m^3	=	Conversion factor, ft^3 to m^3 (0.0283)
$FRAC\_CH_4$	=	Proportion CH_4 in biogas (0.65)
density of CH_4	=	662 (g CH_4/m^3 CH_4)
DE	=	CH_4 destruction efficiency from flaring (0.99 for enclosed flares)
1/10^3	=	Conversion factor, g to kg

As shown in Table F-3 the annual emissions per system were translated to emissions per m^3 of wastewater treated, using the following calculation.

$$CH_4\ \text{Digester Emissions (kg } CH_4/m^3 \text{ wastewater)} = CH_{4\ DIGESTER} \div [10\ \text{MGD} \times 365\ \text{days/yr} \times 0.00378541\ m^3/\text{gal}]$$

Equation F-6

Table F-3. Methane Emissions due to Anaerobic Digestion

System Configuration Level	Biogas Flow, ft^3/min[a]	CH_4 Generated by Digester, kg CH_4/yr	CH_4 Emitted by Digester, kg CH_4/yr	CH_4 Digester Emissions, kg CH_4/m^3 wastewater
1	1.1E+2	6.9E+5	6.9E+3	5.0E-4
2-1	88	5.6E+5	5.6E+3	4.1E-4
2-2	1.2E+2	7.6E+5	7.6E+3	5.5E-4
3-1	85	5.4E+5	5.4E+3	3.9E-4
3-2	85	5.4E+5	5.4E+3	3.9E-4
4-1	85	5.4E+5	5.4E+3	3.9E-4
4-2	87	5.6E+5	5.6E+3	4.1E-4
5-1	85	5.4E+5	5.4E+3	3.9E-4
5-2	82	5.2E+5	5.2E+3	3.8E-4

a – Biogas flow is based on CAPDETWorks™ modeling.

Air emissions other than CH_4 associated with flaring the digester biogas are covered at the end of this Appendix.

F.1.4 Nitrous Oxide Emissions from Effluent Discharged to Receiving Waters

The methodology for calculating nitrous oxide emissions associated with effluent discharge is based on the guidance provided in the IPCC Guidelines for national inventories. N_2O emissions from domestic wastewater (wastewater treatment) were estimated based on the amount of nitrogen discharged to aquatic environments from each of the system configurations, which accounts for nitrogen removed with sewage sludge.

$$N_2O_{EFFLUENT} = N_{EFFLUENT} \times Flow \times 3.785\ L/gal \times 365.25\ days/yr \times 1x10^{-6}\ kg/mg \times EF_3 \times 44/28$$

Equation F-7

where:

$N_2O_{EFFLUENT}$	=	N_2O emissions from wastewater effluent discharged to aquatic environments (kg N_2O/yr)
$N_{EFFLUENT}$	=	N in wastewater discharged to receiving stream, mg/L
Flow	=	Effluent flow, MGD
EF_3	=	Emission factor (0.005 kg N_2O -N/kg sewage-N produced)
44/28	=	Molecular weight ratio of N_2O to N_2

As presented in Table F-4, the annual emissions per system were then translated to emissions per m^3 of wastewater treated, using the following calculation.

$$N_2O\ Effluent\ Emissions\ (kg\ N_2O/m^3\ wastewater) = N_2O_{EFFLUENT} \div [10\ MGD\ x\ 365\ days/yr\ x\ 0.00378541\ m^3/gal]$$

Equation F-8

Table F-4. Nitrous Oxide Emissions from Effluent Discharged to Receiving Waters

System Configuration Level	Effluent Total Nitrogen, mg/L[a]	N_2O Effluent Emissions, kg N_2O /yr	N_2O Effluent Emissions, kg N_2O/m^3 wastewater
1	30	3.2E+3	2.3E-4
2-1	8.0	8.7E+2	6.3E-5
2-2	7.8	8.4E+2	6.1E-5
3-1	6.0	6.5E+2	4.7E-5
3-2	6.0	6.5E+2	4.7E-5
4-1	3.0	3.2E+2	2.4E-5
4-2	3.0	3.3E+2	2.4E-5
5-1	0.78	69	5.0E-6
5-2	1.9	1.7E+2	1.3E-5

a – Effluent nitrogen is based on CAPDETWorks™ modeling and calculated as TKN + nitrate + nitrite.

F.1.5 Methane Emissions and Energy Recovery from Sludge Disposal in Landfills

The methodology for calculating CH_4 emissions associated with landfill disposal are based on the general presumption that the portion of the landfill receiving anaerobic digester sludge operates as a "bioreactor landfill" due to the high BOD and water loading. As such, the anaerobic digestion process will reach steady state quickly. In addition, the anaerobic conversion of BOD to CH_4 will be very similar between anaerobic sludge digesters and anaerobic bioreactor landfills. As such, the ratio of CH_4 evolution to BOD removal in an anaerobic digester will also be applicable to sewage sludge degradation in anaerobic landfills. ERG calculated an emission factor for landfill emissions based on the conversion of organic material to CH_4, as seen in the anaerobic sludge digester. Using modeled outputs from Level 1, ERG calculated an emission factor of 0.61 kg CH_4 emitted per kg BOD added using the following equation:

$$CH_4EF_{LANDFILL} = \text{Digester } CH_4 \text{ Generated} \times [(\text{Digester BOD Inlet} – \text{Digester BOD Outlet}) \times 365.25 \text{ days/yr}]$$

Equation F-9

where:

$CH_4EF_{LANDFILL}$	=	CH_4 emission factor for landfills receiving municipal sludge (kg CH_4 /kg BOD removed)
Digester CH_4 Generated	=	CH_4 emissions generated in anaerobic sludge digester for Level 1 system, kg CH_4 /yr
Digester BOD Inlet	=	BOD entering the digester, kg/day
Digester BOD Outlet	=	BOD exiting the digester, kg/day

CH_4 emissions from domestic wastewater (wastewater treatment) were estimated based on the amount of BOD transferred to the landfill in digested sludge.

$$CH_{4\,LANDFILL} = \text{Sludge Volume} \times \text{BOD} \times 3.785 \text{ L/gal} \times 365.25 \text{ days/yr} \times 1\text{x}10^{-6} \text{ kg/mg} \times CH_4EF_{LANDFILL}$$

Equation F-10

where:

$CH_{4\,LANDFILL}$	=	CH_4 emissions from landfilled sludge (kg CH_4 /yr)
Sludge Volume	=	Volume of sludge transferred to landfill, MGD
BOD	=	BOD concentration in digested sludge, mg/L
$CH_4EF_{LANDFILL}$	=	CH_4 emission factor for landfills receiving municipal sludge (kg CH_4 /kg BOD)

As displayed in Table F-5, the annual emissions per system were then translated per m^3 of wastewater treated, using the following calculation. These values assume no capture of landfill gas.

$$CH_4 \text{ Landfill Emissions (kg } CH_4/m^3 \text{ wastewater)} = CH_{4\,LANDFILL} \div [10 \text{ MGD x 365 days/yr x 0.00378541 } m^3/gal]$$

Equation F-11

Table F-5. Raw Methane Emissions from Sludge Disposal in Landfills

System Configuration Level	Sludge Volume, MGD[a]	Sludge BOD, mg/L[a]	CH_4 Landfill Emissions, kg CH_4/yr	Raw CH_4 Landfill Emissions, kg CH_4 /m^3 wastewater
1	0.02	7.2E+3	1.2E+5	8.9E-3
2-1	0.02	7.0E+3	1.0E+5	7.3E-3
2-2	0.03	5.4E+3	1.4E+5	9.8E-3
3-1	0.02	5.6E+3	9.7E+4	7.0E-3
3-2	0.02	5.6E+3	9.7E+4	7.0E-3
4-1	0.02	5.5E+3	9.7E+4	7.0E-3
4-2	0.02	5.7E+3	1.0E+5	7.3E-3
5-1	0.02	5.5E+3	9.7E+4	7.0E-3
5-2	0.02	5.5E+3	9.4E+4	6.8E-3

a – Sludge volume and sludge BOD is based on CAPDETWorks™ modeling.

However, currently, about 71 percent of CH_4 generated from municipal solid waste landfills is converted to CO_2 before it is released to the environment. 10.6 percent is flared, 56.8 percent is burned with energy recovery, and about 3.8 percent is oxidized as it travels through the landfill cover based on the Inventory of U.S. GHG emissions and sinks (U.S. EPA, 2015b). Overall, only approximately 29 percent of the total CH_4 generated is released as methane without treatment. The net CH_4 emissions from sludge in a landfill, calculated by applying the percentage of CH_4 released without treatment to raw CH_4 emissions reported in Table F-5, is provided in Table F-6.

Table F-6. Methane Emissions from Sludge Disposal in Landfills after Treatment

System Configuration Level	Raw CH_4 Landfill Emissions, kg CH_4 /m^3 wastewater[a]	% CH_4 Released without Treatment	kg CH_4 Released without Treatment/m^3 wastewater
1	8.9E-3	29%	2.6E-3
2-1	7.3E-3	29%	2.1E-3
2-2	9.8E-3	29%	2.8E-3
3-1	7.0E-3	29%	2.0E-3
3-2	7.0E-3	29%	2.0E-3
4-1	7.0E-3	29%	2.0E-3
4-2	7.3E-3	29%	2.1E-3
5-1	7.0E-3	29%	2.0E-3
5-2	6.8E-3	29%	1.9E-3

a – Derived from Table F-5 results.

The U.S. EPA's Landfill Methane Outreach Program Landfill Database indicates that the majority of landfill gas burned with energy recovery is used to produce electricity (U.S. EPA, 2016). The gross energy recovered from combustion of sludge landfill is converted to displaced quantities of grid electricity using an efficiency factor of 1 kWh generated per 11,700 Btu (or 12.34 MJ) of landfill CH_4 burned (U.S. EPA, 2014). Each system configuration is credited with avoiding the GWP associated with production of the offset quantity of grid electricity. The calculations to derive this offset or avoided electricity per system configuration level are shown in Table F-7.

Table F-7. Electricity Generation from Landfill Methane Energy Recovery

System Configuration Level	Raw CH_4 Landfill Emissions, kg CH_4 /m^3 wastewater	% CH_4 Burned with Energy Recovery	kg CH_4 Burned with Energy Recovery/m^3 wastewater	Gross MJ from Landfill Gas Energy Recovery[a]/m^3 wastewater	Net kWh from Landfill CH_4 Energy Recovery/m^3 wastewater[b]
1	8.9E-3	57%	5.0E-3	0.28	0.02
2-1	7.3E-3	57%	4.1E-3	0.23	0.02
2-2	9.8E-3	57%	5.6E-3	0.31	0.03
3-1	7.0E-3	57%	4.0E-3	0.22	0.02
3-2	7.0E-3	57%	4.0E-3	0.22	0.02
4-1	7.0E-3	57%	4.0E-3	0.22	0.02
4-2	7.3E-3	57%	4.1E-3	0.23	0.02
5-1	7.0E-3	57%	4.0E-3	0.22	0.02
5-2	6.8E-3	57%	3.8E-3	0.21	0.02

a – HHV of methane = 11.47 MJ/kg

b – Modeled as avoided electricity with a negative value in the LCA.

F.2 Anaerobic Digester Biogas Flaring

Biogas production for each treatment level is a calculated based on the output of the CAPDETWorks™ model. Emissions inventory information for biogas flaring is compiled from three resources with the maximum reported emission value for each compound being taken as the emission factor for this project. Table F-8 shows the data extracted from each study with the last column displaying the emission factor selected for inclusion in this study. All emission factors in the table are included as kg of compound emitted per cubic meter of biogas flared. Emission factors from Levis and Barlaz 2013 are presented in the original study per cubic meter of biogas CH_4 content.

Table F-8. Biogas Flaring Emission Factors (All values are kg/m^3 Biogas Flared)

Compound	Levis & Barlaz [a]	Alberta Environment [b]	Environment Canada [c]	This Study (Max Value)
Nitrous Oxide	1.1E-5	3.5E-5	4.5E-4	4.5E-4
PM-Total	6.0E-5		8.5E-4	8.5E-4
PM10	1.0E-5		8.5E-4	8.5E-4
PM-2.5	4.7E-6		8.5E-4	8.5E-4
Nitrogen Oxides	0.01			0.01
NMVOCs	2.0E-5			2.0E-5

Table F-8. Biogas Flaring Emission Factors (All values are kg/m^3 Biogas Flared)

Compound	Levis & Barlaz [a]	Alberta Environment [b]	Environment Canada [c]	This Study (Max Value)
Sulfur Oxides	4.3E-4		9.2E-5	4.3E-4
Carbon Monoxide	6.2E-3		5.6E-5	6.2E-3
Ammonia	1.8E-5			1.8E-5
Hydrogen Sulfide	3.9E-6			3.9E-6
PAH			8.7E-6	8.7E-6

Sources:

a – Levis, J.W., and Barlaz, M.A. 2013. Anaerobic Digestion Process Model Documentation. North Carolina State University. http://www4.ncsu.edu/~jwlevis/AD.pdf. Accessed 5 April, 2016

b – Alberta Environment. 2007. Quantification Protocol for the Anaerobic Decomposition of Agricultural Materials Project: Excel Biogas Calculator. http://environment.gov.ab.ca/info/library/7917.pdf. Accessed 5 April, 2016.

c – Environment Canada. 2005. Biogas Flare. https://www.ec.gc.ca/inrp-npri/14618D02-387B-469D-B1CD-42BC61E51652/biogas_flare_e_04_02_2009.xls. Accessed 5 April, 2016

APPENDIX G
EXAMPLE LCI DATA CALCULATIONS

Appendix G: Example LCI Data Calculations

CAPDETWorks™ design and costing software (Hydromantis, 2014) provides the main source of LCI data for treatment plant unit process construction and operation. The relevant elements of the CAPDETWorks™ model output were imported into an Excel document where supplemental calculations were performed to standardize flows to be on the basis of physical units per cubic meter of treated wastewater. Calculation procedures were similar regardless of treatment level. Output LCI associated with the Level 1 treatment system is included in Table G-1 to provide an example of the procedure applied to all treatment levels. Supplementary LCI calculations not associated with CAPDETWorks™ output (e.g., process-level air emissions) are described elsewhere in the report.

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Table G-1. Example Standardization of CAPDETWorks™ Output to LCI per m3 of Treated Wastewater (Level 1)

Unit	*CAPDETWorks™ Model Output*				*Calculated LCI Values*			
	Description	**Value**	**Units**		**Calculated Flow**	**Units**	**Value**	**Assumptions**
Grit Removal	Energy cost	4,690	$/yr		Electricity	kwh/m^3	3.0E-3	$0.10/kWh
Primary Clarifier	Structural	40	years		Building	m^2/m^3	3.4E-8	structural lifespan 40 years
	Area of pump building	201	sqft					
	Electrical energy required	10,100	kWh/yr		Electricity, Total	kwh/m^3	8.4E-4	
	Electrical energy required	1,510	kWh/yr					
	Volume of earthwork required	129,000	cuft		Earthwork, Total	m^3/m^3	2.7E-6	plant lifespan of 100 years
	Volume of earthwork required	1,610	cuft					
	Volume of slab concrete required	10,700	cuft		Concrete, Total	m^3/m^3	9.5E-7	structural lifespan 40 years
	Volume of wall concrete required	7,810	cuft					
Plug Flow Activated Sludge	Electrical energy required	1,880,000	kWh/yr		Electricity, Total	kwh/m^3	0.14	
	Electrical energy required	113,000	kWh/yr					
	Volume of earthwork required	176,000	cuft		Earthwork, Total	m^3/m^3	3.7E-6	plant lifespan of 100 years
	Volume of earthwork required	2,670	cuft					
	Structural	40	years		Concrete	m^3/m^3	5.9E-6	structural lifespan 40 years
	Volume of slab concrete required	75,900	cuft					
	Volume of wall concrete required	38,200	cuft					
	Handrail length	1,290	ft		Steel	kg/m^3	6.4E-6	lifespan of 40 years
	Area of pump building	334	sqft		Building	m^2/m^3	5.6E-8	lifespan of 40 years
Secondary Clarifier	Electrical energy required	11,100	kWh/yr		Electricity, Total	kwh/m^3	1.0E-3	
	Electrical energy required	6,500	kWh/yr					
	Volume of earthwork required	216,000	cuft		Earthwork, Total	m^3/m^3	4.5E-6	plant lifespan of 100 years
	Volume of earthwork required	1,630	cuft					
	Structural	40	years		Concrete, Total	m^3/m^3	1.4E-7	structural lifespan 40 years
	Volume of slab concrete required	17,000	cuft					
	Volume of wall concrete required	9,830	cuft					
	Area of pump building	204	sqft		Building	m2/m3	3.4E-8	structural lifespan 40 years

Table G-1. Example Standardization of CAPDETWorks™ Output to LCI per m3 of Treated Wastewater (Level 1)

Unit	*CAPDETWorks™ Model Output*				*Calculated LCI Values*			
	Description	**Value**	**Units**		**Calculated Flow**	**Units**	**Value**	**Assumptions**
Chlorination	Average chlorine required	832	lb/d		Chlorine	kg/m^3	0.01	operates 365 days per year
	Electrical energy required	131,000	kWh/yr		Electricity	kwh/m^3	9.5E-3	
	Volume of earthwork required	11,900	cuft		Earthwork	m^3/m^3	2.4E-7	plant lifespan of 100 years
	Structural	40.0	years		Concrete, Total	m^3/m^3	4.0E-7	structural lifespan 40 years
	Volume of slab concrete required	2,790	cuft					
	Volume of wall concrete required	4,980	cuft					
	Chlorination building area	220	sqft		Building	m^2/m^3	3.4E-7	structural lifespan 40 years
	Area of chlorine storage building	1,820	sqft					
Dechlorination	Sodium Bisulfite 40% Solution	3.75	mg/L		Sodium bisulfite	kg/m^3	3.8E-3	
	Electrical energy required	131,000	kWh/yr		Electricity	kwh/m^3	9.5E-3	
	Volume of earthwork required	1,980	cuft		Earthwork	m^3/m^3	4.1E-8	plant lifespan of 100 years
	Structural	40.0	years		Concrete, Total	m^3/m^3	1.4E-7	structural lifespan 40 years
	Volume of slab concrete required	464	cuft					
	Volume of wall concrete required	2,330	cuft					
	Dechlorination building area	220	sqft		Building	m^2/m^3	1.5E-7	structural lifespan 40 years
	Area of sodium bisulfite 40% solution storage building	700	sqft					
Gravity Thickening	Electrical energy required	10,300	kWh/yr		Electricity	kwh/m^3	7.5E-4	
	Volume of earthwork required	14,400	cuft		Earthwork	m^3/m^3	3.0E-7	plant lifespan of 100 years
	Structural	40.0	years		Concrete, Total	m^3/m^3	1.6E-7	structural lifespan 40 years
	Volume of slab concrete required	1,260	cuft					
	Volume of wall concrete required	1,860	cuft					

Table G-1. Example Standardization of CAPDETWorks™ Output to LCI per m3 of Treated Wastewater (Level 1)

Unit	*CAPDETWorks™ Model Output*				*Calculated LCI Values*			
	Description	**Value**	**Units**		**Calculated Flow**	**Units**	**Value**	**Assumptions**
Anaerobic Digester	Gas produced	107	cuft/min		Biogas, production	m^3/m^3	0.12	continuous production
	Electrical energy required	253,000	kWh/yr		Electricity	kwh/m^3	0.02	
	Volume of earthwork required	196,000	cuft		Earthwork	m^3/m^3	4.0E-6	plant lifespan of 100 years
	Structural	40.0	years		Concrete, Total	m^3/m^3	1.8E-6	structural lifespan 40 years
	Volume of slab concrete required	6,860	cuft					
	Volume of wall concrete required	27,300	cuft					
	Length of total piping system	833	ft		Steel	kg/m^3	2.4E-5	8" steel pipe, 16.2 kg/ft, lifespan 40 years
	Surface area/floor of 2-story control bldg..	1,180	sqft		Building	m^2/m^3	2.0E-7	
	Heat required	1,350,000	BTU/hr		Natural Gas	m^3/m^3	0.02	38.4 MJ/m^3 Gas HHV
Centrifuge	Polymer dosage	248	lb/d		Polymer	kg/m^3	2.1E-3	operates 5 days per week
	Electrical energy required	237,000	kWh/yr		Electricity	kwh/m^3	0.02	
	Area of building	453	sqft		Building	m^2/m^3	7.6E-8	structural lifespan 40 years
Sludge Hauling & Landfill	Volume of earthwork required	26,700	cuft		Earthwork	m^3/m^3	5.5E-7	plant lifespan of 100 years
	Structural	40	years		Concrete	m^3/m^3	5.7E-7	structural lifespan 40 years
	Volume of slab concrete required	11,100	cuft					
	Sludge storage shed area	10,100	sqft		Building, Total	m^2/m^3	3.4E-6	structural lifespan 40 years
	Surface area of canopy roof	10,100	sqft					
	Sludge hauled	80,286	kg/day		Truck Transport	ton-km/m^3	0.09	25 km haul distance, 365 days per year

APPENDIX H
SUMMARY LCI RESULTS

Appendix H: Summary LCI Result

Table H-1. LCI for Level 1: Conventional Plug Flow Activated Sludge Wastewater Treatment Configuration (per m3 wastewater treated)

	Operation										**Infrastructure**			
	Electricity	**Natural Gas**	**Chlorine Gas**	**Polymer**	**Sodium Bisulfite (40%)**	**Truck Transport**	**Digester Gas, Flared [c]**	**CH_4 Emissions**	**N_2O Emissions**	**Electricity (Avoided)**	**Earthwork**	**Concrete**	**Building**	**Steel**
Unit:	***kWh/m^3***	***m^3/m^3***	***kg/m^3***	***kg/m^3***	***kg/m^3***	***tkm/m^3 [b]***	***m^3/m^3***	***kg/m^3***	***kg/m3***	***kWh/m3***	***m^3/m^3***	***m^3/m^3***	***m^2/m^3***	***kg/m^3***
Screening and Grit Removal	3.4E-3													
Primary Clarifier	8.6E-4										2.7E-6	1.2E-6	3.4E-8	
Plug Flow Activated Sludge	0.14							3.3E-4	4.8E-5		3.7E-6	5.8E-6	5.6E-8	6.4E-6
Secondary Clarifier	1.3E-3										4.5E-6	1.9E-6	3.4E-8	
Chlorination	9.5E-3		1.0E-2								4.9E-7	7.0E-7	3.4E-7	
Dechlorination	9.5E-3				3.8E-3						8.1E-8	1.9E-7	1.5E-7	
Effluent Release [a]									2.4E-4					
Gravity Thickener	7.5E-4										3.0E-7	1.9E-7		
Anaerobic Digester	0.02	0.04					0.12	2.5E-3			5.0E-6	2.0E-6	2.4E-7	2.6E-5
Centrifuge	0.02			2.1E-3									8.4E-8	
Sludge Hauling and Landfill						0.09		2.6E-3		0.02	5.5E-7	5.7E-7	3.4E-6	
Totals	0.20	0.04	1.0E-2	2.1E-3	3.8E-3	**0.09**	**0.12**	5.4E-3	2.9E-4	0.02	1.7E-5	1.3E-5	4.4E-6	3.2E-5

a – All effluent release emissions are presented in Table 1-4.

b – tkm is an abbreviation for ton-kilometers.

c – Biogas flaring emissions are presented in Table F-8

Table H-2. LCI for Level 2-1: Anaerobic/Anoxic/Oxic Wastewater Treatment Configuration(per m3 wastewater treated)

	Operation										Infrastructure			
	Electricity	Natural Gas	Chlorine Gas	Polymer	Sodium Bisulfite (40%)	Truck Transport	Digester Gas, Flared [c]	CH_4 Emissions	N_2O Emissions	Electricity (Avoided)	Earthwork	Concrete	Building	Steel
Unit:	***kWh/m³***	***m³/m³***	***kg/m³***	***kg/m³***	***kg/m³***	***tkm/m³ [b]***	***m³/m³***	***kg/m³***	***kg/m³***	***kWh/m³***	***m³/m³***	***m³/m³***	***m²/m³***	***kg/m³***
Screening and Grit Removal	3.4E-3													
Primary Clarifier	8.5E-4										2.6E-6	1.1E-6	3.4E-8	
Biological Nutrient Removal–3-Stage	0.43							3.3E-3	2.1E-4		9.5E-6	1.2E-5	1.2E-7	1.6E-5
Secondary Clarifier	1.1E-3										4.5E-6	1.9E-6	3.4E-8	
Chlorination	9.5E-3		1.0E-2								4.9E-7	7.0E-7	3.4E-7	
Dechlorination	9.5E-3				3.8E-3						8.1E-8	1.9E-7	1.5E-7	
Effluent Release [a]									6.3E-5					
Gravity Thickener	7.1E-4										2.6E-7	1.8E-7		
Anaerobic Digester	0.02	0.04					0.10	2.1E-3			5.0E-6	2.0E-6	2.4E-7	2.6E-5
Centrifuge	0.01			1.8E-3									7.8E-8	
Sludge Hauling and Landfill						0.07		2.1E-3		0.02	4.7E-7	4.9E-7	2.9E-6	
Totals	0.48	0.04	1.0E-2	1.8E-3	3.8E-3	0.07	0.10	7.5E-3	2.8E-4	0.02	2.3E-5	1.9E-5	3.9E-6	4.2E-5

a – All effluent release emissions are presented in Table 1-4.

b – tkm is an abbreviation for ton-kilometers.

c – Biogas flaring emissions are presented in Table F-8.

Table H-3. LCI for Level 2-2: Activated Sludge, 3-Sludge System Wastewater Treatment Configuration (per m3 wastewater treated)

	Operation													**Infrastructure**			
	Electricity	**Natural Gas**	**Chlorine Gas**	**Polymer**	**Sodium Bisulfite (40%)**	**Al Sulfate**	**Calcium Carbonate**	**Methanol**	**Truck Transport**	**Digester Gas, Flared** [c]	**CH_4 Emissions**	**N_2O Emissions**	**Electricity (Avoided)**	**Earthwork**	**Concrete**	**Building**	**Steel**
Unit:	*kWh/m^3*	*m^3/m^3*	*kg/m^3*	*kg/m^3*	*kg/m^3*	*kg/m^3*	*kg/m^3*	*kg/m^3*	*tkm/m^3* [b]	*m^3/m^3*	*kg/m^3*	*kg/m^3*	*kWh/m^3*	*m^3/m^3*	*m^3/m^3*	*m^2/m^3*	*kg/m^3*
Screening and Grit Removal	3.4E-3																
Primary Clarifier	8.8E-4													2.7E-6	1.2E-6	3.4E-8	
Plug Flow Activated Sludge	0.15										3.3E-3	2.8E-5		3.8E-6	6.1E-6	5.6E-8	6.6E-6
Chemical Phosphorus Removal						0.08											
Nitrification - Suspended Growth	0.16						0.21							3.8E-6	6.1E-6	5.6E-8	6.6E-6
Denitrification - Suspended Growth	0.13							0.05						2.3E-6	1.8E-6	5.6E-8	
Secondary Clarifier	1.3E-3													4.5E-6	1.9E-6	3.4E-8	
Tertiary Clarification (Nitrification)	8.3E-4													4.5E-6	1.9E-6	3.4E-8	
Tertiary Clarification (Denitrification)	1.0E-3													4.5E-6	1.9E-6	3.4E-8	
Chlorination	9.5E-3		1.0E-2											4.9E-7	7.0E-7	3.4E-7	
Dechlorination	9.5E-3				3.8E-3									8.1E-8	1.9E-7	1.5E-7	
Effluent Release [a]												6.1E-5					
Gravity Thickener	8.2E-4													3.8E-7	2.3E-7		
Anaerobic Digester	0.02	0.06								0.13	2.8E-3			6.6E-6	2.7E-6	3.0E-7	3.5E-5
Centrifuge	0.02			3.2E-3												9.0E-8	
Sludge Hauling and Landfill									0.13		2.8E-3		0.03	8.1E-7	8.4E-7	5.1E-6	
Totals	0.51	0.06	1.0E-2	3.2E-3	3.8E-3	0.08	0.21	0.05	0.13	0.13	8.9E-3	8.9E-5	0.03	3.4E-5	2.5E-5	6.3E-6	4.8E-5

a – All effluent release emissions are presented in Table 1-4.

b – tkm is an abbreviation for ton-kilometers.

c – Biogas flaring emissions are presented in Table F-8.

Table H-4. LCI for Level 3-1: 5-Stage Bardenpho System Wastewater Treatment Configuration (per m3 wastewater treated)

	Operation											Infrastructure						
	Electricity	**Natural Gas**	**Chlorine Gas**	**Polymer**	**Sodium Bisulfite (40%)**	**Al Sulfate**	**Truck Transport**	**Digester Gas, Flared [c]**	**CH_4 Emissions**	**N_2O Emissions**	**Electricity (Avoided)**	**Earthwork**	**Concrete**	**Building**	**Steel**	**Sand**	**Gravel**	**Anthracite**
Unit:	*kWh/m³*	*m³/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*tkm/m³ [b]*	*m³/m³*	*kg/m³*	*kg/m³*	*kWh/m³*	*m³/m³*	*m³/m³*	*m²/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*kg/m³*
Screening and Grit Removal	3.4E-3																	
Primary Clarifier	8.5E-4											2.6E-6	1.1E-6	3.4E-8				
Fermenter	8.8E-4											2.1E-7	1.4E-7					
Biological Nutrient Removal–5-Stage	0.46								8.4E-3	5.7E-4		1.1E-5	1.4E-5	1.2E-7	1.9E-5			
Chemical Phosphorus Removal						4.2E-3												
Secondary Clarifier	1.2E-3											4.5E-6	1.9E-6	3.4E-8				
Filtration–Sand Filter	5.6E-3											2.7E-6	1.6E-6			1.1E-3	4.0E-4	2.7E-4
Chlorination	9.5E-3		8.0E-3									4.9E-7	7.0E-7	2.7E-7				
Dechlorination	9.5E-3				3.8E-3							8.1E-8	1.9E-7	1.5E-7				
Effluent Release [a]										4.7E-5								
Gravity Thickener	7.1E-4											2.6E-7	1.8E-7					
Anaerobic Digester	0.02	0.04						0.09	2.0E-3			5.0E-6	2.0E-6	2.4E-7	2.6E-5			
Centrifuge	0.01			1.8E-3										7.9E-8				
Sludge Hauling and Landfill							0.07		2.0E-3		0.02	4.7E-7	4.9E-7	2.9E-6				
Totals	0.52	0.04	8.0E-3	1.8E-3	3.8E-3	4.2E-3	0.07	0.09	0.01	6.2E-4	0.02	2.7E-5	2.2E-5	3.9E-6	4.5E-5	1.1E-3	4.0E-4	2.7E-4

a – All effluent release emissions are presented in Table 1-4.

b – tkm is an abbreviation for ton-kilometers.

c – Biogas flaring emissions are presented in Table F-8.

Table H-5. LCI for Level 3-2: Modified University of Cape Town Process Wastewater Treatment Configuration (per m3 wastewater treated)

	Operation											Infrastructure						
	Electricity	**Natural Gas**	**Chlorine Gas**	**Polymer**	**Sodium Bisulfite (40%)**	**Al Sulfate**	**Truck Transport**	**Digester Gas, Flared [c]**	**CH_4 Emissions**	**N_2O Emissions**	**Electricity (Avoided)**	**Earthwork**	**Concrete**	**Building**	**Steel**	**Sand**	**Gravel**	**Anthracite**
Unit:	***kWh/m^3***	***m^3/m^3***	***kg/m^3***	***kg/m^3***	***kg/m^3***	***kg/m^3***	***tkm/m^3 [b]***	***m^3/m^3***	***kg/m^3***	***kg/m^3***	***kWh/m^3***	***m^3/m^3***	***m^3/m^3***	***m^2/m^3***	***kg/m^3***	***kg/m^3***	***kg/m^3***	***kg/m^3***
Screening and Grit Removal	3.4E-3											-	-	-	-			
Primary Clarifier	8.5E-4											2.6E-6	1.1E-6	3.4E-8	-			
Fermenter	8.8E-4											2.1E-7	1.4E-7	-	-			
Biological Nutrient Removal–4-Stage	0.51								8.4E-3	2.2E-4		1.1E-5	1.4E-5	1.1E-7	1.9E-5			
Chemical Phosphorus Removal						4.2E-3						-	-	-	-			
Secondary Clarifier	1.2E-3											4.5E-6	1.9E-6	3.4E-8	-			
Filtration–Sand Filter	5.6E-3											2.7E-6	1.6E-6	-	-	1.1E-3	4.0E-4	2.7E-4
Chlorination	9.5E-3		8.0E-3									4.9E-7	7.0E-7	2.7E-7	-			
Effluent Release [a]										4.7E-5								
Dechlorination	9.5E-3				3.8E-3							8.1E-8	1.9E-7	1.5E-7	-			
Gravity Thickener	7.1E-4											2.6E-7	1.8E-7	-	-			
Anaerobic Digester	0.02	0.04						0.09	2.0E-3			5.0E-6	2.0E-6	2.4E-7	2.6E-5			
Centrifuge	0.01			1.8E-3								-	-	7.9E-8	-			
Sludge Hauling and Landfill							0.07		2.0E-3		0.02	4.7E-7	4.9E-7	2.9E-6	-			
Totals	0.57	0.04	8.0E-3	1.8E-3	3.8E-3	4.2E-3	0.07	0.09	0.01	2.6E-4	0.02	2.7E-5	2.2E-5	3.9E-6	4.5E-5	1.1E-3	4.0E-4	2.7E-4

a – All effluent release emissions are presented in Table 1-4.

b – tkm is an abbreviation for ton-kilometers.

c – Biogas flaring emissions are presented in Table F-8.

Table H-6. LCI for Level 4-1: 5-Stage Bardenpho System with Denitrification Filter Wastewater Treatment Configuration (per m3 wastewater treated)

	Operation												Infrastructure						
	Electr-icity	Natu-ral Gas	Chlorine Gas	Polym-er	Sodium Bisulfite (40%)	Al Sulf-ate	Met-hanol	Truck Trans-port	Digester Gas, Flared [c]	CH_4 Emiss-ions	N_2O Emiss-ions	Elect-ricity (Avo-i-ded)	Earth-work	Concrete	Building	Steel	Sand	Gravel	Anthracite
Unit:	***kWh/m³***	***m³/m³***	***kg/m³***	***kg/m³***	***kg/m³***	***kg/m³***	***kg/m³***	***tkm/m³ [b]***	***m³/m³***	***kg/m³***	***kg/m³***	***kWh/m³***	***m³/m³***	***m³/m³***	***m²/m³***	***kg/m³***	***kg/m³***	***kg/m³***	***kg/m³***
Screening and Grit Removal	3.4E-3																		
Primary Clarifier	8.5E-4												2.6E-6	1.1E-6	3.4E-8				
Fermenter	8.8E-4												2.1E-7	1.4E-7	-				
Biological Nutrient Removal–5-Stage	0.46									8.4E-3	5.7E-4		1.1E-5	1.4E-5	1.2E-7	1.9E-5			
Chemical Phosphorus Removal						4.2E-3													
Secondary Clarifier	1.2E-3												4.5E-6	1.9E-6	3.4E-8				
Denitrification - Attached Growth	0.13						0.02						1.5E-6	1.1E-6	1.9E-7		2.8E-4	1.2E-4	
Filtration–Sand Filter	5.6E-3												2.7E-6	1.6E-6			1.1E-3	4.0E-4	2.7E-4
Chlorination	9.5E-3		8.0E-3										4.9E-7	7.0E-7	2.7E-7				
Dechlorination	9.5E-3				3.8E-3								8.1E-8	1.9E-7	1.5E-7				
Effluent Release [a]											2.3E-5								
Gravity Thickener	7.1E-4												2.6E-7	1.8E-7					
Anaerobic Digester	0.02	0.04							0.09	2.0E-3			5.0E-6	2.0E-6	2.4E-7	2.6E-5			
Centrifuge	0.01			1.8E-3											7.9E-8				
Sludge Hauling and Landfill								0.07		2.0E-3		0.02	4.7E-7	4.9E-7	2.9E-6				
Totals	0.65	0.04	8.0E-3	1.8E-3	3.8E-3	4.2E-3	0.02	0.07	0.09	0.01	6.0E-4	0.02	2.9E-5	2.3E-5	4.1E-6	4.5E-5	1.4E-3	5.3E-4	2.7E-4

a – All effluent release emissions are presented in Table 1-4.

b – tkm is an abbreviation for ton-kilometers.

c – Biogas flaring emissions are presented in Table C-8.

Table H-7. LCI for Level 4-2: 4-Stage Bardenpho Membrane Bioreactor System Wastewater Treatment Configuration (per m3 wastewater treated)

	Operation											Infrastructure			
	Electricity	**Natural Gas**	**Chlorine Gas**	**Polymer**	**Sodium Bisulfite (40%)**	**Al Sulfate**	**Truck Transport**	**Digester Gas, Flared [c]**	**CH_4 Emissions**	**N_2O Emissions**	**Electricity (Avoided)**	**Earthwork**	**Concrete**	**Building**	**Steel**
Unit:	***kWh/m³***	***m³/m³***	***kg/m³***	***kg/m³***	***kg/m³***	***kg/m³***	***tkm/m³ [b]***	***m³/m³***	***kg/m³***	***kg/m³***	***kWh/m³***	***m³/m³***	***m³/m³***	***m²/m³***	***kg/m³***
Screening and Grit Removal	3.4E-3											-	-	-	-
Primary Clarifier	8.5E-4											2.6E-6	1.1E-6	3.4E-8	-
Biological Nutrient Removal–4-Stage	0.35								8.4E-3	5.6E-4		5.5E-6	7.8E-6	1.2E-7	9.4E-6
Chemical Phosphorus Removal						2.2E-3						-	-	-	-
Membrane Filter	0.23											1.5E-6	3.1E-6	8.2E-8	5.4E-6
Chlorination	9.5E-3		8.0E-3									4.9E-7	7.0E-7	2.7E-7	-
Dechlorination	9.5E-3				3.8E-3							8.1E-8	1.9E-7	1.5E-7	-
Effluent Release [a]										2.4E-5		-	-	-	-
Gravity Thickener	7.0E-4											2.6E-7	1.8E-7	-	-
Anaerobic Digester	0.02	0.03						0.09	2.0E-3			4.5E-6	1.9E-6	2.2E-7	2.5E-5
Centrifuge	0.01			1.8E-3								-	-	7.8E-8	-
Sludge Hauling and Landfill							0.07		2.1E-3		0.02	4.6E-7	4.8E-7	2.9E-6	-
Totals	0.64	0.03	8.0E-3	1.8E-3	3.8E-3	2.2E-3	0.07	0.09	0.01	5.9E-4	0.02	1.5E-5	1.5E-5	3.8E-6	4.0E-5

a – All effluent release emissions are presented in Table 1-4.

b – tkm is an abbreviation for ton-kilometers.

c – Biogas flaring emissions are presented in Table C-8.

Table H-8. Operational LCI for Level 5-1: 5-Stage Bardenpho with Sidestream Reverse Osmosis Wastewater Treatment Configuration (per m3 wastewater treated)

	Electricity	Natural Gas	Chlorine Gas	Polymer	Sodium Bisulfite (40%/12.5 %)	Al Sulfate	Methanol	Antiscalant	Brine Injection (Water Loss)	Truck Transport	Citric Acid	Sodium Hypochlorite	Sulfuric Acid	Sodium Hydroxide	Digester Gas, Flared [c]	CH_4 Emissions	N_2O Emissions	Electricity (Avoided)
Unit:	*kWh/m³*	*m³/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*m³/m³*	*tkm/m³* [b]	*kg/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*m³/m³*	*kg/m³*	*kg/m³*	*kWh/m³*
Screening and Grit Removal	3.4E-3																	
Primary Clarifier	8.5E-4																	
Fermenter	8.8E-4																	
Biological Nutrient Removal – 5-Stage	0.46															8.4E-3	5.7E-4	
Chemical Phosphorus Removal						4.2E-3												
Secondary Clarifier	1.2E-3																	
Denitrification – Attached Growth	0.01						2.3E-3											
Filtration – Sand Filter	5.9E-4																	
Chlorination	9.1E-3		4.9E-3															
Dechlorination	9.1E-3				7.5E-3													
Ultrafiltration	0.17				4.0E-4						1.6E-3	9.9E-4	1.2E-3	3.9E-3				
Reverse Osmosis	0.46							2.7E-3			9.5E-4							
Effluent Release [a]																	5.0E-6	
Gravity Thickener	7.1E-4																	
Anaerobic Digester	0.02	0.04													0.09	2.0E-3		
Centrifuge	0.01			1.8E-3														
Sludge Hauling and Landfill										0.07						2.0E-3		0.02
Underground Injection of Brine	0.33								0.18	2.7E-5								
Totals	1.5	0.04	4.9E-3	1.8E-3	7.9E-3	4.2E-3	2.3E-3	2.7E-3	0.18	0.07	2.5E-3	9.9E-4	1.2E-3	3.9E-3	0.09	0.01	5.8E-4	0.02

a – All effluent release emissions are presented in Table 1-4.

b – tkm is an abbreviation for ton-kilometers.

c – Biogas flaring emissions are presented in Table C-8.

Table H-9. Infrastructure LCI for Level 5-1: 5-Stage Bardenpho with Sidestream Reverse Osmosis Wastewater Treatment Configuration (per m3 wastewater treated)

	Earthwork	Concrete	Building	Steel	Sand	Gravel	Anthracite
Unit:	***m3/m3***	***m3/m3***	***m2/m3***	***kg/m3***	***kg/m3***	***kg/m3***	***kg/m3***
Screening and Grit Removal							
Primary Clarifier	2.6E-6	1.1E-6	3.4E-8				
Fermenter	2.1E-7	1.4E-7					
Biological Nutrient Removal – 5-Stage	1.1E-5	1.4E-5	1.2E-7	1.9E-5			
Chemical Phosphorus Removal							
Secondary Clarifier	4.5E-6	1.9E-6	3.4E-8				
Denitrification – Attached Growth	3.2E-7	4.1E-7	8.5E-8		2.8E-5	1.2E-5	
Filtration – Sand Filter	3.9E-7	2.2E-7			1.1E-4	4.0E-5	2.7E-5
Chlorination	4.0E-7	5.9E-7	2.0E-7				
Dechlorination	6.7E-8	1.8E-7	2.3E-7				
Ultrafiltration	2.6E-6	-	2.7E-6				
Reverse Osmosis	1.6E-6	-	1.7E-6				
Gravity Thickener	2.6E-7	1.8E-7					
Anaerobic Digester	5.0E-6	2.0E-6	2.4E-7	2.6E-5			
Centrifuge			7.9E-8				
Sludge Hauling and Landfill	4.7E-7	4.9E-7	2.9E-6				
Underground Injection of Brine			2.8E-8	2.7E-5			
Totals	2.9E-5	2.1E-5	8.4E-6	7.2E-5	1.4E-4	5.3E-5	2.7E-5

Table H-10. LCI for Level 5-2: 5-Stage Bardenpho Membrane Bioreactor with Sidestream Reverse Osmosis Wastewater Treatment Configuration (per m3 wastewater treated)

	Operation														Infrastructure			
	Electricity	**Natural Gas**	**Chlorine Gas**	**Polymer**	**Sodium Bisulfite (40%)**	**Al Sulfate**	**Antiscalant**	**Brine Injection (Water Loss)**	**Truck Transport**	**Citric Acid**	**Digester Gas, Flared [c]**	**CH4 Emissions**	**N2O Emissions**	**Electricity (Avoided)**	**Earthwork**	**Concrete**	**Building**	**Steel**
Unit:	*kWh/m³*	*m³/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*kg/m³*	*m³/m³*	*tkm/m³ [b]*	*kg/m³*	*m³/m³*	*kg/m³*	*kg/m³*	*kWh/m³*	*m³/m³*	*m³/m³*	*m²/m³*	*kg/m³*
Screening and Grit Removal	3.4E-3																	
Primary Clarifier	8.5E-4														2.6E-6	1.1E-6	3.4E-8	
Fermenter	8.8E-4														2.1E-7	1.4E-7		
Biological Nutrient Removal – 5-Stage	0.39											8.4E-3	5.7E-4		5.3E-6	7.6E-6	1.2E-7	9.1E-6
Chemical Phosphorus Removal						2.1E-3												
Membrane Filter	0.23														1.5E-6	3.1E-6	8.3E-8	5.4E-6
Chlorination	9.1E-3		5.0E-3												4.8E-7	6.9E-7	2.0E-7	
Dechlorination	9.1E-3				7.5E-3										8.0E-8	1.9E-7	2.3E-7	
Reverse Osmosis	0.44						2.5E-3			8.9E-4					1.6E-6	-	1.7E-6	
Effluent Release [a]													1.3E-5					
Gravity Thickener	7.0E-4														2.1E-7	1.5E-7		
Anaerobic Digester	0.02	0.03									0.09	1.9E-3			4.0E-6	1.8E-6	2.0E-7	2.4E-5
Centrifuge	0.01			1.7E-3													7.7E-8	
Sludge Hauling and Landfill									0.07			2.0E-3		0.02	4.5E-7	4.7E-7	2.8E-6	
Underground Injection of Brine	0.33							0.17	2.7E-5								2.8E-8	2.7E-5
Totals	1.4	0.03	5.0E-3	1.7E-3	7.5E-3	2.1E-3	2.5E-3	0.17	0.07	8.9E-4	0.09	0.01	5.8E-4	0.02	1.6E-5	1.5E-5	5.4E-6	6.6E-5

Table H-11. Sludge Quantity Produced by Wastewater Treatment Configuration

Wastewater Treatment Configuration	kg Sludge/m^3 Wastewater Treated[a]	% Change to Level 1, AS
Level 1, AS	0.26	-
Level 2-1, A2O	0.22	-15%
Level 2-2, AS3	0.38	48%
Level 3-1, B5	0.22	3%
Level 3-2, MUCT	0.22	3%
Level 4-1, B5/Denit	0.22	4%
Level 4-2, MBR	0.22	4%
Level 5-1, B5/RO	0.22	4%
Level 5-2, MBR/RO	0.21	0%

[a] 21 percent moisture

APPENDIX I
COST RESULTS BY UNIT PROCESS

Appendix I: Cost Results by Unit Process

This Appendix provides cost results by unit process using the 3% interest and discount rates. Table I-1 and Table I-2 display the detailed results for the total construction costs and total annual costs by unit process. Table I-3 through Table I-7 display the detailed results by total annual cost component (e.g., operational labor, maintenance labor) by unit process. Net present value was not calculated by unit process.

Table I-1. Total Construction Costs by Detailed Unit Process (2014 $)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	$1,890,000	$1,890,000	$1,900,000	$1,890,000	$1,890,000	$1,888,000	$1,890,000	$1,888,000	$1,890,000
Primary clarifier	$1,260,000	$1,230,000	$1,260,000	$1,230,000	$1,230,000	$1,230,000	$1,230,000	$1,230,000	$1,230,000
Activated Sludge	$5,100,000		$5,260,000						
Biological nutrient removal-3-stage		$12,500,000							
Biological nutrient removal-4-stage					$14,800,000		$7,580,000		
Biological nutrient removal-5-stage				$13,800,000		$13,800,000		$13,800,000	$8,550,000
Blower System	$715,000	$770,000	$1,150,000	$787,000	$787,000	$787,000	$2,490,000	$787,000	$2,520,000
Secondary Clarifier	$1,880,000	$1,880,000	$1,890,000	$1,880,000	$1,880,000	$1,880,000		$1,880,000	
Membrane Filter							$13,300,000		$13,300,000
Nitrification, suspended growth			$5,330,000						
Tertiary clarification, nitrification			$1,860,000						
Denitrification, suspended growth			$1,830,000						
Tertiary clarification, denitrification			$1,880,000						
Fermenter				$788,000	$788,000	$788,000		$788,000	$788,000
Chemical Phosphorus Removal			$0	$0	$0	$0	$0	$0	$0
Alum Feed System			$302,000	$214,000	$214,000	$214,000	$214,000	$214,000	$214,000
Denitrification, attached growth						$2,580,000		$560,000	
Sand Filter				$3,810,000	$3,810,000	$3,810,000		$1,100,000	
Ultrafiltration								$11,430,000	
Reverse Osmosis								$12,990,000	$12,340,000
Chlorination	$977,000	$977,000	$977,000	$954,000	$954,000	$954,000	$955,000	$795,000	$860,000
$0Dechlorination	$213,000	$213,000	$213,000	$213,000	$213,000	$213,000	$213,000	$224,000	$235,000
Effluent Release	$0	$0	$0	$0	$0	$0	$0	$0	$0
Gravity Thickener	$1,090,000	$1,010,000	$1,240,000	$1,010,000	$1,010,000	$1,010,000	$1,010,000	$1,010,000	$901,000
Anaerobic Digester	$5,440,000	$5,320,000	$7,450,000	$5,320,000	$5,320,000	$5,320,000	$4,570,000	$5,320,000	$4,830,000
Centrifuge	$2,720,000	$2,370,000	$3,760,000	$2,380,000	$2,380,000	$2,380,000	$2,350,000	$2,390,000	$2,320,000
Sludge Hauling and Landfill	$988,000	$649,000	$1,320,000	$651,000	$651,000	$651,000	$644,000	$651,000	$639,000
Brine Injection Well								$7,790,000	$7,790,000
Other Costs	$33,000,000	$42,600,000	$55,500,000	$51,500,000	$53,000,000	$55,300,000	$53,700,000	$95,400,000	$86,000,000
Total	**$55,300,000**	**$71,400,000**	**$93,100,000**	**$86,400,000**	**$88,900,000**	**$92,800,000**	**$90,100,000**	**$160,000,000**	**$144,000,000**

Table I-2. Total Annual Costs by Detailed Unit Process (2014 $)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	$170,000	$170,000	$174,000	$170,000	$171,000	$172,000	$171,000	$171,000	$171,000
Primary clarifier	$117,000	$117,000	$120,000	$120,000	$117,000	$118,000	$118,000	$118,000	$118,000
Activated Sludge	$518,000		$532,000						
Biological nutrient removal-3-stage		$1,300,000							
Biological nutrient removal-4-stage					$1,540,000		$1,120,000		
Biological nutrient removal-5-stage				$1,380,000		$1,380,000		$1,380,000	$1,140,000
Blower System	$0	$0	$0	$0	$0	$0	$0	$0	$0
Secondary Clarifier	$157,000	$156,000	$160,000	$157,000	$157,000	$158,000		$158,000	
Membrane Filter							$1,230,000		$1,230,000
Nitrification, suspended growth			$554,000						
Tertiary clarification, nitrification			$148,000						
Denitrification, suspended growth			$1,370,000						
Tertiary clarification, denitrification			$155,000						
Fermenter				$72,000	$72,100	$72,800		$72,500	$72,400
Chemical Phosphorus Removal			$1,210,000	$61,500	$61,500	$61,500	$31,000	$61,500	$61,300
Alum Feed System			$124,000	$37,300	$37,300	$37,300	$35,200	$37,300	$37,300
Denitrification, attached growth						$1,030,000		$372,000	
Sand Filter				$128,000	$128,000	$129,000		$47,400	
Ultrafiltration								$487,000	
Reverse Osmosis								$1,200,000	$1,140,000
Chlorination	$313,000	$313,000	$313,000	$266,000	$267,000	$267,000	$267,000	$189,000	$193,000
Dechlorination	$121,000	$122,000	$122,000	$122,000	$122,000	$122,000	$122,000	$171,000	$173,000
Effluent Release	$0	$0	$0	$0	$0	$0	$0	$0	$0
Gravity Thickener	$75,000	$67,000	$92,800	$66,000	$66,600	$67,200	$66,800	$66,900	$64,900
Anaerobic Digester	$591,000	$526,000	$804,000	$523,000	$523,000	$525,000	$510,000	$524,000	$489,000
Centrifuge	$797,000	$717,000	$1,060,000	$720,000	$720,000	$721,000	$711,000	$720,000	$704,000
Sludge Hauling and Landfill	$1,990,000	$1,680,000	$2,910,000	$1,690,000	$1,690,000	$1,680,000	$1,660,000	$1,690,000	$1,640,000
Brine Injection Well								$479,000	$479,000
Other Costs	$288,000	$288,000	$290,000	$288,000	$288,000	$288,000	$288,000	$361,000	$360,000
Total	**$5,140,000**	**$5,470,000**	**$10,150,000**	**$5,800,000**	**$5,960,000**	**$6,840,000**	**$6,330,000**	**$8,320,000**	**$8,080,000**

Table I-3. Total Operational Labor Costs by Detailed Unit Process (2014 $)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	$100,000	$100,000	$101,000	$100,000	$100,000	$100,000	$99,800	$100,000	$99,800
Primary clarifier	$68,900	$68,700	$69,500	$68,700	$68,700	$68,700	$68,600	$68,700	$68,600
Activated Sludge	$148,000		$149,000						
Biological nutrient removal-3-stage		$316,000							
Biological nutrient removal-4-stage					$348,000		$276,000		
Biological nutrient removal-5-stage				$320,000		$320,000		$320,000	$288,000
Blower System	$0	$0	$0	$0	$0	$0	$0	$0	$0
Secondary Clarifier	$90,800	$89,800	$91,400	$90,300	$90,300	$90,300		$90,300	
Membrane Filter							$440,000		$440,000
Nitrification, suspended growth			$154,000						
Tertiary clarification, nitrification			$84,900						
Denitrification, suspended growth			$129,000						
Tertiary clarification, denitrification			$88,500						
Fermenter				$38,600	$38,600	$38,600		$38,600	$38,400
Chemical Phosphorus Removal			$0	$0	$0	$0	$0	$0	$0
Alum Feed System			$118,000	$33,000	$33,000	$33,000	$30,900	$33,000	$33,000
Denitrification, attached growth						$554,000		$221,000	
Sand Filter				$15,400	$15,400	$15,400		$4,140	
Ultrafiltration								$18,800	
Reverse Osmosis								$18,800	$18,800
Chlorination	$74,400	$74,400	$74,400	$66,100	$66,100	$66,100	$66,100	$51,000	$51,400
Dechlorination	$44,200	$44,200	$44,100	$44,200	$44,200	$44,200	$44,200	$57,400	$57,800
Effluent Release	$0	$0	$0	$0	$0	$0	$0	$0	$0
Gravity Thickener	$40,000	$34,900	$50,300	$34,700	$34,700	$34,700	$34,600	$34,700	$34,000
Anaerobic Digester	$134,000	$115,000	$171,000	$114,000	$114,000	$114,000	$113,000	$114,000	$111,000
Centrifuge	$570,000	$521,000	$730,000	$523,000	$523,000	$523,000	$517,000	$523,000	$512,000
Sludge Hauling and Landfill	$204,000	$173,000	$302,000	$174,000	$174,000	$173,000	$171,000	$174,000	$168,000
Brine Injection Well								$9,400	$9,400
Other Costs	$288,000	$288,000	$288,000	$288,000	$288,000	$288,000	$288,000	$361,000	$357,000
Total	**$1,760,000**	**$1,830,000**	**$2,650,000**	**$1,910,000**	**$1,940,000**	**$2,460,000**	**$2,150,000**	**$2,240,000**	**$2,290,000**

Table I-4. Total Maintenance Labor Costs by Detailed Unit Process (2014 $)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	$41,700	$42,200	$44,100	$42,400	$42,500	$43,800	$43,300	$43,200	$43,400
Primary clarifier	$34,500	$34,900	$36,500	$35,100	$35,200	$36,200	$35,800	$35,700	$36,000
Activated Sludge	$74,100		$78,900						
Biological nutrient removal-3-stage		$168,000							
Biological nutrient removal-4-stage					$191,000		$149,000		
Biological nutrient removal-5-stage				$171,000		$176,000		$174,000	$158,000
Blower System	$0	$0	$0	$0	$0	$0	$0	$0	$0
Secondary Clarifier	$45,500	$45,600	$48,000	$46,100	$46,200	$47,700		$47,000	
Membrane Filter							$239,000		$241,000
Nitrification, suspended growth			$81,300						
Tertiary clarification, nitrification			$43,300						
Denitrification, suspended growth			$70,200						
Tertiary clarification, denitrification			$46,100						
Fermenter				$24,300	$24,400	$25,100		$24,800	$24,900
Chemical Phosphorus Removal			$0	$0	$0	$0	$0	$0	$0
Alum Feed System			$0	$0	$0	$0	$0	$0	$0
Denitrification, attached growth						$216,000		$120,000	
Sand Filter				$9,090	$9,110	$9,390		$2,410	
Ultrafiltration								$18,800	
Reverse Osmosis								$18,800	$18,800
Chlorination	$15,600	$15,800	$16,300	$12,800	$12,900	$13,200	$13,100	$8,140	$8,310
Dechlorination	$6,020	$6,120	$6,310	$12,800	$6,160	$13,200	$6,290	$10,100	$10,300
Effluent Release	$0	$0	$0	$0	$0	$0	$0	$0	$0
Gravity Thickener	$22,900	$20,700	$29,000	$20,700	$20,800	$21,400	$21,100	$21,100	$20,900
Anaerobic Digester	$72,100	$63,600	$96,100	$63,500	$63,600	$65,500	$64,500	$64,700	$63,300
Centrifuge	$31,800	$29,800	$44,400	$30,100	$30,200	$31,000	$30,500	$30,600	$30,300
Sludge Hauling and Landfill	$0	$0	$0	$0	$0	$0	$0	$0	$0
Brine Injection Well								$9,400	$9,400
Other Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total	**$344,000**	**$427,000**	**$641,000**	**$461,000**	**$482,000**	**$692,000**	**$603,000**	**$629,000**	**$665,000**

Table I-5. Total Material Costs by Detailed Unit Process (2014 $)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	$23,600	$23,600	$23,700	$23,600	$23,600	$23,600	$23,600	$23,600	$23,600
Primary clarifier	$12,500	$12,200	$12,500	$12,200	$12,200	$12,200	$12,200	$12,200	$12,200
Activated Sludge	$97,400		$100,000						
Biological nutrient removal-3-stage		$228,000							
Biological nutrient removal-4-stage					$259,000		$132,000		
Biological nutrient removal-5-stage				$253,000		$253,000		$253,000	$152,000
Blower System	$0	$0	$0	$0	$0	$0	$0	$0	$0
Secondary Clarifier	$18,700	$18,700	$18,700	$18,700	$18,700	$18,700		$18,700	
Membrane Filter							$130,000		$130,000
Nitrification, suspended growth			$102,000						
Tertiary clarification, nitrification			$18,500						
Denitrification, suspended growth			$6,830						
Tertiary clarification, denitrification			$18,600						
Fermenter				$7,880	$7,880	$7,880		$7,875	$7,875
Chemical Phosphorus Removal			$0	$0	$0	$0	$0	$0	$0
Alum Feed System			$6,040	$4,280	$4,280	$4,280	$4,280	$4,280	$4,280
Denitrification, attached growth						$14,200		$3,270	
Sand Filter				$96,200	$96,200	$96,200		$40,000	
Ultrafiltration								$124,000	
Reverse Osmosis								$162,000	$153,000
Chlorination	$30,600	$30,600	$30,600	$31,400	$31,400	$31,400	$31,400	$29,300	$31,600
Dechlorination	$20,200	$20,200	$20,200	$20,200	$20,200	$20,200	$20,200	$20,600	$20,900
Effluent Release	$0	$0	$0	$0	$0	$0	$0	$0	$0
Gravity Thickener	$10,900	$10,100	$12,400	$10,100	$10,100	$10,100	$10,100	$10,100	$9,010
Anaerobic Digester	$42,400	$40,800	$59,400	$40,800	$40,800	$40,800	$39,100	$40,800	$37,400
Centrifuge	$86,400	$73,500	$128,000	$73,800	$73,800	$73,800	$72,300	$73,800	$71,400
Sludge Hauling and Landfill	$1,790,000	$1,510,000	$2,610,000	$1,520,000	$1,520,000	$1,510,000	$1,490,000	$1,520,000	$1,470,000
Brine Injection Well								$2,900	$2,900
Other Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total	**$2,130,000**	**$1,970,000**	**$3,170,000**	**$2,110,000**	**$2,120,000**	**$2,120,000**	**$1,970,000**	**$2,350,000**	**$2,130,000**

Table I-6. Total Chemical Costs by Detailed Unit Process (2014 $)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	$0	$0	$0	$0	$0	$0	$0	$0	$0
Primary clarifier	$0	$0	$0	$0	$0	$0	$0	$0	$0
Activated Sludge	$0		$0						
Biological nutrient removal-3-stage		$0							
Biological nutrient removal-4-stage					$0		$77,300		
Biological nutrient removal-5-stage				$0		$0		$0	$0
Blower System	$0	$0	$0	$0	$0	$0	$0	$0	$0
Secondary Clarifier	$0	$0	$0	$0	$0	$0		$0	
Membrane Filter							$103,000		$103,000
Nitrification, suspended growth			$0						
Tertiary clarification, nitrification			$0						
Denitrification, suspended growth			$991,000						
Tertiary clarification, denitrification			$0						
Fermenter				$0	$0	$0		$0	$0
Chemical Phosphorus Removal			$1,210,000	$61,500	$61,500	$61,500	$31,000	$61,500	$61,300
Alum Feed System			$0	$0	$0	$0	$0	$0	$0
Denitrification, attached growth						$74,300		$7,430	
Sand Filter				$0	$0	$0		$0	
Ultrafiltration								$91,400	
Reverse Osmosis								$361,000	$341,000
Chlorination	$179,000	$179,000	$179,000	$143,000	$143,000	$143,000	$143,000	$88,200	$89,300
Dechlorination	$50,400	$50,400	$50,400	$50,400	$50,400	$50,400	$50,400	$82,500	$83,500
Effluent Release	$0	$0	$0	$0	$0	$0	$0	$0	$0
Gravity Thickener	$0	$0	$0	$0	$0	$0	$0	$0	$0
Anaerobic Digester	$0	$0	$0	$0	$0	$0	$0	$0	$0
Centrifuge	$84,700	$71,800	$126,000	$72,100	$72,100	$72,100	$70,700	$72,200	$69,800
Sludge Hauling and Landfill	$0	$0	$0	$0	$0	$0	$0	$0	$0
Brine Injection Well								$0	$0
Other Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total	**$314,000**	**$301,000**	**$2,560,000**	**$327,000**	**$327,000**	**$401,000**	**$475,000**	**$764,000**	**$748,000**

Table I-7. Total Energy Costs by Detailed Unit Process (2014 $)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	$4,700	$4,680	$4,720	$4,690	$4,690	$4,690	$4,680	$4,690	$4,680
Primary clarifier	$1,190	$1,180	$1,210	$1,180	$1,180	$1,180	$1,180	$1,180	$1,180
Activated Sludge	$198,000		$204,000						
Biological nutrient removal-3-stage		$592,000							
Biological nutrient removal-4-stage					$737,000		$483,000		
Biological nutrient removal-5-stage				$635,000		$635,000		$635,000	$541,000
Blower System	$0	$0	$0	$0	$0	$0	$0	$0	$0
Secondary Clarifier	$1,760	$1,590	$1,820	$1,660	$1,660	$1,660		$1,660	
Membrane Filter							$319,000		$320,000
Nitrification, suspended growth			$217,000						
Tertiary clarification, nitrification			$1,140						
Denitrification, suspended growth			$175,000						
Tertiary clarification, denitrification			$1,400						
Fermenter				$1,220	$1,220	$1,220		$1,223	$1,220
Chemical Phosphorus Removal			$0	$0	$0	$0	$0	$0	$0
Alum Feed System			$0	$0	$0	$0	$0	$0	$0
Denitrification, attached growth						$174,000		$20,400	
Sand Filter				$7,690	$7,690	$7,690		$820	
Ultrafiltration								$234,000	
Reverse Osmosis								$641,000	$606,000
Chlorination	$13,100	$13,100	$13,100	$13,100	$13,100	$13,100	$13,100	$12,600	$12,600
Dechlorination	$650	$650	$650	$650	$650	$650	$650	$650	$650
Effluent Release	$0	$0	$0	$0	$0	$0	$0	$0	$0
Gravity Thickener	$1,030	$977	$1,130	$975	$975	$975	$972	$975	$965
Anaerobic Digester	$342,320	$306,861	$477,457	$304,875	$304,875	$304,875	$293,400	$304,875	$277,773
Centrifuge	$24,000	$20,500	$34,500	$20,600	$20,600	$20,600	$20,300	$20,600	$20,000
Sludge Hauling and Landfill	$0	$0	$0	$0	$0	$0	$0	$0	$0
Brine Injection Well								$457,000	$457,000
Other Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total	**$587,000**	**$942,000**	**$1,130,000**	**$992,000**	**$1,090,000**	**$1,170,000**	**$1,140,000**	**$2,340,000**	**$2,240,000**

APPENDIX J
LCIA RESULTS BY UNIT PROCESS

Appendix J: LCIA Results by Unit Process

This Appendix provides LCIA results by unit process. Table J-1 through Table J-12 display the detailed results for the twelve impact categories by unit process on the basis of a cubic meter of wastewater treated.

Table J-1. Eutrophication Potential Results by Detailed Unit Process (kg N eq/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	1.2E-5	1.2E-5	1.2E-5	1.2E-5	1.2E-5	1.2E-5	1.2E-5	1.2E-5	1.2E-5
Primary clarifier	3.4E-6	3.4E-6	3.5E-6	3.4E-6	3.4E-6	3.3E-6	3.3E-6	3.4E-6	3.3E-6
Activated sludge	5.0E-4		5.1E-4						
Secondary clarifier	5.1E-6	4.6E-6	5.2E-6	4.8E-6	4.8E-6	4.8E-6		4.8E-6	
Biological nutrient removal-3-stage		1.5E-3							
Biological nutrient removal-4-stage					1.8E-3		1.2E-3		
Biological nutrient removal-5-stage				1.6E-3		1.6E-3		1.6E-3	1.4E-3
Filtration				2.2E-5	2.2E-5	2.2E-5		2.3E-6	
Tertiary clarification, denitrification			4.2E-6						
Tertiary clarification, nitrification			3.5E-6						
Chlorination	1.1E-4	1.0E-4	1.0E-4	9.0E-5	9.0E-5	9.0E-5	9.0E-5	6.7E-5	6.7E-5
Dechlorination	4.3E-5	4.3E-5	4.3E-5	4.3E-5	4.3E-5	4.3E-5	4.3E-5	5.1E-5	5.1E-5
Reverse osmosis								1.7E-3	1.6E-3
Denitrification, attached growth						4.5E-4		5.3E-5	
Denitrification, suspended growth			4.8E-4						
Nitrification, suspended growth			5.5E-4						
Ultrafiltration								6.7E-4	
Chemical phosphorus removal			2.5E-4	1.3E-5	1.3E-5	1.3E-5	6.4E-6	1.3E-5	6.3E-6
Membrane filter							8.3E-4		8.3E-4
Centrifuge	8.6E-5	7.3E-5	1.3E-4	7.4E-5	7.4E-5	7.4E-5	7.2E-5	7.4E-5	7.1E-5
Sludge hauling and landfill	1.7E-3	1.5E-3	2.6E-3	1.5E-3	1.5E-3	1.5E-3	1.4E-3	1.5E-3	1.4E-3
Anaerobic digester	1.4E-4	1.2E-4	1.7E-4	1.2E-4	1.2E-4	1.2E-4	1.2E-4	1.2E-4	1.1E-4
Fermentation				3.1E-6	3.1E-6	3.1E-6		3.1E-6	3.1E-6
Gravity thickener	2.6E-6	2.5E-6	2.9E-6	2.5E-6	2.5E-6	2.5E-6	2.5E-6	2.5E-6	2.5E-6
Effluent release	0.06	6.5E-3	0.01	3.3E-3	3.3E-3	2.2E-3	3.0E-3	5.9E-4	8.5E-4
Underground injection of brine								1.1E-3	1.1E-3
Total	0.07	9.8E-3	0.02	6.8E-3	6.9E-3	6.1E-3	6.8E-3	7.5E-3	7.5E-3

Table J-2. Cumulative Energy Demand Results by Detailed Unit Process (MJ/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Primary clarifier	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Activated sludge	2.0	-	2.1	-	-	-	-	-	-
Secondary clarifier	0.02	0.02	0.02	0.02	0.02	0.02		0.02	-
Biological nutrient removal-3-stage	-	6.1	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	7.2	-	5.0	-	-
Biological nutrient removal-5-stage	-	-	-	6.5	-	6.5	-	6.5	5.6
Filtration	-	-	-	0.09	0.09	0.09	-	9.2E-3	-
Tertiary clarification, denitrification	-	-	0.02	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	0.01	-	-	-	-	-	-
Chlorination	0.35	0.33	0.33	0.29	0.29	0.29	0.29	0.23	0.23
Dechlorination	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.20	0.20
Reverse osmosis	-	-	-	-	-	-	-	6.9	6.5
Denitrification, attached growth	-	-	-	-	-	2.7	-	0.30	-
Denitrification, suspended growth	-	-	3.8	-	-	-	-	-	-
Nitrification, suspended growth	-	-	2.3	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	2.8	-
Chemical phosphorus removal	-	-	0.79	0.04	0.04	0.04	0.02	0.04	0.02
Membrane filter	-	-	-	-	-	-	3.4	-	3.4
Centrifuge	0.39	0.33	0.57	0.33	0.33	0.33	0.33	0.33	0.32
Sludge hauling and landfill	0.51	0.44	0.88	0.45	0.45	0.45	0.43	0.45	0.43
Anaerobic digester	1.8	1.6	2.5	1.8	1.6	1.6	1.6	1.6	1.5
Fermentation	-	-	-	0.01	0.01	0.01	-	0.01	0.01
Gravity thickener	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Effluent release	-	-	-	-	-	-	-	-	-
Underground injection of brine	-	-	-	-	-	-	-	4.7	4.7
Total	5.4	9.1	14	9.7	10	12	11	24	23

Table J-3. Global Warming Potential Results by Detailed Unit Process (kg CO_2 eq/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3	2.7E-3
Primary clarifier	1.0E-3	1.0E-3	1.1E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3	1.0E-3
Activated sludge	0.14	-	0.21	-	-	-	-	-	-
Secondary clarifier	1.6E-3	1.5E-3	1.6E-3	1.5E-3	1.5E-3	1.5E-3		1.5E-3	-
Biological nutrient removal-3-stage	-	0.49	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	0.68	-	0.66	-	-
Biological nutrient removal-5-stage	-	-	-	0.75	-	0.75	-	0.75	0.69
Filtration	-	-	-	4.5E-3	4.5E-3	4.5E-3	-	4.8E-4	-
Tertiary clarification, denitrification	-	-	1.4E-3	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	1.2E-3	-	-	-	-	-	-
Chlorination	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
Dechlorination	9.4E-3	9.4E-3	9.4E-3	9.4E-3	9.4E-3	9.4E-3	9.4E-3	0.01	0.01
Reverse osmosis	-	-	-	-	-	-	-	0.39	0.36
Denitrification, attached growth	-	-	-	-	-	0.12	-	0.01	-
Denitrification, suspended growth	-	-	0.14	-	-	-	-	-	-
Nitrification, suspended growth	-	-	0.13	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	0.15	-
Chemical phosphorus removal	-	-	0.04	2.1E-3	2.1E-3	2.1E-3	1.0E-3	2.1E-3	1.0E-3
Membrane filter	-	-	-	-	-	-	0.19		0.19
Centrifuge	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Sludge hauling and landfill	0.07	0.06	0.09	0.06	0.06	0.06	0.06	0.06	0.05
Anaerobic digester	0.19	0.16	0.23	0.16	0.16	0.16	0.15	0.16	0.15
Fermentation	-	-	-	7.4E-4	7.4E-4	7.4E-4	-	7.4E-4	7.4E-4
Gravity thickener	6.5E-4	6.1E-4	7.2E-4	6.1E-4	6.1E-4	6.1E-4	6.1E-4	6.1E-4	6.0E-4
Effluent release	0.07	0.02	0.02	0.01	0.01	6.8E-3	7.0E-3	1.5E-3	3.9E-3
Underground injection of brine	-	-	-	-	-	-	-	0.26	0.26
Total	0.52	0.77	0.92	1.0	0.96	1.1	1.1	1.8	1.8

Table J-4. Acidification Potential Results by Detailed Unit Process (kg SO_2 eq/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	2.1E-4	2.1E-4	2.1E-4	2.1E-4	2.1E-4	2.1E-4	2.1E-4	2.1E-4	2.1E-4
Primary clarifier	5.7E-5	5.7E-5	5.9E-5	5.7E-5	5.7E-5	5.7E-5	5.7E-5	5.7E-5	5.7E-5
Activated sludge	9.0E-3	-	9.2E-3	-	-	-	-	-	-
Secondary clarifier	8.6E-5	7.8E-5	8.8E-5	8.1E-5	8.2E-5	8.2E-5	-	8.2E-5	-
Biological nutrient removal-3-stage	-	0.03	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	0.03	-	0.02	-	-
Biological nutrient removal-5-stage	-	-	-	0.03	-	0.03	-	0.03	0.02
Filtration	-	-	-	3.5E-4	3.5E-4	3.5E-4	-	3.7E-5	-
Tertiary clarification, denitrification	-	-	6.9E-5	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	5.8E-5	-	-	-	-	-	-
Chlorination	6.5E-4	6.4E-4	6.4E-4	6.3E-4	6.3E-4	6.3E-4	6.3E-4	5.9E-4	5.9E-4
Dechlorination	6.0E-4	6.0E-4	6.0E-4	6.0E-4	6.0E-4	6.0E-4	6.0E-4	5.9E-4	5.9E-4
Reverse osmosis	-	-	-	-	-	-	-	0.03	0.03
Denitrification, attached growth	-	-	-	-	-	7.9E-3	-	9.2E-4	-
Denitrification, suspended growth	-	-	8.0E-3	-	-	-	-	-	-
Nitrification, suspended growth	-	-	9.8E-3	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	0.01	-
Chemical phosphorus removal	-	-	7.5E-4	3.8E-5	3.8E-5	3.8E-5	1.9E-5	3.8E-5	1.9E-5
Membrane filter	-	-	-	-	-	-	0.01	-	0.01
Centrifuge	1.1E-3	9.5E-4	1.6E-3	9.6E-4	9.6E-4	9.6E-4	9.4E-4	9.6E-4	9.2E-4
Sludge hauling and landfill	-	-	-	-9.6E-4	-9.7E-4	-9.7E-4	-9.8E-4	-9.7E-4	-9.3E-4
Anaerobic digester	2.4E-3	2.1E-3	3.0E-3	2.2E-3	2.0E-3	2.0E-3	2.0E-3	2.0E-3	2.0E-3
Fermentation	-	-	-	5.6E-5	5.6E-5	5.6E-5	-	5.6E-5	5.5E-5
Gravity thickener	4.7E-5	4.5E-5	5.2E-5	4.5E-5	4.5E-5	4.5E-5	4.4E-5	4.5E-5	4.4E-5
Effluent release	-	-	-	-	-	-	-	-	-
Underground injection of brine	-	-	-	-	-	-	-	0.02	0.02
Total	0.01	0.03	0.03	0.03	0.04	0.04	0.04	0.09	0.09

Table J-5. Fossil Depletion Results by Detailed Unit Process (kg oil eq/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3	1.1E-3
Primary clarifier	3.1E-4	3.0E-4	3.1E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4	3.0E-4
Activated sludge	0.05	-	0.05	-	-	-	-	-	-
Secondary clarifier	4.6E-4	4.2E-4	4.7E-4	4.4E-4	4.4E-4	4.4E-4	-	4.4E-4	-
Biological nutrient removal-3-stage	-	0.14	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	0.16		0.11	-	-
Biological nutrient removal-5-stage	-	-	-	0.15		0.15	-	0.15	0.12
Filtration	-	-	-	1.9E-3	1.9E-3	1.9E-3	-	2.1E-4	-
Tertiary clarification, denitrification	-	-	3.8E-4	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	3.2E-4	-	-	-	-	-	-
Chlorination	6.0E-3	5.7E-3	5.7E-3	5.2E-3	5.2E-3	5.2E-3	5.2E-3	4.2E-3	4.3E-3
Dechlorination	3.6E-3	3.6E-3	3.6E-3	3.6E-3	3.6E-3	3.6E-3	3.6E-3	4.1E-3	4.1E-3
Reverse osmosis	-	-	-	-	-	-	-	0.15	0.14
Denitrification, attached growth	-	-	-	-	-	0.06	-	6.7E-3	-
Denitrification, suspended growth	-	-	0.09	-	-	-	-	-	-
Nitrification, suspended growth	-	-	0.05	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	0.06	-
Chemical phosphorus removal	-	-	0.01	6.3E-4	6.3E-4	6.3E-4	3.2E-4	6.3E-4	3.2E-4
Membrane filter	-	-	-	-	-	-	0.08	-	0.08
Centrifuge	8.8E-3	7.5E-3	0.01	7.6E-3	7.5E-3	7.5E-3	7.4E-3	7.5E-3	7.2E-3
Sludge hauling and landfill	0.01	9.2E-3	0.02	9.6E-3	9.5E-3	9.5E-3	9.1E-3	9.5E-3	9.0E-3
Anaerobic digester	0.04	0.04	0.06	0.04	0.04	0.04	0.04	0.04	0.03
Fermentation	-	-	-	2.8E-4	2.8E-4	2.8E-4	-	2.8E-4	2.8E-4
Gravity thickener	2.4E-4	2.3E-4	2.7E-4	2.3E-4	2.3E-4	2.3E-4	2.3E-4	2.3E-4	2.2E-4
Effluent release	-	-	-	-	-	-	-	-	-
Underground injection of brine	-	-	-	-	-	-	-	0.10	0.10
Total	0.12	0.20	0.30	0.22	0.23	0.28	0.25	0.54	0.51

Table J-6. Smog Formation Potential Results by Detailed Unit Process (kg O_3 eq/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	1.6E-3	1.6E-3	1.6E-3	1.6E-3	1.6E-3	1.6E-3	1.6E-3	1.6E-3	1.6E-3
Primary clarifier	4.5E-4	4.5E-4	4.6E-4	4.5E-4	4.5E-4	4.5E-4	4.5E-4	4.5E-4	4.5E-4
Activated sludge	0.07	-	0.07	-	-	-	-	-	-
Secondary clarifier	6.8E-4	6.2E-4	7.0E-4	6.5E-4	6.5E-4	6.5E-4	-	6.5E-4	-
Biological nutrient removal-3-stage	-	0.21	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	0.25	-	0.17	-	-
Biological nutrient removal-5-stage	-	-	-	0.22	-	0.22	-	0.22	0.19
Filtration	-	-	-	2.7E-3	2.7E-3	2.7E-3	-	2.9E-4	-
Tertiary clarification, denitrification	-	-	5.5E-4	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	4.7E-4	-	-	-	-	-	-
Chlorination	5.1E-3	5.0E-3	5.0E-3	4.9E-3	4.9E-3	4.9E-3	4.9E-3	4.6E-3	4.6E-3
Dechlorination	5.0E-3	5.0E-3	5.0E-3	5.0E-3	5.0E-3	5.0E-3	5.0E-3	5.3E-3	5.3E-3
Reverse osmosis	-	-	-	-	-	-	-	0.22	0.21
Denitrification, attached growth	-	-	-	-	-	0.06	-	7.1E-3	-
Denitrification, suspended growth	-	-	0.06	-	-	-	-	-	-
Nitrification, suspended growth	-	-	0.08	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	0.08	-
Chemical phosphorus removal	-	-	3.0E-3	1.5E-4	1.5E-4	1.5E-4	7.6E-5	1.5E-4	7.5E-5
Membrane filter	-	-	-	-	-	-	0.11	-	0.11
Centrifuge	8.6E-3	7.3E-3	0.01	7.4E-3	7.4E-3	7.4E-3	7.2E-3	7.4E-3	7.1E-3
Sludge hauling and landfill	-	-	-7.1E-3	-5.9E-3	-5.9E-3	-5.9E-3	-6.0E-3	-5.9E-3	-5.7E-3
Anaerobic digester	0.05	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.04
Fermentation	-	-	-	4.3E-4	4.3E-4	4.3E-4	-	4.3E-4	4.3E-4
Gravity thickener	3.7E-4	3.5E-4	4.0E-4	3.5E-4	3.5E-4	3.5E-4	3.4E-4	3.5E-4	3.4E-4
Effluent release	-	-	-	-	-	-	-	-	-
Underground injection of brine	-	-	-	-	-	4.3E-4	-	0.16	0.16
Total	0.14	0.27	0.29	0.28	0.30	0.34	0.33	0.75	0.72

Table J-7. Human Health- Particulate Matter Formation Potential Results by Detailed Unit Process (kg PM2.5 eq/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	2.4E-5	2.4E-5	2.4E-5	2.4E-5	2.4E-5	2.4E-5	2.4E-5	2.4E-5	2.4E-5
Primary clarifier	6.5E-6	6.5E-6	6.6E-6	6.5E-6	6.5E-6	6.5E-6	6.5E-6	6.5E-6	6.4E-6
Activated sludge	1.0E-3	-	1.0E-3	-	-	-	-	-	-
Secondary clarifier	9.8E-6	8.9E-6	1.0E-5	9.2E-6	9.3E-6	9.3E-6	-	9.3E-6	-
Biological nutrient removal-3-stage	-	3.0E-3	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	3.6E-3	-	2.5E-3	-	-
Biological nutrient removal-5-stage	-	-	-	3.2E-3	-	3.2E-3	-	3.2E-3	2.7E-3
Filtration	-	-	-	3.9E-5	3.9E-5	3.9E-5	-	4.1E-6	-
Tertiary clarification, denitrification	-	-	7.9E-6	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	6.6E-6	-	-	-	-	-	-
Chlorination	7.2E-5	7.1E-5	7.1E-5	7.0E-5	7.0E-5	7.0E-5	7.0E-5	6.6E-5	6.6E-5
Dechlorination	7.0E-5	7.0E-5	7.0E-5	7.0E-5	7.0E-5	7.0E-5	7.0E-5	7.1E-5	7.1E-5
Reverse osmosis	-	-	-	-	-	-	-	3.2E-3	3.1E-3
Denitrification, attached growth	-	-	-	-	-	8.8E-4	-	1.0E-4	-
Denitrification, suspended growth	-	-	8.9E-4	-	-	-	-	-	-
Nitrification, suspended growth	-	-	1.1E-3	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	1.2E-3	-
Chemical phosphorus removal	-	-	6.6E-5	3.3E-6	3.3E-6	3.3E-6	1.7E-6	3.3E-6	1.7E-6
Membrane filter	-	-	-	-	-	-	1.6E-3	-	1.6E-3
Centrifuge	1.3E-4	1.1E-4	1.8E-4	1.1E-4	1.1E-4	1.1E-4	1.1E-4	1.1E-4	1.0E-4
Sludge hauling and landfill	-	-	-1.5E-4	-1.1E-4	-1.1E-4	-1.1E-4	-1.1E-4	-1.1E-4	-1.1E-4
Anaerobic digester	1.8E-4	1.6E-4	2.3E-4	1.7E-4	1.6E-4	1.6E-4	1.6E-4	1.6E-4	1.5E-4
Fermentation	-	-	-	6.2E-6	6.2E-6	6.2E-6	-	6.2E-6	6.2E-6
Gravity thickener	5.3E-6	5.0E-6	5.8E-6	5.0E-6	5.0E-6	5.0E-6	5.0E-6	5.0E-6	4.9E-6
Effluent release	-	-	-	-	-	-	-	-	-
Underground injection of brine	-	-	-	-	-	-	-	2.3E-3	2.3E-3
Total	1.5E-3	3.4E-3	3.5E-3	3.6E-3	3.9E-3	4.5E-3	4.4E-3	0.01	0.01

Table J-8. Ozone Depletion Potential Results by Detailed Unit Process (kg CFC-11 eq/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	1.8E-9	1.8E-9	1.8E-9	1.8E-9	1.8E-9	1.8E-9	1.8E-9	1.8E-9	1.8E-9
Primary clarifier	5.0E-10	5.0E-10	5.1E-10	5.0E-10	5.0E-10	5.0E-10	5.0E-10	5.0E-10	5.0E-10
Activated sludge	6.1E-7	-	3.9E-7	-	-	-	-	-	-
Secondary clarifier	7.6E-10	6.9E-10	7.8E-10	7.1E-10	7.2E-10	7.2E-10	-	7.2E-10	-
Biological nutrient removal-3-stage	-	2.6E-6	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	2.7E-6	-	6.4E-6	-	-
Biological nutrient removal-5-stage	-	-	-	6.6E-6	-	6.6E-6	-	6.6E-6	6.5E-6
Filtration	-	-	-	3.0E-9	3.0E-9	3.0E-9	-	3.2E-10	-
Tertiary clarification, denitrification	-	-	6.1E-10	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	5.1E-10	-	-	-	-	-	-
Chlorination	2.6E-8	2.5E-8	2.5E-8	2.1E-8	2.1E-8	2.1E-8	2.1E-8	1.5E-8	1.5E-8
Dechlorination	6.0E-9	6.0E-9	6.0E-9	6.0E-9	6.0E-9	6.0E-9	6.0E-9	6.7E-9	6.7E-9
Reverse osmosis	-	-	-	-	-	-	-	2.7E-7	2.5E-7
Denitrification, attached growth	-	-	-	-	-	7.4E-8	-	8.5E-9	-
Denitrification, suspended growth	-	-	8.2E-8	-	-	-	-	-	-
Nitrification, suspended growth	-	-	8.6E-8	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	1.1E-7	-
Chemical phosphorus removal	-	-	1.5E-8	7.7E-10	7.7E-10	7.7E-10	3.9E-10	7.7E-10	3.8E-10
Membrane filter	-	-	-	-	-	-	1.3E-7	-	1.3E-7
Centrifuge	1.1E-8	9.1E-9	1.5E-8	9.2E-9	9.1E-9	9.1E-9	9.0E-9	9.1E-9	8.8E-9
Sludge hauling and landfill	4.9E-9	4.4E-9	1.2E-8	4.9E-9	4.8E-9	4.8E-9	4.4E-9	4.8E-9	4.6E-9
Anaerobic digester	5.9E-7	4.9E-7	6.5E-7	4.7E-7	4.7E-7	4.7E-7	4.8E-7	4.7E-7	4.5E-7
Fermentation				4.8E-10	4.8E-10	4.8E-10	-	4.8E-10	4.8E-10
Gravity thickener	4.1E-10	3.9E-10	4.5E-10	3.9E-10	3.9E-10	3.9E-10	3.9E-10	3.9E-10	3.8E-10
Effluent release	2.6E-6	6.9E-7	6.7E-7	5.2E-7	5.2E-7	2.5E-7	2.6E-7	5.5E-8	1.4E-7
Underground injection of brine	-	-	-	-	-	-	-	1.8E-7	1.8E-7
Total	3.9E-6	3.8E-6	2.0E-6	7.6E-6	3.7E-6	7.4E-6	7.3E-6	7.7E-6	7.7E-6

Table J-9. Water Depletion Results by Detailed Unit Process (m^3 H_2O/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	8.2E-6	8.1E-6	8.2E-6	8.2E-6	8.2E-6	8.2E-6	8.1E-6	8.2E-6	8.1E-6
Primary clarifier	5.9E-6	5.8E-6	6.0E-6	5.8E-6	5.8E-6	5.8E-6	5.8E-6	5.8E-6	5.8E-6
Activated sludge	3.6E-4	-	3.8E-4	-	-	-	-	-	-
Secondary clarifier	9.4E-6	9.1E-6	9.5E-6	9.2E-6	9.2E-6	9.2E-6	-	9.2E-6	-
Biological nutrient removal-3-stage	-	1.1E-3	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	1.3E-3	-	8.7E-4	-	-
Biological nutrient removal-5-stage	-	-	-	1.2E-3	-	1.2E-3	-	1.2E-3	9.7E-4
Filtration	-	-	-	1.6E-5	1.6E-5	1.6E-5	-	1.7E-6	-
Tertiary clarification, denitrification	-	-	8.7E-6	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	8.3E-6	-	-	-	-	-	-
Chlorination	1.7E-4	1.6E-4	1.6E-4	1.3E-4	1.3E-4	1.3E-4	1.3E-4	9.0E-5	9.1E-5
Dechlorination	3.7E-5	3.7E-5	3.7E-5	3.7E-5	3.7E-5	3.7E-5	3.7E-5	4.9E-5	4.9E-5
Reverse osmosis	-	-	-	-	-	-	-	1.7E-3	1.6E-3
Denitrification, attached growth	-	-	-	-	-	3.5E-4	-	4.0E-5	-
Denitrification, suspended growth	-	-	4.1E-4	-	-	-	-	-	-
Nitrification, suspended growth	-	-	4.1E-4	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	1.4E-3	-
Chemical phosphorus removal	-	-	2.4E-3	1.2E-4	1.2E-4	1.2E-4	6.0E-5	1.2E-4	6.0E-5
Membrane filter	-	-	-	-	-	-	6.7E-4	-	6.7E-4
Centrifuge	6.3E-5	5.3E-5	9.1E-5	5.4E-5	5.4E-5	5.4E-5	5.3E-5	5.4E-5	5.1E-5
Sludge hauling and landfill	9.0E-5	7.8E-5	1.5E-4	8.0E-5	8.0E-5	8.0E-5	7.7E-5	8.0E-5	7.6E-5
Anaerobic digester	5.7E-5	5.1E-5	7.4E-5	5.5E-5	5.1E-5	5.1E-5	5.0E-5	5.1E-5	4.8E-5
Fermentation	-	-	-	2.6E-6	2.6E-6	2.6E-6	-	2.6E-6	2.6E-6
Gravity thickener	2.4E-6	2.3E-6	2.7E-6	2.3E-6	2.3E-6	2.3E-6	2.3E-6	2.3E-6	2.2E-6
Effluent release	-	-	-	-	-	-	-	-	-
Underground injection of brine	-	-	-	-	-	-	-	0.18	0.17
Total	8.0E-4	1.5E-3	4.1E-3	1.7E-3	1.8E-3	2.0E-3	2.0E-3	0.19	0.17

Table J-10. Human Health-Cancer Results by Detailed Unit Process (CTU_h/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	1.1E-11	1.1E-11	1.1E-11	1.1E-11	1.1E-11	1.1E-11	1.1E-11	1.1E-11	1.1E-11
Primary clarifier	5.0E-12	4.9E-12	5.1E-12	4.9E-12	4.9E-12	4.9E-12	4.9E-12	4.9E-12	4.9E-12
Activated sludge	4.8E-10	-	5.0E-10	-	-	-	-	-	-
Secondary clarifier	7.5E-12	7.1E-12	7.6E-12	7.2E-12	7.2E-12	7.2E-12	-	7.2E-12	-
Biological nutrient removal-3-stage	-	1.4E-9	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	1.7E-9	-	1.2E-9	-	-
Biological nutrient removal-5-stage	-	-	-	1.5E-9	-	1.5E-9	-	1.5E-9	1.3E-9
Filtration	-	-	-	1.9E-11	1.9E-11	1.9E-11	-	2.0E-12	-
Tertiary clarification, denitrification	-	-	6.6E-12	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	6.0E-12	-	-	-	-	-	-
Chlorination	1.9E-10	1.4E-10	1.4E-10	1.2E-10	1.2E-10	1.2E-10	1.2E-10	8.4E-11	8.5E-11
Dechlorination	5.4E-11	5.4E-11	5.4E-11	5.4E-11	5.4E-11	5.4E-11	5.4E-11	7.3E-11	7.4E-11
Reverse osmosis	-	-	-	-	-	-	-	1.7E-9	1.6E-9
Denitrification, attached growth	-	-	-	-	-	4.8E-10	-	5.6E-11	-
Denitrification, suspended growth	-	-	5.6E-10	-	-	-	-	-	-
Nitrification, suspended growth	-	-	5.6E-10	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	7.6E-10	-
Chemical phosphorus removal	-	-	4.9E-9	2.4E-10	2.4E-10	2.4E-10	1.2E-10	2.4E-10	1.2E-10
Membrane filter	-	-	-	-	-	-	8.1E-10	-	8.1E-10
Centrifuge	8.8E-11	7.5E-11	1.3E-10	7.6E-11	7.6E-11	7.6E-11	7.4E-11	7.6E-11	7.3E-11
Sludge hauling and landfill	2.6E-10	2.3E-10	3.8E-10	2.4E-10	2.5E-10	2.4E-10	2.7E-10	2.8E-10	2.8E-10
Anaerobic digester	9.0E-11	8.1E-11	1.2E-10	8.7E-11	8.1E-11	8.1E-11	7.9E-11	8.1E-11	7.6E-11
Fermentation	-	-	-	3.1E-12	3.1E-12	3.1E-12	-	3.1E-12	3.1E-12
Gravity thickener	2.7E-12	2.6E-12	3.0E-12	2.6E-12	2.6E-12	2.6E-12	2.6E-12	2.6E-12	2.5E-12
Effluent release	3.1E-9	3.1E-9	2.5E-9	2.1E-9	1.5E-9	2.4E-9	1.0E-9	4.0E-10	1.7E-10
Underground injection of brine	-	-	-	-	-	-	-	1.1E-9	1.1E-9
Total	4.3E-9	5.1E-9	9.9E-9	4.5E-9	4.1E-9	5.2E-9	3.7E-9	6.4E-9	5.7E-9

Table J-11. Human Health-NonCancer Results by Detailed Unit Process (CTU_h/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	1.1E-10	1.1E-10	1.1E-10	1.1E-10	1.1E-10	1.1E-10	1.1E-10	1.1E-10	1.1E-10
Primary clarifier	6.1E-11	6.0E-11	6.1E-11	6.0E-11	6.0E-11	6.0E-11	6.0E-11	6.0E-11	6.0E-11
Activated sludge	4.8E-9	-	4.9E-9	-	-	-	-	-	-
Secondary clarifier	9.3E-11	8.9E-11	9.4E-11	9.1E-11	9.1E-11	9.1E-11	-	9.1E-11	-
Biological nutrient removal-3-stage	-	1.4E-8	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	1.7E-8	-	1.2E-8	-	-
Biological nutrient removal-5-stage	-	-	-	1.5E-8	-	1.5E-8	-	1.5E-8	1.3E-8
Filtration	-	-	-	1.8E-10	1.8E-10	1.8E-10	-	2.0E-11	-
Tertiary clarification, denitrification	-	-	8.4E-11	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	7.8E-11	-	-	-	-	-	-
Chlorination	2.0E-9	1.6E-9	1.6E-9	1.3E-9	1.3E-9	1.3E-9	1.3E-9	9.2E-10	9.3E-10
Dechlorination	9.6E-10	9.6E-10	9.6E-10	9.6E-10	9.6E-10	9.6E-10	9.6E-10	1.6E-9	1.6E-9
Reverse osmosis	-	-	-	-	-	-	-	1.6E-8	1.5E-8
Denitrification, attached growth	-	-	-	-	-	4.5E-9	-	5.3E-10	-
Denitrification, suspended growth	-	-	5.1E-9	-	-	-	-	-	-
Nitrification, suspended growth	-	-	5.4E-9	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	1.1E-8	-
Chemical phosphorus removal	-	-	1.2E-8	5.8E-10	5.8E-10	5.8E-10	3.0E-10	5.8E-10	2.9E-10
Membrane filter	-	-	-	-	-	-	8.0E-9	-	8.0E-9
Centrifuge	9.3E-10	7.9E-10	1.3E-9	8.0E-10	8.0E-10	8.0E-10	7.8E-10	8.0E-10	7.7E-10
Sludge hauling and landfill	4.5E-9	4.2E-9	5.8E-9	4.9E-9	5.3E-9	4.9E-9	6.3E-9	6.6E-9	6.7E-9
Anaerobic digester	2.1E-9	1.9E-9	2.9E-9	2.1E-9	1.9E-9	1.9E-9	1.8E-9	1.9E-9	1.8E-9
Fermentation	-	-	-	3.2E-11	3.2E-11	3.2E-11	-	3.2E-11	3.2E-11
Gravity thickener	2.9E-11	2.7E-11	3.2E-11	2.7E-11	2.7E-11	2.7E-11	2.7E-11	2.7E-11	2.6E-11
Effluent release	1.0E-7	1.0E-7	1.0E-7	7.6E-8	6.2E-8	7.6E-8	1.9E-8	1.1E-8	2.1E-9
Underground injection of brine	-	-	-	-	-	-	-	1.1E-8	1.1E-8
Total	1.2E-7	1.3E-7	1.4E-7	1.0E-7	9.0E-8	1.1E-7	5.0E-8	7.7E-8	6.1E-8

Table J-12. Ecotoxicity Results by Detailed Unit Process (CTU_e/m^3 Wastewater Treated)

Process	Level 1, AS	Level 2-1, A2O	Level 2-2, AS3	Level 3-1, B5	Level 3-2, MUCT	Level 4-1, B5/Denit	Level 4-2, MBR	Level 5-1, B5/RO	Level 5-2, MBR/RO
Screening and grit removal	0.59	0.58	0.59	0.59	0.59	0.59	0.58	0.59	0.58
Primary clarifier	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Activated sludge	25	-	26	-	-	-	-	-	-
Secondary clarifier	0.29	0.27	0.29	0.28	0.28	0.28	-	0.28	-
Biological nutrient removal-3-stage	-	74	-	-	-	-	-	-	-
Biological nutrient removal-4-stage	-	-	-	-	88	-	61	-	-
Biological nutrient removal-5-stage	-	-	-	80	-	80	-	80	68
Filtration	-	-	-	1.0	1.0	1.0	-	0.11	-
Tertiary clarification, denitrification	-	-	0.24	-	-	-	-	-	-
Tertiary clarification, nitrification	-	-	0.21	-	-	-	-	-	-
Chlorination	5.2	4.9	4.9	4.3	4.3	4.3	4.3	3.2	3.2
Dechlorination	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.5	2.6
Reverse osmosis	-	-	-	-	-	-	-	83	78
Denitrification, attached growth	-	-	-	-	-	23	-	2.7	-
Denitrification, suspended growth	-	-	25	-	-	-	-	-	-
Nitrification, suspended growth	-	-	28	-	-	-	-	-	-
Ultrafiltration	-	-	-	-	-	-	-	34	-
Chemical phosphorus removal	-	-	14	0.68	0.68	0.68	0.35	0.68	0.34
Membrane filter	-	-	-	-	-	-	42	-	42
Centrifuge	3.5	3.0	5.1	3.0	3.0	3.0	3.0	3.0	2.9
Sludge hauling and landfill	11	11	12	14	14	14	17	18	18
Anaerobic digester	7.3	6.4	9.7	7.0	6.4	6.4	6.2	6.4	6.0
Fermentation	-	-	-	0.16	0.16	0.16	-	0.16	0.16
Gravity thickener	0.14	0.13	0.15	0.13	0.13	0.13	0.13	0.13	0.13
Effluent release	2.8E+2	2.8E+2	2.8E+2	1.6E+2	1.6E+2	1.6E+2	72	25	6.0
Underground injection of brine	-	-	-	-	-	-	-	57	57
Total	3.4E+2	3.9E+2	4.1E+2	2.7E+2	2.8E+2	2.9E+2	2.1E+2	3.2E+2	2.9E+2

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Errata to:

Life Cycle and Cost Assessments of Nutrient Removal Technologies in Wastewater Treatment Plants

Prepared for:

U.S. Environmental Protection Agency
Standards and Health Protection Division
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June 2023

EPA 832-R-21-006ES

ERRATA

ERG identified an error in Appendix F of the Life Cycle and Cost Assessments of Nutrient Removal Technologies in Wastewater Treatment Plants (EPA 832-R-21-006), dated August 2021. Equation F-3, the equation used to calculate nitrous oxide (N2O) emissions from wastewater treatment processes, included an incorrect molecular weight conversion factor of N to N2O of 44/14. The correct conversation factor is 44/28.

This error only affects N2O emission from biological treatment. The corrected emissions are half as much as those presented in the report, as shown in Table 1 below. Emissions of N2O only affect the global warming potential (GWP) impact category but are reflected in all related charts and discussion (Figures 6-5, 8-1 and 9-3 and Tables 8-1 and 8-3). Figure 1 compares the GWP impact of treatment systems before and after correction of the N2O conversion factor (Figure 6-5 in the report).

Table 1. Comparison of N_2O Emissions from Biological Treatment

System Configuration Level	N_2O Emitted by Process (kg N_2O/yr)	
	Original Estimate[a]	Corrected Estimate
1	6.6E+02	3.3E+02
2-1	2.9E+03	1.5E+03
2-2	3.9E+02	1.9E+02
3-1	7.8E+03	3.9E+03
3-2	3.0E+03	1.5E+03
4-1	8.2E+03	4.1E+03
4-2	7.7E+03	3.9E+03
5-1	7.8E+03	3.9E+03
5-2	7.7E+03	3.9E+03

a – Estimates included in Table F-2 of *Life Cycle and Cost Assessments of Nutrient Removal Technologies in Wastewater Treatment Plants (*EPA 832-R-21-006.

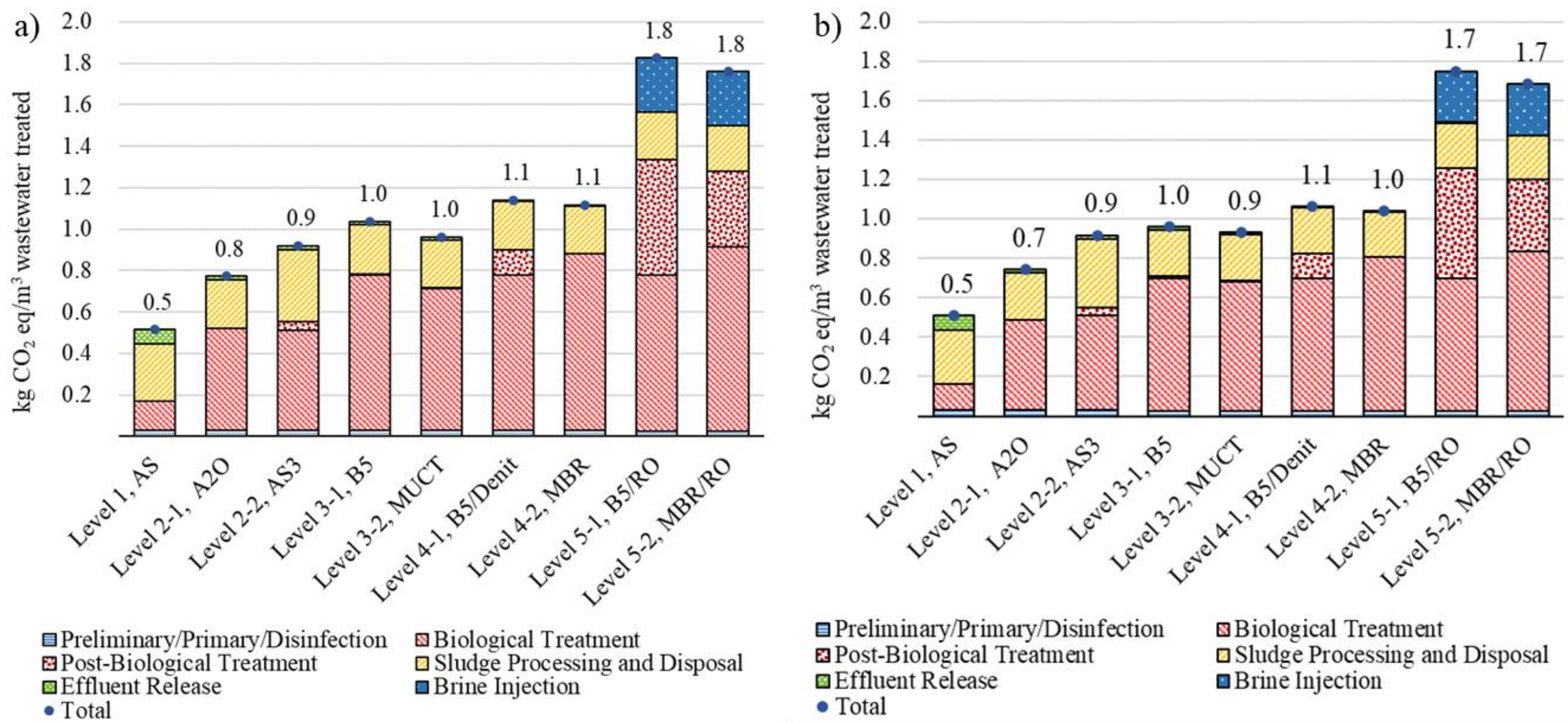

Figure 1. Comparison of Global Warming Potential Impact prior to (panel a) and following (panel b) correction of the N_2O conversion factor.

Because the error affected the calculation of biological treatment emissions, which are included for all systems, it has a limited effect on the comparative results between systems. Correction of the error alters the height of the biological treatment bars of each system. Prior to correction of the error, N2O emissions from biological treatment contributed between 0.8% and 15% of total GWP emissions.

- The largest contribution of N_2O to GWP is observed for treatment levels 3-1, 4-1, and 4-2 (14-15%). Using the updated conversion factor the contribution of N_2O to GWP drops to between 7 and 8%.
- More moderate contributions are observed for treatment levels 2-1, 3-2, 5-1 and 5-2 (6-8%). Using the updated conversion factor the contribution of N_2O to GWP drops to between 3 and 4%.
- The smallest contribution of N_2O to GWP is observed for treatment levels 1 and 2-2 (0.8-3%). Using the updated conversion factor the contribution of N_2O to GWP drops to between 0.4 and 1.3%.

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A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution

U.S. Environmental Protection Agency
Office of Water
EPA 820-F-15-096

May 2015

General Abbreviations and Acronyms

BNR	biological nutrient removal
BMP	best management practice
ENR	enhanced nutrient removal
EPA	[United States] Environmental Protection Agency
gpd	gallons per day
HAB	harmful algal bloom
lb	pound
µg/L	micrograms per liter
mg/L	milligrams per liter
mgd	million gallons per day
MLE	modified Ludzack-Ettinger
O&M	operations and maintenance
QAPP	quality assurance project plan
TA	total ammonia nitrogen
TIN	total inorganic nitrogen
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorous
TSS	total suspended solids
WWTP	wastewater treatment plant

EXECUTIVE SUMMARY

Nutrient pollution, defined as excess amounts of nitrogen and phosphorus in aquatic systems, is one of the leading causes of water quality impairment in the United States. This report compiles current information regarding the costs of nutrient pollution. Such costs may be of two broad types. Some costs are associated with reducing nutrient pollution at its sources. Other costs are associated with the impacts of nutrient pollution in the environment. The latter category of costs is referred to as "external costs" or "externalities," because they are "external" to the owners of the farms, businesses, or facilities that generate them.

The data in this compilation were collected from a range of sources including published, peer-reviewed journals, government-funded research and reports, academic studies and other data sources that met data quality objectives and procedures set forth in this report as described in the Methods section. This report provides users with a collection of other researchers' data from 2000 through 2012 as well as references to the literature cited. The U.S. Environmental Protection Agency's (EPA's) intent is to provide information that users can evaluate and use to form their own conclusions about appropriate management actions for controlling nutrient pollution in specific watersheds and waterbodies. Of course, readers should use caution and careful judgment in applying these results, as circumstances are rarely the same from one context to another. Moreover, as the report notes, not all estimates of monetary impacts can be directly translated into economically meaningful cost estimates.

Cost is a major factor in the management and control of nutrient pollution. External costs – costs borne by the public more generally – associated with the impacts from uncontrolled or under-controlled nutrient pollution and delayed action are important considerations. The adverse biological and ecological effects of nutrient pollution can result in economic losses across multiple industries and economic sectors. Managing and controlling nutrient pollution must also include consideration of the costs associated such actions, including the development, implementation, and enforcement of pollution control plans, wastewater treatment plant upgrades, municipal stormwater controls, agricultural best management practices, homeowner septic system improvements, and other actions.

Although it may not be appropriate to directly compare the costs of controlling nutrients to the economic impacts associated with nutrient pollution because the studies vary in their analyses, methodologies, starting conditions and initial assumptions, the document will help users to understand the substantial economic costs of *not* controlling nutrient pollution. The data and information compiled for this report are instructive in that they provide relative order of magnitude estimates appropriate for screening or feasibility analyses, and can be used to add perspective to the costs of not implementing controls. The information in this report may inform state, tribal, and local processes to develop policies and tools to reduce nutrient pollution. The information suggests that nitrogen and phosphorus may be expensive to control after they are released to the environment. Preventing them from entering the system is potentially a more cost-effective strategy for addressing nutrient pollution and its impacts.

External Costs Associated with Nutrient Pollution Impacts

Excessive nutrient loading to waterbodies can lead to excessive plant and algal growth, resulting in a range of adverse economic effects. Several studies have documented significant economic losses or increased costs[1] associated with anthropogenic nutrient pollution in the following categories:

- *Tourism and recreation*. Studies from Ohio, Florida, Texas, and Washington (Section III.A.1) provide quantitative estimates of declining restaurant sales, increased lakeside business closures, decreased tourism-associated spending in local areas, and other negative economic impacts of algal blooms. For example, a persistent algal bloom in an Ohio lake caused $37 million to $47 million in lost local tourism revenue over two years.
- *Commercial fishing*. Several studies (Section II.A.2) document the negative impacts of algal blooms to commercial fisheries throughout coastal areas of the United States, including reduced harvests, fishery closures, and increased processing costs associated with elevated shellfish poisoning risks. For example, a harmful algal bloom (HAB) outbreak on the Maine coast prompted shellfish bed closures, leading to losses of $2.5 million in soft shell clam harvests and $460,000 in mussel harvests.
- *Property values*. Elevated nutrient levels, low dissolved oxygen levels, and decreased water clarity can depress the property values of waterfront and nearby homes. Studies in the New England, Mid-Atlantic, Midwest, and Southeast regions (Section III.A.3) have demonstrated these impacts using hedonic analyses[2] that measure the impact of water clarity or direct water quality metrics such as pollutant concentrations on property sales price. In New England, for example, a 1-meter difference in water clarity is associated with property value changes up to $61,000 and in Minnesota, property values changed up to $85,000.
- *Human health*. Algal blooms can cause a variety of adverse health effects (in humans and animals) through direct contact with skin during recreation, consumption through drinking water, or consumption of contaminated shellfish, which can result in neurotoxic shellfish poisoning and other effects. For example, a study from Florida (Section III.A.4) documented increased emergency room visit costs in Sarasota County for respiratory illnesses resulting from algal blooms. During high algal bloom years, these visits can cost the county more than $130,000.
- *Drinking water treatment costs*. Excess nutrients in source water for drinking water treatment plants can result in increased costs associated with treatments for health risks and foul taste and odor. For example, a study in Ohio (Section III.B.1) documents expenditures of more than $13 million in two years to treat drinking water from a lake affected by algal blooms.
- *Mitigation*. Nutrients that enter waterbodies can accumulate in bottom sediments, acting as sources of loadings to the water column. In-lake mitigation measures such as aeration, alum treatments, biomanipulation, dredging, herbicide treatments, and hypolimnetic withdrawals may be necessary to address the resultant algal blooms. Several studies (Section III.B.2) have documented these measures and the costs associated with them for individual waterbodies. These costs range from $11,000 for a single year of barley straw treatment to more than $28

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[1] Unless otherwise indicated, all dollar values are updated to 2012$ using appropriate indices.

[2] Hedonic means of or relating to utility. In a hedonic econometric model, the independent variables relate to quality, such as the quality of a home one might buy.

million in capital and $1.4 million in annual operations and maintenance for a long-term dredging and alum treatment plan.

- *Restoration*. There are substantial costs associated with restoring impaired waterbodies, such as developing total maximum daily loads (TMDLs), watershed plans, and nutrient trading and offset programs (Section III.B.3). For example, there are several trading and offset programs that have been developed specifically to assist in nutrient reductions. One developed for the Great Miami River Watershed in Ohio for nitrogen and phosphorus had estimated costs of more than $2.4 million across 3 years.

Costs Associated with Nutrient Pollution Control

Addressing nutrient pollution entails the deployment of nutrient pollution controls for point and/or nonpoint sources. Data were extracted and compiled from recent studies related to the costs for treatment systems and other controls that have been employed by point and nonpoint sources to reduce the discharge of nutrients to surface waters. Highlights of the data and information collected are provided here.

- *Municipal Wastewater Treatment Plants*. The capital and operation and maintenance (O&M) costs for nitrogen and phosphorus were found to vary based on numerous factors, including the types of treatment technologies and controls used and the scale of the plant (Section IV.A.1). Many of the best performing plants (in terms of final effluent concentrations achieved) utilized some form of biological nutrient removal (BNR) process paired with filtration. Unit costs for these types of systems were generally lower as the size of the plant increased. Most treatment technologies designed for nitrogen removal were reported to achieve effluent concentrations between 3 mg/L and 8 mg/L, and most treatment schemes for phosphorus removal (which typically involved one or more treatment processes) were reported to achieve effluent concentrations of 1 mg/L or less.

- *Decentralized Wastewater Treatment Systems*. Limited data were available to assess costs associated with nutrient control in small communities, with all available data originating from three sources (Section IV.A.2). Data regarding phosphorus removal were extremely limited, and associated costs could not be reliably estimated.

- *Industrial Wastewater Treatment*. Data on nutrient control in industrial wastes were largely limited to one source on meat and poultry products processors and reported on the nutrient control performance of three treatment strategies (Section IV.A.3). In general, an enhanced aeration treatment process produced the most reliably low nitrogen effluent concentrations, while chemical phosphorus removal produced the most reliably low phosphorus effluent concentrations.

- *Urban and Residential Runoff*. Costs associated with the control of nutrients in stormwater runoff from urban and residential areas were reported for a range of structural and non-structural best management practices. For example, infiltration basins were found to have a phosphorus removal efficiency of 65% with costs ranging from $\$819/m^3$ to $\$1{,}768/m^3$, and programs to identify and correct illicit discharges into storm sewer systems had costs (based on 20-year present worth) as low as $8.82 per pound of nitrogen removed and $35 per pound of phosphorus removed.

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I. INTRODUCTION

This report presents the findings from a U.S. Environmental Protection Agency (EPA) effort to compile current information regarding costs associated with nutrient pollution. Such costs may be of two broad types. Some costs are associated with reducing nutrient pollution at its sources. Other costs are associated with the impacts of nutrient pollution in the environment. This latter category of costs is referred to as "external costs" or "externalities," because they are "external" to the owners of the farms, businesses, or facilities that generate them. The EPA is providing this work to help states, tribes, and other stakeholders consider cost data from various sources, geographic locations, scales, and waterbody types in the development of policies and tools to reduce nutrient pollution.

I.A. What is nutrient pollution and why is it a concern?

In this report, the term "nutrient" refers to nitrogen and phosphorus, two essential elements for the growth and proliferation of flora (e.g., plants and algae), which in turn support various grazers and consumers across the food web. In aquatic environments, nitrogen and phosphorus are available in organic and inorganic forms and in dissolved and particulate forms. Nitrogen and phosphorus can come from natural sources through physical, chemical, geological and biological processes, but they can also come from anthropogenic sources like agriculture (e.g., animal manure, synthetic fertilizer application), municipal and industrial wastewater discharges (e.g., wastewater treatment plants, septic systems), stormwater runoff, and fossil fuel combustion. This report focuses solely on anthropogenic sources of nutrients to surface waters.

While some amount of nutrients is needed to support aquatic communities, excess nitrogen and phosphorus (or "nutrient pollution") can cause an overstimulation and overabundance of plant and algal growth that can lead to a number of deleterious environmental, human health and economic impacts (Dodds et al., 2009; Weaver, 2010). For example, nutrient pollution can lead to harmful algal blooms (HABs) that produce toxins that can sicken people and pets, contaminate food and drinking water sources, kill fish and other fauna, and disrupt the balance of natural ecosystems. As it decays, the large amount of organic material generated by the bloom can cause oxygen concentrations in the water to decline below levels needed to support many aquatic organisms, leading to areas called "dead zones" in lakes, estuaries and coastal waters. HABs can also raise the cost of drinking water treatment, depress property values, close beaches and fishing areas, and negatively affect the health and livelihood of many Americans.

In the summer of 2014, for example, a massive bloom of cyanobacteria (or blue-green algae) in Lake Erie resulted in the closure of drinking water facilities that served 500,000 people in Toledo, OH (see The Blade, August 2, 2014; New York Times, August 8, 2014). The shutdown garnered national attention and brought focus to the problem of algal blooms around the country.

According to the EPA's Fiscal Year 2014 *National Water Program Guidance*, "nitrogen and phosphorus pollution is one of the most serious and pervasive water quality problems" in the United States (U.S. EPA, 2013). The finding that nutrient pollution is the leading cause of use impairment in U.S. waters is supported by data from states' water quality assessment reports, National Aquatic Resources Surveys, and associated reports to Congress (see the EPA's Nitrogen and Phosphorus Pollution Data Access Tool for these reports and surveys at http://www2.epa.gov/nutrient-policy-data/nitrogen-and-phosphorus-pollution-data-access-tool#other).

An Urgent Call to Action—Report of the State-EPA Nutrient Innovations Task Group (U.S. EPA, 2009) acknowledged that the degradation of surface waters associated with nutrient pollution has been extensively studied and documented. The report concluded that the rate and impact of nutrient pollution will continue to accelerate when coupled with continued population growth. Several scientific studies indicate that global climate change, mainly warming conditions, is expected to exacerbate the nutrient pollution problem (Paerl and Huisman, 2009; O'Neil et al., 2012; Paerl and Paul, 2012).

Whether in groundwater, lakes or reservoirs, rivers or streams, estuaries or marine coastal waters, the impacts from nutrient pollution continue to increase year after year. The *Urgent Call to Action* report (U.S. EPA, 2009) noted that current actions to control nutrients have largely been inadequate. Reducing nutrient pollution continues to be a high priority for the EPA and its federal, state and local partners.

I.B. What can state, tribal, and local governments do?

The EPA has released several documents in recent years about actions that state, tribal, and local governments can take to reduce nutrient pollution. Each of these documents encourages states and tribes to make strong progress to achieve near-term reductions in nutrient loadings as they work to develop numeric nutrient criteria in water quality standards to guide longer term reductions.

An Urgent Call to Action (U.S. EPA, 2009) recommended that a common framework of responsibility and accountability for all point and nonpoint pollution sources is central to ensuring balanced and equitable upstream and downstream environmental protection. The report concluded that available tools to reduce nutrient loadings are underutilized and poorly coordinated. It also called for broader reliance on incentives, trading, and corporate stewardship.

In the "Recommended Elements of a State Framework for Managing Nitrogen and Phosphorus Pollution," [3] the EPA described the eight elements a state should include in a Nutrient Pollution Reduction Strategy. States should (1) identify the watersheds that contribute the largest loadings of nutrients, (2) set watershed load reduction goals, (3) ensure effectiveness of point source permits in priority sub-watersheds, (4) develop plans for effective practices in agricultural areas, (5) identify reductions in storm water and septic systems, (6) develop accountability and verification measures, (7) have public reporting on implementation and load reductions, and (8) develop a schedule for numeric nutrient criteria development. Overall, these approaches seek to make meaningful and measurable near-term reductions in nutrient pollution while continuing to work on longer-term effort such as numeric criteria development and implementation.

In terms of the activities identified for controlling nutrient pollution, the EPA's *National Water Program Guidance* (U.S. EPA, 2013) states:

> *EPA encourages states to begin work immediately setting priorities on a watershed or statewide basis, establishing nutrient reduction targets, and adopting numeric nutrient criteria for at least one class of waterbodies by no later than 2016.*

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[3] The framework was provided as an attachment to the EPA Memorandum from Nancy K. Stoner, Acting Assistant Administrator, Office of Water, to Regional Administrators, Regions 1-10. March 16, 2011. "Working in Partnership with States to Address Phosphorus and Nitrogen Pollution through Use of a Framework for State Nutrient Reductions."

I.C. How can this report help?

Cost is a major factor in the management and control of nutrient pollution. The *Urgent Call to Action* report (U.S. EPA, 2009) noted that cost data associated with nutrient-related pollution impacts were limited. This report aims to address that deficiency. Stakeholders and partners at the federal, state, tribal and local levels need a better understanding of the cost implications of nutrient pollution, including both the external costs borne by local economies and the costs that would be incurred to curtail nutrient pollution. In many cases, these considerations can drive stakeholders' decisions to pursue nutrient controls, including the development and implementation of nutrient water quality standards.

This report provides users with a compilation of current economic information and references to assist stakeholders – state and tribal managers, local governments, legislators, the regulated community, and the general public – in understanding and evaluating the costs of removing nutrients at their source or preventing the manifestation of nutrient pollution (e.g., harmful algal blooms (HABs)), relative to the costs associated with no or delayed action (e.g., HAB impacts). The information in this document may help interested parties evaluate other cost estimates.

Controlling nutrient pollution is costly, but the external costs of not acting or delaying action can also be significant. As this report shows, the adverse effects of nutrient pollution cause economic losses across many sectors and scales (i.e., local to national) and impose costs to protect human health and aquatic life. For example, a number of published studies pointed to substantial impacts in sectors such as recreation, tourism, aquaculture, fisheries, real estate, and public/private water supply due to HABs. In addition, the report found significant costs for waterbody mitigation (e.g., alum addition) and restoration of nutrient-polluted waterbodies.

The assessment of the actual costs associated with the impacts of nutrient pollution, as well as the costs for controlling the pollution, are site specific and depend on numerous factors, such as the characteristics of the waterbody/watershed (e.g., geographic location, type of waterbody, level of impairment, nutrient sources) and the form of the nutrient criteria (narrative[4] vs. numeric) and stringency of water quality criteria and standards. It can also often be difficult to fully complete the chain of reasoning required to link nutrient pollution to an accurate estimate of external costs. For example, nutrient pollution has been shown to be related to the occurrence of HABs (see, e.g., Heisler, et al. 2008), and a number of studies estimate the economic consequences of HABs. Other factors also affect the occurrence of HABs, however, and it can be difficult to distinguish their effects from those of nutrients. Thus, it is often difficult or impossible to say *how much more* likely an HAB is because of nutrient pollution. This information is needed in order to estimate external costs, however. Moreover, accurate calculation of external costs often requires observing some careful distinctions. If a decline in local water quality were to lead to a seaside restaurant closing, the cost of that closure would not be measured by the lost revenues of the restaurant, or even its lost profits, but rather, by the *difference* between the profits the restaurant could make when the water was clean and the profits that would be earned by whatever other business might subsequently occupy the site.

The control costs data and information compiled for this report are instructive in that they provide relative order of magnitude estimates appropriate for screening or feasibility analyses, and can be used to add perspective to the costs of not implementing controls. Readers can take the information

[4] Narrative criteria are descriptive, non-numeric expressions for the desired condition of a given parameter.

in this report to inform and initiate the process at the state, tribal, and local level to develop policies and tools to reduce nutrient pollution.

I.D. What is the scope of this report?

This report compiles data and information from the technical literature related to the economic impacts of nutrient pollution (i.e., the external costs associated with not taking or delaying action to reduce nutrients in receiving waters, resulting in negative impacts such as economic losses and increased costs) and the costs associated with the control of nutrient pollution (i.e., point and nonpoint source controls, restoration, and mitigation). Where data were available, this report includes information on nutrient reductions expected from various control strategies to provide additional perspective on the range of performance relative to the cost of implementing the strategy.

This compilation focuses on data from a range of sources including published, peer-reviewed journals, government-funded research and reports, academic studies and other data sources that met data quality objectives and procedures set forth in this report (see Methods section). The main body of this report includes results from studies that met the screening criteria specified in the Quality Assurance Project Plan (QAPP) for this project. In accordance with the EPA's policies, the QAPP ensured the quality and reproducibility of the data collected and subsequently used for this report. The QAPP established the project approach for data assessment and acceptance. The screening criteria were established to identify relevant (e.g., quantitative cost data were provided) recent studies from a variety of sources.

The main body of this report does not include results from anecdotal reports that mention impact costs due to nutrient pollution (e.g., media reports, newspaper and magazine articles) that could not be traced or independently verified. However, Appendix A contains those for readers interested in the full gamut of reported costs.

Similarly, this report does not include results of cost-benefit studies and other reports of methodologies for developing cost estimates to support state-specific criteria derivation (e.g., the costs to attain proposed water quality criteria and associated effluent limitations) in the body of the report because these analyses were conducted with specific assumptions and conditions that are different from the purpose of this study. This report does, however, consider and use the source data from those cost-benefit studies. Appendices B and C contain those references.

A companion spreadsheet to this report contains the compiled cost data and information.

I.E. What doesn't this report include?

This report focuses solely on impacts of anthropogenic sources of nutrients on surface waters such as streams, lakes, estuaries, and coastal waters. Due to resource limitations, this report does not include nutrient-related impacts on wetlands and groundwater. Likewise, this report does not include nutrients from air deposition, overflows of combined sewer systems, or groundwater sources. While the EPA recognizes that there are cost data associated with the control of nitrogen from these sources, as well as external costs associated with their impacts, this study excluded them at this time to limit the scope of the review and meet resource limitations.

Although agricultural activities (e.g., crops and agricultural fields, livestock management) can be a significant non-point source of anthropogenic nitrogen and phosphorus into surface waters, we did not include information in this report on the costs to control nutrients (e.g., from best management practices) because of the significant breadth and depth of approaches. We intend to focus on those approaches and costs in a supplement or addendum to this report.

While this report provides data relevant to the external costs and control costs for nutrient pollution to inform decision making, this report does not compare the results in these two categories. It would not be appropriate to do so because the various studies vary in their analyses, methodologies, starting conditions and initial assumptions, making it difficult to compare them directly. In addition, not all costs are relevant to every localized nutrient analysis.

In addition, the reader should not use the results in this report to claim that certain investments to upgrade a given facility or implement a best management practice (BMP) will eliminate the exact external costs reported here associated with nutrient pollution that would apply in a site-specific area. This report provides baseline cost information for each category that would not necessarily be valid to extrapolate to a specific circumstance.

This report does not attempt to calculate the economic benefits[5] of particular levels of reduction of nutrient pollution. For interested readers, Appendix B describes some state-level cost and benefit studies. Additional references for benefit studies are in Appendix D.

I.F. How is the rest of this report organized?

The remainder of this report is organized as follows:

- Section II highlights the methods used to collect and compile cost information for this project. This discussion is organized around a graphical representation of how nutrients affect the ecology of a waterbody and how nutrient pollution changes that ecology and affects various uses. The conceptual diagrams served as a guide and framework for this project.
- Section III summarizes the costs attributable to impacts of nutrient pollution and controlling its effects.
- Section IV summarizes the data and information related to the costs to control the sources of nutrients.
- Section V provides references.
- Appendix A includes additional evidence of the costs of nutrient pollution.
- Appendix B summarizes cost-benefit analyses that have been performed in support of various nutrient rulemaking efforts.
- Appendix C provides supplemental anecdotal point source control costs.
- Appendix D lists additional references for benefit studies.
- Appendix E provides a compilation of the abbreviations and acronyms used in Section IV related to treatment technology abbreviations and acronyms.

[5] Market values do not represent the total economic value that may be affected by nutrient pollution. See Chapter 1 of Restore America's Estuaries' "The Economic and Market Value of Coasts and Estuaries: What's at Stake?" (Pendleton, 2008) for an easy-to-understand discussion of how economic activities that generate few revenues still generate significant economic value (e.g., bird watching and beach going). This total economic value is the subject of benefits analyses.

- Appendix F provides a users' guide for using the project spreadsheet that contains all the data compiled for the project (described in Section II.F).

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II. Methods

This section describes the methods used to compile the costs related to the economic impacts of nutrient pollution. It also presents information on the cost of nutrient source control and remediation.

II.A. Model of Nutrient Pollution Pathways

Contributions to nutrient pollution originate from various sources, resulting in many potentially adverse effects to uses of surface waters (see Box 1). Examples of uses that are impacted by nutrient pollution include municipal and private water supply, recreation, aquatic life, agricultural and industrial water supply, and wildlife habitat. We present the following discussion to delineate the scope of this document in terms of analyzing nutrient-related costs, and to define the categories used as the basis for the literature review for nutrient control costs.

We portray through diagrams the pathways where nutrients entering waterbodies and watersheds may lead to potential economic losses and impacts to uses. This report uses a conceptual diagram by Weaver (2010) that relates nutrient enrichment to impacts on human health and aquatic life in areas such as commercial and recreational fishing, tourism, aquaculture, swimming, species diversity, organism condition, ecosystem function, and nursery areas. For example, Weaver (2010) illustrates the pathway from nutrient pollution to algal dominance changes, decreased light availability, and increased organic decomposition. These primary responses can then result in secondary responses that include presence of harmful algae, loss of submerged aquatic vegetation, and low dissolved oxygen levels. Dodds et al. (2009) also identify effects of increased nutrients that could influence the value of freshwater ecosystem goods and services.

Box 1. Uses Potentially Impacted by Nutrient Pollution

States and tribes identify the specific uses of waters within their jurisdictions. In general, those uses include:

- Municipal and private water supply
- Recreation (swimming, boating)
- Aquatic life, including cold water and warm water fisheries
- Agricultural and industrial water supply
- Navigation

Figures II-1 and II-2 show modified versions of Weaver's (2010) conceptual diagram for lakes and flowing water (Figure II-1) and for estuarine and coastal waters (Figure II-2). There are some slight differences between the two models, such as the list of potentially impacted sectors. There are also no examples of short-term, direct waterbody mitigation approaches in estuarine and coastal waters. As detailed in the figures, anthropogenic sources of nutrient pollution that may need to be site-specifically controlled to reduce negative impacts include:

- Municipal and industrial wastewater treatment plants
- Agricultural sources
- Urban stormwater
- Onsite septic systems.

Figures II-1 and II-2 thus illustrate the pathways from potential sources of nutrient pollution to the potential economic losses and increased costs that may result from nutrient impairment in fresh and estuarine waters:

- Commercial fisheries losses
- Recreation and tourism losses
- Reductions in property values
- Increased costs to treat municipal or private drinking water
- Short-term, waterbody mitigation costs (e.g., dredging, alum treatments, aeration, destratification of the water column)
- Costs of regulatory actions triggered by impaired water quality (e.g., Safe Drinking Water Act compliance, total maximum daily loads (TMDLs), watershed plans).

II.B. Literature Review Search Categories

As described in the previous section, the modified versions of Weaver's diagram portray the pathways where nutrients may lead to economic losses and negative impacts to uses. From these diagrams, Table II-1 presents the categories of nutrient sources used as the basis for the extensive literature search and review for nutrient control costs.

Table II-1. Categories Used for Collecting Nutrient Control Cost Data

Cost Category	Subcategory
Point source	Municipal treatment
	Industrial treatment
	Onsite septic systems
Non-point source	Urban runoff
	Commercial forestry

Table II-2 presents the categories used as the search criteria for the literature review for economic impact costs associated with nutrient pollution.

Table II-2. Sectors and Types of Impacts Used for Economic Cost Data

Sector	Economic Impact
Tourism-related Industries	Lost revenue
Commercial Fisheries	Lost revenue
Households	Decreased property value
	Cost of illness
Other Industry	Increased operational costs
Municipalities	Increased cost of drinking water treatment

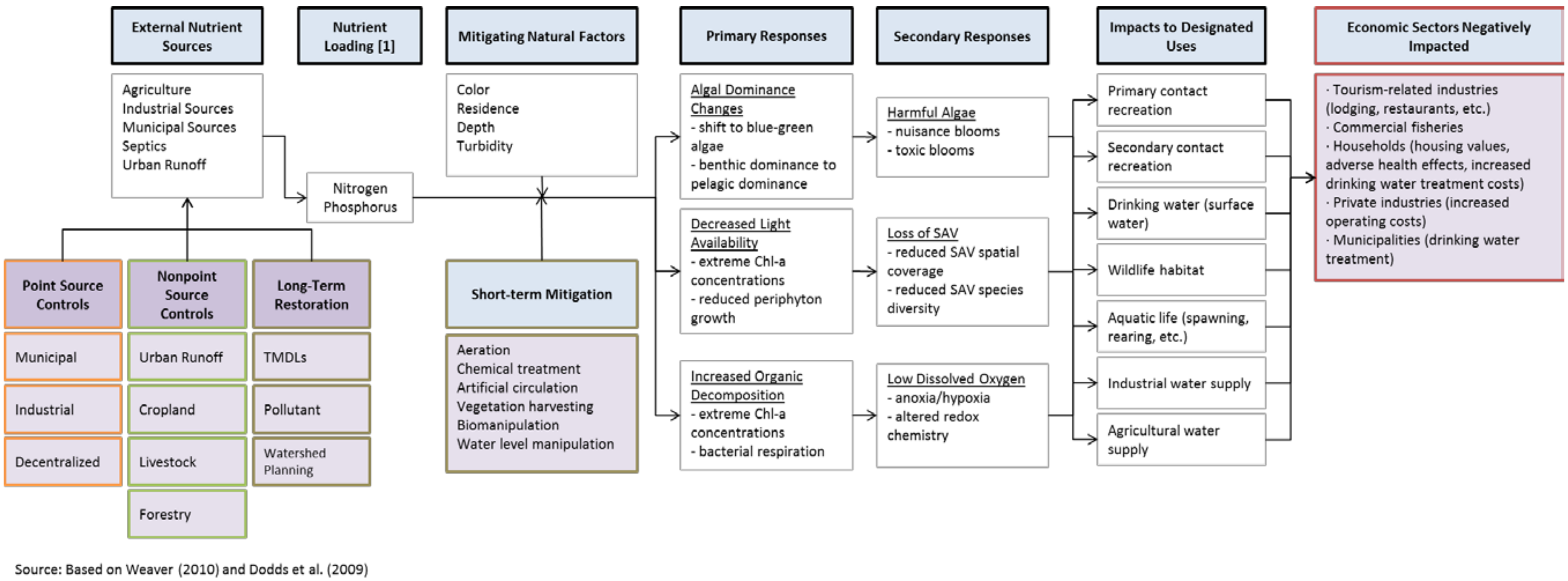
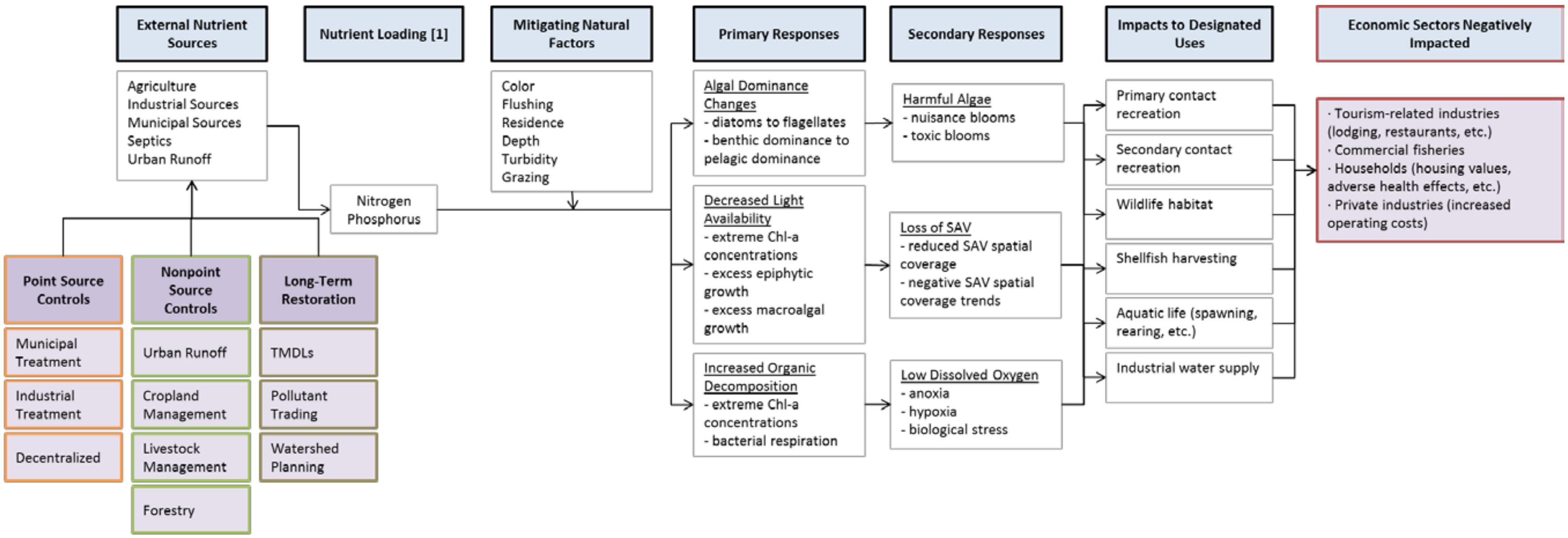


Figure II-1. Relationship of nutrient discharges to economic impacts associated with water quality in lakes and flowing waters.

Source: Based on Weaver (2010); Dodds et al. (2009).

[1] Loads to surface waters. Infiltration throughout the watershed may also contaminate groundwater used for drinking water source water.



Source: Based on Weaver (2010)
1. Loads to surface waters. Infiltration throughout the watershed may also contaminate groundwater used for drinking water source water.

Figure II-2. Relationship of nutrient discharges to economic impacts associated with water quality in estuaries and coastal waters.

Source: Based on Weaver (2010).
[1] Loads to surface waters. Infiltration throughout the watershed may also contaminate groundwater used for drinking water source water.

After a waterbody becomes negatively impacted (or "impaired" from a regulatory standpoint) due to nutrient pollution, costs may also be incurred from actions taken to mitigate the impacts directly in a waterbody. We report further costs in restoration efforts from regulatory and non-regulatory actions to address the impairment of a waterbody. Table II-3 presents the categories used as the basis for the literature review for collecting cost data related to direct waterbody mitigation and restoration costs.

Table II-3. Categories Used for Collecting Cost Data Related to Mitigation and Restoration Costs

Cost Category	Subcategory
Mitigation	Lakes/reservoirs
	Rivers/streams
	Coasts/estuaries
Restoration	Total maximum daily loads
	Pollutant trading
	Watershed planning

II.C. Literature Review Screening Criteria

We used screening criteria to focus the abundant data and information that exist in the technical literature related to the impacts of, and costs to control, nutrient pollution. The following describes the specific criteria used to select the literature (e.g., studies, reports, papers) from which cost data were considered for this project:

- Quantitative cost data were provided.
- The cost data were developed based on the control of, or impacts from, actual or existing occurrences of nutrient pollution.
- The cost data were developed from original research or methods to avoid secondary interpretation by authors and researchers.
- The reported cost data were directly related to the impacts from, or controls for, nutrient and nutrient pollution. Cost data were also included from studies and reports related to dissolved oxygen or harmful algal bloom (HAB) impacts that were or may be attributable to nutrients.
- In general, cost data prior to the year 2000 were not considered, especially for nutrient controls. Post-2000 cost data better reflect recent technologies (i.e., state-of-the-art) as well as improved control performance. For costs of economic impacts and mitigation and restoration, older data were considered if the data were directly attributable to nutrient pollution and more recent data were not available. The majority of the literature review ended with publications in 2012. A few publications that came to our attention after 2012 were considered, if time allowed for a thorough review.
- As a means to assure data quality and reproducibility, studies, reports, or papers containing cost data were selected only from published, peer-reviewed literature or from documents prepared for use by the U.S. Government or state governments with similar standards for quality and associated data quality objectives.

II.D. Literature Sources

Based on the search categories and screening criteria in Sections II.B and II.C, we reviewed the literature to identify possible sources of cost data and information relevant to impacts from nutrient pollution. We used several resources as the primary source of studies, reports, and papers:

- Existing studies related to nutrient pollution impacts and control costs performed and underway by the EPA Office of Water and other EPA offices. Data already analyzed as part of EPA regulatory impact analyses met EPA-approved quality data objectives and procedures. For example, the studies that formed the basis for biological nutrient removal treatment technology unit costs originally developed by the EPA's Office of Wastewater Management were used for EPA's economic analysis of numeric nutrient criteria for Florida waters because they provide appropriate and relevant estimates for this project.
- A general Internet search for cost data was conducted using websites such as Google Scholar. In addition, website searches were performed of journals by relevant industry associations (e.g., Water Environment Research Foundation). Key search terms included, but were not limited to, those indicated in Section II.B.
- The subscription-based, online information service ProQuest Dialog.
- Studies, reports, and papers provided by EPA regional offices and state water quality protection representatives.

II.E. Data Quality Review

For this project, we assessed the quality of secondary data and information collected from the literature review considering the five assessment factors recommended by the EPA Science Policy Council's *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (U.S. EPA 2003). The five factors excerpted directly from the EPA Science Policy Council's guidance are:

- **Soundness:** The extent to which the scientific and technical procedures, measures, methods, or models employed to generate the information is reasonable for, and consistent with, the intended application.
- **Applicability and Utility:** The extent to which the information is relevant for the agency's intended use.
- **Clarity and Completeness:** The degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations, and analyses employed to generate the information are documented.
- **Uncertainty and Variability:** The extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, methods, or models are evaluated and characterized.
- **Evaluation and Review:** The extent of independent verification, validation, and peer review of the information or of the procedures, measures, methods, or models.

We assessed each of the studies, reports, and papers collected as part of the literature review for quality as described in the guidance. If a source met the data quality requirements contained in the QAPP prepared for this project, we extracted the cost data from the source for use in this report. We updated all dollar values from the original reported results to 2012 dollars (2012$) using the Consumer Price Index.

II.F. Project Spreadsheet/Database

We compiled the detailed data and information collected and extracted for this project in a project spreadsheet that can be accessed through the EPA's nutrient pollution policy and data website at http://www2.epa.gov/nutrient-policy-data/reports-and-research. Appendix F provides a brief users' guide to assist interested parties in navigating the spreadsheet and on the use of the detailed data.

We retained relevant or recently published material that could be considered for this report or for any future updates elsewhere. Likewise, we also collected and retained information that was excluded from the scope of this work as outlined in Section I.C (e.g., nutrient impacts in wetlands and groundwater) for any future expansion of this report. Researchers and other parties may submit information that we may have missed or new information that was not available at the time of review to the project lead, Mario Sengco (sengco.mario@epa.gov), or send the information to the following address: U.S. Environmental Protection Agency, OW/OST/SHPD, 1200 Pennsylvania Avenue NW, MC 4305T, Washington D.C. 20460. If those submissions pass the screening and quality control requirements, we will add them to any updates of the database of information and the report.

II.G. References Cited

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III. Cost of Nutrient Pollution

This section summarizes the results of a literature search of recent studies documenting the adverse economic impacts of anthropogenic (human-caused) nutrient pollution and costs associated with programs to reduce these impacts. All dollar values were updated from the original reported results to 2012 dollars (2012$) using the Consumer Price Index.[6] Excessive nutrient loading to waterbodies in the United States can lead to over-enrichment and algal blooms, resulting in a myriad of adverse economic effects in sectors that include commercial fisheries, real estate, and tourism and recreation, and an increase in health care and drinking water treatment costs. Additionally, mitigation measures that local governments use to reduce the effects in the water (such as algal blooms) can cost millions of dollars for a single year of treatment.

A number of studies reported estimates of economic losses and increased costs that have resulted from the processes described in Section II. To provide some differentiation regarding the available information, the studies were screened using certain criteria for reliability (see Box 2). The studies summarized here do not encompass all impacts of nutrient pollution; instead, they represent a subset of what has occurred or is available in the literature between the years 2000 and 2012, including some relevant information before 2000 where more recent information is insufficient. The literature does not provide complete information on many such impacts throughout the United States since there is not adequate documentation of all impacts. Anecdotal and other information on the external costs of nutrient pollution are summarized in Section III.A.5 and Section III.B.4. Appendix A provides further details.

Box 2. Screening Criteria for Studies of the Economic Impacts of Nutrient Pollution

- Quantitative estimates of adverse economic impacts from nutrient pollution
- Primary studies
- Specific to nutrients, dissolved oxygen, or algal blooms
- Estimates related to actual or existing occurrences of nutrient pollution (e.g., excludes estimates related to projected nutrient pollution, such as a proposed nutrient criteria rule)
- Peer-reviewed, government-funded, academic, or other quality data sources.

This literature review relates to the economic losses, or external costs, associated with nutrient pollution. For an overview of selected cost-benefit analyses of specific nutrient-reducing regulatory programs, see Appendix B.

III.A. Economic Losses

The studies summarized here document the economic losses arising from anthropogenic nutrient pollution. However, some of the losses documented in this section are the result of "red tides," a type of harmful algal bloom (HAB) that affects coastal areas. Red tides can occur naturally; as such, the impacts associated with red tide events may be partially or fully attributable to natural drivers rather than to anthropogenic nutrient loading. In some cases, however, the impacts associated with harmful algal blooms are likely attributable to nutrient runoff from human sources (e.g., Gulf of Mexico hypoxic zone) (see National Academy of Science, 2009). Evidence has shown that red tide events have been increasingly frequent and severe in recent decades, with anthropogenic nutrient

[6] For drinking water treatment costs, the Construction Cost Index was used to update estimates to 2012$.

pollution providing significant quantities of nutrients that drive blooms, especially near shore (Heisler et al. 2008; Hochmuth et al. 2011).

The areas of economic impact are divided into tourism and recreation, commercial fishing, property values (separated into specific geographic areas of the country), and human health.

III.A.1. Tourism and Recreation

Harmful algal blooms were the primary examples of nutrient-related impacts found in the literature review. These blooms can lead to beach closures, health advisories, aesthetic degradation, and other impacts that are damaging to tourism industries surrounding affected waterbodies. Table III-1 summarizes documented impacts of HABs to local tourism and recreation industries from examples in Ohio, Texas, Washington, and Florida.

Table III-1. Examples of Estimated Tourism and Recreation Economic Losses due to HABs

Study	State	Waters	Economic Losses (2012$)[1]
Davenport and Drake (2011); Davenport et al. (2010)	OH	Grand Lake St. Marys	• $37–$47 million estimated loss in tourism revenues in 2009 and 2010. • 5 lakeside business closures. • $632,000 loss due to regatta cancellation. $263,000 decline in park revenues.
Oh and Ditton (2005)	TX	Possum Kingdom Lake	• 5% (2001) and 1.9% (2003) decrease in total economic output. • 57% (2001) and 19.6% (2003) decline in state park visitation.
Evans and Jones (2001)	TX	Galveston Bay	• In 2000, 85 shellfish bed closure days resulted in $13.2– $15.3 million direct impact and $21.3–$24.6 million total impact.
Larkin and Adams (2007)	FL	Ft Walton Beach and Destin areas	• $4.2 million and $5.6 million in reduced restaurant and lodging revenues, respectively, during HAB events.
Morgan et al. (2009)	FL	Southwest coast	• Reduced daily restaurant sales of $1,202 to $4,390 (13.7%–15.3%) during HAB events.
Dyson and Huppert (2010)	WA	Beaches in Grays Harbor and Pacific Counties	• Typical closure (2–5 days) results in $2.23 million in lost labor income and $6.13 million in sales impacts due to decreased visitation.

HABs = harmful algal blooms

[1] *All economic losses updated to 2012$ using the Consumer Price Index.*

For example, Grand Lake St. Marys is the largest inland lake in Ohio, covering 13,000 acres. It is a shallow lake that supplies water for the City of Celina and the Village of St. Marys. As a result of agricultural runoff, failing home sewage systems, internal nutrient loading, and other runoff, the lake is hyper-eutrophic, experiencing large algal blooms and frequent fish kills (Davenport and Drake, 2011). In 2009, sampling showed dangerously high levels of toxins produced by blue-green algae, and the Ohio EPA subsequently posted signs advising people to avoid contact with the water. Algal blooms in 2010 caused scum and fish kills throughout the lake, as well as 23 reported cases of human illnesses and dog deaths.

These advisories and blooms have had profound impacts on the area's tourism industry, which had previously accounted for $158 million in annual economic activity (Davenport and Drake, 2011; Davenport et al. 2010). According to Davenport and Drake (2011), small businesses around the lake have lost $37 million to $47 million in revenues, and several local marinas and boat dealers have gone out of business. Additionally, a nearby state park has lost approximately $260,000 in revenues (Davenport and Drake, 2011; Davenport et al., 2010). A regatta was also canceled as a result of the algal blooms, resulting in a loss of $632,000 (Davenport et al., 2010).

Another example of the adverse economic impacts of HABs on lake tourism economies is the golden algae (*Prymnesium parvum*) outbreaks in Possum Kingdom Lake in Texas in 2001 and 2003. These events had significant adverse effects on the industries supporting recreational fishing in the lake (Oh and Ditton, 2005). During the golden algae outbreak of 2001, more than 200,000 fish were killed, including many prized game species. In 2003, another golden algae outbreak caused a fish kill of more than 1.4 million fish. Oh and Ditton (2005) found that state park visitor numbers during the two outbreak years declined 57% and 19.6%, respectively.

Oh and Ditton (2005) estimated the economic impacts of associated decreases in recreational expenditures in three counties surrounding the lake using angler surveys together with economic modeling software (IMPLAN [7]). Their estimates showed a decrease of 5% and 1.9% in total economic output in five tourism sectors[8] in 2001 and 2003, respectively. The authors note that there are also likely to be longer-term adverse impacts associated with golden algae outbreaks since anglers perceive diminished fishing opportunities in the area as a result of publicized events.

HABs can also have adverse effects in coastal areas. For example, authorities in Washington regularly sample shellfish in coastal razor clam fisheries for toxins produced by HABs. These algal toxins cause adverse health effects, including amnesic or paralytic shellfish poisoning (Dyson and Huppert 2010). When the toxins exceed critical levels, recreational razor clam fisheries close, causing local economic impacts. Dyson and Huppert (2010) surveyed visitors to four razor clam fishing beaches in two counties in coastal Washington to collect data on expenditure and visitation patterns during fishery openings and closures. They used these data in an economic input-output model,[9] estimating that a typical closure (2 to 5 days) results in lost labor income of $2.23 million and a total spending impact of $6.13 million at the four beaches.

In other coastal areas, red tides[10] can discolor water, cause fish kills, contaminate shellfish, and cause respiratory distress in humans and other mammals (Evans and Jones 2001). These effects can result in significant economic impacts, including lost tourism and recreation opportunities. For example, in 2000 a red tide event in Galveston Bay had a profound economic impact on Galveston County in Texas. Evans and Jones (2001) used IMPLAN to estimate that this event, which resulted in 85 days

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7 IMPLAN is a regional economic impact model that can be used to forecast the direct, indirect, and induced economic impacts of programs, policies, or events.

8 Includes food and beverage stores; food services and drinking places; general stores not otherwise classified; hotels and motels; and other amusement-gambling and recreation businesses.

9 Dyson and Huppert (2010) used a custom input-output model (a simple linear representation of the economy) designed for the two counties. The input for this model is expenditures by razor clammers, and the outputs are net sales impact, labor employment, and labor income.

10 As noted above, red tide events can be natural phenomena; as such the impacts of red tide documented in these studies may be at least partially attributable to natural drivers rather than anthropogenic nutrient loading. However, as noted above (see Section III.A), anthropogenic nutrient loading likely contributes to increased frequency and severity of such events.

of shellfish bed closures, had a direct economic impact of $13.2 million to $15.3 million on the county. Including indirect and induced effects, the total impact was $21.3 million to $24.6 million.

Several authors have also used modeling to estimate the tourism and recreation impacts of red tide events in Florida. Larkin and Adams (2007) used a time series model to estimate that restaurant and lodging revenues decline by $4.2 million and $5.6 million, respectively, per month along a 10-mile stretch of shoreline. This represents 29% of revenue in the restaurant sector and 35% in lodging along that 10-mile stretch of shoreline. The authors note that their results capture only month-to-month variation, while the effects of daily fluctuations and other shorter term conditions are not captured.

According to Morgan et al. (2009), the Small Business Association provided 36 businesses in southwest Florida with loans between $5,680 and $96,295 as a result of red tide events between 1996 and 2002. Morgan et al. (2009) used daily sales data from three coastal restaurants in southwest Florida to estimate the impact of red tide events on revenues. They found that individual restaurant sales decreased by $868 to $3,734 (13.7% to 15.3%) each day during red tide events.

As noted by Morgan et al. (2009), Larkin and Adams (2007), and Evans and Jones (2001), the documented tourism impacts arising from algal blooms are localized. In response to outbreaks that impede recreation in one area, visitors may shift their activities to other areas. To the extent that this occurs, the adverse economic impacts associated with HABs represent transfers of economic activity between areas, rather than a true economic loss. As such, the tourism results presented in this section represent only the impacts within the geographic boundaries specified within each study. The impacts described do not necessarily represent true economic losses considering larger geographical areas. On the other hand, there may be a halo effect[11] in which localized events spur avoidance of a much larger area surrounding the affected waterbody, expanding the geographic size and severity of impacts associated with a particular event.

III.A.2. Commercial Fishing

Algal blooms can have extremely damaging impacts to commercial fishing industries in marine coastal areas of the United States due to fish kills, shellfish poisoning, and associated additional processing of affected harvests. In Galveston Bay, Texas, for example, the red tide event that resulted in significant adverse impacts to the tourism and recreation industries (as described in Section III.A.1) also caused economic losses to the commercial oyster industry when shellfish beds were closed for 85 days. According to Evans and Jones (2001), economic losses were valued at $240,000 for the decline in harvests between September and December 2000.

Red tide events also have significant adverse economic impacts elsewhere in the country. Jin et al. (2008) developed estimates of the impacts of a 2005 red tide event that affected commercial shellfisheries in New England. Due to that event, shellfish beds in Massachusetts, Maine, New Hampshire, and 15,000 square miles of federal waters were closed for more than a month during the peak harvest season. As a result, Maine and Massachusetts received federal emergency assistance. In Maine, these closures from April to August in 2005 caused losses of $2.5 million in soft shell clam harvests and $460,000 in harvests of mussels (Jin et al., 2008). Jin et al. (2008) also estimated that impacts to the shellfish industry in Massachusetts may have been as high as $21 million.

[11] The halo effect is a phenomenon in which a localized event causes larger collateral economic impacts, usually in reference to large-scale reductions in seafood consumption in response to local fish kills or health warnings (Anderson et al. 2000; Hoagland et al. 2002).

In Alaska, for example, HABs can cause paralytic shellfish poisoning, which has led to human fatalities and illnesses, and economic losses to shellfish industries since 1990 (RaLonde, 2001). As a result of that poisoning, shellfish harvesters must conduct costly additional testing and processing of their harvests. RaLonde (2001) used harvest revenue data and sales prices of raw and processed clams and crabs to estimate the economic impact of these requirements. In 1998, necessary processing of geoduck clams in Alaska coastal fisheries reduced revenues by $1.1 million. Processing of crabs from the Kodiak/Aleutian crab fishery resulted in losses of $293,000 (RaLonde 2001).

In addition to HABs, nutrient pollution can reduce dissolved oxygen concentrations, which can cause adverse economic impacts to commercial fisheries. In the Patuxent River in Maryland, reductions in dissolved oxygen resulting from nutrient pollution led to a 49% reduction in crab harvests. This reduction caused lost revenues of $304,000 annually (Mistiaen et al., 2003).

Low dissolved oxygen has also caused decreased harvests of commercial fish species in the Neuse River and Pamlico Bay in North Carolina. Huang et al. (2010) estimated the lagged effects of hypoxia on commercial harvests of brown shrimp in these waterbodies. The authors used bioeconomic modeling, assuming that the environmental effects associated with a hypoxia event accumulate over a 60-day period.[12] They found that between 1999 and 2005, the brown shrimp harvest declined by 13.1% (or $44,100) due to hypoxia in the Neuse River. In Pamlico Sound, there was a 13.4% decline worth $1.7 million over the same 7-year period.

Table III-2 summarized losses sustained by commercial fisheries as a result of nutrient loading and algae blooms.

Table III-2. Estimated Commercial Fisheries Losses Due to Reduced Water Quality

Study	State	Waters	Water Quality	Resource Impact	Economic Losses (2012$)[1]
Evans and Jones (2001)	TX	Galveston Bay	HABs	Shellfish bed closures (85 days)	$240,000 (oysters)
Jin et al. (2008)	ME	Maine Coast	HABs	Reduced shellfish harvests due to bed closures	$2,450,000 (soft shell clams); $460,000 (mussels)
Mistiaen et al. (2003)	MD	Patuxent River	Low dissolved oxygen	Reduced crab harvests due to population decline	$304,000 per year
RaLonde (2001)	AK	Coast	HABs	Shellfish poisoning[2]	$1,097,500 (geoduck); $292,900 (crab)
Huang et al. (2010)	NC	Neuse River and Pamlico Bay	Hypoxia	Reduced brown shrimp harvests due to population decline	$44,100 (Neuse River); $1,708,900 (Pamlico Sound)

HABs = harmful algal blooms
[1] All economic losses updated to 2012$ using the Consumer Price Index.
[2] Requires processing of harvest which reduces price compared to raw sales.

[12] The authors also estimated harvest reductions under alternative lagging assumptions (between 30 days and 100 days); these alternative assumptions also resulted in significant effects, with harvests reduced by 9.23%–14.92%.

III.A.3. Property Values

Studies have shown that elevated nutrient levels, low dissolved oxygen levels, and decreased water clarity have resulted in depressed property values of waterfront and nearby homes. Table III-3 summarizes the results of such studies in the New England, Mid-Atlantic, Midwest, and Southeast regions. These studies are hedonic analyses, in which the authors use water quality metrics as variables in house-price regression models to estimate the implicit price of the water quality metric. Most authors use water clarity measures, but some use more direct measures of pollutant concentrations.

Table III-3. Estimated Decreases in Property Values due to Reduced Water Quality

Study	State	Waters	Water Quality	Impact on Home Price (2012$)[1]
Gibbs et al. (2002)	NH	Lakes	Poor water clarity	$1,911 to $16,713 (1% to 6.7%) per 1 meter change in Secchi depth
Poor et al. (2001)	ME	Lakes and ponds	Poor water clarity	$3,917 to $13,535 (3.5% to 8.7%) per 1 meter change in Secchi depth
Boyle et al. (1998)	ME	Lakes	Poor water clarity	$616 to $60,624 (less than 1% to 78%) per 1 meter change in Secchi depth
Michael et al. (2000)	ME	Lakes	Poor water clarity	$1,296 to $15,713 (1.0% to 29.7%) per 1 meter change in Secchi depth
Poor et al. (2007)	MD	Rivers	Elevated dissolved inorganic nitrogen	$22,014 (8.8%) per 1 mg/L increase in dissolved inorganic nitrogen
Kashian and Kasper (2010)	WI	Tainter Lake; Lake Menomin	Algal blooms	$128 to $402 decrease/shoreline foot compared to next comparable lake
Krysel et al. (2003)	MN	Lakes	Poor water clarity	$1,678 to $84,749 per 1 meter change in clarity
Ara et al. (2006)	OH	Lake Erie	Poor water clarity	$25 increase per 1 centimeter increase in clarity; 1.93% change per 1 meter change in clarity
Czajkowski and Bin (2010)	FL	St. Lucie River; St. Lucie Estuary; Indian River Lagoon	Poor water clarity	$6,397 (0.6%) increase in average property value for a 1% increase in clarity
Walsh et al. (2012)	FL	Orange County Lakes	Elevated TN, TP, chlorophyll	17% increase in pollutant causes waterfront properties to decrease: trophic state index = $12,346 (2.1%); TN = $10,307 (1.8%); TP = $7,418 (1.3%); chlorophyll = $4,106 (0.7%)

Secchi depth is a measure of water transparency in lakes and is related to water turbidity.
mg/L = milligrams per liter
TN = total nitrogen
TP = total phosphorus
[1] *All economic impacts updated to 2012$ using the Consumer Price Index.*

New England— Several studies use hedonic analysis to assess the impacts of reduced water clarity on home values in Maine (Boyle et al., 1998; Michael et al. 2000; and Poor et al. 2001) and New Hampshire (Gibbs et al. 2002). Boyle et al. (1998) examined the impacts of water clarity on lakefront home prices (full-time resident homes and vacation homes) in seven groups of lakes across Maine. In four of the markets evaluated, water clarity was a significant variable impacting home prices, with lower clarity resulting in lower home prices. In these markets, a 1 meter increase in water clarity led to a price increase of 1% to 25%. A decrease in water clarity had larger impacts, ranging between less than 1% to greater than 78% for a 1 meter decrease.

Michael et al. (2000) conducted a similar analysis using home sales around 32 lakes in three distinct markets in Maine, but used a wider variety of water quality variables including historical clarity, current clarity, and seasonal variability in clarity. They found that results varied widely depending on residents' perceptions of water quality versus actual water quality metrics, and the timing of the sale versus the water quality measurement. For example, seasonal variation had a much larger impact (8.1% change in house price for a 1 meter change in clarity over the course of a season) than year-to-year variation (1% change in house price for a 1 meter change in clarity from one year to the next). Across all of the variables, the authors found that a 1 meter change in water clarity resulted in a house price change of 1% to 29.7%.

Poor et al. (2001) similarly evaluated the impact of water clarity on lakefront home prices in four markets throughout Maine, comparing the results using objective measures (secchi depth measurements) and subjective measures (survey of lakefront property purchasers) of water clarity. They found that objective measures were a better predictor of sales prices, with a 1 meter change in water clarity resulting in a 3.0% to 6.0% change in house price. Subjective measures of water clarity tended to underestimate clarity (compared to the objective measures), and had a larger impact on house prices (with a 1 meter change resulting in a 3.2% to 8.7% change). However, the subjective measures were worse predictors of sales prices.

Gibbs et al. (2002) conducted a hedonic analysis of lakefront property sales in four markets in New Hampshire, also using water clarity as the water quality variable. They found that a 1 meter change in water clarity resulted in a 0.9% to 6.6% change in property sale price.

Mid-Atlantic— Poor et al. (2007) conducted a hedonic study of waterfront and non-waterfront property sales in the St. Mary's River watershed in Maryland using concentrations of dissolved inorganic nitrogen (DIN) from around the watershed. According to their results, a 1 mg/L change in the dissolved inorganic nitrogen concentration[13] at the nearest monitoring station corresponds to an 8.8% change in home price.

Midwest— Ara et al. (2006) did a study evaluating the impact of water clarity on house prices near 18 Lake Erie beaches in Ohio. At the mean distance to the beach (12.6 kilometers), a 1 meter change in water clarity was associated with a 1.93% change in home value. The authors noted that, as the distance to the beach increased, the impact of clarity on value decreased.

Krysel et al. (2003) did a hedonic study in the Mississippi River headwaters area of Minnesota, using lakefront property sales on 37 lakes, grouped into six distinct markets. They found that water quality had a significant impact on property price in all markets, with a 1-meter change in water clarity resulting in a price change between $1,678 and $84,749 depending on the location/market.[14]

Kashian and Kasper (2010) evaluated two lakes in Wisconsin which both suffer from severe algal blooms, comparing lakefront property sale prices on these lakes to properties on nearby lakes that

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[13] Average concentrations across the monitoring stations used were between 0.082 mg/L and 0.956 mg/L; as such, a 1 mg/L would represent a relatively large change in water quality.

[14] Two lakes had higher price effects ($300,571 and $522,018 for a 1-meter change), but these are in a national forest and on an Indian Reservation with considerable publicly owned lakeshore property; as such, additional factors not included in the analysis likely drive the price effects.

are not eutrophic. They found that in the degraded lakes, property values were lower by $128 to $402 per shoreline foot in relation to the next comparable lake.

Southeast— Walsh et al. (2012) assessed the impacts of multiple pollutant concentrations on home values within 1,000 meters of lakes in Orange County, Florida. They estimated the implicit price associated with a 17% change in concentrations of total nitrogen, total phosphorus, chlorophyll, and trophic state index (a composite of the three other nutrient pollutants). For waterfront properties, the impacts ranged from less than 1% of the sales price for chlorophyll to 2.1% for trophic state index. A 17% change in total nitrogen concentrations led to a 1.8% impact on home values; for total phosphorus the impact was 1.3%. The authors note that the impacts were much higher for waterfront homes, with the impacts diminishing with distance to the beach.

Also in Florida, Czajkowski and Bin (2010) used water quality data on the St. Lucie River, St. Lucie Estuary, and Indian River Lagoon to quantify the impact of water quality measures on waterfront home prices in urban coastal housing markets. They found that a 1% increase in water clarity results in the average property price increasing by $6,397 (0.6%), with a range of $2,240 to $10,597 (0.2% to 0.9%).

Variability and Uncertainty— There are several notable sources of variability and uncertainty in all hedonic studies that attempt to discern the impact of water quality on property values. Due to methodological, locational, and situational variability, comparisons across study results and applications of results to other waterbodies can be problematic.

First, the impacts of water clarity are location-dependent. As noted by Gibbs et al. (2002), real estate markets, baseline water clarity, environmental conditions, and population preferences are likely to be highly variable, including within a single region. Gibbs et al. (2002) found that there is little comparability even between Maine and neighboring New Hampshire, with different lake sizes, average home prices, levels of development, and proximity to highways and urban areas.

Poor et al. (2007) noted that their study area was a county adjacent to the Chesapeake Bay, where public opinion polls have shown that local homeowners are knowledgeable about water quality issues and willing to pay for improvements. As such, their results may not be representative of other areas where public education and advocacy for water quality is not as strong. Similarly, Walsh et al. (2012) evaluated the impact of voluntary neighborhood programs where residents pay taxes to control nutrients in particular lakes; in neighborhoods where these programs exist, impacts of water quality changes to home prices are more pronounced.

Baseline water clarity is also an important factor. If water quality is already poor, a 1-meter change can have a larger impact on public perception and sales price than if water quality is high (Michael et al. 2000; Gibbs et al. 2002).[15] Other lake or property characteristics can also influence purchase price, and excluding these characteristics from analyses can result in biased or uncertain results. For example, Gibbs et al. (2002) note that lake clarity has a larger impact on purchase prices when the lake has a larger surface area.

Methodological specifications can also influence the results of hedonic analyses, introducing additional uncertainty. As noted by Michael et al. (2000), authors frequently select water quality variables based on data availability rather than on the best representation of homebuyers' perceptions of water quality. They show that the use of different variables (such as seasonal

[15] Most authors address this issue by using non-linear functional forms for water quality variables.

variation, current water quality, or historical averages) results in a broad range of implicit prices for water quality. This result indicates that the selection of the water quality variable is important to the validity of the model, but that it is unclear which measure is the best indicator of water quality impacts.

Another source of variability across studies is the use of disparate variables to measure water quality. For example, some studies attempt to isolate the impact of water clarity alone, while others use interaction variables which capture the impacts of multiple characteristics. For example, Gibbs et al. (2002) use a water quality variable that accounts for lake size in conjunction with water clarity, arguing that their variable is more robust because it accounts for more of the lake's characteristics.

III.A.4. Human Health

HABs can cause a variety of adverse health effects (in humans and animals) through direct contact with skin during recreation, consumption through drinking water, or consumption of contaminated shellfish, which can result in neurotoxic shellfish poisoning and other effects. According to Davenport and Drake (2011), the HABs in Grand Lake St Marys (described in Section III.A.1) resulted in 23 reported cases of human illnesses and dog deaths. Additionally, proximity to coastal areas where red tide conditions are present may lead to respiratory illness through inhalation of associated airborne toxins (through beach visitation, for example) (Hoagland et al. 2009).

Hoagland et al. (2009) assessed the relationship between red tide blooms and emergency room visits for respiratory illnesses in Sarasota County, Florida and developed estimates of the associated costs. Controlling for other factors that may explain emergency room visits,[16] the authors used a statistical exposure-response model to estimate that there are approximately 39 annual emergency room visits due to red tide during low bloom levels and 218 during high bloom levels. Based on estimated medical treatment costs of $58 to $240 per illness and lost productivity of $335 per illness (for 3 days), red tide events in Sarasota County result in $21,000 to $138,600 in human health impacts.

Hoagland et al. (2009) noted that their study was limited to emergency room visits and excluded the impacts of milder cases of respiratory illnesses. The economic impacts of these cases are likely to be small on an individual case basis (for instance, requiring over-the-counter medicine purchases or short-term loss of work or leisure time; Hoagland et al. 2009), but could be significant when aggregated. Additionally, Hoagland et al. (2009) did not account for the pain and suffering associated with illnesses, nor for the potential for red tide to contribute to long-term chronic respiratory illnesses. Table III-4 summarizes the economic impacts of HABs with respect to human health.

Table III-4. Estimated Human Health Economic Impacts

Study	State	Waters	Water Quality	Health Impacts (2012$)[1]
Hoagland et al. (2009)	FL	Coast	HABs[2]	• $21,000 per year for low bloom levels. • $138,600 per year for high bloom levels.

HABs = harmful algal blooms
[1] All impacts updated to 2012$ using the Consumer Price Index.
[2] Varying level of HABs causing respiratory illnesses.

[16] Including low temperatures, a high incidence of influenza outbreaks, high pollen levels, and large numbers of tourists.

III.A.5. Anecdotal Evidence and Additional Studies

Additional studies may provide supporting information on the adverse impacts of anthropogenic nutrient loading. These include both anecdotal evidence of adverse economic impacts from nutrient pollution, such as newspaper accounts of algal bloom events, and additional studies that use broader assumptions or methodologies than those meeting this report's screening criteria. Appendix A provides more detail on the anecdotal evidence and additional studies.

III.B. Increased Costs

The studies summarized in this section document the increased cost associated with anthropogenic (human-caused) nutrient pollution. The majority of these costs will be incurred by government entities including federal, state, and local governments, or passed on to consumers through utility bills, for example.

III.B.1. Drinking Water Treatment

Excess nutrients in source water for drinking water treatment plants can result in a number of potential health risks and increased treatment costs. For example, algal blooms can result in taste and odor issues which often require treatment plants to add granular or powdered activated carbon. Drake and Davenport (2011) indicate that some municipalities are purchasing equipment to monitor for and treat the toxins associated with HABs. Excess algae also produce precursors to carcinogenic and toxic disinfection byproducts. These byproducts form when disinfectants used in water treatment plants (e.g., chlorine) react with natural organic matter, such as decaying vegetation or algae. The EPA regulates these disinfection byproducts due to their harmful effects on human health. Hence, increased concentrations could result in increased treatment costs for removal.

Lastly, high levels of nitrates in source water above the maximum contaminant level are a concern because nitrates have been linked to health effects such as methemoglobinemia, a condition involving a decrease in the ability of red blood cells to carry oxygen, also known as blue baby syndrome (Deana et al., 2006).

Higher pollutant concentrations of nutrients and algae in the source water result in higher treatment costs for municipalities and their residents due to the additional treatment needed to remove the pollutants. For example, drinking water treatment plants may need to install additional process controls or increase chemical addition to target nutrients or algae in source waters. However, studies documenting these increased costs are not readily available. Table III.5 shows the results from the two recent studies that met the screening criteria for this project. Numerous anecdotal reports on the increased costs and impacts associated with excess nutrients in source water are in Appendix A.

Drake and Davenport (2011) reported increased drinking water treatment costs for Grand Lake St. Marys in Ohio associated with a 2010 blue-green algae outbreak, which prompted recreational, human health, and fish consumption advisories for the lake. As of October 2010, the City of Celina estimated that it had spent \$13.1 million, of which \$3.6 million was total operations and maintenance (O&M) costs to date to install treatment controls and set up toxic algae testing. This estimate is conservative and does not account for the alum, lime, and sludge costs associated with the high organic loads resulting from the algal bloom.

EPA Region 6 tasked a contractor, The Cadmus Group Inc. (2014), who compiled data from the City of Waco, Texas, to estimate the total costs incurred from 2002 through 2012 to address poor drinking water quality due to excess nutrients. They estimated that the city incurred \$70.2 million in costs, with 92% attributable to upgrades to the drinking water treatment process, 4% for nutrient-related watershed water quality monitoring, 2% for increased treatment chemical usage, 1% for influent and treated water monitoring beyond regulatory sampling requirements, and 1% for increased energy usage related to the treatment plant upgrades. Also, they estimated that the City of Waco potentially lost up to $10.3 million in revenue due to taste and odor problems resulting in decreased water sales to neighboring communities prior to the treatment plant upgrades (although some of the lost sales might have been attributable to drought conditions).

Table III-5. Increased Drinking Water Treatment Costs Attributable to Algal Blooms

Date	State	Waters	Water Quality	Costs (2012$)[1]
2010	OH	Grand Lake St. Marys	Blue-green algae outbreak	$13,080,000 ($3,570,000 in O&M to date)[2]
2002-2012	TX	Lake Waco	High total phosphorus and chlorophyll-a concentrations	Watershed Monitoring = $2,597,118 Influent/Treated Water Monitoring = $740,705 Chemical Usage = $1,169,151 Plant Upgrades = $64,877,721 Plant Energy Costs = $812,755 Lost Revenue from purchased water = $10,300,000

Source: Davenport and Drake (2011) for Ohio; The Cadmus Group Inc. (2014) for Texas.
[1] *Costs updated to 2012$ using the construction cost index.*
[2] *For treatment installation, toxic algae testing set-up, and total O&M (excludes alum, lime, and sludge costs).*

III.B.2. Mitigation Costs in Lakes[17]

In this section, the term "mitigation" refers to approaches that attempt to address the nutrients in the waterbody directly, prevent the manifestation of the nutrient problem (e.g., limit nutrient availability, uptake, and formation of algal blooms), and moderate algal blooms and their impacts in the system. Other terms for these approaches include waterbody management (as opposed to watershed management where nutrients are controlled at sources in the watershed), or in-lake/in-system management. Most of the examples found were done in lakes and freshwater systems at varying scales. There were no examples in estuarine or marine waters at this time.

The reader should note that mitigation costs may or may not reflect full external costs of nutrient pollution. In some instances it might cost more to mitigate damage than it would be worth to the affected community to simply live with a degraded waterbody. In other instances, mitigating damages might not reflect full costs if, for example, even after waters were restored to their original conditions fish populations might still not have fully recovered. The figures that follow might be treated with caution for these reasons. However, the fact that many of these costs are, in fact, incurred, shows that there would be savings if nutrients were reduced in many contexts.

Phosphorus that enters a waterbody with poor outflow or circulation will settle and accumulate in the bottom sediments, acting as a source of phosphorus loading to the water column. Uncontrolled inputs over long periods of time (e.g., from agricultural or urban runoff) can exacerbate this legacy load. These releases often lead to persistent algal blooms, eutrophication, and macrophyte growth.

[17] All unit costs in this section are presented per acre *treated* (not per acre of lake area).

Source reduction efforts in these watersheds will do little to reduce these effects due to the continued release of legacy phosphorus from the sediments.

Thus, mitigation measures are often needed to reduce phosphorus loads and achieve the desired water quality. The costs associated with these measures can be significant. Table III-6 summarizes studies documenting the costs of various mitigation measures that have been used in or considered for particular lakes. The details are provided after the table.

Table III-6. Mitigation Costs Associated with Excess Phosphorus in Lakes

Study	State	Waterbody	Description	Capital Costs (2012$)[1]	Annual O&M Costs (2012$/yr)[1]
Aeration System					
Berkshire Regional Planning Commission (2004)	MA	Onota Lake	Deep-hole system.	$355,621–$411,772	$49,912
ENSR Corporation (2008)	MA	Lovers Lake and Stillwater Pond	Hypolimnetic aeration only. Based on vendor quote.	$94,907	$5,260
ENSR Corporation (2008)	MA	Lovers Lake & Stillwater Pond	Artificial circulation	$117,195	$7,990
Chandler (2013)	MN	Twin Lake	Solar powered system.	$139,157	$4,945
Chandler (2013)	MN	Twin Lake	Bubbler system.	$232,424	$34,616
City of Lake Stevens (2013)	WA	Lake Stevens	Actual costs over 6 years, includes power consumption, staffing, and repairs.	Not reported	$35,000–$110,000
Alum Treatment					
ENSR Corporation (2008)	MA	Lovers Lake and Stillwater Pond	Treatment to last 15 years for application area of 19 acres for Lovers Lake and 9.25 acres for Stillwater Pond.	$211,676–$243,667	$0
Barr (2005)	MN	Keller Lake	Treatment for the whole lake, based on lake-specific data.	$58,780	$0
Barr (2005)	MN	Kohlman Lake	Treatment for the whole lake, based on lake-specific data.	$165,759	$0
Barr (2012)	MN	Spring Lake	Treatment for the whole lake, based on lake-specific data; intended to last 10–32 years.	$986,000–$1,086,000	$0
Chandler (2013)	MN	Twin Lake	Alum addition to 19 of the 20 acres of the lake twice in 3 years (intended to last 10–20 years).	$146,377	$0
The LA Group (2001)	NY	Cossayuna Lake	Partial lake treatment (35 of 776 acres); intended to last 5 years.	$22,687	$0
Osgood (2002)	SD	Lake Mitchell	Based on $150,000 in the first year, $120,000 for 2 years after, and $100,000 per year thereafter.	$127,623–$238,246	$0
Herrera Environmental Consultants (2003)	WA	Green Lake	Intended to last 10 years.	$1,883,115	$0

Study	State	Waterbody	Description	Capital Costs (2012$)[1]	Annual O&M Costs (2012$/yr)[1]
King County (2005)	WA	Lake Hicks	Also includes public outreach costs.	$54,762	$0
Burghdoff and Williams (2012)	WA	Lake Ketchum	Whole lake treatment intended to last 4 years.	$198,015	$0
Burghdoff and Williams (2012)	WA	Lake Ketchum	Costs represent single dose for a year to treatment the water column only (not sediment).	$36,745	$0
Tetra Tech (2004)	WA	Lake Lawrence	Whole lake treatment intended to last 10 years.	$986,921	$204,192
Cedar Lake Protection and Rehabilitation District (2013)	WI	Cedar Lake	Partial lake treatment; costs represent 2 applications over 10 years.	$2,175,881	$0
Hoyman (2011)	WI	East Alaska Lake	Whole lake treatment; life of treatment not specified.	$168,221	$0
Barley Straw					
Chandler (2013)	MN	Twin Lake	Costs represent a yearly cost.	$11,057	$0
Biomanipulation					
Chandler (2013)	MN	Twin Lake	Costs based on a total of four stockings conducted in years 1, 2, 4, and 6 over a 10-year period.	$279,403	$0
Dredging					
ENSR Corporation (2008)	MA	Lovers Lake and Stillwater Pond	Removal of 32,850 cubic yards from Lovers Lake and 28,500 cubic yards from Stillwater Pond; intended to last 10 years or less.	$1,546,246	$0
Barr (2005)	MN	Keller Lake	Dredging for the whole lake.	$628,944–$1,390,731	$0
Barr (2005)	MN	Kohlman Lake	Dredging for the whole lake.	$968,692–$2,143,112	$0
Chandler (2013)	MN	Twin Lake	Dredging for the whole lake.	$2,541,824	$0
The LA Group (2001)	NY	Cossayuna Lake	Partial lake treatment (300 out of 776 acres).	$5,905,143–$9,794,369	$0
Tetra Tech (2004)	WA	Lake Lawrence	Includes alum treatment; intended to last >50 years.	$28,124,132	$1,404,218
Herbicide Treatment					
Berkshire Regional Planning Commission (2004)	MA	Onota Lake	Represents actual costs for application of the herbicide SONAR over the whole lake, with follow-up spot treatment.	$172,264	$0
The LA Group (2001)	NY	Cossayuna Lake	Partial lake treatment (35 out of 776 acres); intended to last 5 years.	$29,169	$0
Hypolimnetic Withdrawal					
Chandler (2013)	MN	Twin Lake	Lasts 20 years.	$583,532	$39,561

Capital costs = fixed, one-time expenses incurred on the purchase of land, buildings, construction, and equipment used in the production of goods or in the rendering of services. O&M = Operation and Management.

[1] *Costs updated to 2012$ using the Consumer Price Index.*

The studies described in this section meet the evaluation criteria in Section II.E. Table A-3 in Appendix A summarizes additional anecdotal evidence of mitigation costs. Note that mitigation in the absence of controlling inputs from existing point and non-point sources will not likely be effective in the long term because the phosphorus will continue to accumulate in sediments, resulting in the need for future mitigation.

There are several mitigation techniques that can be used to reduce legacy nutrient loads, most of which primarily target the sediment. Costs for these measures are waterbody specific and depend on the selected technique, extent and history of nutrient pollution, past mitigation measures employed (if any), hydrologic characteristics (e.g., water depth, circulation), climate/rainfall, and water quality (e.g., acidity, hardness, presence of other contaminants). Thus, it may be difficult to compare costs across waterbodies and technologies.

Aeration System— Aeration involves the addition of oxygen to the hypolimnion layer (e.g., the lake bottom waters) to reduce the release of phosphorus from lake sediment. Sediment-bound phosphorus is most soluble, and thus readily released, in oxygen-poor waters. Oxygenating these waters results in less phosphorus released into the water column from sediments. The effectiveness of aeration in controlling algae depends on both sufficient oxygen to meet the hypolimnetic demand and an adequate supply of phosphorus binders either naturally or through the addition of reactive aluminum or iron compounds to bind phosphorus before it enters the water column. Aeration systems typically require installation of capital equipment and annual maintenance and operation of that equipment.

Berkshire Regional Planning Commission (2004) estimated costs of a deep-hole aeration system for Onota Lake in Massachusetts. The system was estimated to cost $355,621–$411,772 and included three columns, air lines, ballast, a compressor house, compressor, ventilation system, electric circuitry, and air valving system. Annual O&M is approximately $49,912 and included an annual service contract. Unit costs based on treating this 617-acre lake were approximately $580 to $670 per acre for capital and $81 per acre per year for O&M. Berkshire Regional Planning Commission (2004) did not report the expected useful life of the aeration system equipment.

ENSR Corporation (2008) estimated costs for hypolimnetic aeration for two lakes in Massachusetts (Lovers Lake and Stillwater Pond). Based on vendor quotes, they estimated capital costs of $94,907 and annual O&M of $5,260 for both lakes. ENSR Corporation (2008) also estimated costs for artificial circulation (which operates under the same concept as aeration) for the lakes of $117,195 in capital and $7,990 per year for O&M. These estimates equate to unit costs associated with aeration techniques of approximately $1,700–$2,100 per acre for capital and $95–$140 per acre per year for 55.5 total acres (37.7 for Lovers Lake and 17.8 for Stillwater Pond). ENSR Corporation (2008) estimated a useful life for the aeration equipment of 15 years.

Chandler (2013) estimated costs for two aeration systems for Twin Lake in Minnesota: a solar-powered system and a bubbler system. The Solar Bee solar-powered mixing system consists of a tube with an impeller that pulls water from the bottom of the tube to the surface. The colder water then plunges outside of the tube, causing the lake to de-stratify and presumably improve dissolved oxygen. The tube can be placed at a depth below the thermocline to access cold water. Capital costs are $139,157, and O&M costs are minimal because the system is solar-powered, and only labor associated with spring placement and fall removal is necessary (for an estimated annual cost of $4,945). Unit costs for the 20-acre lake are approximately $6,958 per acre for capital and $247 per acre per year for O&M. Chandler (2013) and were based on an estimated useful life for the solar-powered aeration system of 20 years.

The alternative aeration system considered by Chandler (2013) was a bubbler system, which consists of flexible tubing (soaker hoses) installed at the lake bottom and pumps that provide compressed air to the tubing. Chandler (2013) estimated capital costs and O&M costs of $232,424 and $34,616 per year, respectively, based on a past lake aeration project. This equates to $11,600 per acre for capital and $1,731 per acre per year for O&M. Chandler (2013) estimated a useful life for the bubbler aeration system of 20 years.

The City of Lake Stevens (2013) in Washington reported the actual annul O&M costs associated with its existing aeration system over the past six years. Historically, operating costs were around $35,000 per year for power consumption and staffing. However, recently, due to repairs and replacement parts, operating costs have increased to about $110,000 per year. Unit costs for the 1,013-acre lake range from $35–$109 per acre per year. The City of Lake Stevens (2013) did not specify the useful life of the aeration system.

Alum Treatment— Aluminum sulfate, otherwise known as alum, is a chemical commonly used to mitigate nutrient pollution in lakes. When added to the water column, the alum precipitates as a floc, which removes phosphorus from the water. The floc then settles on the sediment at the bottom of the lake. If enough alum is added, the settled floc forms a barrier that prevents the release of phosphorus from sediment. Costs for alum treatment vary based on the number of applications needed over a given timeframe. In most cases, the time period over which the alum treatment will last is highly lake-specific and depends on the extent of controls on existing inputs, initial alum dose, natural water circulation, and extent of phosphorus pollution/target concentrations or reductions.

Several studies have examined the use of alum as a mitigation technique for phosphorus in lakes. Barr (2005) evaluated alum treatment as a potential mitigation technique for internal phosphorus loading in two Minnesota lakes. For Kohlman Lake, which had an estimated sediment internal loading rate of 9.7 $mg{\cdot}m^{-2}\ d^{-1}$, the study recommended alum treatment as a feasible option, with an estimated capital cost of $165,759 for a single application. This equates to unit costs of $2,240 per acre to treat all 74 acres of the lake. The authors estimated alum treatment costs for Keller Lake to be $58,780 for a single application, or $816 per acre to treat all 72 acres of the lake. However, they recommended other mitigation options due to the lake's lower sediment internal loading rate. Barr (2005) does not indicate how long the alum treatment will last before another treatment would be necessary.

Barr (2012) calculated the alum dose necessary to treat phosphorus in the sediment of Spring Lake, Minnesota. The study based its dosage calculation on treating the upper 6 cm of sediment across the entire lake, and estimated a capital cost of $986,000–$1,086,000. The treatment is for the entire 409 acres of the lake, resulting in unit costs of $2,411 to $2,655 per acre. The range in costs represent the difference between a one-time full application of alum and breaking the full dose up into three separate applications (higher costs because there is more labor and start-up associated with each application even though the amount of alum does not change). Barr (2012) estimates that the alum treatment could last 10 to 32 years.

Burghdoff and Williams (2012) conducted a study to identify the best methods of controlling the internal and external phosphorus sources and resulting algae blooms in Lake Ketchum, Washington. Authors showed that alum treatment of the sediment could reduce average lake phosphorus concentration from 277 µg/L to 71 µg/L over a four-year period. They estimated the costs of treatment for phosphorus in the upper 10 cm of sediment to be $198,015. They also estimated costs for treating only the water column with alum to be $36,745 annually. Note that while the sediment alum treatment is higher, it lasts for 4 years, whereas the water column alum addition must be repeated each year. Both treatment options would treat all 25.5 acres of the lake, resulting in unit costs of approximately $7,800 per acre and $1,400 per acre, respectively.

The Cedar Lake Protection and Rehabilitation District (2013) estimated the alum dose necessary to treat phosphorus associated with excess algae growth in Cedar Lake, Wisconsin. The study recommended a partial lake treatment of the upper 6 to 8 cm of sediment at water depths greater than 20 feet. The authors estimated that the costs associated with this recommendation would be nearly $2.2 million for two applications, with a useful life of approximately 10 years, and would reduce phosphorus concentrations from 0.068 mg/L to 0.030 mg/L. The Cedar Lake Protection and Rehabilitation District (2013) did not specify the total number of acres to be treated so unit costs cannot be estimated.

Chandler (2013) studied the feasibility of alum treatment for the eutrophic conditions caused by phosphorus in Twin Lake, Minnesota. Chandler (2013) concluded that alum addition for 19 of the 20 acres of the lake twice in 3 years would cost $146,377 or approximately $7,700 per acre, and reduce phosphorus concentrations from 70 μg/L to 20 μg/L.

ENSR Corporation (2008) assessed alum treatment as a technique to reduce the release of phosphorus from sediment in Lovers Lake and Stillwater Pond, Massachusetts. The authors indicated that partial lake treatment (19 of 37.7 acres for Lovers Lake and 9.25 of 18.7 acres for Stillwater Pond) would provide sufficient treatment for 15 years at a one-time cost of $211,676–$243,667 or $7,493–$8,625 per acre.

Herrera Environmental Consultants (2003) reported on the use of alum to treat phosphorus associated with periodic blue-green algae blooms in Green Lake, Washington. The study determined that a 23 mg/L alum dose would reduce phosphorus concentration from 13 μg/L to 2 μg/L for about 10 years at a one-time cost of approximately $1.9 million or $7,261 per acre to treat all 259 acres of the lake.

Hoyman (2011) studied the feasibility of alum treatment for reducing internal phosphorus loading in East Alaska Lake, Wisconsin. The authors concluded that an alum application rate of 132 g/m^2 to areas of the lake with depths greater than 10 feet, and 40 g/m^2 to areas with depths between 5 and 10 feet would provide a 90% reduction in internal phosphorus loading. The study estimated the one-time cost of this treatment at $168,221 or $4,143 per acre to treat the 41-acre lake.

King County (2005) identified alum treatment as a management strategy for reducing phosphorus concentrations in Lake Hicks, Washington. The goal was to reduce phosphorus concentrations to less than 20 μg/L, at which point the lake would no longer be listed as impaired for nutrients. The study reported that alum treatment for Lake Hicks, including pre- and post-treatment monitoring, would cost $54,762 for a single application or $13,690 per acre to treat 4 acres. The study did not specify how long the alum treatment was expected to last, however, it references Welch and Cooke (1999), which states that benefits of alum treatment could last for more than 10 years.

Osgood (2002) gave recommendations on an alum treatment plan for Lake Mitchell, which serves as the water supply for the City of Mitchell, South Dakota. The report concluded that three years of whole-lake alum applications (acres not specified) would be sufficient to reduce phosphorus concentrations in the lake from 241 μg/L to 90 μg/L, with per application costs of $238,246 for the first year, $204,042 for the next two years, and $127,623 annually thereafter. Osgood (2002) does not specify how long the annual treatments would last.

Tetra Tech (2004) examined the feasibility of alum treatment as a method for the inactivation of phosphorus cycling in Lake Lawrence, Washington. The authors estimated that a 6-day, whole-lake alum treatment (330 acres) would provide water quality benefits lasting more than 20 years. They reported that the one-time capital cost of treatment would be $986,921 or $2,991 per acre and the cost of 80 days of monitoring per year would be $204,192 or $619 per acre per year.

The LA Group (2001) considered alum treatment as a technique for the management of aquatic vegetation in Cossayuna Lake. The study reported that treating 35 of the lake's 776 acres with alum would cost $22,687 for a single application or $648 per acre. This cost covers a five-year planning period.

Barley Straw— Barley straw application is a method in which straw is placed along the edge of waterbodies so that it degrades and releases a chemical that inhibits new algal growth. Barley straw does not remove nutrients; as such, it needs to be applied annually to be effective (Chandler, 2013). Chandler (2013) evaluated barley straw as a potential mitigation strategy for Twin Lake in Minnesota. Assuming a straw application rate of 300 lbs/acre, and accounting for delivery, materials, and labor, the study calculated an annual application cost of $11,057, or $553 per acre for the 20-acre lake.

Biomanipulation— Biomanipulation involves the introduction of piscivores to control the population of planktivorous fish, which feed on zooplankton. Fewer planktivorous fish allow zooplankton populations to thrive and consume more algae (Chandler, 2013). Chandler (2013) developed a plan to use biomanipulation to control algae in Twin Lake in Minnesota. The plan consisted of three parts: removing rough fish (planktivores), stocking the lake with pike and bass (piscivores), and monitoring fish migration to determine if the stocking was successful. The authors estimated that the total costs for this plan, assuming a total of four stockings, would be $279,403, or $13,970 per acre for the 20-acre lake.

Dredging— Dredging can be used to remove phosphorus trapped in lake-bottom sediment, which reduces internal phosphorus cycling. Barr (2005) investigated dredging as an option to remove phosphorus from Keller and Kohlman lakes in Minnesota. The study determined that dredge depths of 15 cm in Kohlman Lake and 10 cm in Keller Lake would be necessary to remove excess total phosphorus. The authors estimated the total capital cost of dredging and sediment disposal to be $968,692–$2,143,112 for the 74-acre Kohlman Lake and $628,944–$1,390,731 for the 72-acre Keller Lake; unit costs are $13,090 to $28,961 per acre for Kohlman Lake and $8,735 to $19,316 per acre for Keller Lake. The authors did not report how long the impacts of dredging would last.

Chandler (2013) considered dredging as an option to reduce phosphorus concentrations in Twin Lake, Minnesota. The report determined that sediments from dredging would have to be disposed offsite because of limited space surrounding the lake. Estimated total capital costs were $2,541,824, based on a dredging depth of 15 cm across the 20-acre lake, construction of an onsite dewatering facility, and shipment of dewatered solids to a landfill; unit costs are $127,091 per acre. Chandler (2013) did not report how long the impacts of dredging would last.

ENSR Corporation (2008) evaluated a plan to dredge sediment from Lovers Lake and Stillwater Pond in Massachusetts. The study determined that not all sediments were nutrient rich, and thus full-lake dredging was not necessary. Based on dredging two feet of sediment at water depths greater than 20 feet for a total of 19 acres, capital costs would be $1,546,246 (for unit costs of $81,339 per acre). The authors stated that they expect the benefits of dredging to last for at least 10 years.

Tetra Tech (2004) reported on the feasibility of dredging Lake Lawrence, Washington. They recommended dredging a total of 2,100,600 cubic yards of sediment at depths of 0–2.5 m across the lake. Total capital costs for dredging 330 acres, sediment transport and disposal, and post-dredging alum treatment would be $28,124,132, and total O&M costs would $1,404,218. Unit costs are $85,225 per acre for capital and $4,255 per acre for O&M. The authors expected that the benefits of the dredging and alum treatment would last for more than 50 years.

The LA Group (2001) estimated costs for a partial dredging of Cossayuna Lake in New York. Estimated capital costs to excavate 4 to 6 feet of sediment across 300 of the lake's 776 acres were between $5,905,143 and $9,794,369; unit costs were estimated to be $19,683 to $32,647 per acre. The authors did not report how long the dredging benefits would last.

Herbicide/Copper Sulfate Treatment— Herbicide treatment is used to remove nuisance algae species caused by the presence of excess nutrients. The Berkshire Regional Planning Commission reported that in 1998, approximately one-third of Lake Onota was covered with milfoil and was virtually unusable for recreational purposes. In 1999, due to the critical need to combat the milfoil, the City implemented a whole lake treatment with the herbicide SONAR. In 2000, they conducted follow-up spot treatment. The total cost of the treatment was $172,264, and the program successfully eliminated well over the contractually required 90% of the milfoil. Unit costs for the 617-acre lake are $279 per acre.

Copper sulfate is an algaecide that kills excess algae in lakes. Note that this treatment is not feasible in all waters because fish populations in waters with total alkalinity values less than 50 mg/L are sensitive to copper. The LA Group (2001) estimated the cost of annual copper sulfate doses to compare to the cost of alum treatment of 35 acres out of 776 acres in Cossayuna Lake in New York. They estimated the total cost of treatment over 5 years as $29,169, assuming annual doses, which translates to approximately $833 per acre for 5 years of treatment.

Hypolimnetic Withdrawal— Hypolimnetic withdrawal involves the direct removal of phosphorus-laden lake bottom waters. A hypolimnetic withdrawal system includes a pipe and perforated riser that is installed along the lake bottom, near the deepest point. The pipe connects to a shoreline treatment system consisting of pumps, tanks to hold chemicals, and a clarifier to settle treated water (Chandler, 2013). In smaller lakes, water must be added back in to maintain lake levels. Chandler (2013) estimated costs of hypolimnetic withdrawal for Twin Lake in Minnesota to be $583,532 for capital (including construction, engineering and design, and contingency) and $39,561 per year for O&M (including electricity, chemicals, and settled flocculent disposal); unit costs for this treatment are approximately $29,000 per acre for capital and $2,000 per acre per year for O&M for the 20-acre lake. Chandler (2013) indicated that the technique should last 20 years.

III.B.3. Restoration Costs

In addition to economic impacts and costs associated with nutrient pollution in surface waters, there can also be costs for activities that aim to restore impaired waterbodies. This section provides illustrative information on potential costs to public sector entities that implement programs to deal with nutrient pollution.

Development and Implementation of Total Maximum Daily Loads (TMDL) and Watershed Plans

Under Section 303(d) of the Clean Water Act, states and tribes are required to develop lists of impaired waters. The states and tribes identify all waters where required pollution controls are not sufficient to attain or maintain applicable water quality standards. They are then required to establish priorities for the development of TMDLs for waters listed on the Section 303(d) list. The costs for the development and implementation of TMDLs and watershed plans developed for Clean Water Act section 319 purposes vary based on watershed size and complexity. For example, in the

Chesapeake Bay watershed the Chesapeake Bay Regulatory and Accountability Program Grants, which resulted from Executive Order 13508, help jurisdictions develop new regulations, design TMDL watershed implementation plans, reissue and enforce permits, and provide technical and compliance assistance to local governments and regulated entities. The amounts each jurisdiction receives in grants (federal and state combined) range from approximately $900,000 per year in West Virginia to $5.7 million per year in Maryland.

However, developing a TMDL and/or implementation plan for a much smaller watershed is likely to cost much less. U.S. EPA (2001) estimated the cost of developing TMDLs based on performing eight basic steps:

- Characterizing the watershed
- Modeling and analyzing the waterbody and its pollutants to determine the reduction in the pollutant load that would eliminate the impairment
- Allocating load reductions to the appropriate sources
- Preparing an implementation plan
- Developing a TMDL support document for public review
- Performing public outreach
- Conducting formal public participation and responding to it
- Managing the effort (including tracking, planning, legal support, etc.).

As shown in Table III-7, U.S. EPA (2001) provides unit costs of developing TMDLs at different levels of aggregation: a single cause of impairment, the need for multiple TMDLs, and a submission that may range from a single TMDL for a single waterbody to many TMDLs for all the waterbodies in a watershed. The estimates reflect TMDL costs from 35 states and cover more than 60 types of causes submitted over the period April 1998 through September 2000. These estimates in Table III-7 do not cover the implementation of the TMDLs.

Table III-7. Costs of Developing TMDLs

Level of Aggregation	Typical Cost Range
Cost per single cause of impairment (for single TMDL)	$6,000–$154,000 (2000$)[1]
Cost per single waterbody (for single TMDLs to multiple TMDLs)	$26,000 to >$500,000
Cost per submission (for single waterbody to multiple waterbodies)	$26,000 to >$1,000,000

Source: U.S. EPA (2001).

[1] *Estimates reflect TMDL costs from 35 states and cover more than 60 types of causes submitted over the period April 1998 through September 2000.*

Setting Up Programs for Water Pollutant Trading and Offsets

Water pollutant trading is an approach that can be used to achieve water quality goals by allowing sources to purchase equivalent or better pollution reductions from another source, typically at a lower cost. Similarly, water quality offset occurs where a source implements controls that reduce the levels of pollution for the purpose of creating sufficient assimilative capacity to allow for the discharge of a pollutant for which they may otherwise have to install more expensive treatment or controls. The use of trading and offsets can improve nutrient-impaired waterbodies potentially at lower costs. Several states have developed policies and programs to encourage trading and offsets as a means to reduce the burden on sources in complying with TMDLs and applicable water quality criteria.

Breetz et al. (2004) performed a comprehensive survey of water quality trading and offsets in the United States. As part of the survey, the costs to administer the trading and offset programs were compiled along with general information about the program. Table III-8 presents a summary of the costs associated with trading and offsets related to nutrients.

Table III-8. Summary of Costs to Administer Nutrient Trading and Offset Programs

Program Name (Location)	Type of Program	Nutrient(s) Involved	Description of Costs (2012$)
Boulder Creek Trading Program (CO)	Offset	Nitrogen	The total cost was estimated at $1.58–$1.70 million. Costs included the costs of gathering data for planning and evaluation, construction, materials, labor, and time. The overall cost was brought down by the donation of volunteer labor, time, materials, and land easements from landowners.
Chatfield Reservoir Trading Program (CO)	Trading	Phosphorus	A $122 application fee to cover administrative costs is required for point sources to apply for increased discharge through trading. Credits that enter the pool are sold at a price that reflects the cost of nonpoint-source reduction projects, costs associated with the pooling program, and costs incurred by the Authority to administer the trading program. Exact costs are unknown, but the monitoring program was estimated to cost $71,000/year.
Cherry Creek Basin (CO)	Trading	Phosphorus	Coming from a combination of property taxes and user fees, the budget for 2003 was $1.7 million, of which at least 60% had to be spent on the construction and maintenance of pollution reduction facilities. The remaining 40% is used in research, planning documents, technical reports, and administrative costs. State grants finance a smaller portion of the work, particularly that involving educational campaigns about nonpoint-source pollution and construction of pollution reduction facilities.
Long Island Sound (CT)	Trading	Nitrogen	The trading program carried out two years of credit exchange with relatively limited financial resources, besides the state and federal funds used to implement nitrogen removal projects. The Connecticut Department of Environmental Protection employs the equivalent of two full-time employees to work on the exchange; the advisory board does not receive monetary compensation.
Rahr Malting Company Permit (MN)	Offset	Nitrogen and phosphorus	During the two-year permitting phase, Rahr spent about $20,000 ($14,600 for consultants and $5,500 for staff time), while the Minnesota Pollution Control Agency (MPCA) spent about $63,000 on staff time. During the implementation phase, Rahr spent about $2,700 on staff time, the MPCA spent about $40,000 on staff time, a local citizen’s group spent about $900, and nonpoint sources spent about $600 on legal assistance. The grand total for transaction costs during these two phases was about $128,000, 81% of which were borne by the MPCA as it designed the overall program structure.

Program Name (Location)	Type of Program	Nutrient(s) Involved	Description of Costs (2012$)
New York City Watershed Program (NY)	Offset	Phosphorus	For development of the comprehensive strategies in the Croton System, the New York City Department of Environmental Protection allocated up to $1.2 million to each county required to develop a water quality protection plan.
Tar-Pamlico Nutrient Reduction Trading Program (NC)	Trading	Nitrogen and phosphorus	The Tar-Pamlico Basin Association gave $182,000 to the state Department of Environmental Management during Phase I to fund a staff position, and the trading ratio includes 10% for administrative costs.
Great Miami River Watershed Water Quality Credit Trading Pilot Program (OH)	Trading	Nitrogen and phosphorus	Estimated 3-year project cost of $2,430,810 including $607,000 to fund BMPs. The program receives in-kind support primarily in the form of water quality monitoring, and the training of soil and water conservation professionals by other organizations.

Source: Breetz et al. (2004)

III.B.4. Anecdotal Evidence and Additional Studies

Similar to Section III.A.5, additional anecdotal evidence and studies related to increased costs of nutrient pollution, including drinking water treatment costs and mitigation costs are presented in Appendix A.

III.C. Data Limitations

As described in the previous section, there are a number of studies documenting the economic impacts of nutrient pollution in surface waters across the United States (Table III-9). These studies demonstrate that the impacts associated with surface water nutrient pollution can be very damaging to locally important economic industries (e.g., tourism in Florida communities, lakefront real estate in areas of Maine, and others). However, a number of additional reports do not meet the screening criteria for documentation of impacts due to various reasons (e.g., method not clearly described, data sources not identified or documented). These additional studies (also reflected in Table III-9) suggest that the economic impacts from nutrient pollution may be more widespread than the screened studies indicate.

Table III-9. Summary of Nutrient Pollution Cost Documentation

Impact	Number of Studies Found (Number that Match Criteria)	Waterbody Types	Locations
Tourism and recreation	13 (7)	Lakes, bays, rivers, coasts	MD, OH, FL, TX, WA; national
Commercial fishing	9 (5)	Bays, rivers, coasts	ME, MD, NC, FL, TX, AK; national
Property values	15 (9)	Lakes, rivers, coasts	ME, NH, VT, MD, OH, SC, FL, WI, MN, HI; national
Human health	2 (1)	Coasts	FL; national
Drinking water treatment costs	11 (2)	Lakes, rivers, coasts	OH, IA, FL, CA, KS, TX; national
Mitigation costs	31 (31)	Lakes	MN, MA, WA, WI, SD, NY
Restoration costs	14 (14)	Watersheds	CT, NY, PA, OH, MN, CO, CA, OR; national

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IV. Cost of Nutrient Pollution Control

Attaining numeric or narrative water quality standards for nutrients entails the deployment of nutrient pollution controls for point and/or nonpoint sources in most waterbodies. This section summarizes the data and information collected from recent studies related to the costs for treatment systems and other controls that have been employed by point and nonpoint sources to reduce the discharge of nutrients to surface waters. All dollar values were updated to 2012 dollars (2012$) for technologies based on the Construction Cost Index and for best management practices based on the Consumer Price Index.

The types and extent of controls required to reduce nutrient pollution will depend on a number of factors, including for example, the number and types of sources contributing to the pollution requiring controls, geographic location, and stringency of water quality standards. In addition, the extent of the nutrient pollution controls required may also depend on the specific control plans (e.g., TMDLs, watershed plan) established by state and local regulatory authorities. Therefore these factors should be considered prior to use of cost data provided throughout this section.

IV.A. Point Source Control Costs

Point sources include discharges of pollutants from either municipal wastewater treatment plants (WWTPs) or industrial waste treatment facilities directly to surface waters through pipes, outfalls, and conveyance channels. Although these facilities play a vital role in maintaining public health and protecting natural waters by providing waste treatment services to businesses and local communities throughout the United States, they can be significant contributors of nutrient pollution to waterbodies of the United States.

This section summarizes cost and treatment effectiveness information extracted during the literature search for technologies used at point source facilities to control the discharge of nutrients. This section is organized according to the type of point source[18]:

- Municipal WWTPs
- Decentralized treatment systems for small communities
- Industrial wastewater treatment plants.

Most cost data collected during the course of the literature review were normalized to a unit cost based on the information provided in each source; however, a portion of the data collected for treatment of industrial sources of nutrient pollution was not normalized since treatment capacities were not available for individual facilities.

All the studies from which data were extracted include the cost and some measure of nutrient control performance (i.e., effluent concentration and/or percent removal), however the reported costs may not be specific to the associated performance measure for a single pollutant by itself. For

[18] Stormwater discharges from many municipal separate storm sewer systems (MS4s) are regulated under section 402(p) of the Clean Water Act and are required to obtain NPDES permits for their point source discharges. For organizational purposes in this report, and to acknowledge that not all MS4s are regulated at this time, costs and performance for urban and residential runoff are contained in the nonpoint source section.

example, a source may provide the capital cost for a treatment system designed to remove total nitrogen and total phosphorus and the associated treatment performances for both pollutants. However, if the system was designed primarily for phosphorus removal, then the costs will be driven by removal of phosphorus and may overestimate costs for removing nitrogen alone. In the vast majority of cases where performance metrics for both nitrogen and phosphorus were provided for a facility, the source did not indicate which (if any) parameters were design limiting and determinative of final capital and annual operation and maintenance (O&M) costs.

This section limits the discussion of results to descriptive analysis due to the character of the information collected in the literature review. The discussion does not include statistical analysis or modeling of the collected data. Extracted data do not in all cases include independent observations, nor do the data necessarily constitute a representative and statistically valid sample set of nutrient removal facilities throughout the United States. The resulting dataset contains information collected from a diverse set of research articles and reports, each focused on the site-specific situation and needs for nutrient pollution control, and do not constitute a comprehensive survey of nutrient treatment in the United States. In addition, not all cost and performance data correspond to individual facilities. Some studies and reports included cost and nutrient treatment performance curves, but the original data upon which these curves were based were not available. In these cases, multiple data points were extracted from the curves, which served to capture the cost and performance information in the performance curves.

The nutrient control information collected and compiled for this project provides a snapshot of recent cost and performance information for a variety of treatment technologies. This information can be used to gauge the reasonableness of nutrient cost-to-treat estimates developed by government agencies, discharger associations, and other interest groups. This information may also prove a useful starting point in the development of cost estimates and in conducting related literature searches.

IV.A.1. Municipal Wastewater Treatment Plants

Local governments use municipal WWTPs to control and treat sanitary wastewater and sometimes, when the municipality possesses a combined sewer system, stormwater. Some publicly owned treatment works also provide treatment services for discharges from industrial and commercial facilities. This section summarizes the cost and performance data collected for nutrient controls at municipal WWTPs.

As described in Table IV-1, the collected records represent empirical and modeled results for a variety of locations, nutrient types, and WWTPs. Highlights include:

- Cost data represented treatment design capacities for plants ranging from 0.1 million gallons per day (mgd) to 683 mgd.
- Costs associated with the construction of new WWTPs, as well as costs associated with the upgrade, expansion or retrofit of existing facilities were collected.
- Cost data were developed on either the basis of engineering cost estimates (i.e., modeled estimates) or realized, empirical costs for completed facilities.
- Costs data were collected for more than 30 point source control technologies and various combinations thereof.
- Cost data were representative of projects located in a variety of states and geographic regions.

Table IV-1. Summary of Cost and Performance Data for Municipal WWTPs

Category	Number of Records
Total number of records	370
Records which Include Data for Nitrogen and/or Phosphorus [1]	
Nitrogen only	128
Phosphorus only	144
Nitrogen and Phosphorus	98
Records for New Plants or Retrofit/Expansion of Existing Plants	
New construction	47
Retrofit/Expansion	323
Records for a Modeled Estimate or Empirical Data	
Empirical	12
Modeled	358
WWTP Locations	
EPA Region 1	2
EPA Region 2	2
EPA Region 3	53
EPA Region 4	6
EPA Region 5	37
EPA Region 6	3
EPA Region 7	0
EPA Region 8	1
EPA Region 9	1
EPA Region 10	189
Outside United States	2
Location not reported [2]	74
Treatment Capacity	
0.10 mgd – 0.99 mgd	43
1.00 mgd – 4.99 mgd	101
5.00 mgd – 9.99 mgd	25
10.00 mgd– 49.99 mgd	119
> 50.00 mgd	82

[1] *Ninety-eight records include cost and performance data for both nitrogen and phosphorus.*

[2] *A location was registered as "Not Reported" for modeled estimates where the authors did not indicate an assumed location in their methodology. Location information was included for all records associated with empirical results.*

Several sources reviewed during the literature search merit special note for those investigating issues regarding nutrient control at municipal WWTPs. U.S. EPA (2008) provides a broad synthesis of information on nutrient removal at these facilities, including a survey of commonly used treatment technologies, their capabilities and limitations, and planning level costs for treatment technologies. The TMDL report (U.S. EPA, 2001) also documents detailed case studies for plants located in the Chesapeake Bay watershed. In 2011, the Washington State Department of Ecology (WASDE, 2011) produced a technical report wherein they developed cost estimates for a suite of treatment technologies to achieve a number of different effluent quality performance targets. The suite of technologies evaluated was diverse and representative of the variety of existing treatment strategies employed in the United States.

An examination of all collected and compiled cost data for municipal WWTPs (Figures IV-1 and IV-2) shows some economies of scale for nutrient control technologies, demonstrated by the downward sloping diagonal below which there are no observations. Economies of scale are efficiencies gained from operating a larger plant resulting in a reduced average cost per unit of waste treated. These efficiency gains are present for both new plants and for the retrofitting of existing treatment plants.

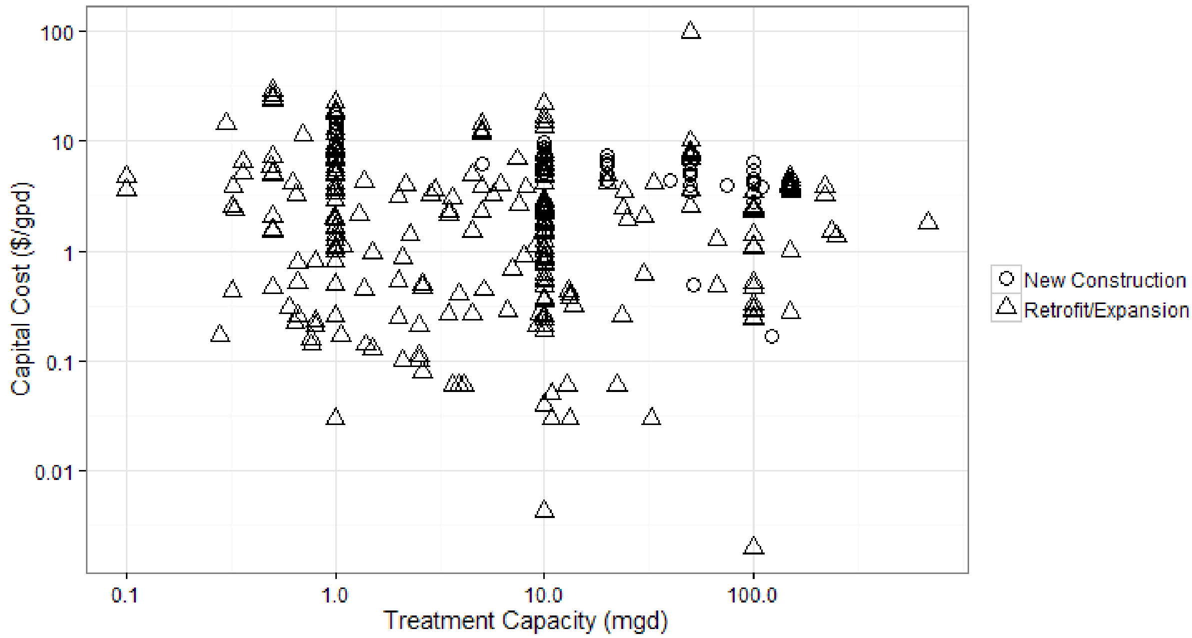


Figure IV-1. Capital costs and treatment capacities for municipal WWTPs (2012$).

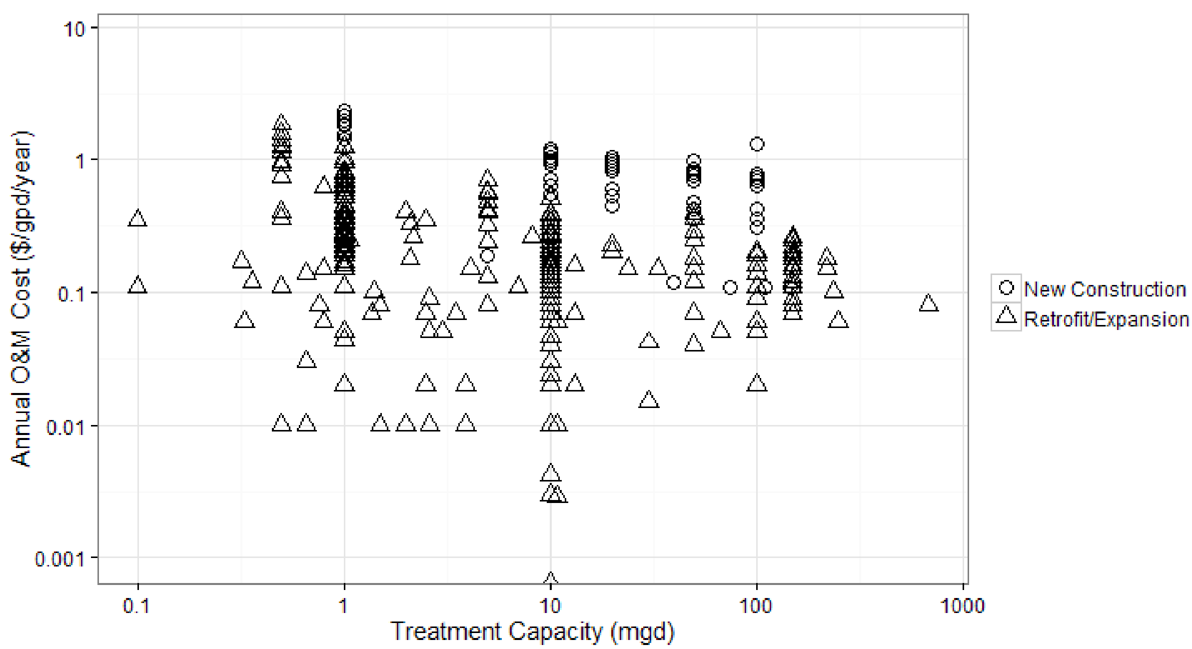


Figure IV-2. Annual O&M costs and treatment capacities for municipal WWTPs (2012$).

Cost and Performance Information – Nitrogen

Cost and performance data were collected and compiled for several forms of nitrogen including total ammonia nitrogen, total inorganic nitrogen, and total nitrogen (TN). Costs and treatment performance ranges for each form of nitrogen are summarized in Table IV-2.

Capital costs (Figures IV-3 and IV-5) were typically less than $25 per gpd, with the exception of a single aerobic lagoon facility with capital costs approaching $100/gpd. Annual O&M costs (Figures IV-4 and IV-6) for total ammonia nitrogen were typically less than $0.10/gpd/year and for TN were frequently less than $0.25/gpd/year, though costs were observed as high as $0.51/gpd/year. Total inorganic nitrogen O&M costs displayed a greater range than those for the other nitrogen parameters with costs ranging as high as $1.85/gpd/year. All costs for total inorganic nitrogen were derived from a single literature source (WASDE, 2011).

Table IV-2. Nitrogen Cost and Treatment Performance for Municipal WWTPs

Effluent Quality (mg/L as N)	Removal Efficiency Range (%)	Capital Cost Range ($/gpd)[1]	Annual O&M Cost Range ($/gpd/year)[1]	Technologies
Total Ammonia Nitrogen (n = 3)				
0.6 – 1.4	94 – 98	1.27 – 3.58	0.05 – 0.09	Variety of biological nutrient removal (BNR) systems and filtration technologies.
Total Inorganic Nitrogen (n = 129)				
3.0 – 8.0	79 – 92	< 0.10 – 98.40	< 0.01 – 1.85	Activated sludge, lagoons, membrane bioreactors, rotating biological contactors, sequencing batch reactors, and trickling filters.
Total Nitrogen (n = 95)				
2.0 – 16.4	29 – 94	< 0.10 – 22.17	0.02 – 0.51	Variety of BNR, typically paired with filtration or other tertiary treatment systems.

[1] *All costs are presented in 2012 dollars (2012$).*

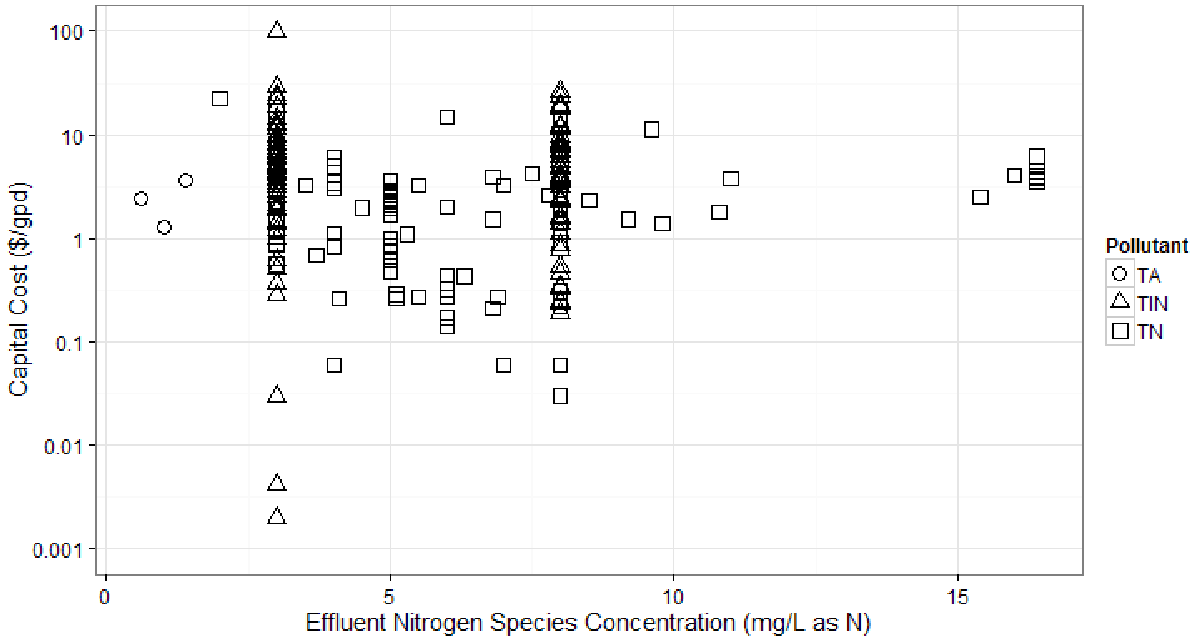


Figure IV-3. Capital cost and nitrogen effluent concentration for municipal WWTPs (2012$).

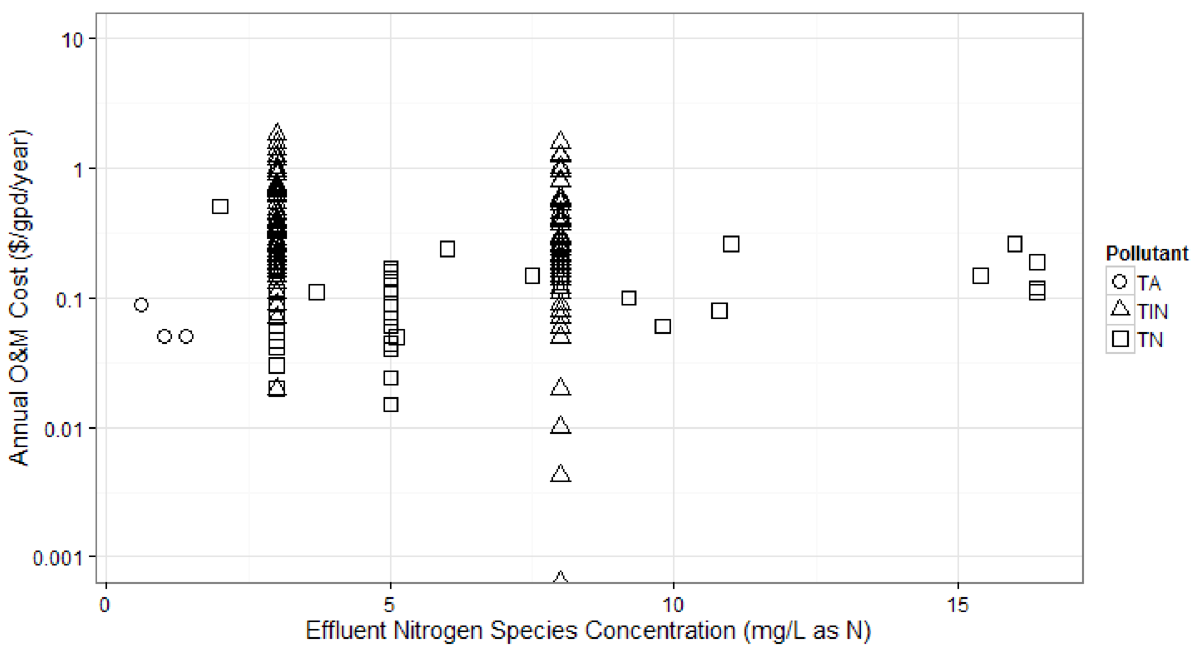


Figure IV-4. Annual O&M cost and nitrogen effluent concentration for municipal WWTPs (2012$).

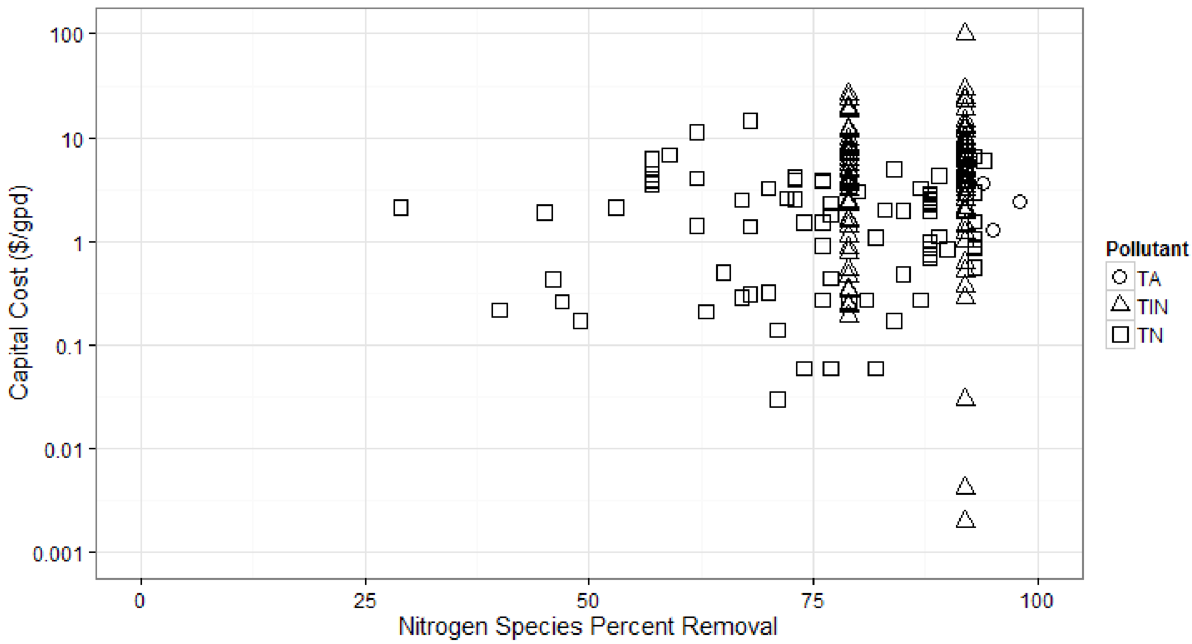


Figure IV-5. Capital cost and nitrogen removal for municipal WWTPs (2012$).

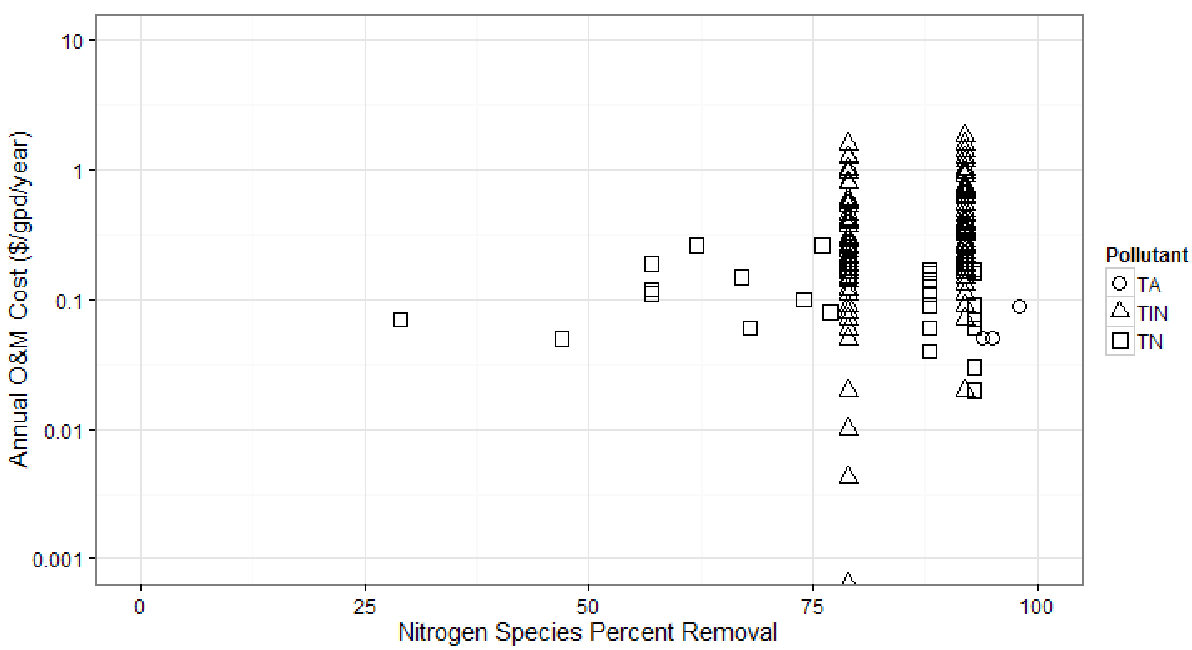
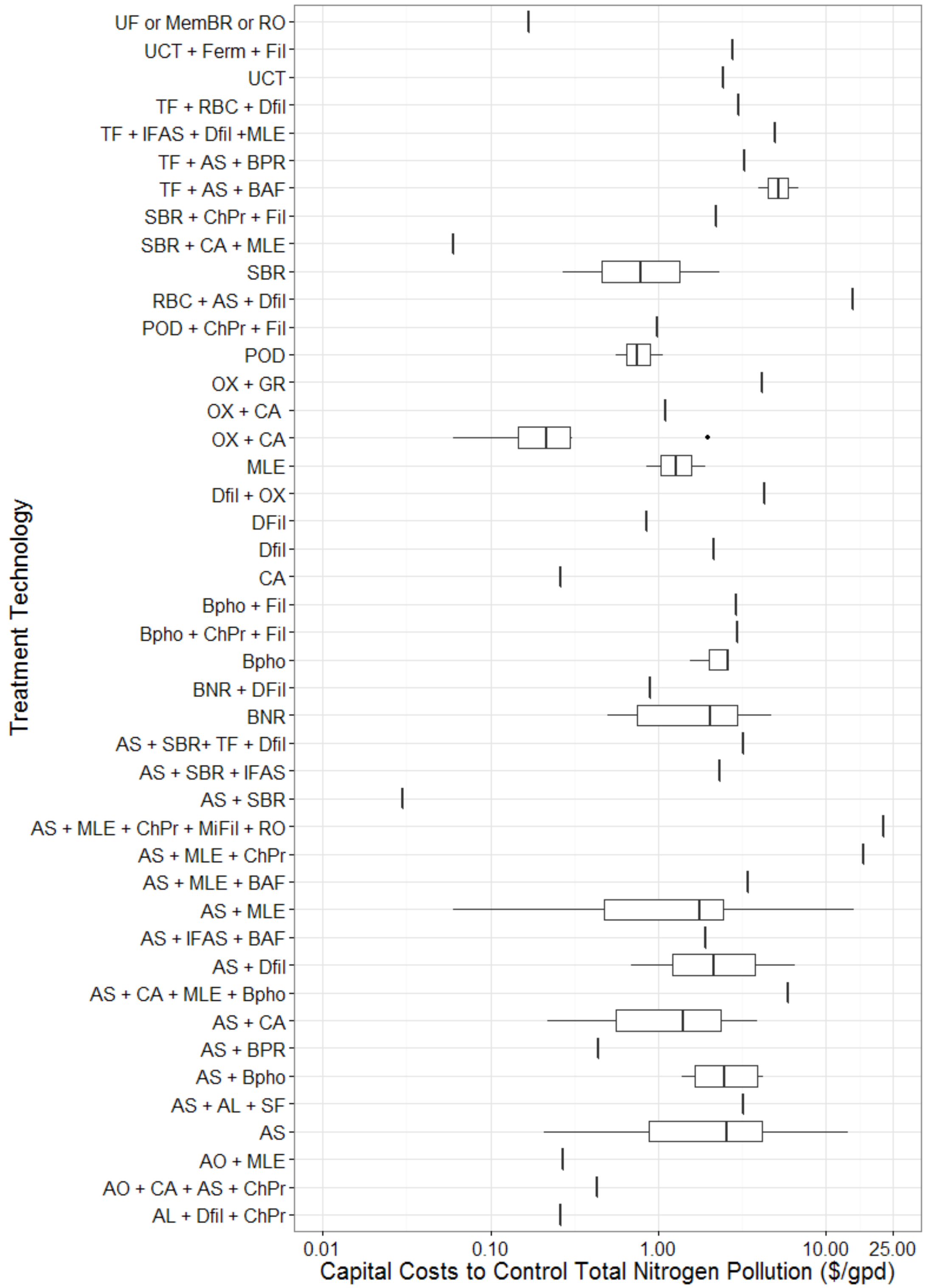


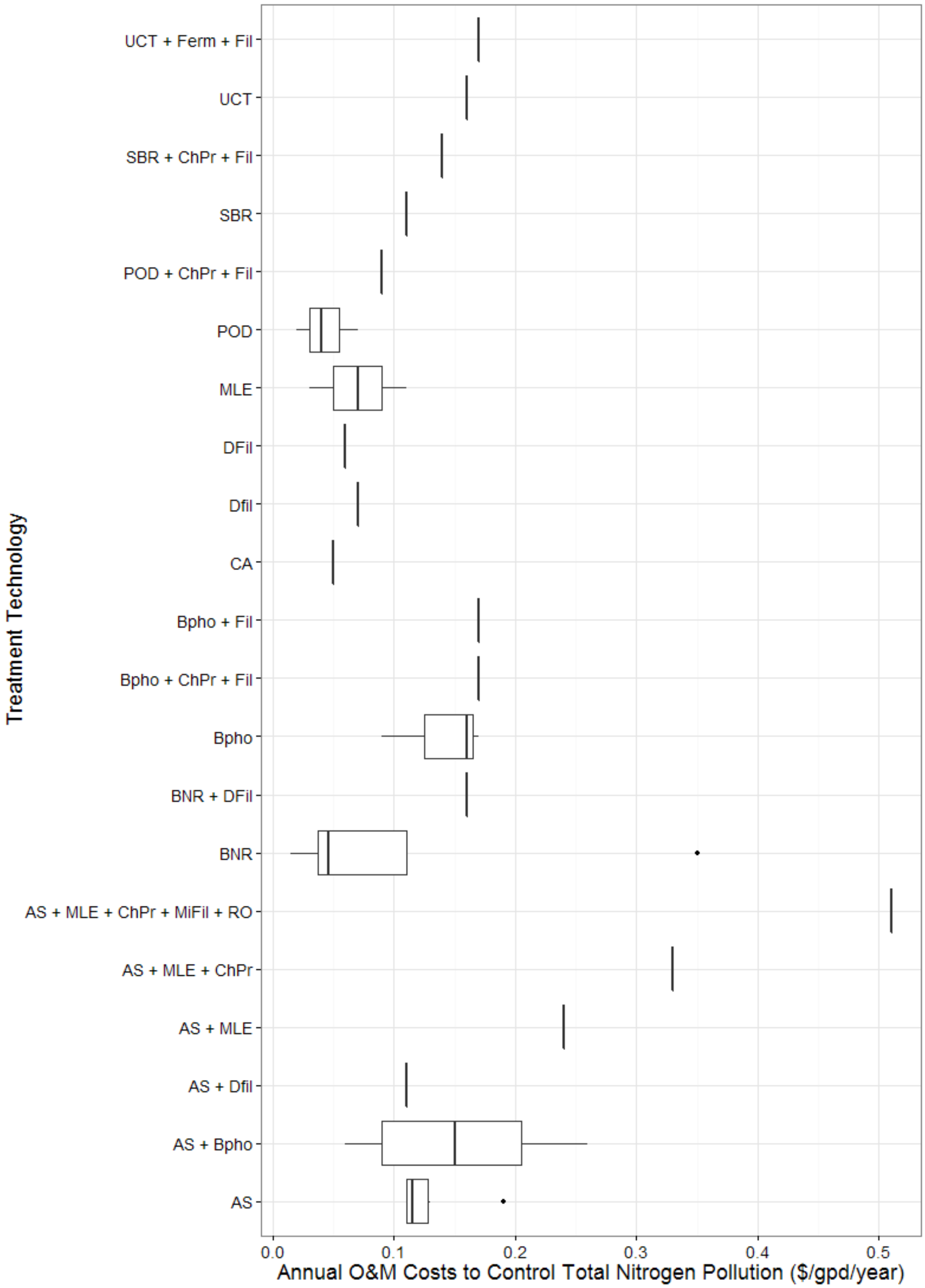
Figure IV-6. Annual O&M cost and nitrogen removal for municipal WWTPs (2012$).

The greatest diversity in treatment technologies for nitrogen was associated with the control of TN (Figures IV-7 and VI-8). The majority of records for TN control include some form of BNR and some form of filtration. Most TN treatment technologies are able to achieve effluent concentrations between 3 and 8 mg/L as N (Figure IV-9).



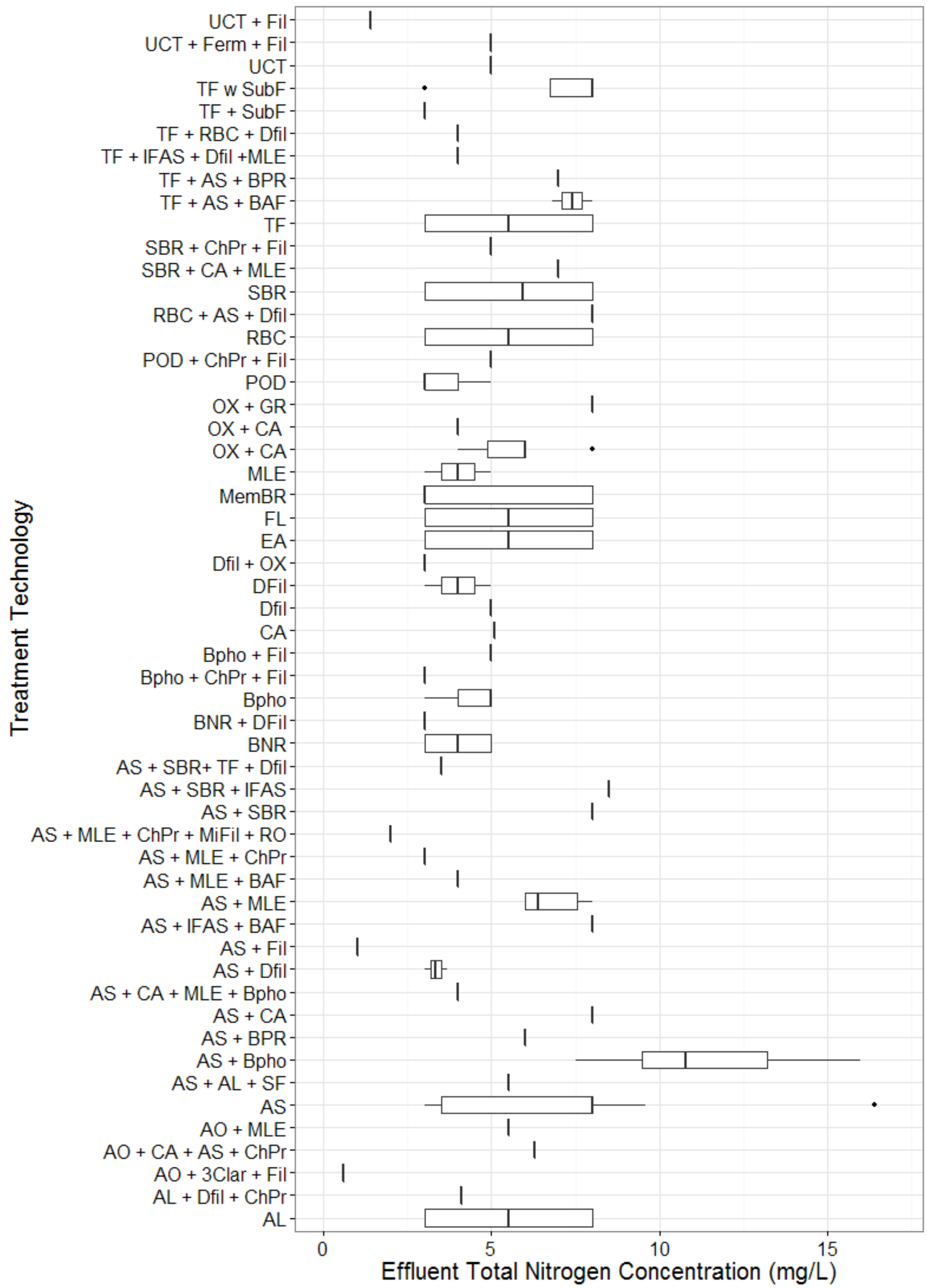
Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-7. Capital costs for TN treatment technologies (2012$).



Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-8. Annual O&M costs for TN treatment technologies (2012$).



Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-9. Effluent TN concentrations for municipal treatment technologies.

Cost and Performance Information – Phosphorus

Cost and performance data were collected and compiled for total phosphorus (TP). Cost and treatment performance ranges for TP are summarized in Table IV-3. Capital costs (Figures IV-10 and IV-12) were typically less than $22/gpd for most technologies, though lagoon-based technologies and oxidation ditches were sometimes reported as more expensive. Annual O&M costs (Figures IV-11 and IV-13) for TP were less than $2/gpd/year and tended to decrease as effluent concentrations increased. New construction costs were frequently higher than costs for improvement of existing plants.

Table IV-3. Total Phosphorus Cost and Treatment Performance for Municipal WWTPs

Effluent Quality (mg/L as P)	Removal Efficiency Range (%)	Capital Cost Range ($/gpd)[1]	Annual O&M Cost Range ($/gpd/year)[1]	Technologies
< 1.0	75 – 99	0.03 – 22.17	<0.01 – 2.33	Chemical precipitation or any of a variety of BNR technologies—BNR frequently used in combination with tertiary filtration, ultrafiltration, and/or reverse osmosis.
< 1.0	81 – 99	0.14 – 98.40	0.04 – 1.85	Lagoons and oxidation ditches capable of meeting this standard but at relatively higher unit costs.
> 1.0	22 – 85	0.05 – 12.82	<0.01 – 1.55	Oxidation ditches, lagoons, and a variety of BNR systems.

[1] *All costs are in 2012$*

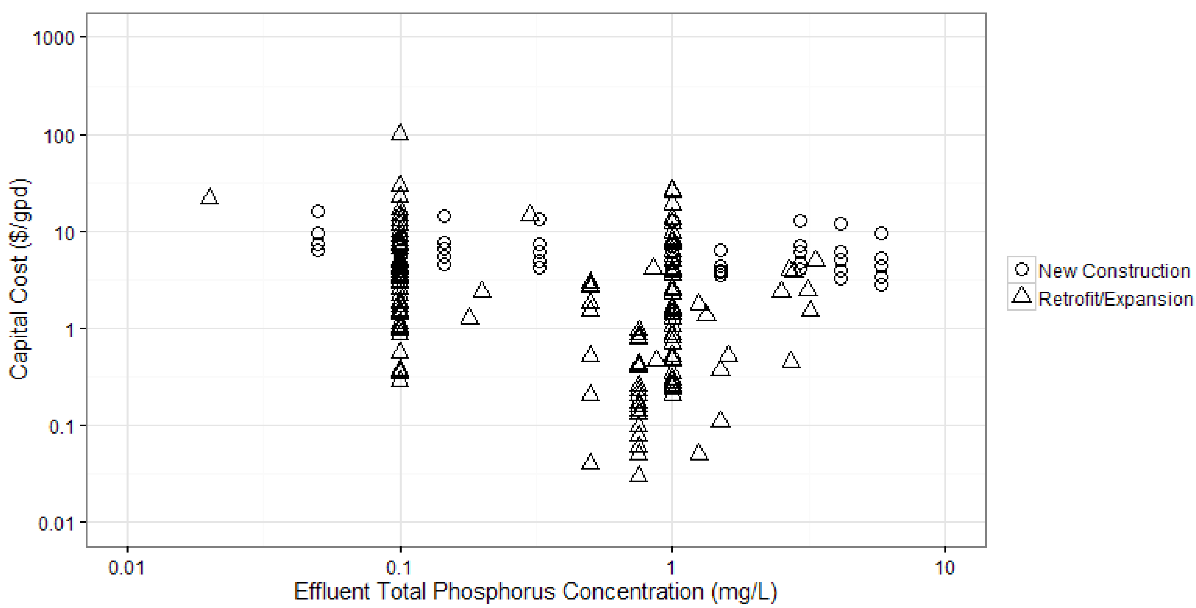


Figure IV-10. Capital cost and phosphorus effluent concentration for municipal WWTPs (2012$).

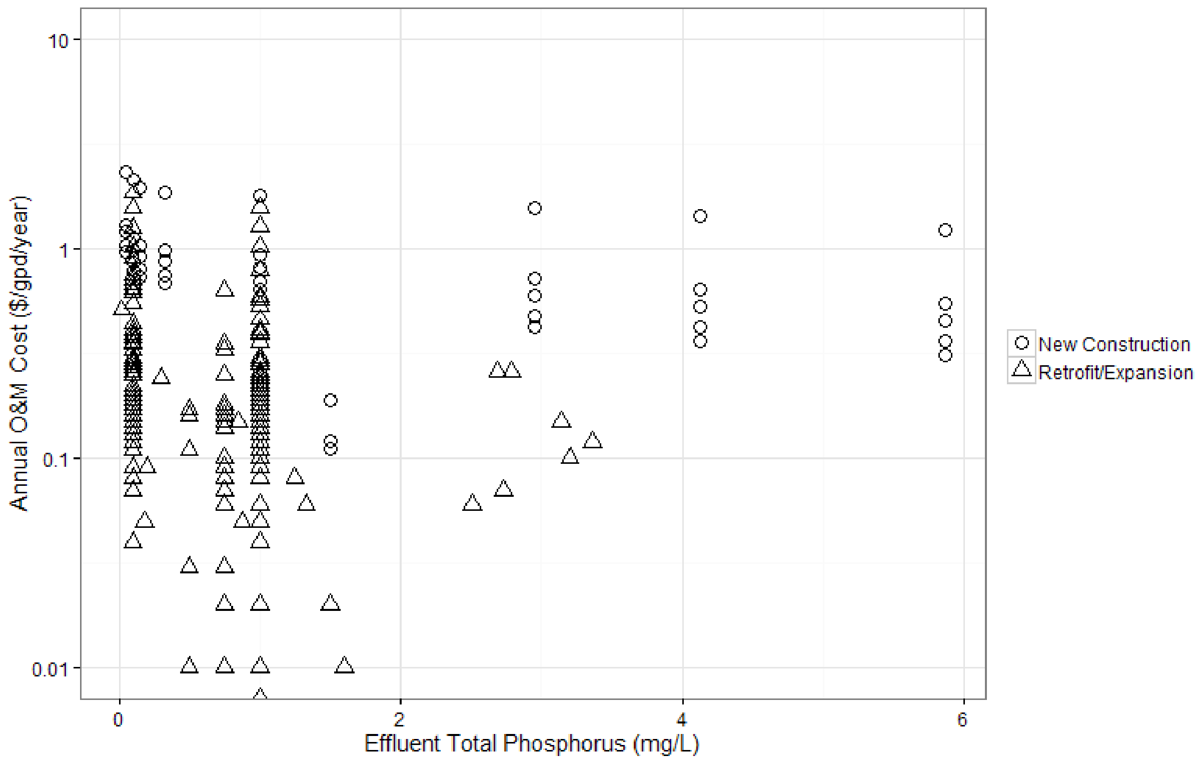


Figure IV-11. Annual O&M cost and phosphorus effluent concentration for municipal WWTPs (2012$).

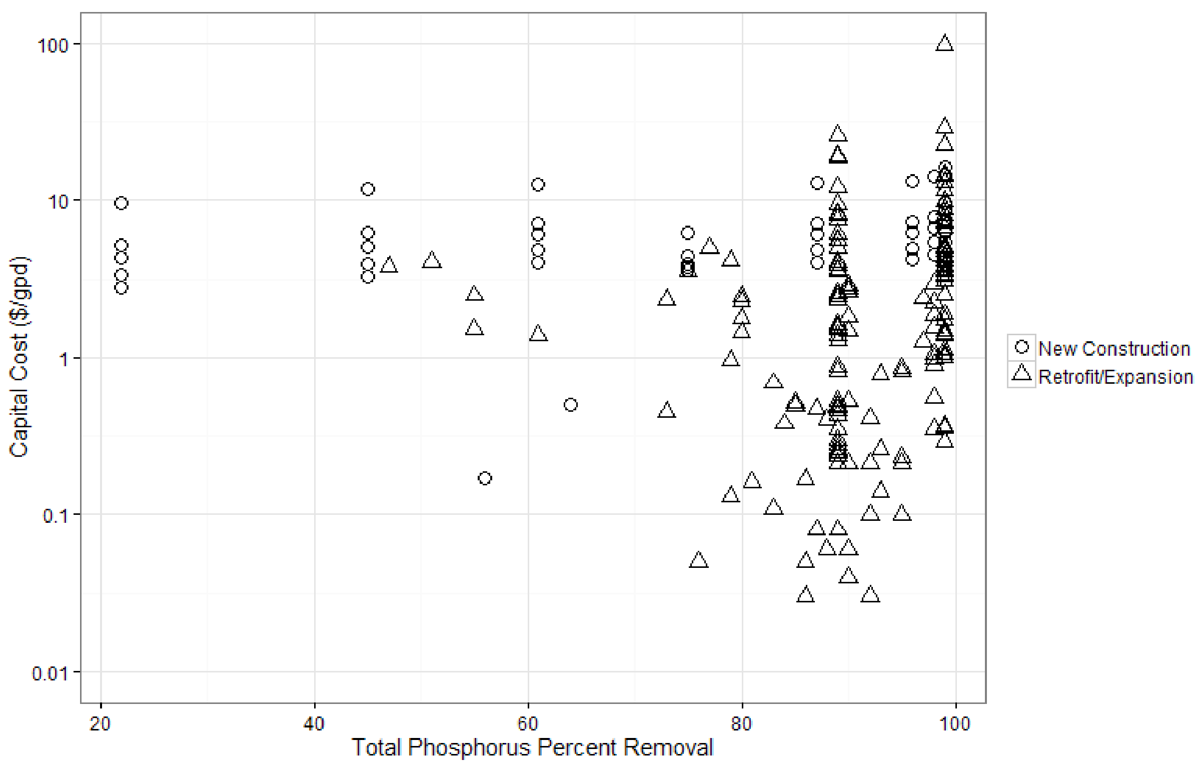


Figure IV-12. Capital cost and TP removal for municipal WWTPs (2012$).

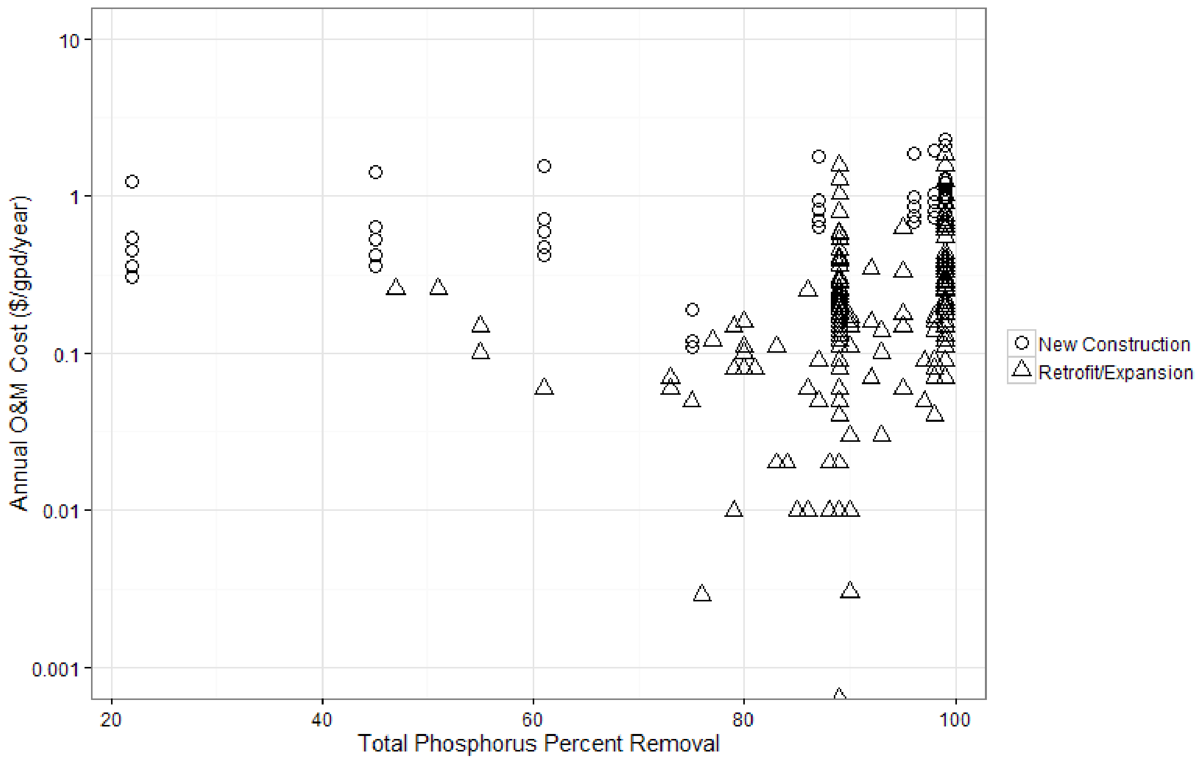
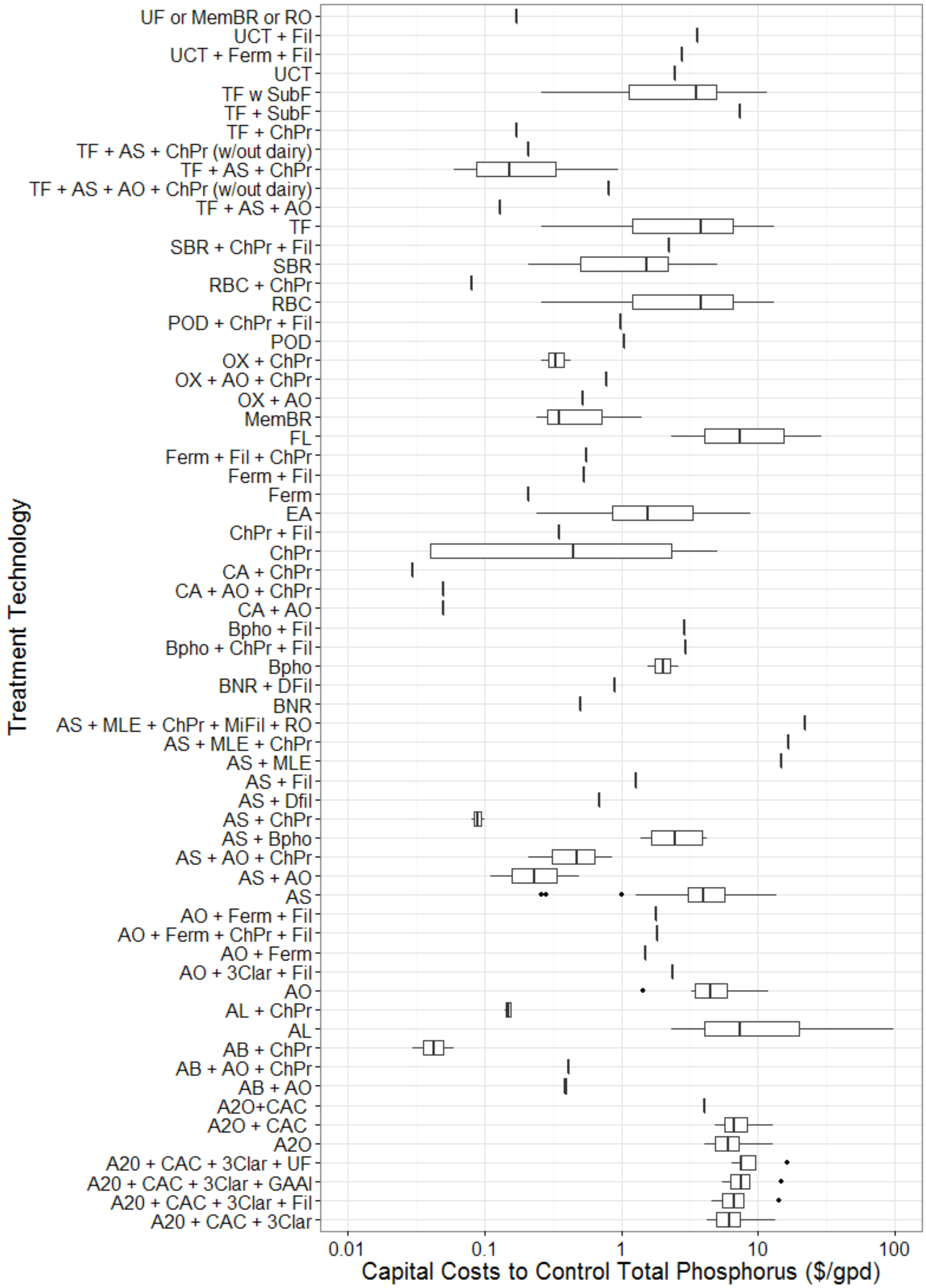


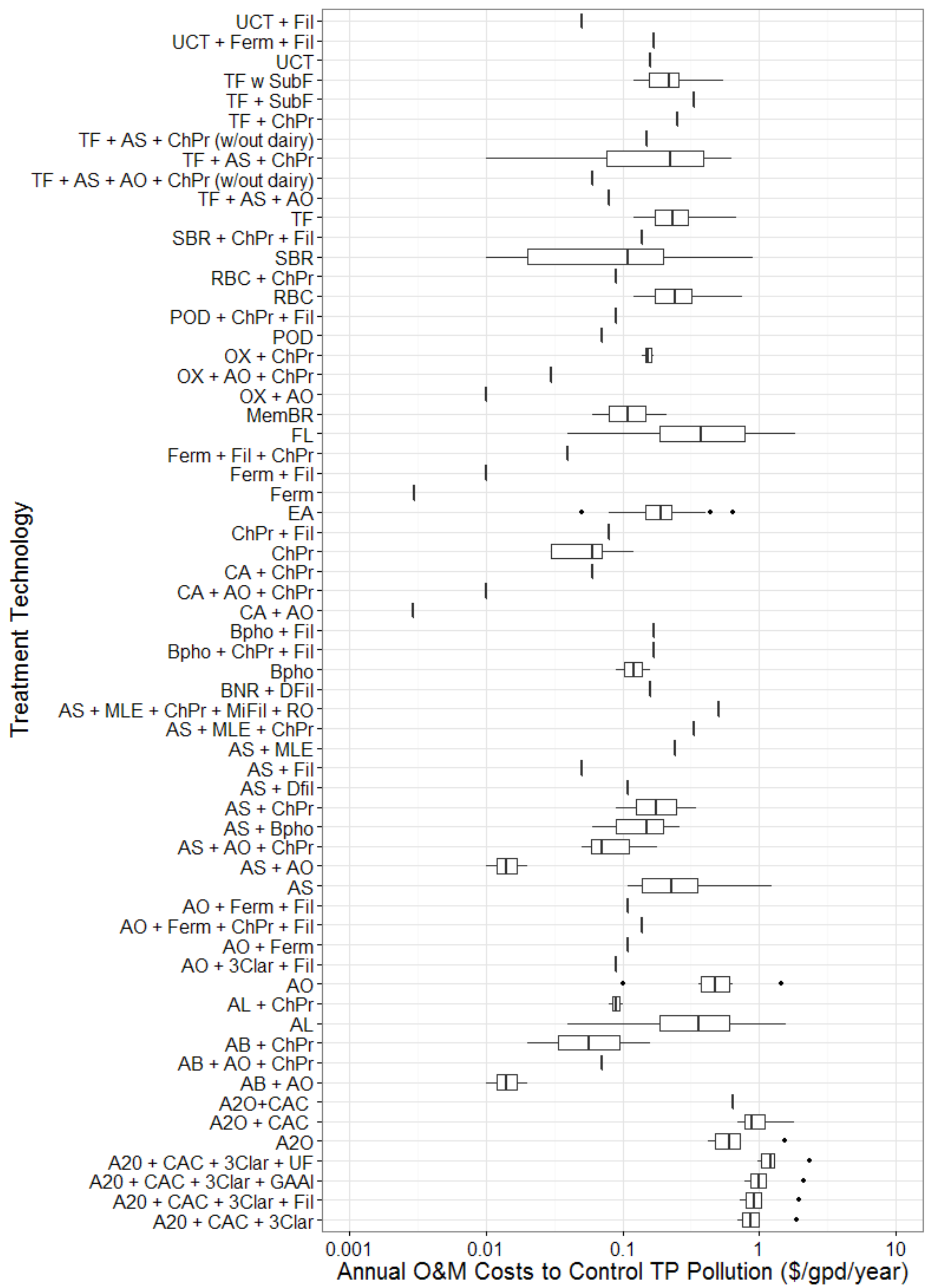
Figure IV-13. Annual O&M cost and TP removal for municipal WWTPs (2012$).

Figures IV-14 and IV-15 display capital costs and annual O&M costs as a function of treatment technology. As shown in Figure IV-16, most of the treatment schemes extracted from the available literature (which involved either technologies operated singly or in combination) can achieve an effluent quality at or below 1 mg/L, and a substantial fraction of the treatment schemes were capable of achieving effluent quality levels at or below 0.5 mg/L (Figure IV-16).



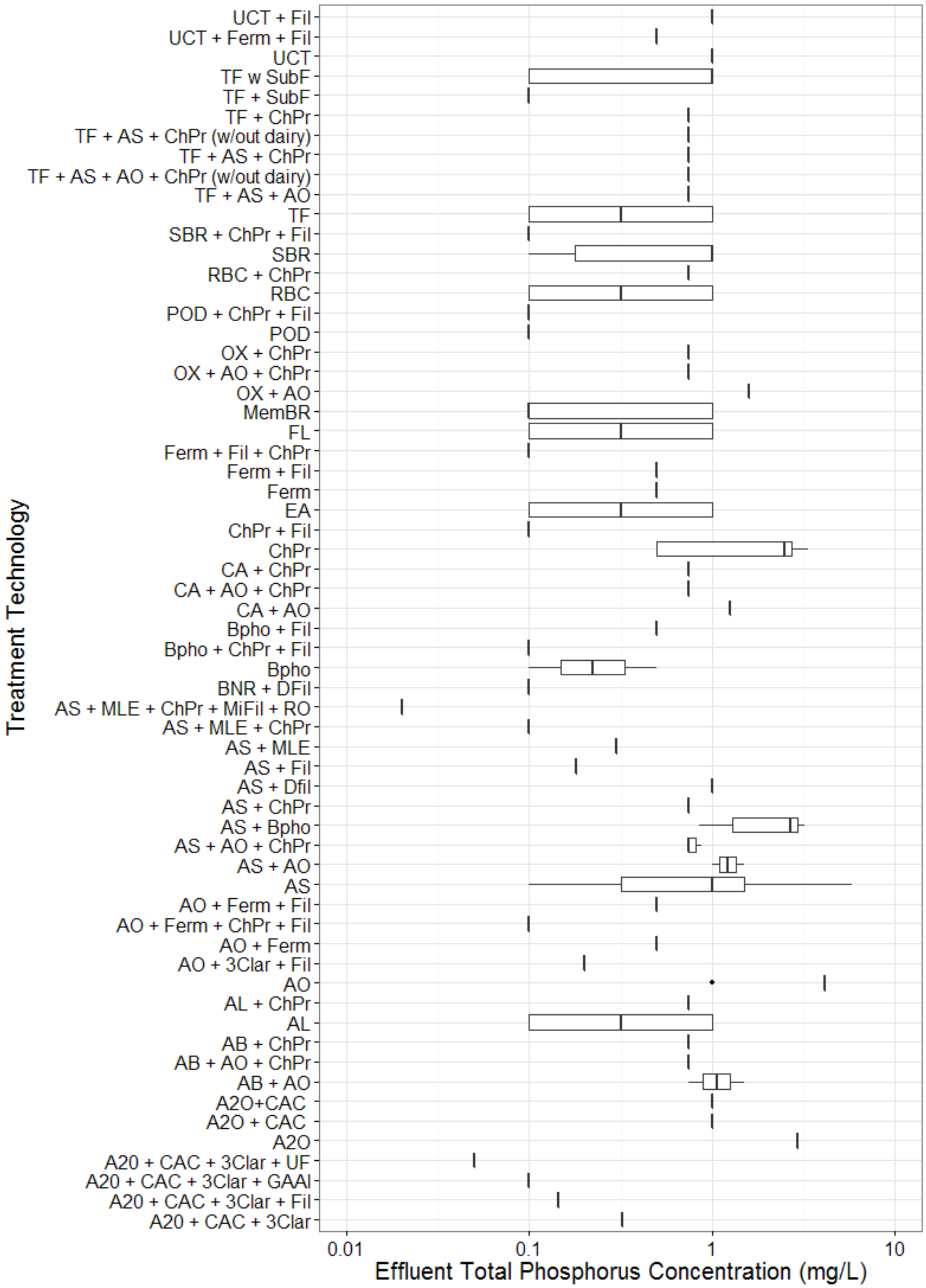
Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-14. Capital costs for TP treatment technologies (2012$).



Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-15. Annual O&M costs for TP treatment technologies (2012$).



Refer to Appendix E for a key to abbreviations and acronyms. Technologies associated with only a single record are represented by a vertical bar.

Figure IV-16. Effluent TP concentrations for municipal treatment technologies.

Anecdotal Nutrient Cost Data for Municipal Wastewater Treatment Plants

The Maryland Department of the Environment (MDE) maintains estimates of the cost for BNR and enhanced nutrient removal (ENR) at WWTPs in the state. These cost estimates are for completed and planned upgrades using biological and enhanced nutrient removal to ensure compliance with applicable nutrient water quality standards for the Chesapeake Bay. The costs for the completed and planned upgrades have been shared by the state.

In 2004, MDE required all significant municipal WWTPs in the state to upgrade to ENR. In addition, the December 29, 2010 final nutrient TMDL established by the EPA for the Chesapeake Bay allocated waste load allocations for TN and TP for WWTPs in Maryland. The state has revised the cost estimates to reflect the required use of ENR. Because the initial and final TN and TP effluent concentrations (i.e., performance) are not included for each plant, nor are details regarding what the costs represent, these cost estimates were not considered and described earlier in this section. However, these cost data are included in Appendix C as it provides potentially useful information related to the relative cost for upgrades across a wide range of wastewater treatment plant sizes.

IV.A.2. Decentralized Wastewater Treatment Systems

Decentralized wastewater treatment systems provide wastewater treatment for small communities, rural residential areas, and single residences. For purposes of this project, decentralized systems include technologies designated as satellite systems or septic systems, include technologies typically used in municipal wastewater treatment, and that possess treatment capacities of less than 0.1 mgd.

In the course of the literature review, nutrient control cost and treatment performance information were collected. The collected records represent empirical and modeled results for a variety of locations, pollutants, and technologies (Table IV-4).

Table IV-4. Cost and Performance Data for Decentralized Treatment Systems

Category	Number of Records
Total Number of Records	15
Records which Include Data for Nitrogen and/or Phosphorus	
Nitrogen	12
Phosphorus	3
Records for New Plants or Retrofit/Expansion of Existing Plants	
New Construction	0
Retrofit/Expansion	15
Records for Modeled Estimates or for Empirical Data	
Empirical	5
Modeled	10
Regions Where Records are Located	
EPA Region 1	10
EPA Region 2	0
EPA Region 3	2
EPA Region 4	0
EPA Region 5	0
EPA Region 6	3
EPA Region 7	0
EPA Region 8	0
EPA Region 9	0
EPA Region 10	0

Category	Number of Records
Outside United States	0
Location Not Reported [1]	0
Decentralized System Treatment Capacity	
Minimum	0.000175 mgd (175 gpd)
Median	0.0044 mgd (4,400 gpd)
Maximum	0.3 mgd (300,000 gpd)

[1] *A location was registered as "Not Reported" for modeled estimates where the authors did not indicate an assumed location in their methodology. Location information was included for all records associated with empirical results.*

Information regarding decentralized treatment systems was extracted from three sources. As part of a program to reduce nutrient loading to surface waters in the Cape Cod region of Massachusetts, a report by Barnstable County Wastewater Cost Task Force (Barnstable, 2010) contained estimates of costs and TN removal performance for a variety of small systems which scaled from systems designed for single residences up to satellite treatment systems which are appropriate for neighborhoods or clusters of residences.

U.S. EPA (2003) assessed the costs associated with achieving nutrient and sediment reductions in the Chesapeake Bay. In this report, the authors reported cost and performance associated with upgrades to two small treatment systems (an integrated fixed-film activated sludge system and a sequencing batch reactor). The small flows treated by these systems made their inclusion with the decentralized systems more appropriate than inclusion with larger municipal WWTPs would have been.

Keplinger et al. (2003) contains an assessment of the economic and environmental implications of meeting nutrient standards at treatment plants located along the North Bosque River in Texas. In this report, the authors report on results observed at a number of communities, including some that meet criteria for decentralized treatment.

In general, the available information suggests that, on a unit cost basis, greater cost effectiveness can be achieved with larger treatment units (Figures IV-17 and IV-18). Costs for systems with treatment capacities less than or equal to 330 gpd ranged from approximately $13/gpd to $168/gpd for capital costs, and $0.66/gpd/year to $19/gpd/year for annual O&M costs. Cost for units with capacities between 4,000 gpd and 300,000 gpd ranged from approximately $0.16/gpd to $21/gpd for capital costs, and approximately $0.01/gpd/year to $0.67/gpd/year for annual O&M costs. No studies or data were found for capacities between 330 gpd and 4,000 gpd.

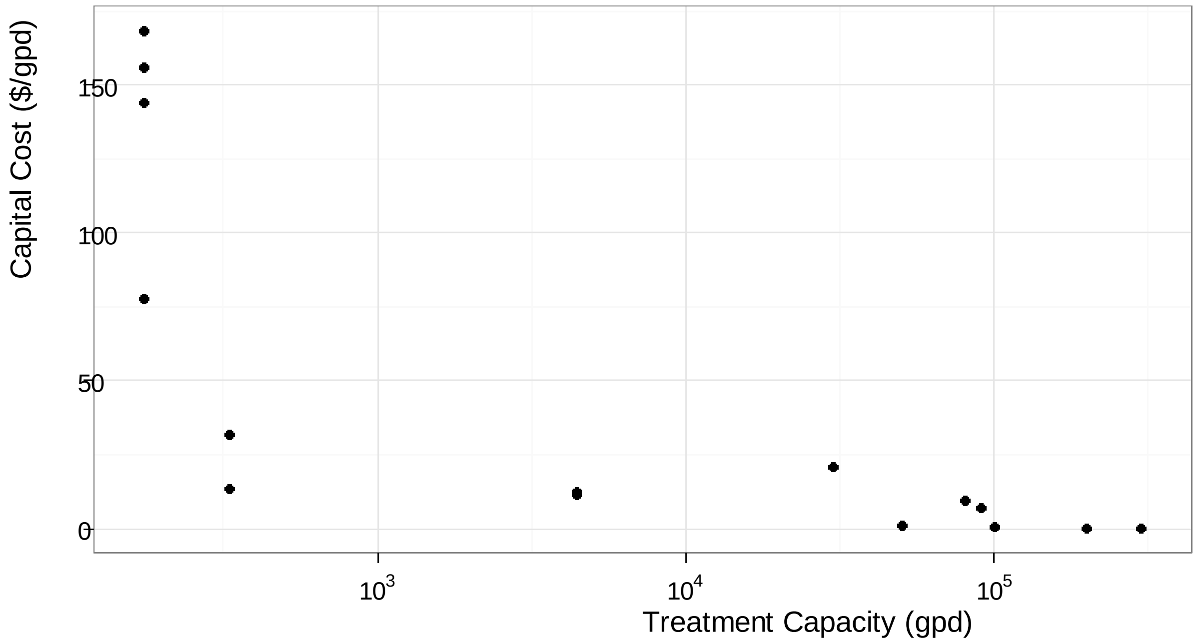


Figure IV-17. Capital costs and treatment capacities for decentralized treatment systems (2012$).

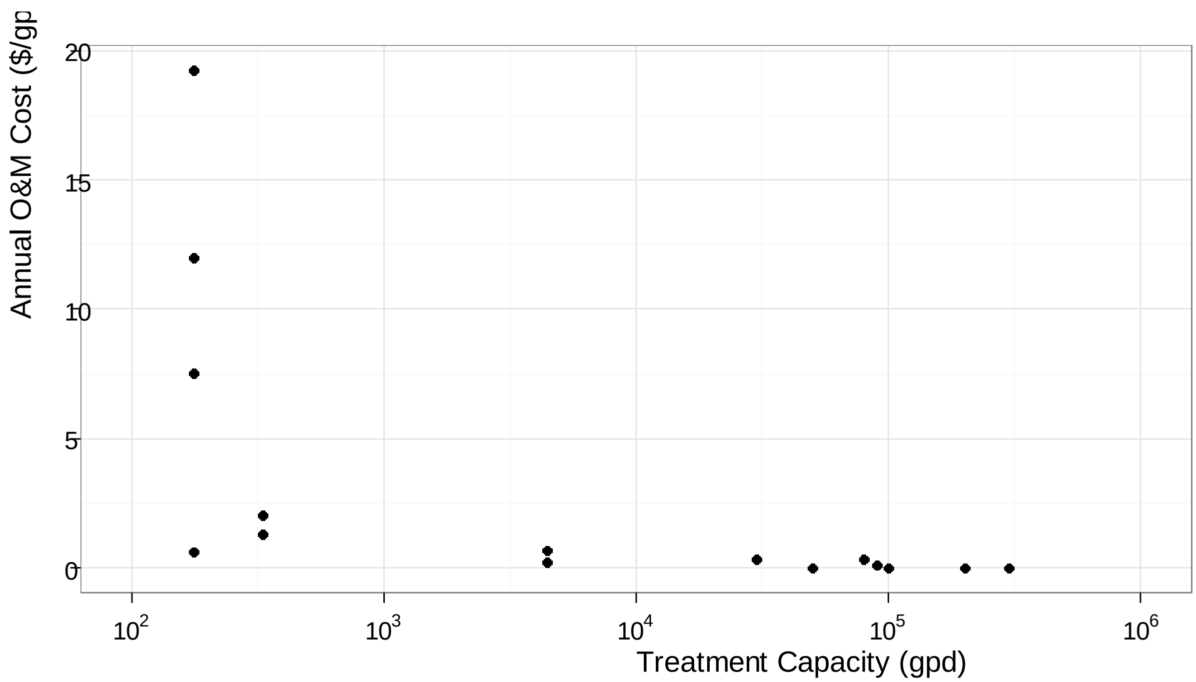


Figure IV-18. Annual O&M costs and treatment capacities for decentralized treatment systems (2012$).

Cost and Performance Information - Nitrogen

The available data suggests that, while larger systems should be able to achieve relatively low TN effluent concentrations, performance of smaller onsite systems may not (Figure IV-19). Capital costs and annual O&M costs as a function of TN effluent quality are shown in Figures IV-20 and IV-21. Costs as a function of TN performance appear to be technologically idiosyncratic, with the lowest costs and best effluent quality delivered by satellite treatment systems and package plants for small communities.

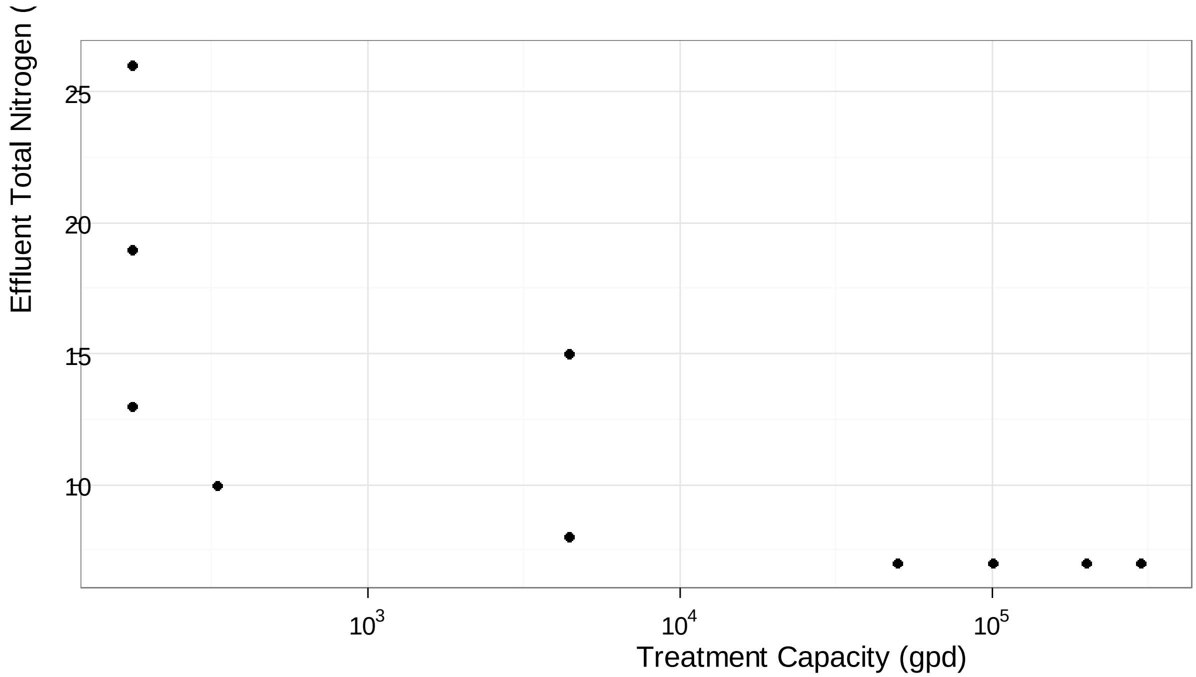


Figure IV-19. TN effluent quality and decentralized treatment system capacity.

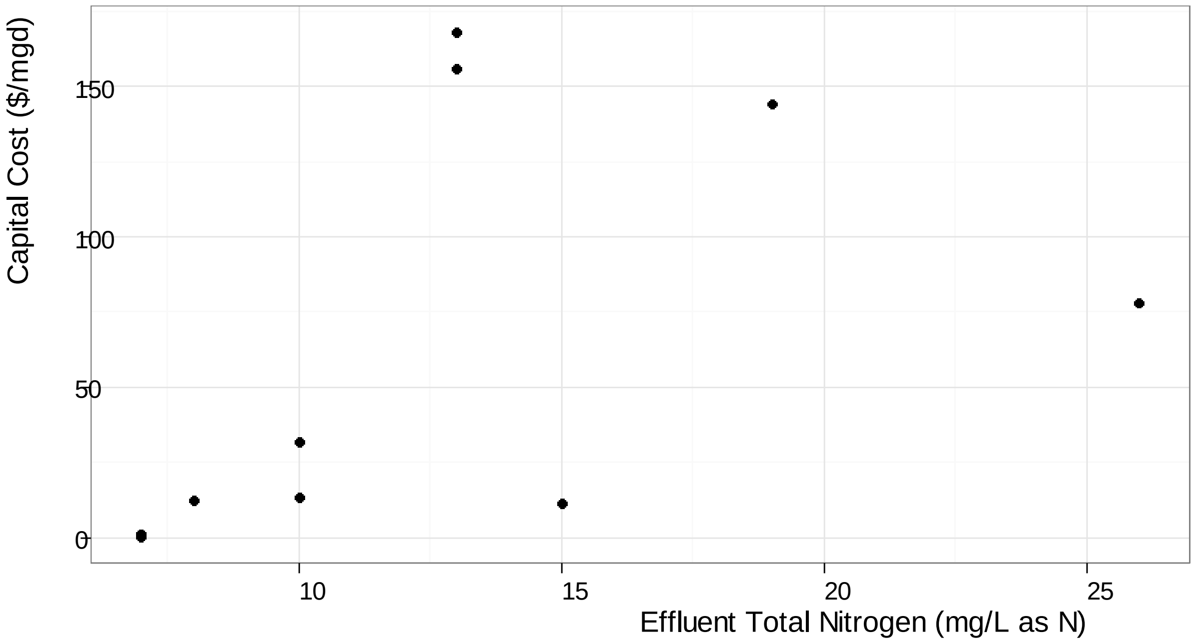


Figure IV-20. Capital costs and TN effluent quality for decentralized systems (2012$).

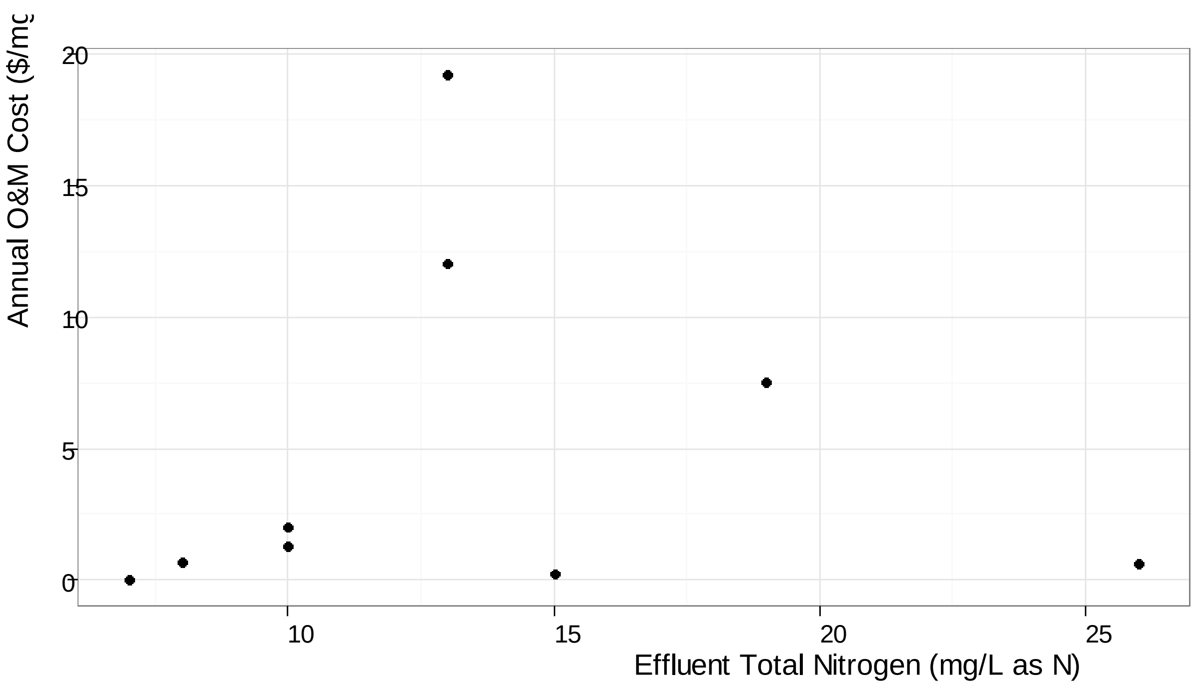


Figure IV-21. Annual O&M costs and TN effluent quality for decentralized systems (2012$).

Cost and Performance Information – Phosphorus

A limited amount of data regarding phosphorus control for decentralized systems was extracted during the literature review. The available information is limited to three data points, all of which are for chemical phosphorus removal systems (0.03 mgd, 0.08 mgd, and 0.09 mgd). These systems were able to achieve TP effluent concentrations between 2.9 and 3.5 mg/L as P. Capital costs ranged from $7.25/gpd (largest system) to $20.85/gpd (smallest system). Annual O&M costs ranged from $0.14/gpd/year (largest system) to $0.36/gpd/year (smallest system).

IV.A.3. Industrial Wastewater Treatment

Industrial wastewater treatment systems provide water pollution control capabilities to industrial point source dischargers. The types of wastewater treated by industrial treatment systems vary according to the type of manufacturing or industrial activity conducted at a given site. Certain types of industrial waste tend to possess greater quantities of nutrients. These may include but are not limited to processors of foodstuffs, beverages, livestock, and agricultural products.

Data extracted during the literature search in accordance with the screening criteria and quality assurance requirements were limited to two available sources (U.S. EPA, 1999; U.S. EPA, 2004) containing cost and treatment information from meat and poultry product processors. This limitation is due to a lack of availability of paired nutrient performance and cost information from other industries. In addition, the available data on meat and poultry processing facilities did not include system treatment capacities or factors which would allow for the calculation of capital and annual O&M unit costs. Therefore, all costs for this section are presented in terms of total dollars per facility and have not been normalized on a unit cost basis (i.e., as $/gpd).

Cost and Performance Information – Nitrogen & Phosphorus

The available information on the treatment of nutrients in wastewater from meat and poultry product processing includes cost and performance data associated with upgrades at existing facilities. These upgrades cover the installation of one of the following treatment options: (1) enhanced aeration, (2) a modified Ludzack-Ettinger (MLE) process, or (3) a MLE process paired with chemical phosphorus removal. Table IV-5 summarizes the results of EPA (2004).

Table IV-5. Effluent Quality, Capital Costs, and Annual Operation and Maintenance Costs for Meat and Poultry Processors[1]

Parameter	Treatment Technology		
	Enhanced Aeration	**Modified MLE Process**	**MLE Process + Chemical Phosphorus Removal**
Number of Records	5	5	10
Total Nitrogen Effluent Quality (mg/L as N)			
Minimum	3.6	34	1.9
Median	3.6	34	23.75
Maximum	4.97	34	34
Total Kjeldahl Nitrogen (TKN) Effluent Quality (mg/L as N)			
Minimum	3.6	3.6	1.34
Median	4.285	3.6	3.4
Maximum	4.97	4.97	4.97
Total Inorganic Nitrogen Effluent Quality (mg/L as N)			
Minimum	Not Available	29.2	0.52

Parameter	Treatment Technology		
	Enhanced Aeration	Modified MLE Process	MLE Process + Chemical Phosphorus Removal
Median		30.6	19.75
Maximum		30.6	30.6
Total Phosphorus Effluent Quality (mg/L as P)			
Minimum	Not Available	8.3	2.3
Median		8.3	5.1
Maximum		8.3	8.3
Capital Cost ($/facility)			
Minimum	105,445	395,069	427,405
Median	388,039	2,160,927	1,081,870
Maximum	1,317,364	3,693,400	5,902,128
Annual Operation and Maintenance Cost ($/facility)			
Minimum	52,020	127,940	139,188
Median	102,633	230,574	719,137
Maximum	390,851	894,177	2,785,164

[1] *Source: U.S. EPA (2004)*

Effluent TN quality for the three treatment strategies varied from 1.4 to 34 mg/L as N. Low TN concentrations were most frequently observed in the effluent of the enhanced aeration units. Effluent TP concentrations ranged from 2.3 to 8.3 mg/L as P with the best performance provided by the MLE process paired with chemical phosphorus removal.

The lowest costs were associated with the enhanced aeration systems. Lacking treatment capacity information to normalize the data with, it is difficult to directly compare the cost of the different systems or determine whether the costs exhibit economies of scale. While the modified Ludzack-Ettinger systems were more expensive than the other two options, it is not clear whether this is a result of treating a larger flow (therefore, necessitating larger systems) or due to relative treatment inefficiencies inherent in these process configurations.

Information for a single facility was extracted from U.S. EPA (1999) for the upgrade of a 1.1 mgd treatment system at an agricultural products processing facility. Post-upgrade the facility possessed an anaerobic lagoon, a modified Ludzack-Ettinger process, a denitrification filter, and a cycled aeration system. It was capable of achieving TN effluent concentrations of 12 mg/L at a unit capital cost of $15.6/gpd.

IV.B. Nonpoint Source Control Costs

Nonpoint sources can be significant contributors to nutrient impairment in surface waters. Nonpoint source pollution originates from rainfall and snowmelt running over and through the ground and entraining pollutants such as nutrients. Eventually the contaminated water migrates to surface waters where the entrained nutrient loadings may contribute to impairment of surface waters. The size and composition of the nutrient loading is, in part, a function of the land use types through which rainfall and snowmelt are deposited, or through which surface water runoff migrates.

Managing nonpoint source pollution plays a vital role in maintaining public health and protecting natural waters. Agricultural and urban residential land uses are critical components of the built environment and are widespread throughout the United States. The availability of adequate land to both produce the food supply and to provide housing is central to the proper functioning of the economy. Agricultural and urban land uses are also potential sources of nonpoint source nutrient pollution, which has the potential to degrade and impair the beneficial uses of surface and ground waters.

This section examines the costs of controlling anthropogenic sources of nonpoint-source nutrient pollution focusing mainly on urban areas. We did not include information in this report at this time on the costs to control nutrients in agricultural areas (e.g., from best management practices) because of the significant breadth and depth of approaches. We intend to focus on those approaches and costs in a supplement or addendum to this report. The literature search also included silviculture and forestry land use types. However, literature meeting the project screening criteria and quality requirements was unavailable for these two land use categories.

IV.B.1. Urban and Residential Runoff

Rainwater and snowmelt falling in urban and other residential areas can be a major nonpoint source contributor to nutrient impairments of surface waters. Rainwater and snowmelt falling on streets, roofs, lawns, and parking lots can capture nutrients. This results in subsequent transport of nutrients to waterways through runoff into storm sewers and waterbodies. Nonpoint source nutrient pollution from urban sources may be controlled through a variety of BMPs. These BMPs include the construction of structures designed to capture and treat the runoff (i.e., structural BMPs). They also include programs and activities (i.e., non-structural BMPs), which communities can implement to decrease the quantity of runoff and/or nutrients deposited in surface waters.

Table IV-6. BMP Cost and Performance for TN and TP Control for Urban and Residential Runoff

Description		Performance	Unit Cost	Reference
Total Nitrogen				
Structural BMPs	Baffle Boxes	15% reduction	$480/acre	SWET (2008)
	Bioretention Units	--	$338-$2,000/lb removed	CWP (2013)
	Bioswales	15-25% reduction	$3,500-$7,000/acre	SWET (2008)
		--	$308/lb removed	CWP (2013)
	Detention Basins	15-20% reduction	$4,400-$8,800/acre	SWET (2008)
		--	$1,100-$4,600/lb removed	CWP (2013)
	Impervious Surfaces	--	$2,428/lb removed	CWP (2013)
	Infiltration Basin	--	$486-$494/lb removed	CWP (2013)
	Media Filtration	--	$975-$1,060/lb removed	CWP (2013)
	Porous Pavement	--	$1,900-$14,000/lb removed	CWP (2013)
Non-Structural BMPs	Illicit Discharge Control Program	--	$8.82-$17.62/lb removed	CWP (2013)
	Lawn Fertilization Programs	15-30% reduction	<$1-$17/acre	SWET (2008)
	Pet Waste Programs	--	$0.43/lb removed	CWP (2013)
	Street Sweeping	--	$3,500-$14,600/lb removed	CWP (2013)
		2% reduction	$22/acre	SWET (2008)
Total Phosphorus				
Structural BMPs	Baffle Boxes	20% reduction	$480/acre	SWET (2008)
	Bioretention Units	--	$338-$2,000/lb removed	CWP (2013)
		72% reduction	$415/$m^3$ (large units) $939/$m^3$ (small units)	Weiss, et.al. (2007)

Description		Performance	Unit Cost	Reference
	Bioswales	25-50% reduction	\$3,500-\$7,000/acre	SWET (2008)
		--	\$2,642/lb removed	CWP (2013)
	Chemical Precipitation and Media Filtration	70% reduction	\$3,500/acre	SWET (2008)
	Detention Basins	65-80% reduction	\$4,400-\$8,800/acre	SWET (2008)
		--	\$10,500-\$21,000/lb removed	CWP (2013)
		25% reduction	\$23-\$318/m^3	Weiss, et.al. (2007)
	Impervious Surfaces	--	\$7,322/lb removed	CWP (2013)
	Infiltration Basins	--	\$3,237-\$3,383/lb removed	CWP (2013)
	Infiltration Trenches	65% reduction	\$819-\$1,768/m^3	Weiss, et.al. (2007)
	Media Filtration	--	\$4,500-\$4,900/lb removed	CWP (2013)
		42% reduction	\$235-\$5,000/m^3	Weiss, et.al. (2007)
	Porous Pavement	--	\$12,000-\$70,000/lb removed	CWP (2013)
	Wetlands	46% reduction (Constructed Wetlands)	\$9-\$191/m^3	Weiss, et.al. (2007)
		52% reduction (Wetland Basin)	\$13-\$295/m^3	
Non-Structural BMPs	Illicit Discharge Control Program	--	\$35-\$71/lb removed	CWP (2013)
	Lawn Fertilization Programs	5% reduction	<\$1-\$17/acre	SWET (2008)
	Pet Waste Programs	--	\$3.35/lb removed	CWP (2013)
	Street Sweeping	--	\$1,400-\$2,200/lb removed	CWP (2013)
		15% reduction	\$22/acre	SWET (2008)

IV.C. Data Limitations

As described in the previous sections, there are a number of studies documenting costs and performance information for nutrient control technologies and BMPs across the United States. They demonstrate that strategies exist for controlling nutrient pollution that are applicable to a variety of circumstances and that may vary in terms of their respective cost efficiencies. However, additional data sets and information exist which did not meet the screening acceptability criteria of this literature review effort for various reasons (e.g., lack of availability of both cost and nutrient control performance information was one of the principal barriers to inclusion). As shown in Table IV-6, processes for treatment of industrial waste sources lacked a robust set of information sources meeting screening acceptability criteria. Further, some topics, such as process optimization (see Box 3) where performance at existing WWTPs is improved via optimizing operational control of the treatment systems rather than construction of new unit processes, were not fully represented in the literature but provide promising avenues for cost-effective control of nutrient pollution.

Box 3. Process Optimization

When upgrading an existing plant to meet new nutrient effluent limitations, it is not always necessary to design and construct entirely new treatment units. Plants that possess adequate capacity can consider adopting process optimization measures in order to increase nutrient removal. Process optimization involves making alterations to operationally controlled factors (e.g., aeration control, mean cell retention time) in order to increase the quantity of nitrification or denitrification occurring. An example of this is adding cycled aeration to existing activated sludge processes (see "AS + CA' in Figures IV-7 and IV-9) in order to increase total nitrogen removal. Process optimization measures can often be a more cost-effective means of controlling nutrients as compared to designing and installing new treatment processes.

Table IV-7. Summary of Nutrient Control Cost Documentation

Control	Number of Studies	Locations
Municipal Wastewater Treatment Plants	11	CT, DC, FL, IL, MD, MN, MT, NC, NV, NY, PA, TX, VA, WA, national, and Spain
Decentralized Wastewater Treatment Systems	3	DC, MA, MD, PA, TX, and VA
Industrial Wastewater Treatment	2	Not Available
Urban and Residential Runoff	3	FL, IA, IL, IN, ME, MI, MN, NJ, OH, PA, VA, WI, and national

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Appendix A: Additional Evidence Of The Costs Of Nutrient Pollution

The studies described in Section III.A.1 through Section III.A.4 meet the evaluation criteria shown in Box 2 in Section III.A Additional studies may provide supporting information on the adverse impacts of anthropogenic nutrient loading. These include both anecdotal evidence of adverse economic impacts from nutrient pollution, such as newspaper accounts of algal bloom events, and additional studies that use broader assumptions or methodologies than those meeting the criteria. This appendix provides more detail on the anecdotal evidence and additional studies.

Table A-1 and Table A-2 provide anecdotal evidence and summarize additional studies of the local economic impacts and increased costs associated with nutrient pollution. Table A-3 provides a summary of anecdotal mitigation costs (in the form of restoration and water quality improvement projects designed to meet phosphorus load reductions under Florida's Upper Ocklawaha River Basin TMDL (UOBWG, 2007)). Note that this is not a comprehensive listing, and new information is continually emerging. The dollar values are in the original reported year dollars.

Anecdotal Evidence—Many HAB events and excessive nutrient concentrations have caused economic impacts that receive the attention of local news outlets. Table A-1 in Appendix A provides details of anecdotal evidence of impacts in the commercial fishing, tourism and recreation, and real estate industries. For example, liver toxins produced by algae near beaches in Buckeye Lake, Ohio have necessitated warnings against swimming for three summers, resulting in revenue losses to surrounding tourism businesses (Hunt 2013). According to The Columbus Dispatch (Hunt 2013), the Ohio EPA has spent more than $700,000 on identifying sources of excessive phosphorus and reducing in-lake algae. In Northwest Creek, Maryland, HABs have necessitated the closures of beaches, cancelation of planned events, 18 fish kills, and declines in property values. The Baltimore Sun (Wheeler 2013) reports that plans to restore the creek would cost approximately $1 million.

Additional Studies—Table A-2 provides details of studies that do not meet the economic impact evaluation criteria but nonetheless provide quantitative estimates of the economic impact of nutrient pollution. In some cases, the impacts documented in these studies were not fully attributable to anthropogenic nutrient pollution (i.e., algal blooms and other manifestations were attributable to natural causes) or used modeling to estimate the impacts of prospective events rather than past events. However, these studies still provide evidence of the magnitude of economic impacts that anthropogenic nutrient pollution can inflict.

For example, Athearn (2008) used regression analysis as well as input-output modeling to estimate the economic impacts of a 2005 red tide event on the commercial fishing industry in Maine. The author estimated that this event resulted in $6 million in losses to soft shell clam, mahogany quahog, and mussel harvesters, as well as $14.8 million in lost sales and $7.9 million in income (including indirect and induced impacts; 2005$). However, some of these impacts may also have been attributable to flooding and other concurrent events.

Additionally, some studies compile estimates of the economic impacts of nutrient pollution at the national level across multiple sectors. For example, Anderson et al. (2000) estimated the potential annual impacts of HABs nationally by compiling estimates in public health, fisheries, recreation and tourism, and monitoring and management. The authors note that their results are underestimates due to additional unquantified categories of impacts, but estimated that (2000$):

- Shellfish and ciguatera fish poisoning[19] resulted in $33.9 million to $81.6 million in public health expenditures annually.
- Wild harvest and aquaculture losses associated with shellfish poisoning, ciguatera, and brown tides resulted in $18.5 million to $24.9 million in annual commercial fishing losses.
- Tourism industries in North Carolina, Oregon, and Washington lost up to $29.3 million annually.
- Monitoring and management programs (such as routine shellfish toxin monitoring) distributed among 12 states cost $2.0 million to $2.1 million annually.

Dodds et al. (2009) also developed national level estimates of the impacts of nutrient pollution. They compared nutrient concentrations for EPA ecoregions to reference conditions to identify areas potentially impacted by nutrient pollution; then estimated annual impacts to recreation, real estate, spending on threatened and endangered species recovery, and drinking water. Their results for each sector were (2001$):

- $189 million–$589 million in annual fishing expenditure losses and $182 million–$567 million in annual boating expenditure losses (based on lake area closures and expenditures)
- $0.3 billion–$2.8 billion in annual property value losses (depending on the assumed land availability)
- $44 million in spending to develop conservation plans for 60 species impacted by eutrophication
- $813 million in annual expenditures on bottled water due to taste and odor issues in public water supplies attributable to eutrophication.

In the following discussion, supplementary information on drinking water treatment costs and mitigation costs are presented.

Anecdotal Evidence—A large body of anecdotal evidence (such as newspaper articles) documents the need for increased expenditures on drinking water treatment as a result of algal blooms. Some of this evidence is shown in Table A-1. In some cases, health hazards resulting from HABs have caused drinking water treatment plants to go offline altogether, as happened in Carroll Township on Lake Erie, a facility serving 2,000 residents (Henry, 2013). Also on Lake Erie, the City of Toledo has spent more than $3,000 to $4,000 per day on carbon activated filtration during bloom events (Lake Erie Improvement Association 2012). In the summer of 2014, about 500,000 residents in Toledo lost access to drinking water due to a large algal bloom that affected the city's treatment facilities.

KDHE (2011) reports that the City of Wichita installed an $8.5 million ozone facility at Cheney Reservoir to control taste and odor problems, and that there have been incidences throughout the

[19] Ciguatera fish poisoning (or ciguatera) is an illness caused by eating fish that contain toxins produced by a marine microalga called *Gambierdiscus toxicus*. People who have ciguatera may experience nausea, vomiting, and neurologic symptoms, such as tingling fingers and toes.

state of drinking water treatment plants being forced to shut down during moderate to severe algal blooms due to the inability to adequately treat the source water.

With regard to mitigation, UOBWG (2007) presents costs for ongoing or completed mitigation projects that the basin workgroup identified as necessary to meet phosphorus load reductions under Florida's Upper Ocklawaha River Basin TMDL. Mitigation techniques include alum treatment, dredging, fish removal, and modification of hydrodynamics. The workgroup identified 14 restoration and water quality improvement projects totaling approximately $162 million. These projects are summarized in Table A-3.

Additional Studies—Table A-2 provides details of studies that do not meet the evaluation criteria but nonetheless provide quantitative estimates of the increased drinking water treatment costs associated with nutrient pollution. In some cases, the additional needs for treatment were not fully attributable to anthropogenic nutrient pollution (i.e., algal blooms and other manifestations were attributable to natural causes) or the technologies evaluated are outdated. However, these studies still provide evidence of the scale of increased drinking water treatment costs associated with anthropogenic nutrient pollution.

Table A-1. Summary of Anecdotal Evidence of the Costs of Nutrient Pollution

Source	Source Type	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Tourism and Recreation					
Hunt (2013)	Newspaper article	Algal blooms	OH	Buckeye Lake	Due to the presence of a liver toxin produced by algae near beaches, state park officials have posted warnings for swimmers along the beaches of Buckeye Lake in Fairfield, Licking, and Perry Counties for the last 3 summers, and revenues have declined. The toxic algae is attributed to excess phosphorus loading from manure, sewage, and fertilizers. Since 2011, the Ohio Environmental Protection Agency has spent more than $700,000 on efforts to identify sources of phosphorus loading and to reduce algae at Buckeye Lake.
HARRNESS (2005)	Strategy document	Algal blooms	WA and OR	Recreational razor clam fishery closed due to domoic acid (from harmful algae) contamination throughout WA and OR coastal communities	Estimated reductions in recreational spending of $10 million to $12 million in small coastal communities; loss of subsistence fishing for Native American coastal tribes.

Source	Source Type	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Times Standard (2013)	Newspaper article	Algal blooms	CA	Reaches of the Klamath River including the Copco and Iron Gate Reservoirs	Blue-green algae blooms have necessitated warnings against human and animal contact with and consumption of water in the river due to health concerns. Economic impacts are not quantified but could include decreased tourism and recreational revenues.
The Associated Press (2013)	Newspaper article	Algal blooms	KY	Four Kentucky lakes: Rough River, Barren River, Taylorsville, and Nolin.	HABs have been detected at 4 Kentucky lakes during the summer of 2013. Collectively, these lakes receive approximately 5 million visitors per year, and a lake manager reports that some visitors have cancelled campground reservations.
Wheeler (2013)	Newspaper article	Algal blooms	MD	Northwest Creek	Harmful algal blooms have necessitated warnings against swimming and beach closures, with scheduled Girl Scout camps being closed, and property values declining; there have been 18 fish kills in Northwest Creek since 1986. Plans to restore the creek are estimated to cost $1 million.
Commercial Fishing					
Glass (2003)	Workshop presentation	Algal blooms	TX	Freshwaters in Texas impacted by golden algae (*Prymnesium parvum*).	Conservative estimate of the number of fish killed is 17.5 million; estimated value of fish killed is more than $7 million. Unknown indirect losses to local tourism, sport fishing, and state revenues.
Property Values					
Wheeler (2013)	Newspaper article	Algal blooms	MD	Northwest Creek	Harmful algal blooms have necessitated warnings against swimming and beach closures, with scheduled Girl Scout camps being closed, and property values declining; there have been 18 fish kills in Northwest Creek since 1986. Plans to restore the creek are estimated to cost $1 million.
Drinking Water Treatment					
Lollar (2008)	Newspaper article	Algal blooms	FL	Caloosahatchee River	Harmful algal blooms caused the closure of a water treatment facility.

Source	Source Type	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Des Moines Register (2013)	Newspaper article	Nitrate concentrations	IA	Des Moines River and Raccoon River	Health-threatening levels of nitrates in surface waters used for drinking water necessitated the use of a nitrate removal plant, which has not been needed since 2007 (the plant cost $4 million to construct in 1992). The plant costs about $7,000 per day to run, although it is not clear if those are operating costs at full capacity or at current capacity (the plant is only using 4 of the 8 treatment cells).
Henry (2013)	Newspaper article	Algal blooms	OH	Lake Erie	Extremely high levels of toxic algae in the lake knocked the water treatment plant offline (which serves 2,000 residents of Carroll Township).
Lake Erie Improvement Association (2012)	Association plan documentation	Algal blooms	OH	Lake Erie	The City of Toledo spent $3,000 to $4,000 per day on carbon activated filtration during algal blooms, plus additional costs to treat water with potassium permanganate.
City News Service (2011)	Newspaper article	Algal blooms	CA	Drinking water in eastern Los Angeles County and parts of Orange County, western San Bernardino County, and southwest Riverside County	Algal blooms caused taste and odor issues for drinking water in Los Angeles County and parts of Orange County, San Bernardino County, and Riverside County. Utilities have applied copper sulfate to control the bloom, but the taste and odor issues persisted, affecting approximately 7 million people in the area.
KDHE (2011)	Report	Algal blooms	KS	Reservoirs throughout Kansas impacted by excess algae	The city of Wichita constructed an $8.5 million ozone facility at Cheney Reservoir to control taste and odor problems. In Kansas, there have been a few incidences of drinking water treatment plants being forced to shut down during moderate to severe algal blooms due to the inability to adequately treat the source water.

Table A-2. Summary of Additional Studies of the Costs of Nutrient Pollution

Study	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
National Aggregate				
Anderson, et al. (2000)	Algal blooms	National	Coastal waters throughout the U.S.	• Annual economic impacts $33.9 million–$81.6 million (2000$). • Public health (shellfish and ciguatera poisoning) $18.5million–$24.9 million. • Commercial fishery (wild harvest and aquaculture losses associated with shellfish poisoning, ciguatera, and brown tides) $13.4 million–$25.3million. • Recreation/tourism (impacts documented in NC, OR, and WA in various years) $0–$29.3 million. • Monitoring/management (cost of routine shellfish toxin monitoring programs, plankton monitoring, and other activities in 12 states) $2.0 million–$2.1 million.
Dodds, et al. (2009)	Eutrophication	National	Freshwaters throughout the United States	• Fishing and boating trip-related expenditure annual losses of $189 million–$589 million and $182 million–$567 million, respectively (2001$). • Property value annual losses (scaled over 50 years) of $0.3 billion, $1.4 billion, and $2.8 billion for the low (5% private), intermediate (25% private), and high (50% private) assumed land availabilities, respectively. • Aquatic biodiversity impacts of $44 million per year to develop 60 plans for the species that are at least partially imperiled due to eutrophication. • Drinking water impacts of $813 million per year for bottled water because of taste and odor problems potentially linked to eutrophication (2001 dollars).
Tourism and Recreation				
Morgan and Larkin (2006)	Red tide	FL	Coastal waters	Presence of red tide on a given day reduces restaurant sales by $616 (2005 dollars) (5% to 14% of daily sales for the 3 restaurants evaluated); however, impacts may also be caused at least partially by natural drivers, and authors note that the model is likely to be mis-specified.
Adams, et al. (2002)	Red tide	FL	Ft Walton Beach and Destin areas	In one zip code, the monthly losses associated with a red tide event are $2.23 million for restaurants and $2.29 million for hotels; however, impacts may also be caused at least partially by natural drivers.

Study	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Commercial Fishing				
Athearn (2008)	Red tide	ME	Coastal fisheries	$6 million in losses for harvesters of soft-shell clams, mahogany quahogs, and mussels, including indirect and induced impacts $14.8 million lost in sales and $7.9 million in lost income (2005$); however, some damages were attributable to sources besides or in addition to anthropogenic nutrient pollution, such as flooding.
Gorte (1994)	Algal blooms	FL	Florida Bay in Monroe County	Losses of 500 jobs and $32 million in annual personal income due to decline in pink shrimp harvest between 1986 and 1994. Unable to attribute commercial fishing revenue changes to nutrient enrichment since revenues went down statewide during the same period due to a weak economy.
Huang, et al. (2012)	Hypoxia	NC	Coastal waters	Between 1999 and 2005, the average number of hypoxic days (61) led to a $261,372 welfare loss (2005$).
Property Values				
Carey and Leftwich (2007)	Algal blooms	SC	Greenwood County shore of Lake Greenwood	Chl-a concentrations and the presence of algal blooms (as indicated by a dummy variable for year of bloom and immediately after) are both insignificantly related to the house price. Primary model only uses a dummy variable for whether the sale occurred between July 1999 and July 2001 (the period of the bloom and immediately after); however, it is unclear whether there were nutrient or algal bloom problems in any other years besides 1999 through 2001.
Steinnes (1992)	Reduced clarity	MN	53 lakes	An additional foot of clarity raises the value of a lakefront lot by between $206 and $240; however, clarity problems are not explicitly tied to nutrient pollution.
Young (1984)	Algal blooms	VT	Lake Champaign	The value of properties is depressed by 20% ($4,500 on average) when the properties are located on an area of the lake that has degraded water quality (St. Albans Bay). Water quality variable was a one-time ranking of water quality by 30 individuals at 10 locations throughout the study area, while property data covered 6 years of sales.
van Beukering and Cesar (2004)	Algal blooms	HI	Coral reefs off the coast of Maui (Kihei area)	Reducing nutrients results in a $30 million (approximate) increase in property values of houses, hotels, and condominiums that are associated with coral reefs.
Cesar, et al. (2002)	Algal blooms	HI	Coastal waters	Units in algae zones were about 43% as valuable as units in algae-free areas. Extrapolating to all 754 "algae zone" units yields depreciation value of $9.4 million per year in lost value. Conclusions rely heavily on public perception and not statistical or data-driven analysis.

Study	Water Quality Issue	Location	Waterbody or Resource Description	Reported Loss (Original Dollar Years)
Drinking Water Treatment				
Ribaudo, et al. (2011)	Nutrient concentrations	National	U.S. drinking water supplies	Nitrate removal from U.S. drinking water supplies costs more than $4.8 billion per year; however, the cost estimates are based on 1996 technologies and as such may not be applicable.
Caron et al. (2010)	Red tide	CA	Pacific Ocean	Harmful algal blooms (red tide in this case) can cause operational issues at desalination plants, including increased chemical consumption, increased membrane fouling rates, and in some cases plant shut-downs; however, these events are not necessarily attributable to anthropogenic nutrient pollution.
Oneby and Bollyky (2006)	Algal blooms (turbidity)	KS	Cheney Reservoir outside of Wichita, Kansas	Cost to install ozonation system prior to drinking water treatment plant was $8.5 million (completed in 2005). Study does not provide description of what project costs entailed or source/citation of costs.

Table A-3. Summary of Anecdotal Mitigation Costs in Florida

Project Number - Project Name	General Location / Description	Estimated TP Load Reduction (lbs /yr)	WBID No.	Lead Entity / Funding Source / Project Partners	Project Cost (Original Dollar Year)
ABC01 - Nutrient Reduction Facility	Apopka-Beauclair Canal/CC Ranch / Water in Apopka-Beauclair Canal treated offline with alum. Removes TP from Lake Apopka discharge. Reduces loading from Lake Apopka to Lake Beauclair and Apopka-Beauclair Canal.	5,000	2835A; 2834C	LCWA / LCWA; Legislature / SJRWMD/DEP	$5,200,000
BCL02 - Suction dredging of western Lake Beauclair	Western end of Lake Beauclair / Suction dredging to remove 1 million cubic yards of sediment in western end of Lake Beauclair.	Unknown	2834C	FWC/LCWA/SJRWMD / cost share/ --	$12,000,000
BCL03 - Gizzard shad harvest	Lake Beauclair in-lake removal of fish / Harvest of gizzard shad by commercial fishermen. Removal of fish removes nutrients from lake. Reduces recycling of nutrients from sediments and reduces sediment resuspension—total suspended solids (TSS). Stabilizes bottom to reduce TSS.	Unknown	2834C	SJRWMD / SJRWMD Ad valorem; Legislative appropriation / --	$150,000/year in 2005 and 2006

Project Number - Project Name	General Location / Description	Estimated TP Load Reduction (lbs /yr)	WBID No.	Lead Entity / Funding Source / Project Partners	Project Cost (Original Dollar Year)
DORA13 - Gizzard shad harvest	Lake Dora in-lake removal of fish / Harvest of gizzard shad by commercial fishermen. Part of experimental assessment with UF and FWC. Removal of fish removes nutrient from lake. Reduces recycling of nutrients from sediments and reduces sediment resuspension (TSS). Stabilizes bottom to reduce TSS.	Unknown	2831B	SJRWMD / SJRMWD Ad valorem; Legislative appropriation / --	$150,000/year in 2005 and 2006
EUS25 - Pine Meadows Restoration Area	Pine Meadows Restoration Area. Muck farm is east of Trout Lake and discharges to Hicks Ditch. / Reduce TP loadings from former muck farm. Restore aquatic, wetland, and riverine habitat. Chemical treatment of soil (alum) to bind phosphates. Reduce nutrient outflow to feasible level of 1.1 kg/ha/yr of TP, or about 1 lb. per acre. Trout Lake is tributary to Lake Eustis. Reduction in nutrient loading benefits both Lake Eustis and Trout Lake.	1,487 - Lake Eustis; 726 - Trout Lake	2817B	SJRWMD / SJRWMD / --	$1,300,000 combined cost for both lakes
GRIF01 - Lake Griffin Emeralda Marsh Restoration	Emeralda Marsh Conservation Area (northeast marshes) north of Haines Creek /Lake Griffin Emeralda Marsh restoration: To be managed for wetland restoration, planting; alum treatment to bind phosphates in sediments; manage excess nutrient outflow. Remove phosphates and TSS, wetland habitat restoration. Manage nutrient outflow to Lake Griffin to feasible loading of 1.1 kg/ha/yr, or about 1 lb. per acre.	41,450	2814A	SJRWMD / SJRWMD Ad valorem; Legislative appropriation / --	$15,000,000 for land acquisition

Project Number - Project Name	General Location / Description	Estimated TP Load Reduction (lbs /yr)	WBID No.	Lead Entity / Funding Source / Project Partners	Project Cost (Original Dollar Year)
GRIF02 - Gizzard Shad Harvest	Lake Griffin in-lake removal of fish / Gizzard shad removal from Lake Griffin by commercial fishermen. Expanded to Lake Dora and Lake Beauclair, with possible future expansion to other lakes in Harris Chain. Remove and export nutrients via fish. Reduces recycling of nutrients from sediments and reduces sediment resuspension (TSS). Stabilizes bottom to reduce TSS.	Unknown	2814A	SJRWMD / SJRWMD Ad valorem; Legislative appropriation; LCWA / --	$1,000,000 spent since 2002 harvest
HAR02 - Lake Harris Conservation Area	North shore of Lake Harris / Restoration of former muck farm. Chemical treatment of soil (alum) to bind phosphates for nutrient control. Aquatic and wetland habitat restoration. Reduce and manage nutrient outflow to Lake Harris to feasible loading of 1.1 kg/ha/yr, or about 1 lb. per acre.	6,665	2838A	SJRWMD / Ad valorem; Legislative appropriation / --	$550,000
HAR03 - Harris Bayou Conveyance Project	Harris Conservation Area to Lake Griffin/ Establish water flow connection to Lake Griffin. Modification of hydrodynamics to accommodate higher flows of water.	Unknown	2838A	SJRWMD / Ad valorem; Legislative appropriation / --	$5,000,000
LAP05 - Lake Apopka Constructed Marsh flow-way Phase 1	Northwest shore of Lake Apopka / Constructed marsh on northwest shore of lake. Lake water pumped through marsh to remove particulates and nutrients from lake water. Marsh designed to treat about 150 cubic feet per second (cfs).	External reduction: 4,864 and flow-way: 17,640 to 22,050	2835D	SJRWMD / SJRWMD – SWIM Legislative Appropriation/ Ad Valorem/Beltway Mitigation Lake County/LCWA - $1,000,000 EPA - $1,000,000 / LCWA/ Lake County/EPA	Total $~15 million in land acquisition / $4.32 million Phase 1 flow-way construction
LAP06 - North Shore Restoration	North shore of Lake Apopka / Wetland habitat restoration. Remediate pesticide "hot spots" in soil.	99,960	2835D	SJRWMD / SJRWMD/Legislative appropriation - P2000:SOR: CARL; USDA WRP / USDA	$~100 million in land acquisition

Project Number - Project Name	General Location / Description	Estimated TP Load Reduction (lbs /yr)	WBID No.	Lead Entity / Funding Source / Project Partners	Project Cost (Original Dollar Year)
LAP07 - With-in Lake Habitat Restoration Area	Lake Apopka / Planting of wetland vegetation in littoral zone, largely north shore. Helps improve fishery, improves water quality and may reduce nutrient levels, stabilize bottom, and reduce TSS.	Unknown	2835D	SJRWMD / SJRWMD ad valorem / --	~$10,000 annually
LAP08 - Removal of Gizzard Shad	Lake Apopka / Harvest of gizzard shad by commercial fishermen. Removal of fish removes nutrient from lake. Reduces recycling of nutrients from sediments and reduces sediment resuspension (TSS). Stabilizes bottom to reduce TSS.	Unknown	2835D	SJRWMD / SJRWMD ad valorem; Lake County; LCWA; Legislature appropriation / Lake County/LCWA	~$500,000 annually
TROUT01 - Pine Meadows Restoration Area	Pine Meadows Restoration Area. Muck farm is east of Trout Lake and discharges to Hicks Ditch. / Reduce TP loadings from former muck farm. Restore aquatic, wetland, and riverine habitat. Chemical treatment of soil (alum) to bind phosphates. Reduce nutrient outflow to feasible level of 1.1 kg/ha/yr of TP, or about 1 lb. per acre. Trout Lake is a tributary to Lake Eustis. Reduction in nutrient loading benefits both Lake Eustis and Trout Lake.	1,487 - Lake Eustis; 726 - Trout Lake	2817B; 2819A	SJRWMD / SJRWMD / --	$1,300,000 combined cost for both lakes

Source: UOBWG (2007)

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Appendix B: Cost-Benefit Analyses Of Nutrient Rulemakings

The literature review summarized in Section III does not include studies with estimates of the benefits of reduced nutrient loadings, nor does it include the anticipated impacts associated with particular rulemaking proposals. Table B-1 summarizes some benefit-cost studies of planned nutrient pollution rulemaking at the state level.

Table B-1. Summary of State Level Cost-Benefit and Economic Analyses of Proposed Nutrient Reduction Regulations

Study	Location	Description of Rulemaking	Description of Study
CDPHE (2011)	CO	Establishment of technology-based controls on facilities that discharge nutrients to Colorado waters, specifically domestic and nondomestic wastewater treatment facilities.	Assessment of the expected costs, environmental benefits, and drinking water treatment cost reductions. Benefits that were assessed only qualitatively include potable water supplies (substantial), property values (potentially substantial), recreational activities (moderate), intrinsic values (unknown), and agriculture (minimal).
UDWQ (2013)	UT	Potential nutrient removal requirements for publicly owned treatment works statewide.	Contingent valuation survey to estimate statewide willingness-to-pay to either maintain current water quality or to improve water quality (improving means reclassifying 78% of "poor" waterbodies to "fair," and 20% of "fair" to "good." Costs are quantified, in a separate report—UDWQ (2010)—by analyzing four potential discharge levels or tiers for model publicly owned treatment works.
U.S. EPA (2010)	FL	Numeric nutrient criteria for Florida lakes and flowing waters.	Potential costs for point and nonpoint source controls that may be needed to attain the criteria. Benefits include transfer of water treatment plant function for incremental water quality improvements at the waterbody level expected to result from compliance with proposed numeric nutrient criteria, aggregated across all waters expected to improve as a result of numeric nutrient criteria.
U.S. EPA (2012)	FL	Numeric nutrient criteria for Florida estuaries, coastal waters, and South Florida inland flowing waters.	Potential costs for point and nonpoint source controls that may be needed to attain the criteria. Benefits include transfer of water treatment plant function for incremental water quality improvements at the waterbody level expected to result from compliance with proposed numeric nutrient criteria, aggregated across all waters expected to improve as a result of numeric nutrient criteria.
WDNR (2012)	WI	Regulations to decrease phosphorus discharges from industrial and municipal dischargers, adopted June 2010.	Benefits transfer for property values (based on Dodds et al. 2009) and recreational benefits (from Kaval and Loomis 2003); avoided cost methods to estimate reductions in need for managing algal blooms.

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APPENDIX C: ANECDOTAL POINT SOURCE CONTROL COSTS

Table C-1 shows costs for biological nutrient removal (BNR) and enhanced nutrient removal (ENR) at wastewater treatment plants (WWTPs) in Maryland (MDE 2012). Listed costs are for state grant funds for BNR and ENR upgrades, total upgrade funds originating from all other sources, and the total upgrade cost for BNR and ENR (i.e., the sum of state funding and other funding). For projects that have a listed completion date for both BNR and ENR, the reported costs are actual; for all others, reported costs are a combination of actual BNR costs and projected ENR costs.

Table C-1. Costs for BNR and ENR at WWTPs in Maryland

Major WWTP	Capacity (mgd)		Completion Year		Upgrade Cost (Original Dollar Years)			
	Before Expansion	After Expansion	BNR	ENR	BNR (State Share)	ENR (State Share)	Total Other	Total Upgrade Cost
ABERDEEN	4	--	1998	--	$1,317,417	$14,982,000	$13,079,817	$29,379,234
ANNAPOLIS	13	--	2000	--	$2,994,313	$13,700,000	$23,495,778	$40,190,091
APG-ABERDEEN*	2.8	--	2006	2006	$0	$0	Unknown	Unknown
BACK RIVER (BNR REFINEMENT)	180	--	1998	--	$73,135,745	$267,000,000	$218,592,442	$558,728,187
BALLENGER CREEK	6	15	1995	--	$1,000,000	$31,000,000	$111,033,621	$143,033,621
BLUE PLAINS (Grants MD PORTION)	169.6	--	--	--	$38,831,231	$203,298,000	$837,870,769	$1,080,000,000
BOONSBORO (MINOR; STATE $ FOR BNR ONLY)	0.53	--	2010	2010	$2,601,676	$0	$9,954,718	$12,556,394
BOWIE	3.3	--	1991	2011	$96,960	$8,870,000	$1,986,799	$10,953,759
BROADNECK	6	8	1994	--	$206,897	$7,851,000	$21,161,593	$29,219,490
BROADWATER	2	--	2000	--	$2,589,960	$6,000,000	$9,694,382	$18,284,342
BRUNSWICK	1.4	--	2008	2008	$2,333,661	$8,263,000	$4,029,488	$14,626,149
CAMBRIDGE	8.1	--	2003		$4,728,221	$8,944,000	$11,039,167	$24,711,388
CELANESE	1.66	--	2006	2006	$3,606,579	$2,333,382	$10,154,290	$16,094,251
CENTREVILLE***	0.5	--	2005	--	$3,279,858	$1,000,000	$6,382,042	$10,661,900
CHESAPEAKE BEACH	1.18	--	1992	--	$0	$9,157,000	$20,688,400	$29,845,400
CHESTERTOWN	0.9	--	2008	2008	$2,858,405	$1,490,854	$5,452,355	$9,801,614
CONOCOCHEAGUE	4.1	4.5	2001	--	$2,612,390	$27,537,000	$12,606,897	$42,756,287
COX CREEK	15	--	2002	--	$4,265,000	$140,485,000	$27,371,580	$172,121,580
CRISFIELD	1	--	2010	2010	$1,986,639	$4,231,000	$4,052,884	$10,270,523
CUMBERLAND	15	--	2001	2011	$5,091,863	$26,780,000	$15,264,198	$47,136,060
DAMASCUS	1.5	--	1998	--	$830,600	$5,235,000	$26,186,280	$32,251,880
DELMAR	0.65	--	--	--	$515,000	$2,540,000	$4,755,793	$7,810,793

Major WWTP	Capacity (mgd)		Completion Year		Upgrade Cost (Original Dollar Years)			
	Before Expan sion	After Expan sion	BNR	ENR	BNR (State Share)	ENR (State Share)	Total Other	Total Upgrade Cost
DENTON	0.8	--	2000	--	$1,879,935	$4,609,000	$4,748,326	$11,237,261
DORSEY RUN***	2	--	1992	--	$0	$3,900,000	$0	$3,900,000
EASTON	2.35	--	2007	2007	$8,930,000	$8,660,000	$21,563,791	$39,153,791
ELKTON	2.7	3.2	2009	2009	$8,842,410	$7,960,000	$23,908,502	$40,710,912
EMMITSBURG	0.75	--			$5,346,000	$8,153,000	$10,361,000	$23,860,000
FEDERALSBURG	0.75	--	2010	2010	$2,360,000	$3,360,000	$3,767,713	$9,487,713
FREDERICK (BNR REFINEMENT)	8	10.49	2002	--	$8,450,281	$27,411,000	$37,739,915	$73,601,196
FREEDOM DISTRICT (BNR REFINEMENT)	3.5	--	1994	--	$4,834,000	$7,891,000	$20,444,118	$33,169,118
FRUITLAND	0.8	1.06	2003	--	$3,192,975	$3,100,000	$9,009,000	$15,301,975
GEORGES CREEK	0.6	--	2010	2010	$5,984,613	$10,588,000	$12,092,306	$28,664,919
HAGERSTOWN	8	10.5	2000	2010	$4,359,643	$10,860,000	$11,851,425	$27,071,068
HAMPSTEAD	0.9	--	--	--	$10,000,000	$2,000,000	$10,000,000	$22,000,000
HAVRE DE GRACE (BNR REFINEMENT)	1.89	3.3	2002	--	$8,722,976	$11,289,000	$33,885,998	$53,897,974
HURLOCK	1.65	--	2006	2006	$2,507,171	$941,148	$4,137,043	$7,585,362
INDIAN HEAD	0.5	--	2008	2008	$2,560,860	$6,484,000	$5,896,777	$14,941,637
JOPPATOWNE	0.95	--	1996	--	$464,299	$2,999,732	$4,317,815	$7,781,846
KENT ISLAND	3	--	2007	2007	$7,838,606	$6,380,645	$19,773,557	$33,992,808
LA PLATA	1.5	--	2003	--	$2,046,387	$9,378,000	$9,081,613	$20,506,000
LEONARDTOWN	0.68	1.2	2003	--	$1,189,501	$6,951,000	$13,003,146	$21,143,647
LITTLE PATUXENT	25	29	1994	--	$2,000,000	$35,494,000	$94,218,500	$131,712,500
MARLAY TAYLOR (PINE HILL RUN)	6	--	1998	--	$1,865,859	$11,000,000	$28,059,978	$40,925,837
MARYLAND CITY	2.5	--	1990	--	$0	$3,400,000	$5,000,000	$8,400,000
MARYLAND CORRECTIONAL INSTITUTE***	1.6	--	1995	--	$0	$3,000,000	$0	$3,000,000
MATTAWOMAN***	15	--	2007	--	$10,000,000	$0	$19,491,191	$29,491,191
MAYO LARGE COMMUNAL	0.615	1.14	--	--	$5,456,000	$3,000,000	$31,304,000	$39,760,000
MOUNT AIRY	1.2	--	1999	2010	$2,005,000	$3,500,000	$3,638,869	$9,143,869
NORTHEAST RIVER	2	--	2005	--	$1,675,927	$9,000,000	$24,709,795	$35,385,722
PARKWAY	7.5	--	1992	--	$5,000,000	$16,052,000	$12,998,114	$34,050,114
PATAPSCO	73	81	--	--	$75,150,000	$218,500,000	$97,546,400	$391,196,400
PATUXENT	7.5	--	1999	--	$500,000	$13,800,000	$7,384,690	$21,684,690
PERRYVILLE	1.65	--	2010	2010	$3,243,974	$4,000,000	$6,516,104	$13,760,078

Major WWTP	Capacity (mgd)		Completion Year		Upgrade Cost (Original Dollar Years)			
	Before Expansion	After Expansion	BNR	ENR	BNR (State Share)	ENR (State Share)	Total Other	Total Upgrade Cost
PISCATAWAY	30	--	2000	--	$9,642,175	$6,324,000	$11,035,767	$27,001,942
POCOMOKE CITY	1.47	--	2004	--	$1,578,539	$3,224,000	$3,426,249	$8,228,788
POOLESVILLE	0.75	--	1995	2010	$692,381	$235,000	$2,320,519	$3,247,900
PRINCESS ANNE	1.26	--	2004		$1,701,116	$4,000,000	$2,479,064	$8,180,180
SALISBURY	8.5	--	2010	2010	$22,817,000	$3,000,000	$52,203,887	$78,020,887
SALISBURY CORRECTIVE ACTION	--	--	--	--	$11,000,000	$12,000,000	$31,270,000	$54,270,000
SENECA	20	26	2003	--	$12,011,129	$6,900,000	$93,188,812	$112,099,941
SNOW HILL	0.5	0.667		--	$3,765,000	$3,527,000	$7,072,870	$14,364,870
SOD RUN	20	--	2000	--	$8,249,178	$42,633,450	$46,843,650	$97,726,278
SWAN POINT**	0.6	--	2007	2007	$0	$0	Unknown	Unknown
TALBOT COUNTY REGION II (St. Michael's)	0.66	--	2008	2008	$2,729,349	$2,000,000	$8,306,928	$13,036,277
TANEYTOWN	1.1	--	2000	--	$1,497,408	$2,870,000	$6,886,587	$11,253,995
THURMONT	1	--	1996	--	$926,660	$6,889,000	$5,426,115	$13,241,775
WESTERN BRANCH	30	--	1995	--	$15,739,370	$29,000,000	$66,394,690	$111,134,060
WESTMINSTER	5	--	2001	--	$2,036,263	$16,940,000	$13,239,584	$32,215,847
WINEBRENNER	1	--	--	--	$2,100,000	$7,000,000	$8,565,200	$17,665,200

Source: Maryland Department of the Environment (MDE). 2012. Cost Estimates for Phase II WIP.
BNR = biological nutrient removal
ENR = enhanced nutrient removal
mgd = million gallons per day
** Funded by the U.S. Army.*
*** Funded by private developer*
**** Based on current performance, ENR upgrade may not be required. Further evaluation is necessary.*

Appendix D: References for Benefit Studies

The literature review summarized in Section III does not include studies with estimates of the benefits of reduced nutrient loadings, nor does it include the anticipated impacts associated with particular rulemaking proposals. Table B-1 lists several such studies that evaluate benefits. In addition, Table B-2 summarizes some benefit-cost studies of planned nutrient pollution rulemaking at the state level.

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Appendix E: Municipal WWTP Technology Abbreviations and Acronyms

3Clar	tertiary clarification
A2O	three-stage phoredox
AB	aeration basin
AL	aerobic lagoons
AO	phoredox
AS	activated sludge
BAF	biological activated filter
BNR	unspecified biological nutrient removal process
Bpho	bardenpho
BPR	unspecified biological phosphorus removal process
CA	cycled aeration
CAC	chemically assisted clarification
ChPr	chemical phosphorus removal
DFil	denitrification filter
EA	extended aeration
Ferm	fermenter
Fil	media filtration (does not include granular activated carbon)
FL	facultative lagoon
GAAl	granular activated aluminum
GR	grit removal
IFAS	integrated fixed-film activated sludge
MemBR	membrane bioreactor
MiFil	microfiltration
MLE	modified Ludzack-Ettinger
POD	phased oxidation or isolation ditch
OX	oxidation ditch
RBC	rotating biological contactor
RO	reverse osmosis
SBR	sequential batch reactor

SF	sand filter
SubF	submerged biological filter
TF	trickling filter
UCT	university of capetown process
UF	ultrafiltration

Note: Sequenced processes should be denoted by "___ + ___". (i.e., Activated sludge followed by filtration would be "AS + Fil").

APPENDIX F: USERS' GUIDE FOR THE EPA'S COMPILATION OF COST DATA ASSOCIATED WITH THE IMPACTS AND CONTROL OF NUTRIENT POLLUTION

A. Introduction

This appendix provides instructions for the navigation and use of a database containing references, data tables and diagrams that the EPA assembled for its compilation of cost data associated with the impacts and control of nutrient pollution. The data and information contained in the database serve as the basis for this report. The database provides baseline information for developing and/or evaluating cost estimates, which might be useful in various contexts, including policy-making and nutrient criteria adoption. Information on both the impacts and control of nutrient pollution will allow users to gather information on the costs of nutrient controls as well as the impacts of uncontrolled nutrient pollution in an effort to develop a range of management approaches.

The database provides information on the costs associated with point source controls, nonpoint source controls, direct mitigation of nutrient pollution in waterbodies, and restoration efforts. It also includes diagrams showing the pathways for impacts of nutrients on lakes, streams, estuaries, and coasts, and a summary of the literature on economic impacts and control costs. Relevant studies are described in tabs organized according to economic sector (including commercial fisheries, tourism/recreation, property values, health effects, and drinking water treatment) and type of control activity. Sources that are relevant to economic impacts of nutrient pollution but do not meet all the evaluation criteria are included as anecdotal impacts or additional studies (as described below). Finally, cost-benefit and economic analyses supporting state-level nutrient rulemakings are briefly summarized.

The EPA is sharing the database so that users can find the source material from the report. A user who is interested in learning more about a particular study or is interested in gathering information from a specific geographic location can use this database to find those data. We have provided two examples of how to use this database at the end of this User's Guide.

B. Database Navigation and Use

The database was developed using Microsoft Excel™. Use of the database assumes users have a working knowledge of Microsoft Excel™ functions. The database is organized as a series of worksheets that are listed at the bottom of the database page. The "**Instructions**" worksheet provides some general instructions on how to use the database to access the data and information about the economic impacts (i.e., costs) of nutrient pollution and the costs of nutrient pollution control.

1. Navigating Within the Database

The database provides several ways to access the data within. The opening page ("**File Info**" worksheet) of the database acts as the table of contents for the database, where a description of the database and its contents are provided. This worksheet also briefly describes the primary worksheets in the database and provides links to the other worksheets contained in the workbook. While in the "**File Info**" worksheet, the user can click on the name of a worksheet to go directly to that worksheet or scroll through the list of worksheets along the bottom. The user can navigate the list of worksheets using the left-right arrow on the bottom right corner (Figure F-1).

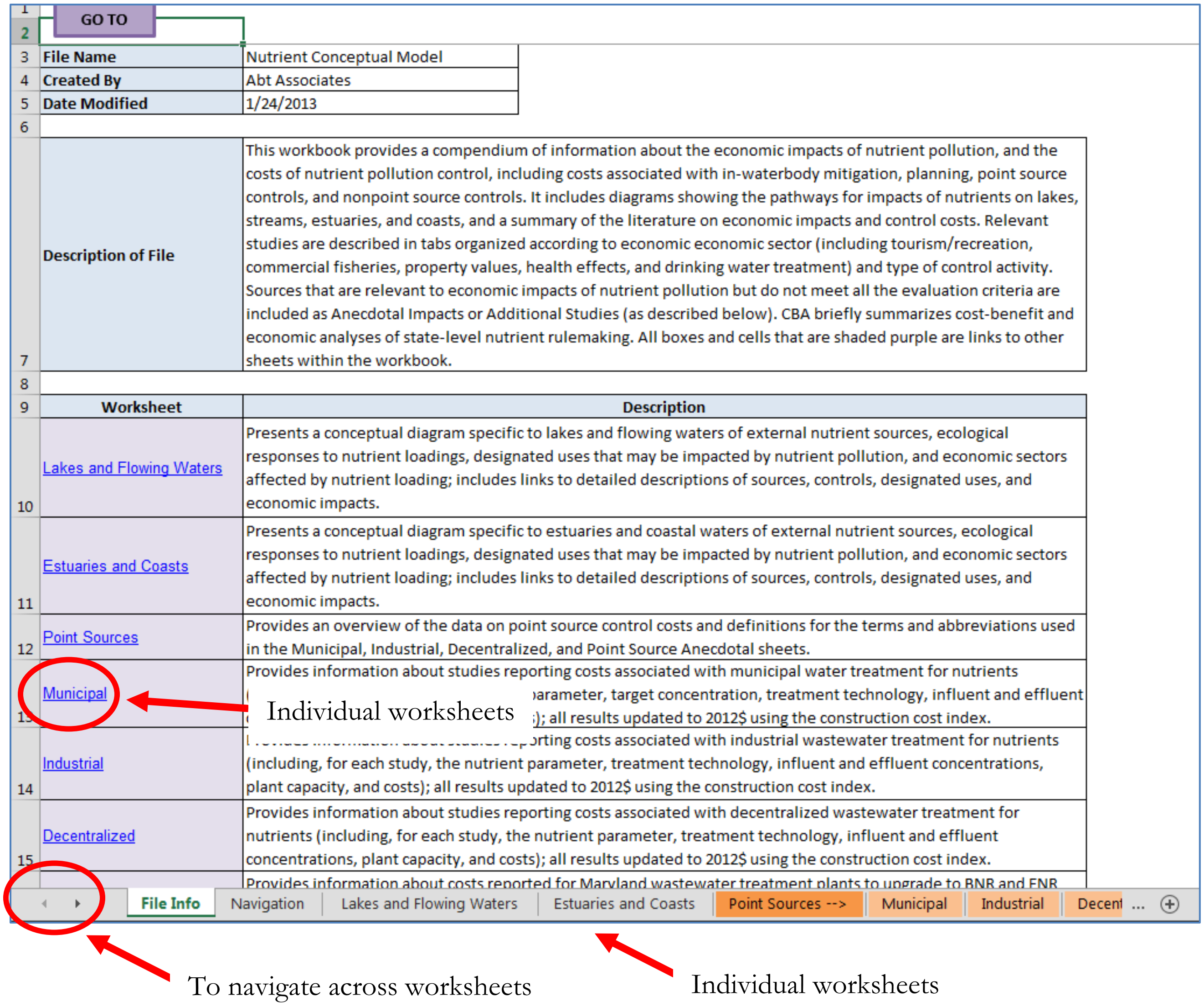

Figure F-1. Opening page of the database – "**File Info**" worksheet. [Note: Worksheets can be accessed from either the titles in the worksheet table or from the list along the bottom. Navigate the list of worksheets using the left-right arrows on the bottom left.]

The second worksheet in the database titled "**Navigation**" also acts as a table of contents for the database by providing a diagram of the organization of the database (Figure F-2). The listing of worksheets generally follows this organization. All of the text boxes in the navigation diagram that are shaded purple are hyperlinks to the relevant worksheet in the database. The user can click on the name of a worksheet in the diagram to go directly to that worksheet in the database or scroll through the list of worksheets along the bottom.

Further, throughout all of the worksheets in the database, purple cells and purple text boxes are hyperlinks to other parts of the database. Along the top left part of each worksheet, there are purple text boxes that provide quick links to other related worksheets. Each text box labeled “GO TO” links back to the Navigation page, where the user can quickly access any other worksheet.

2. Navigating Within Worksheets

Two helpful tools exist to aid users in extracting data from the database: filter tools and Excel’s search functionality.

Filtering can be accomplished by clicking on the grey boxes in the lower right-hand corner of each column heading (as indicated in Figure F-3). Once clicked, a drop-down menu will appear which will allow you to filter out elements within the column or to sort the elements within the column. By utilizing the filtering and sorting tools, the user may organize the data within a given page according to options like pollutant type, cost, and geographic location. For example, if the user wished to only look at municipal point source data relating to total nitrogen, the filter function could be used to hide all data specific to total ammonia and total inorganic nitrogen, leaving only data relating to total nitrogen displayed in the worksheet.

In some cases the user may wish to search the database for a value or text string. A search can be accomplished using Excel’s “Find” function which can be accessed from the “Editing” menu (see Figure F-4). It can also be accessed using the hotkey sequence “Ctrl”+F—just press the “Ctrl” key and the “F” key on the keyboard simultaneously.

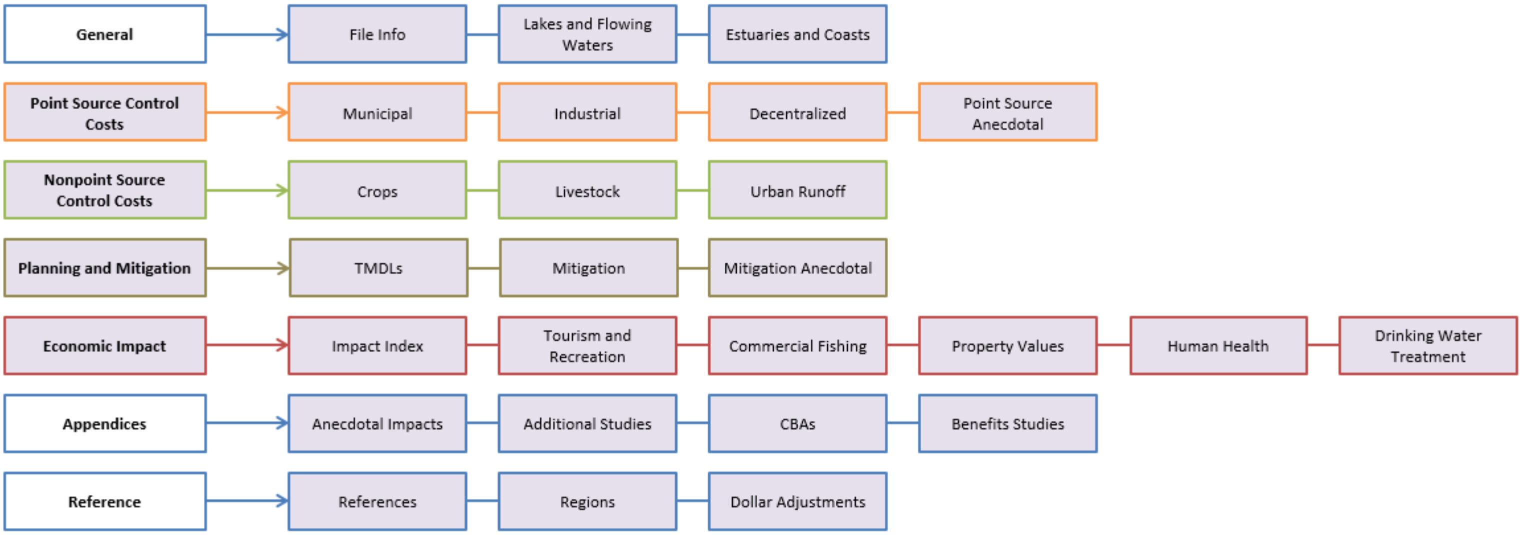

Figure F-2. Organization of the database – "**Navigate**" worksheet. [Note: Worksheets can be accessed from either the boxes in the diagram in the worksheet or from the list along the bottom. Navigate the list of worksheets using the left-right arrows on the bottom left.]

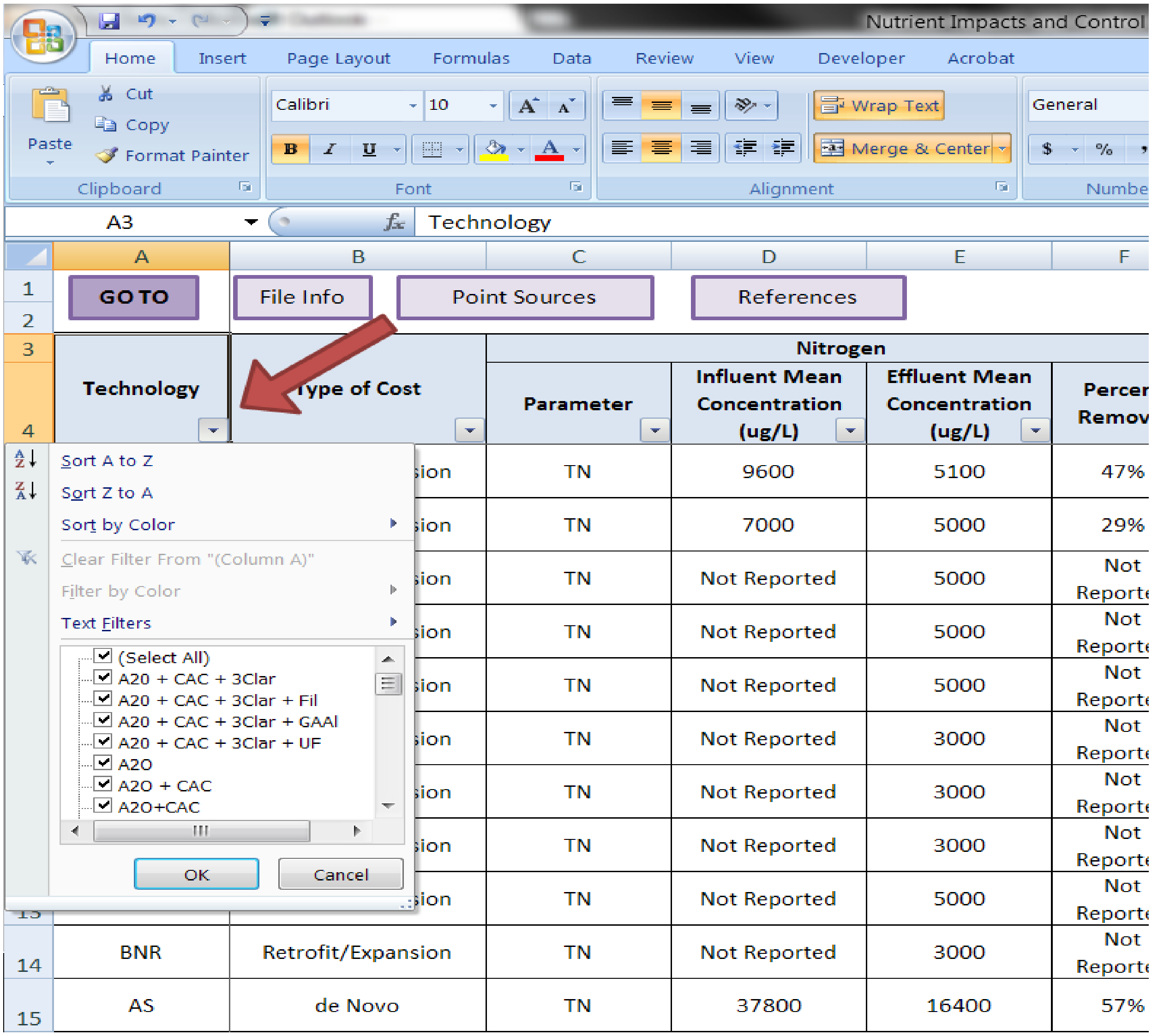

Figure F-3. Filter data using the drop-down menus located in each column heading.

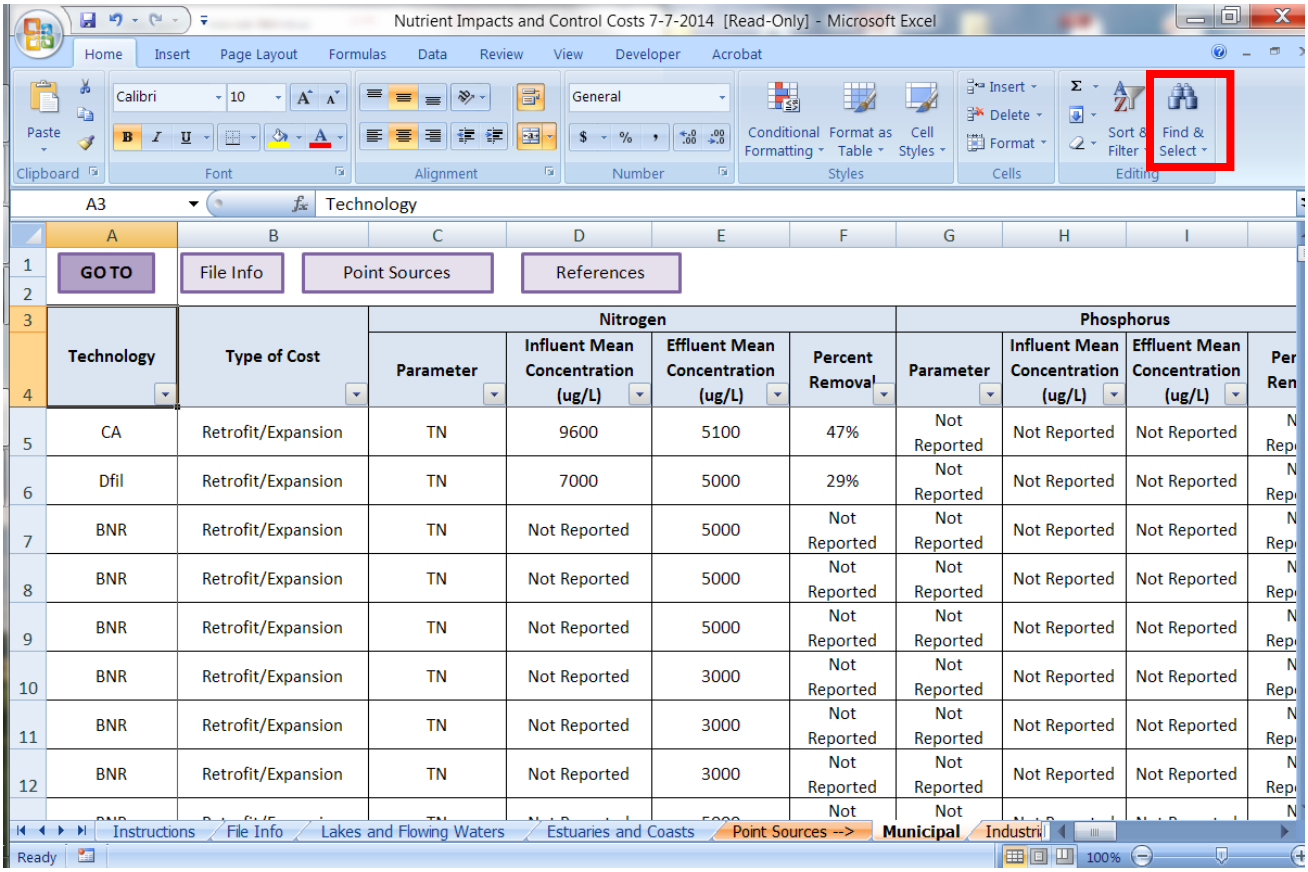

Figure F-4. Search within the worksheets for specific numbers or strings using the "Find" function located in the "Editing" menu.

C. Worksheet Descriptions

This section provides descriptions of each of the worksheets contained in the database. The worksheet descriptions are provided in the same order as they are contained in the database.

1. The worksheet entitled "**Lakes and Flowing Waters**" presents a conceptual diagram specific to lakes and flowing waters of external nutrient sources, ecological responses to nutrient loadings, uses that may be impacted by nutrient pollution, and economic sectors affected by nutrient loading. The worksheet includes links to detailed descriptions of sources, controls, uses, and economic impacts. Similarly, the next worksheet entitled "**Estuaries and Coasts**" presents a conceptual diagram specific to estuaries and coastal waters of external nutrient sources, ecological responses to nutrient loadings, uses that may be impacted by nutrient pollution, and economic sectors affected by nutrient loading. The worksheet includes links to detailed descriptions of sources, controls, uses, and economic impacts.

2. The worksheet entitled "**Point Sources**" provides an overview of the data on point source control costs and definitions for the terms and abbreviations used in the "**Municipal**",

"**Industrial**", "**Decentralized**", and "**Point Source Anecdotal**" worksheets that follow. All results in these worksheets are presented in 2012$ (updated using the construction cost index, unless otherwise indicated).

- "**Municipal**" - provides data and information from studies reporting costs associated with municipal wastewater treatment for nutrients (including, for each study, the nutrient parameter, target concentration, treatment technology, influent and effluent concentrations, plant capacity, and costs).

- "**Industrial**" - provides data and information from studies reporting costs associated with industrial wastewater treatment for nutrients (including, for each study, the nutrient parameter, treatment technology, influent and effluent concentrations, plant capacity, and costs).

- "**Decentralized**" - provides data and information from studies reporting costs associated with decentralized wastewater treatment for nutrients (including, for each study, the nutrient parameter, treatment technology, influent and effluent concentrations, plant capacity, and costs).

- "**Point Source Anecdotal**"- provides information about costs reported for Maryland wastewater treatment plants to upgrade to biological nutrient removal (BNR) and enhanced nutrient removal (ENR) treatment processes (including, for each plant, NPDES permit number, Maryland County, current and expansion treatment capacity, completion year, costs for state grant funds for BNR and ENR upgrades, total upgrade funds originating from all other sources, and the total upgrade cost for BNR and ENR).

3. The next portion of the database covers "**Nonpoint Sources**". The "**Nonpoint Sources**" worksheet provides an overview of the data on nonpoint source control costs and definitions for the terms and abbreviations used in the "**Urban Runoff**" worksheet that follow. All results in these worksheets are presented in 2012$ (updated using the Consumer Price Index, unless otherwise indicated).

   - "**Urban Runoff**" - provides data and information from studies reporting costs associated with reducing nutrient pollution from urban runoff (including, for each study, the nutrient parameter, treatment technology, removal performance, size, location, and costs).

4. The "**Restoration and Mitigation**" worksheet provides an overview of the data on restoration and direct mitigation costs and provides definitions for the terms and abbreviations used in "**Restoration**", "**Mitigation**", and "**Mitigation Anecdotal**" worksheets. All results in these worksheets are presented in 2012$ (updated using the Consumer Price Index, unless otherwise indicated).

- "**Restoration**" - provides data and information from studies quantifying the costs associated with nutrient reduction (including, for each study, the waterbody type, restoration activity and description, location, year, resource description, water quality impact, data sources, and costs).

- "**Mitigation**" - provides data and information from studies quantifying the costs associated with in-lake nutrient mitigation technologies and methods (including, for each study, the waterbody type, the activity and description, location, year, resource description, water quality impact, data sources, and costs).

- "**Mitigation Anecdotal**" - provides information about water quality improvement projects planned to meet phosphorus load reductions for Florida's Upper Ocklawaha River Basin TMDL (including, for each project, the estimated load reduction, project cost, and completion date). Presented in original dollar years.

5. The worksheet for "**Economic Impacts**" provides an overview of the data on economic impacts presented in the "**Tourism**", "**Fisheries**", "**Property Value**", "**Health Effects**", and "**Drinking Water Treatment**" worksheets. All results in these worksheets are presented in 2012$ (updated using the Consumer Price Index, unless otherwise indicated).

   - "**Impact Index**" - provides a summary of all documented nutrient impacts in the model. The impacts can be filtered by state, region, year, source categorization, economic sector, or waterbody type.

   - "**Tourism**" - provides information about studies valuing nutrient impacts to tourism and recreation (including, for each study, the waterbody type, location, year, resource description, water quality impacts, data, methodology, and results).

   - "**Fisheries**" - provides information about studies valuing nutrient impacts to fisheries (including, for each study, the waterbody type, location, year, resource description, water quality impacts, data, methodology, and results).

   - "**Property Values**" - provides information about studies valuing nutrient impacts to property values (including, for each study, the waterbody type, location, year, resource description, water quality impacts, data, methodology, and results).

   - "**Health Effects**" - provides information about studies valuing nutrient impacts to human health (including, for each study, the waterbody type, location, year, the health effect/measure being evaluated, water quality impacts, data, methodology, and results).

   - "**Drinking Water Treatment**" - provides information about studies valuing nutrient impacts to drinking water treatment costs (including, for each study, the waterbody type, location, year, resource description, water quality impacts, data, methodology, and results).

6. The remaining worksheets provide information about studies that did not meet all screening criteria, but have relevant information and results documenting impacts from nutrient pollution.

 - "**Anecdotal Impacts**" - provides information about anecdotal evidence of the economic impacts of nutrient pollution.

 - "**CBAs**" - Cost Benefit Analysis provides a summary of cost-benefit and economic analyses of state-level nutrient rulemaking.

 - "**Benefit Studies**" - provides a list of studies that assess the benefits of nutrient reductions.

 - "**References**" - provides full references for all sources used in conceptual diagram.

 - "**Regions**" - provides a reference for the region categorizations in the Impact Index.

 - "**Dollar Adjustments**" - provides the Consumer Price Index factors used to normalize cost and impact estimates to 2012$ and the construction cost index factors used to normalize drinking water and wastewater treatment cost estimates to 2012$.

D. Examples for Navigating the Database to Extract Data and Information

The following examples illustrate how a user can use the database to gather control cost information.

1. Using Point Source Control Cost Data

 - <u>Situation</u>: State is assessing the potential costs that would be incurred by point sources to achieve effluent limitations based on numeric water quality criteria for nitrogen

 - <u>Assume</u>: Only one major municipal wastewater treatment facility to be affected; 4 million gallon per day (mgd) WWTP (service population of approximately 40,000 persons) that must meet **5 mg/L TN end-of-pipe limits**

 - <u>Approach</u>: Use the project database to assess possible project costs

   Step 1: Navigate to "**Municipal**" point source control costs worksheet

   Step 2: Filter data

- o By nitrogen parameter (i.e., "TN")
- o By effluent concentration (i.e., show all data ≤5 mg/L)
- o By flow (i.e., all systems between 1 mgd and 10 mgd)

Step 3: Assess resulting data

- o Potential technologies include: oxidation ditches, trickling filters, denitrification filters, and activated sludge systems designed for biological nutrient removal
- o Estimated unit capital costs range from $1/gpd - $5/gpd
- o There are fewer data points for annual O&M costs but these range from $0.024/gpd – $0.11/gpd annually

Step 4: Estimate project costs

- o Total capital costs are between $4 million - $20 million
- o On an annualized basis (assuming a useful life of 20 years and a 3% interest rate) these capital costs are $0.3 million/year – $1.3 million/year
- o Assuming annual O&M costs of $0.06/gpd, total annual project costs are anticipated to be between $0.4 million/year – $1.8 million/year
- o If desired, user-fee increases could be estimated
  - ▪ In this example, fee increases could range between $9/year – $45/year

Step 5 (Optional): Review of anecdotal data to support estimates

- o Navigate to "**Point Source Anecdotal**" worksheet
- o Filter data by Current Capacity for desired flows; results for those around 4 mgd are shown in Table E-1.

Table F-1. Upgrade Costs for Wastewater Treatment Plants around 4 mgd (million gallons per day) based on Point Source Anecdotal Data.

Plant Name	Current Capacity (MGD)	Expansion Capacity (MGD)	COST SUMMARY				
			Total Upgrade Cost	Total BNR State Share	Total BNR	Total ENR State Share	Total Other
HAVRE DE GRACE (BNR REFINEMENT)	1.89	3.3	$53,897,974	$8,722,976	$17,445,953	$11,289,000	$33,885,998
ELKTON	2.7	3.2	$40,710,912	$8,842,410	$17,684,820	$7,960,000	$23,908,502
KENT ISLAND	3		$33,992,808	$7,838,606	$15,677,212	$6,380,645	$19,773,557
BOWIE	3.3		$10,953,759	$96,960	$193,920	$8,870,000	$1,986,799
FREEDOM DISTRICT (BNR REFINEMENT)	3.5		$33,169,118	$4,834,000	$9,668,000	$7,891,000	$20,444,118
ABERDEEN	4		$29,379,234	$1,317,417	$2,634,834	$14,982,000	$13,079,817
CONOCOCHEAGUE	4.1	4.5	$42,756,287	$2,612,390	$5,224,780	$27,537,000	$12,606,897
WESTMINSTER	5		$32,215,847	$2,036,263	$4,072,526	$16,940,000	$13,239,584

2. Using Nonpoint Source Control Cost Data

- Situation:
  - State desires to assess the potential costs that would be incurred by nonpoint sources to achieve effluent limitations based on numeric water quality criteria for phosphorus
- Assume:
  - A municipal separate storm sewer system (MS4) permit would require **5% TP reduction** in runoff from 200 acre industrial park
  - Existing TP load is 1.5 lbs/acre/year, or 300 lbs/year
  - A 5% reduction is 15 lbs/year

- Approach: Use the project database to assess possible project costs

  Step 1: Navigate to "**Urban Runoff**" nonpoint source control costs worksheet

  Step 2: Filter data
  - By parameter (i.e., "TP")
  - By appropriate technology options (e.g., dry detention basin or "DB")

  Step 3: Assess resulting data
  - A number of data points exist; the State elects to use the most up-to-date empirical cost information (released in 2013) rather than older data based on modeled estimates

  Step 4: Estimate project costs
  - Data from two projects indicate observed total project costs of $21,100/lb TP removed and $10,500/lb TP removed over 20 years

- Based on this unit cost and a desired reduction of 15 lbs TP per year, total project cost could range from approximately $160,000 - $320,000
- Annualized over a 20 year project life and assuming a 3% interest rate, the total project cost is between $10,800/year - $21,500/year
- If desired, cost to users could be estimated
  - Assuming all 40,000 residential users are affected, this translates into an estimated user-fee increase of between $3/year - $11/year.

Submitted via Public Comment Portal
Jon Kenning
Water Quality Program
State of Washington Department of Ecology
P.O. Box 47696
Olympia, WA 98504-7696

August 27, 2025

Re: City of Tacoma Comments on Draft 2025 Puget Sound Nutrient Reduction Plan

Dear Mr. Kenning:

The City of Tacoma (Tacoma, City) appreciates the opportunity to comment on the Washington State Department of Ecology (Ecology) draft 2025 Puget Sound Nutrient Reduction Plan (2025 Reduction Plan) and June 2025 Puget Sound Nutrient Source Reduction Project Vol 2: Model Updates and Optimization Scenarios, Phase 2 ("Bounding Scenarios Phase 2").[1] The City operates two wastewater treatment plants discharging to Commencement Bay in Puget Sound and therefore has both a significant stake in, and serious concerns about, Ecology's proposed nutrient regulation pathway.

Protecting environmental health is a longstanding priority for Tacoma. For more than a decade, the City has been a leader and steadfast partner in regional efforts to find the right balance between nutrient management, protecting the health of Puget Sound, ensuring prudent public-utility management, affordability, managing for growth, and evolving science. The City continues to advocate for sustainable, long-term solutions grounded in reliable science and the best available data – solutions that deliver measurable environmental gains while maintaining cost sustainability for ratepayers, particularly when proposed actions could have a negative effect on housing supply and affordability and potentially limit the resources the utilities have to respond to other environmental concerns, including contaminants of emerging concern (CECs).

For decades, Puget Sound clean water utilities, including the City, have met or bettered regulatory requirements for secondary treatment, wet weather controls, stormwater management (including toxics reduction), and beneficial use of biosolids. These responsibilities demand complex and coordinated planning, funding, construction, operation, and maintenance –

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[1] Puget Sound Nutrient Source Reduction Project. Volume 2: Model Updates and Optimization Scenarios, Phase 2

representing billions in infrastructure investment. Any new regulatory mandates with substantial technical, operational, and economic impacts must be rigorously evaluated for achievability and costs versus benefits. Addressing uncertainty through permit structures that enable adaptive management is essential to ensure investments remain targeted, effective, and yield tangible results.

The City supports water quality standards, including natural conditions provisions, for dissolved oxygen and temperature that are protective of aquatic life and grounded in sound science. Updated biologically based dissolved oxygen standards should be developed in tandem with natural conditions provisions, recognizing that the latter apply only when numeric criteria cannot be met. In some cases, this integrated approach could eliminate the need for separate application of natural conditions criteria because dissolved oxygen conditions could be assessed by monitoring in the field rather than requiring hypothetical computer simulations.

After reviewing Ecology's recent nutrient draft documents[2], the City provides the executive summary below outlining its principal concerns, with detailed comments attached.

1. **Significant Cost Implications – Massive Investment Required**

The June 2025 Draft Puget Sound Nutrient Reduction Plan (2025 Reduction Plan) introduces stricter limits than those found in both iterations of the Puget Sound Nutrient General permits (2022 and 2025). Attempting to comply with these limits would require unprecedented upgrades to Tacoma's wastewater treatment plants – a major investment borne by ratepayers. As part of its compliance with the requirements of the 2022 General Permit, the City began a Nutrient Reduction Evaluation (Nutrient Evaluation, or "NRE") to explore treatment alternatives. When the 2022 PSNGP was later invalidated, the City continued working on the NRE, including developing preliminary cost projections and estimating the potential impact on wastewater utility rates.

Under the invalidated 2022 General Permit, the City was required to evaluate treatment technologies to achieve All Known, Available, and Reasonable Treatment (AKART) for its two specific wastewater treatment plants as well as a specified Total Inorganic Nitrogen (TIN) seasonal (April through October) effluent limit of 3 mg/L. The City also evaluated treatment technologies to achieve the changed effluent limits presented at the Nutrient Forum in March

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[2] 2025 Draft Puget Sound Nutrient General Permit and draft Fact Sheet (June 18); Draft Puget Sound Nutrient Reduction Plan (June 12); Puget Sound Nutrient Source Reduction Project Volume 2: Model Updates and Optimization Scenarios, Phase 2 (June 12)

2025. The estimated capital cost to upgrade both of Tacoma's wastewater treatment plants to meet the 3/5/8 mg/L limits for TIN and 8 mg/L for carbonaceous biological oxygen demand (CBOD) is **$625 million to $1.25 billion**. The average monthly wastewater utility bill would rise from the current rate of **$68 to $419 by 2050 –** exclusive of additional costs required to replace aging infrastructure or ongoing costs to operate/maintain these systems once they are installed. The new proposed limits in the 2025 Reduction Plan, based on Total Nitrogen (TN) versus TIN and the addition of CBOD, go beyond those studied in the NRE, meaning costs would likely rise even higher, with upgrades that may not be financially or technically feasible.

Given these projected impacts, the City respectfully requests that Ecology carefully reconsider the financial and technical challenges detailed here in order to strike the right balance between achieving environmental goals and implementing practical, affordable solutions in partnership with stakeholders.

2. **Regulatory Strain on Households and Utilities**

Without substantial external funding or a reassessment of requirements, the proposed regulations would impose a severe financial strain on ratepayers in Tacoma and across the Puget Sound region – while jeopardizing the City's ability to comply. Existing federal and state funding falls far short of what's needed to upgrade more than 50 wastewater treatment plants in Puget Sound by 2050. The United States Environmental Protection Agency (EPA) considers wastewater bills unaffordable when they exceed two percent of household income. Under the updated NRE limits alone, the share of "burdened" Tacoma households – those paying above that threshold – is projected to skyrocket from **14 percent (12,000 households)** to **67 percent (60,000 households) by 2050**.

This sharp increase in in burdened households underscores the urgent need for additional funding sources or more achievable regulatory targets to avoid placing an untenable burden on our community.

3. **Balancing Nutrient Limits with Growth Obligations**

If Ecology's 2025 Reduction Plan moves forward without changes to the draft, it would cap effluent flows at 2014 flow conditions as well as currently perceived "limit of technology" treatment levels. In turn, this would force Tacoma to undertake upgrades far beyond those in its existing Engineering and Facility planning documents or even its current draft NRE while still meeting its legal obligations under the Growth Management Act and National Pollutant Discharge Elimination System (NPDES) permits to provide capacity for future growth. These caps ignore permitted design flows, risk locking in constraints under anti-backsliding rules, and could leave the City unable to serve growth or result it being in violation of its permits until

2050, if nutrient reduction is successfully implemented by then. This is a pivotal concern that should prompt Ecology to reconsider its regulatory approach – seeking a fact-based understanding of what is both technically and financially achievable, how long it realistically takes, and collaborating with utilities to develop feasible solutions.

4. Power Demand Impacts of Nutrient Treatment Upgrades

As part of its NRE, the City assessed the energy impacts of proposed nutrient treatment upgrades to meet the proposed nutrient regulations for the 3/5/8 mg/L limits for TIN and 8 mg/L for CBOD. The preliminary evaluation indicated that power consumption will increase by approximately **2.8 times at the Central Treatment Plant (CTP)** and **3.6 times at the North End Treatment Plant (NETP)**—a significant demand increase on the local power grid.

Preliminary discussions with Tacoma Power revealed a lack of awareness about the scale of these projected increases, underscoring a critical coordination gap between regulatory planning and utility infrastructure readiness. With over 50 regional wastewater treatment plants expected to implement similar upgrades by 2050 under the 2025 Puget Sound Nutrient Reduction Plan (PSNRP), the cumulative energy demand could be substantial.

This challenge is compounded by broader regional electrification trends, including transportation, heating, and data center growth, which are already straining power utilities. Uncoordinated wastewater-related energy demands risk exacerbating grid reliability, cost, and capacity issues.

The City urges the Washington State Department of Ecology to proactively collaborate with regional power providers to assess and plan for the cumulative energy impacts of nutrient reduction regulations. A coordinated, forward-looking approach is essential to ensure infrastructure readiness and avoid unintended consequences.

5. Modeling Concerns and the Need for a Stronger Scientific Foundation

Ecology's evaluation of compliance with the State's Dissolved Oxygen Standard relies heavily on its application and interpretation of the Salish Sea Model. However, the transparency and rigor of this application are insufficient to support defensible regulatory decisions. Greater clarity is needed on the model's input data assumptions and the scientific basis for Ecology's conclusions about dissolved oxygen impairment in Puget Sound, including but not limited to:

- The use of non-representative wastewater treatment plant effluent data (limited to monthly, quarterly, or annual samples)
- The treatment of scientific uncertainties within the model

- The process for identifying the dominant species or beneficial use relevant to impairment determinations
- The geographic and ecological basis for where the standard should apply to protect that species or use

While the underlying Salish Sea Model has undergone peer review, it is the City's understanding that Ecology's specific application – such as input assumptions, calibration choices, and postprocessing steps – has not been subjected to a robust independent review. For the modeling effort to be credible, its methods, datasets, and analytical choices should be fully documented, publicly accessible, and reproducible so other experts can replicate the results and further examine the issues. Many of the documents only recently became accessible after the publication of the draft documents in June 2025 and realistically, cannot be accessed without sophisticated computer software and equipment. Ecology has not allowed Tacoma sufficient time to fully understand the model updates and implications for the 2025 Reduction Plan.

6. Concerns Regarding the Dissolved Oxygen Standard

The City joins other concerned entities in objecting to the continued use of the current dissolved oxygen water quality criteria adopted in 1967 without any demonstrated scientific foundation. In the more than five decades since its adoption, substantial statutory and regulatory frameworks have been enacted, yet no updated standard has been developed to meet these binding requirements. Maintaining outdated and/or unsubstantiated standards is inconsistent with both sound science and the legal requirement that there be a scientific basis for state water quality standards. At a practical level, applying the current dissolved oxygen standard will result in wastewater treatment plants investing billions of dollars to meet scientifically unsupported criteria. This is particularly concerning given that wastewater treatment plants contribute only 7 percent of the total nitrogen load to Puget Sound, raising serious questions about whether such costly upgrades and investment would yield any measurable improvement in dissolved oxygen levels or any tangible benefit to aquatic species, which remains unknown.

7. Need for a Targeted Reasonable Potential Analysis

The Bounding Scenarios Reports (Phase 1 and 2) suggest that Ecology did not conduct a facility specific or watershed level assessment to determine whether each wastewater treatment plant has a reasonable potential to cause or contribute to DO impairment – whether through nearfield or farfield impacts. Federal regulation (40 CFR 122.44(d)(1)(iii)) requires that a Reasonable Potential Analysis account for "the variability of the pollutant or pollutant parameter in the effluent."

For TIN, variability cannot be accurately determined from the limited 2014 monthly, quarterly, or annual nutrient data available from wastewater treatment plants. Despite requiring Puget Sound wastewater treatment plants to collect expanded monitoring data since 2022, Ecology has not incorporated this more robust dataset into its current regulatory approach. This omission undermines both the precision and defensibility of the proposed limits, and underscores the need for a targeted, data driven Reasonable Potential Analysis before advancing new requirements.

8. Basing Regulatory Decisions on Approved Policy and the Latest Science

Ecology's decision to advance nutrient reduction modeling (e.g. Salish Sea Model) using the unapproved Natural Conditions Provision, while significant new research on nutrient dynamics in Puget Sound remains unincorporated, poses both scientific and procedural risks. Proceeding under a provision that has not yet received EPA approval jeopardizes the credibility and durability of the resulting limits, especially if subsequent federal review requires changes. At the same time, bypassing newly available, peer reviewed science risks adopting measures that are less effective, misaligned with true environmental drivers, or unnecessarily costly. Ecology should reconsider its reliance on the unapproved provision, integrate the latest findings into its modeling, and meaningfully collaborate with leading research institutions, including the University of Washington's Puget Sound Institute and the Washington State Academy of Sciences, to ensure regulatory actions are both scientifically defensible and consistent with EPA's requirements for the State's natural condition provision.

9. Evaluating Nutrient Reduction Plans as an Alternative to TMDLs

The City recognizes that the State has discretion under the Clean Water Act to address nutrient impairments through mechanisms other than a formal Total Maximum Daily Load (TMDL), such as an Advanced Restoration Plan, provided the chosen approach is transparent, science based, and capable of achieving water quality objectives. While an Advanced Restoration Plan can offer flexibility in implementation and allow for adaptive management as new data emerges, its success depends on clear technical justification, equitable allocation of responsibilities, and strong stakeholder engagement. A well-designed plan should incorporate the best available science, reflect real world feasibility, and establish measurable milestones to ensure progress toward dissolved oxygen and other water quality goals. However, concerns have been raised that the approach proposed by Ecology effectively skips incremental, achievable steps without assessing effectiveness for feedback and adjustment and moves directly to requirements that exceed current technological limits, creating questions about feasibility and cost effectiveness.

10. Request for More Meaningful Collaboration and Partnership

We appreciate that Ecology has offered meetings and opportunities for public comment. The City's experience, however, is that those opportunities occur after decisions have already been made by Ecology and have less flexibility to be responsive to public comment. Although the public process box is checked, the opportunities for real collaboration and engagement have not been achieved. Consequently, we are losing opportunities to strike a balance for viable and cost-effective alternatives that may be equally effective. The City has and continues to request more meaningful collaboration to tackle the complicated issues surrounding nutrient reduction. By way of more recent examples, Ecology staff indicated during the March 2025 Nutrient Forum that Ecology intends to issue the finalized 2025 PSNGP and 2025 Reduction Plan by the end of the year (2025). However, we did not receive any further details until the draft documents were issued for public comment in June 2025. This proposed accelerated timeline undermines the opportunity for meaningful engagement and transparency to address the following significant concerns:

- **Conflicting effluent limits** between the draft General Permit and the draft nutrient reduction plan, which creates confusion and complicates planning and implementation of treatment plant upgrades.
- **An insufficient stakeholder process**, with only a brief Public Comment Period from mid- June through August, including a partial denial for a reasonable extension to the end of September, to evaluate and respond to more than 2,500 pages of technical and regulatory material.
- **Limited dialogue at the August 11 Nutrient Forum**, where Ecology did not facilitate substantive discussion. Instead, participants were directed to submit concerns via written comments.
- **Unresolved issues from prior processes**, including concerns raised by Utilities during the previous PSNGP development and appeal (which were not addressed by the Pollution Control Hearings Board (PCHB)) and continue to be concerns in the draft 2025 PSNGP.
- **Delayed Technical Advisory Committee engagement**, scheduled after regulatory commitments and implementation timelines – extending to 2050 – are already in place.

This lack of a comprehensive and inclusive process is a recurring concern throughout the City's comments below. Accordingly, the City respectfully requests that Ecology commit to a robust, transparent, and more collaborative stakeholder process to ensure the best, most achievable path forward is developed in partnership with affected communities and utilities prior to finalizing in

December. The City requests that Ecology meet with all of the partners on a regular (at least monthly) basis prior to finalizing the 2025 General Permit and the 2025 Reduction Plan.

11. Technical Advisory Committee

Tacoma looks forward to participating in the Technical Advisory Committee (TAC) that was outlined in Appendix H of the 2025 Reduction Plan, The City requests that Ecology convene the TAC promptly and before finalizing the 2025 Reduction Plan. Given the limited opportunities for input during the draft phase, establishing the TAC now in a collaborative environment would allow for meaningful contributions and result in a more robust final 2025 Reduction Plan. This approach would demonstrate Ecology's genuine interest in feedback from utilities

Thank you for your consideration. Please see the attached document for the City’s more detailed comments. We trust our comments are useful. If you have any questions or would like additional information please contact Teresa Peterson, P.E. at 253-591-5766 or tpeterson@tacoma.gov.

Sincerely,

DocuSigned by:
Ramiro Chavez
1FE94B0C44CE498...

Initial
GMS

Ramiro A. Chavez, P.E., PgMP
Director/City Engineer City of Tacoma, Environmental Services

Attached: Puget Sound Nutrient Reduction Plan – Draft City of Tacoma Comments

City of Tacoma Environmental Services Detailed Comments Table of Contents

1.0 Regulations Shift and Financial Considerations

1.1 *Ecology Regulatory Shift from Total Inorganic Nitrogen to Total Nitrogen*

Total nitrogen (TN) in municipal wastewater liquid streams is present in six basic forms, as shown on Figure 1. These are divided into particulate and soluble, organic and inorganic, and degradable and unbiodegradable forms.

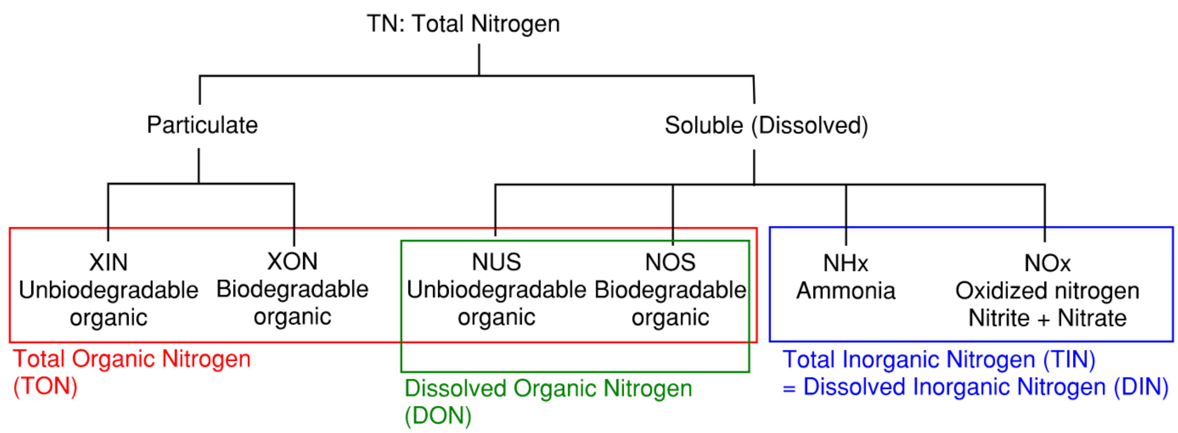

Figure 1. Nitrogen Species Present in Wastewater

Particulate inorganic nitrogen is not shown on Figure 1. Its presence in municipal wastewater influent is limited and generally removed in the primary clarifiers. Struvite crystals, such as those found in at the bottom of a digester, are an example of particulate inorganic nitrogen. This form of nitrogen speciation is considered negligible in effluent and is not considered further in this analysis. Therefore, total inorganic nitrogen (TIN) is typically equal to dissolved inorganic nitrogen (DIN) in wastewater effluent.

The difference between TN and TIN is the organic nitrogen, which comes in four forms including:

- particulate: particulate inert nitrogen (XIN) and particulate organic nitrogen (XON)
- dissolved: unbiodegradable soluble nitrogen (NUS) and organic soluble nitrogen (NOS)

Particulate organic material is mostly removed during solids/liquid separation such as clarifiers, and systems with membrane filtration or tertiary filtration will have very low levels of this material in the effluent. Of the soluble organic material, most of the NOS will be converted to ammonia (NHx) within the treatment plant, while the unbiodegradable nitrogen (NUS) will pass through the treatment plant and discharge with the effluent. NUS is not available for eutrophication and should not have any impact on Puget Sound dissolved oxygen.

In June 2025, the Washington State Department of Ecology (Ecology) issued 3 documents that discuss potential permit limits or considerations based on 3 different measures of nitrogen:

- DIN – Salish Sea Model (SSM) and Puget Sound Nutrient Source Reduction Project Vol 2: Model Updates and Optimization Scenarios, Phase 2 ("Bounding Scenarios Phase 2")
- TIN – 2022 and 2025 Puget Sound Nutrient General Permits (2022 and 2025 PSNGP)
- TN – 2025 Puget Sound Nutrient Reduction Plan (2025 PSNRP, 2025 Reduction Plan)

Ecology stated in the July 1, 2025, meeting (draft 2025 PSNGP, online Information Presentation) that review of the 2025 PSNGP should be done without consideration to the content of the PSNRP. However, the lack of clear future regulatory requirements regarding nitrogen discharge is a significant obstacle to the City's planning efforts. For example, an effluent TN limit could require consideration of a completely different set of alternatives compared to an effluent TIN limit.

It appears that Ecology may not have accounted for the Soluble Organic Nitrogen (SON) present in all municipal wastewater in the range of 1 to 3 mg/L that cannot be removed with biological nutrient removal technology because it is not biodegradable. Furthermore, because SON may not be bioavailable in receiving waters, it may not be relevant to Ecology's intent to improve water quality. If Ecology does not account for the SON included in TN, the effluent nitrogen scenarios that have been modeled at 3/5/8 mg/L TIN may lead to effluent limits that are technically infeasible without molecular removal through reverse osmosis.

At present, the City has limited data to support their understanding of organic nitrogen fractions. The total organic nitrogen noted in the City's Central Treatment Plant (CTP) effluent has varied from 0.1 to 11.5 milligrams per liter (mg/L), averaging 5.1 mg/L over 17 samples taken between 2023 and 2024. Data on soluble organic nitrogen are more limited, with values ranging from zero to 6.5 mg/L, averaging 4.3 mg/L across 10 nonzero results taken between 2023 and 2024. This lack of data is likely similar for other wastewater treatment plants. **The City requests that Ecology require additional monitoring for all nitrogen species to understand the impacts of changing from TIN to TN in the 2025 Reduction Plan before finalizing the document.**

The amount of scatter in the available data makes it difficult to draw conclusions. However, given the available data, one may suggest that a conventional effluent TIN of 3 mg/L may equate to an effluent TN of 8.1 mg/L. In a filtered effluent, with non-detectable solids, an effluent TIN of 3 mg/L may equate to an effluent TN of 7.3 mg/L. **Flipping those numbers around, setting an effluent TN limit of 3 mg/L would result in an effective TIN limit of less than 1 mg/L. This may be impossible to meet with currently evaluated technologies (e.g Membrane Bioreactor (MBR)) and will likely require more advanced treatment systems (e.g. reverse osmosis), in addition to MBR, resulting in even more significant costs.**

Tacoma requests the following:

- **Align the 2025 PSNGP Nutrient Reduction Evaluation (NRE) effluent requirements with the 2025 Reduction Plan. This will be more efficient for utilities to plan for upgrades. Additional time will also be needed if the limits for the NRE are changed from the 2022 PSNGP.**
- **Reconsider the change from TIN to TN in the 2025 Reduction Plan. While the Plan indicated this change was to provide "more flexibility", the reality is that it is stricter than the proposed limits in the 2022 PSNGP NRE requirements. In addition, including all nitrogen species may not actually result in a water quality improvement or benefit to species in Puget Sound.**

1.2 Regulatory Shift to Add CBOD

In addition to changing the effluent removal target from TIN to TN, Ecology also added carbonaceous oxygen demand (CBOD) to the 2025 PSNRP. This shift is significant since it was not included in the 2022 PSNGP NRE requirements or discussed with the utilities.

Ecology justified the inclusion of CBOD by referencing the June 2011 "Technical and Economic Evaluation of Nitrogen and Phosphorus Removal at Municipal Wastewater Treatment Facilities", Ecology Publication 11-10-060, commonly known as the "2011 Tetra Tech Report". On page 32 of the draft 2025 PSNRP, it states:

"Dissolved inorganic nitrogen was used as the target nitrogen species for applying nitrogen reductions from marine point sources in the model based on previous technical and economic evaluations of biological nitrogen removal (BNR) at wastewater treatment plants (Tetra Tech, 2011). Our modeling approach assumed that all facilities reducing DIN loads would also achieve an annual average carbonaceous biochemical oxygen (CBOD) concentration of 8 mg/L year-round (Tetra Tech, 2011), which is translated to a facility specific reduction in dissolved organic carbon (DOC) load in the model (McCarthy et al., 2018)."

However, this justification is flawed. The City could not locate the reference that nutrient removal technologies can also achieve an average annual 8 mg/L CBOD conclusion within the cited 2011 Tetra Tech Report. Additionally, the 2011 Tetra Tech Report was questioned by many engineering consultants for being overly generalized and not accounting for the variability of wastewater treatment plants, site constraints, service areas, and treatment processes. This same reference was also noted as the basis for the modeling efforts for CBOD in the Bounding Scenarios Reports (Phases 1 and 2). Using the 2011 Tetra Tech Report as a continued reference is concerning. There are many more current and available resources that Ecology should have reviewed before setting CBOD effluent limits including:

- The United States Environmental Protection Agency (EPA) 2023 revision to its Publication EPA 832-R-21-006A, "Life Cycle and Cost assessments of Nutrient Removal Technologies in Wastewater Treatment Plants" (EPA Nutrient Lifecycle Guidance). A previous version was also available in August 2021.
- Ecology could have waited for the utilities to complete the PSNGP NRE's to understand what is financially and technically feasible instead of relying on reports that provide general information.

The 2011 Tetra Tech Report does not account for the site-specific constraints faced by existing Puget Sound wastewater treatment facilities. Further, Ecology's association of an annual effluent quality of 8 mg/L CBOD with the nitrogen limits of 3/5/8 do not appear to be supported by the 2011 Tetra Tech report. The City is currently underway in determining the site-specific details necessary to evaluate the actual potential for nutrient removal at existing facilities, which is the purpose of the NRE and All Known, Available and Reasonable Treatment (AKART) analysis originally called for in the 2022 PSNGP. The NRE and AKART evaluations that the City and other wastewater dischargers are invested in preparing should provide the basis that Ecology uses to determine the feasible level of nitrogen removal performance and the potential costs. The information provided by the NRE and AKART analyses should also supersede the 2011 Tetra Tech report and the effluent nitrogen limits assumed by Ecology for the Bounding Scenarios Phase 2 Salish Sea Modeling. Furthermore, the addition of CBOD will likely require addition tertiary filtration after the nutrient removal treatment to consistently meet the 8 mg/L CBOD on an annual basis.

Questions:

- **Where did Ecology find the 8 mg/L annual CBOD reference in the 2011 Tetra Tech Report?**
- **Why was this regulatory shift not discussed with Utilities?**
- **Why was this not included in the 2022 and 2025 PSNGP NRE requirements?**

1.3 Significant Cost Implications

For the past two years, Tacoma has been preparing a NRE, or engineering evaluation, to investigate nitrogen reduction options at its Central (CTP) and North End (NETP) Treatment Plants in accordance with one of the requirements of the 2022 PSNGP. The 2022 PSNGP, issued in January 2022 by Ecology, required municipal wastewater treatment plants (WWTP) discharging to the Salish Sea to evaluate alternatives to reduce TIN concentrations to Puget Sound. The requirements of the 2022 PSNGP NRE include:

- An AKART analysis that presents a recommended alternative representing the greatest TIN reduction that is reasonably feasible on an annual basis, and
- an alternative that can achieve a final effluent concentration of 3 mg/L TIN seasonally (April-October).

Concurrently, Ecology has been using the Salish Sea Model (SSM), a 3-dimensional hydrodynamic and water-quality predictive tool to evaluate the impact of reduced DIN scenarios discharged from watersheds and WWTPs on dissolved oxygen (DO). In June 2025, Ecology issued their latest findings in the Bounding Scenarios Phase 2. The Bounding Scenarios Phase 2 Report concluded the refined Optimization Scenario “Opt2_8” reduced the level of DO noncompliance days while requiring slightly less nutrient reduction than other scenarios. This scenario modeled seasonal DIN limits based on hot (summer), warm (spring/fall), and cool (winter) temperatures. The scenario modeled DIN limits of 8/3/3 mg/L (cool/warm/hot) for CTP and limits of 3/5/8 mg/L for NETP.

Following the invalidation of the 2022 PSGNP, but prior to the June issuance of documents referenced above, the City directed its NRE consultant team to complete a planning level comparison identifying any key differences between meeting three potential regulatory scenarios. The scenarios described below are based on initial information presented in the Nutrient Forum Meeting hosted by Ecology on March 27, 2025, on the Bounding Scenarios Phase 2 results and 2025 PSNRP introduction.

- **Permit Scenario A:** Meeting a seasonal 3 mg/L TIN discharge limit between April through October as prescribed in the 2022 PSNGP’s requirements for NRE analysis. Using the seasonal convention defined above, this would be a 3/3/NL mg/L requirement for hot/warm/cool seasons (where NL means no limit during the cool period).

- **Permit Scenario B:** A scenario limiting the City's WWTP effluent discharges to concentration limits of 3/5/8 mg/L for hot/warm/cool seasons, adding a year-round CBOD limit of 8 mg/L. Subsequently, Appendix H of the 2025 PSNRP indicated that this permit scenario may only apply to the NETP, while the CTP could be required to achieve hot/warm/cool TIN limits of 3/3/8 mg/L. The 3/3/8 mg/L scenario was not evaluated as part of this work, but it is not expected to be substantially different from the evaluated 3/5/8 mg/L scenario.
- **Permit Scenario C:** Applying Permit Scenario B concentration limits at the SSM's 2014 flow condition. The resulting mass limits were adjusted to accommodate the Year 2050 NRE projected flows to determine an equivalent effluent TIN concentration limit as shown below:

$$Effluent\ TIN\ Concentration_{2050} = \frac{WWTP\ Loading\ Limit_{2014}}{WWTP\ Flow_{2050}}$$

These permit scenarios were used as the performance criteria for the analysis and informed the development and refinement of alternatives. Notably, each of the permit scenarios aims to meet specific effluent regulations, without consideration of whether the approaches are reasonable, cost-effective, or environmentally constructive.

Resulting concentration limits for the three permit scenarios are summarized in Table 1.

Table* 1. *Permit Scenario Effluent TIN and CBOD Levels

Permit Scenario	**Effluent TIN Level (mg/L)**			**Effluent CBOD (mg/L)**
Season/ Months	Hot/ July, August, September	Warm/ April, May, June, October	Cool/ November, December, January, February, March	Year Round
Scenario A - NRE	3	3	N/A	N/A
Scenario B – Nutrient Forum	3	5	8	8
Scenario C – 2014 Flow Cap NETP	2.4	4.2	6.9	8[1]
Scenario C – 2014 Flow Cap CTP	2.0	3.6	6.2	8[1]

Note:
1. It is unclear if Ecology plans to cap CBOD at 2014 flows, similar to the cap for nitrogen in the 2025 PSNRP.

An effluent TIN concentration of 3.0 mg/L is generally considered to be the limit of technology for conventional biological nutrient removal as stated by Ecology in the 2022 PSNGP Fact Sheet. There are utilities which have implemented more advanced levels of treatment to reduce effluent TIN below 3.0 mg/L, but this comes with increased cost and risk. There are relatively few examples of installations reliably meeting effluent TIN limits of less than 3.0 mg/L on a long-term basis. Alternatives discussion to achieve the lower TIN limits associated with Scenario C below are intended for comparative purposes and further site-specific analysis is needed to determine the practicality of these limits.

As part of the NRE, a range of technology alternatives were developed to meet the 2022 PSGNP limits. The initial screening process used pass/fail criteria, a collaborative brainstorming session with the City, and the development of preliminary site layouts for each plant upgrade option. Included in the site layouts was the planned CTP solids improvements, which is a project Tacoma must implement first to keep up with growth, replace aging infrastructure, and to create the necessary space for any future nutrient removal upgrades at the space-constrained CTP site. This resulted in a refined list of 21 plant alternatives with representative technologies. Of the 21 alternatives, 10 represented AKART scenarios, designed to reduce effluent nitrogen loadings while not necessarily meeting a prescribed effluent TIN concentration. The other 11 alternatives were designed to meet the NRE's proposed 3/3/NL mg/L seasonal TIN limits.

These plant alternatives were then conceptually developed and qualitatively scored. Based on the preliminary scoring results and discussions with the City, the following two plant alternatives were selected to complete the planning level comparison of the two potential regulatory scenarios:

- NETP: MBR
- CTP C2: MBR with Sidestream Anammox

Capital costs were developed to estimate the upfront investment required to construct the new infrastructure for each systemwide alternative. The capital cost estimates follow the Association for Advancement of Cost Engineering International ("AACE") Recommended Practice 18R-97 classification system as a Class 5 estimate, with an expected accuracy range of -50% to 100%. The capital costs include allowances for contractor markups and professional services.

The capital costs are similar across all the alternatives and permit scenarios with up to $50 million in differences falling well within the expected range of uncertainty for a Class 5 cost estimating effort. The similarity in capital costs across permit scenarios and alternatives is driven by two primary factors:

- Alternatives at both CTP and NETP are constrained by flow. Flow to the secondary process is limited to 65 mgd at CTP and 8 mgd at NETP. Even though permit scenarios B and C include a winter nitrogen removal requirement, the maximum hydraulic flow for those scenarios is the same as that for Scenario A.
- Nitrogen removal is more difficult at cold temperatures, since nitrifying bacteria are temperature-sensitive, and are less efficient in the cold. To overcome this sensitivity, systems which nitrify in cold weather must operate at a longer solids retention time (SRT), which generally requires larger basins. Even though permit Scenarios B and C require nitrogen removal during the regulatory cool months, the permit conditions are both relaxed in the cool months, with targets of 8 mg/L (Scenario B) and 6 to 7 mg/L (Scenario C) and in the warm months, with targets of 5 mg/L (Scenario B) and 3.5 to 4.2 mg/L (Scenario C). These relaxed limits allow nitrification to be turned down during the cool months, which offsets the effect of colder temperatures.
- The 2014 load cap (Scenario C) doesn’t significantly impact sizing compared to Scenario B because while Scenario C has lower effluent TIN limits year-round, the target concentration difference is 0.6 to 1.8 mg/L depending on the season and plant. This additional TIN reduction is driven by increased denitrification and carbon addition but does not impact sizing which was driven by nitrification performance across the alternatives.

The preliminary capital cost estimate for the nutrient upgrades was $625 million to $1.25 billion. The preliminary annual Operations and Maintenance (O&M) costs for the nutrient upgrades is $14.4 million. The average monthly wastewater utility bill would rise from $68 to $419 by 2050 (based on lower range estimate of $625 million), exclusive of additional rate increases needed to replace aging infrastructure, the CTP solids project and O&M cost increases referenced above. The new proposed limits in the Plan using TN go beyond those studied in the NRE, meaning costs would likely rise even higher, with upgrades that may not be financially or technically feasible.

Without substantial external funding or a reassessment of requirements, the proposed regulations would impose a severe financial strain on ratepayers in Tacoma and across the Puget Sound region – while jeopardizing the City’s ability to comply. Existing federal and state funding falls far short of what’s needed to upgrade more than 50 wastewater treatment plants in Puget Sound by 2050. The EPA considers wastewater bills unaffordable when they exceed two percent of household income. Under the updated NRE limits alone, the share of “burdened” Tacoma households – those paying above that threshold – is projected to skyrocket from **14 percent (12,000 households)** to **67 percent (60,000 households) by 2050**. This sharp increase on burdened households underscores the urgent need for additional funding sources or more achievable regulatory targets to avoid placing an untenable burden on our community.

Given these projected impacts, the City respectfully requests that Ecology carefully consider the financial and technical challenges detailed here in order to strike the right balance between achieving environmental goals and implementing practical, affordable solutions in partnership with stakeholders.

1.4 Ecology Financial Capability Guidance

The City previously expressed its concerns regarding Ecology's "Interim Financial Capability Guidance" (Ecology FCA Guidance, Ecology Publication 24-10-034) for the 2022 PSNGP on August 14, 2024. The City is troubled that many of these key concerns were not addressed in the final version. Additionally, Ecology continues to reference the Ecology FCA Guidance as the preferred method for assessing affordability. The key concerns that the City still has include the following.

1.4.1 City's Previous NRE FCA Efforts

The City started its evaluation for the financial capability assessment (FCA) as required by the PSNGP for the NRE earlier in 2024. In June of 2024, Ecology issued the Ecology FCA Guidance which tailors the 2023 EPA Clean Water Act FCA Guidance[3] (2023 EPA FCA Guidance) to Washington State utilities. The Ecology FCA Guidance is primarily grounded in the latest 2023 EPA FCA Guidance; however, there are several key takeaways from the Ecology FCA Guidance that will affect the City's FCA approach.

The Ecology FCA Guidance provides for the evaluation of impacts with Washington specific data using EPA FCA Guidance Alternative 1. Using national benchmarks limits the evaluation of community impacts in the State of Washington and can misrepresent local hardship. The updated guidance uses Washington State financial metrics as a benchmark rather than national financial metrics. The City generally agrees with this approach; however, Tacoma also has some concerns that are detailed in this comment letter.

A notable aspect of the Ecology FCA Guidance is the use of the lowest quintile residential indicator (LQRI) as a preferred metric for assessing the burden on low-income households. The LQRI examines the costs of clean water services for households at the 20th percentile of income (LQI) instead of the median, better reflecting low-income burdens. This metric has been

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[3] Clean Water Act Financial Capability Assessment Guidance | US EPA

recommended by industry groups, and the City has calculated the LQRI as part of its initial assessment.

In its initial evaluation using EPA FCA Guidance, the City compared Tacoma's median household income (MHI) to the national MHI (and similarly for the lowest quintile income). Tacoma's MHI is $81,616, Washington State's MHI is $90,325, and the national MHI is $74,755. The Ecology FCA Guidance evaluates local income and assigns a mid-range result when it is within +/- 25% of the benchmark MHI. Tacoma's MHI is 9.18% higher than the national benchmark and 9.64% lower than the Washington State metric, resulting in the same outcome under either approach. However, this does not highlight that Tacoma's income is below the statewide median rather than above the national median, which is crucial for understanding Tacoma's affordability concerns.

Another element modified by the Ecology FCA Guidance is the lowest quintile poverty indicator (LQPI). This assessment compares income at the LQI, population below 200% of the federal poverty level, households receiving SNAP benefits, vacant housing units, and employment rates to a national/state benchmark. Shifting from a national to a state benchmark results in minimal changes to the overall score, with both indicating a medium impact for Tacoma with current wastewater rates. This medium impact does not account for other rate impacts, including the renewal and replacement of aging infrastructure, evolving regulatory requirements (e.g., emerging contaminants), and significant capital projects needed to maintain the existing utility and capacity for growth. These factors are practical realities for wastewater utilities and their ratepayers to consider when assessing affordability and financial capacity.

As part of the NRE, Tacoma has already started using EPA FCA Guidance Alternative 2 and other affordability metrics to more holistically evaluate long-term rate impacts on the City's burdened communities. It is concerning that the Ecology FCA Guidance did not consider Alternative 2 or other criteria. The use of Alternative 2 and alternative metrics or criteria is further discussed later in this letter.

1.5 It is Unclear if Ecology Will Only Consider Its FCA Approach

The Ecology FCA Guidance highlights several differences from the EPA FCA Guidance and explains why it is better suited for analyzing the economic and environmental justice impacts of Washington-specific and Nutrient Permit-specific projects. However, it remains unclear whether the Ecology FCA Guidance is the only acceptable approach for permittees under the PSNGP or if alternative methods for NRE will be accepted.

For example, the Ecology FCA Guidance states, "while Ecology recommends continued use of EPA's FCA guidance, the release of the February 2023 version (revised March 2024) and updated EPA spreadsheet tool created an opportunity to review and improve its usefulness for evaluating public project impacts in the context of state-specific data." Department of Ecology, Draft Interim Financial Capability Assessment Guidance (Updated June 2024), pg. 9. Additionally, while the Ecology FCA Guidance references the opportunity to "improve" the usefulness of the EPA FCA, it does not discount the EPA FCA's usefulness entirely. Id.

The term "recommend" appears multiple times throughout the document, such as where the agency "recommends" certain considerations in the Ecology FCA Guidance, steps to take when performing the analyses, or materials permittees should submit to the agency's Water Quality Permitting Portal. Id. at 10-11. The pervasive usage of the word "recommend" makes the Ecology FCA Guidance appear non-binding, thus allowing permittees to utilize approaches other than the Ecology FCA Guidance when conducting the required NRE. However, Ecology also incorporates more binding language, such as the statement that "permittees shall provide project costs at the Class 5 level of estimates." Id. at 14. Further, although Ecology is "recommending" certain actions, the Ecology FCA Guidance appears written with an assumption that all permittees will utilize its new tools and amended process for analysis.

Question:

- **Is Ecology's FCA Guidance the only accepted approach or will Ecology accept other alternative methods?**

1.5.1 EPA Guidance on Financial Assessments

The Ecology FCA Guidance does not allow for evaluation of the life cycle cost assessments and the impact to long-term utility rates. In August 2023, EPA released a revision to its Publication EPA 832-R-21-006A, "Life Cycle and Cost assessments of Nutrient Removal Technologies in Wastewater Treatment Plants" (EPA Nutrient Lifecycle Guidance). In its Executive Summary, EPA stated the following:

> Overall, two key findings emerged from this analysis. First, clear trade-offs in cost and potential environmental impact were demonstrated between treatment level configurations. This suggests that careful consideration should be given to the benefits from lower nutrient levels compared to the potential environmental and economic costs associated with treatment processes used to achieve those levels. Combining outcomes into metrics such as nutrients removed per dollar or per unit energy may help to identify configurations that strike an efficient balance

> between these objectives. For example, this analysis found that electricity per unit of total N and P equivalents removed remained consistent from Level 2 through Level 4 but was 2-3 times higher for Level 5 configurations. Second, this analysis demonstrated the value of a life cycle approach to assessing costs and benefits. For example, considering trace pollutants from a life cycle perspective illuminated that the benefits of increased trace pollutant removal from effluent could be outweighed by trace pollutant emissions from materials and energy usage for the Level 5 configuration, an insight that would not have been gained by analyzing on-site WWTP processes alone. In summary, considering multiple economic, social, and environmental costs and benefits from a life cycle perspective can provide critical insights for informed decision making about wastewater treatment technologies.

The 2022 and 2025 PSNGP call for treatment alternatives to be developed for achieving AKART for nitrogen removal on an annual basis and a seasonal average of 3 mg/L TIN from April through October. Achieving effluent TIN of 3 mg/L is an extraordinarily level of treatment that is expected to be costly and result in external environmental impacts that should be carefully considered before being required. Ecology's seasonal average of 3 mg/L TIN would be equivalent to EPA's Level 4 in the Life Cycle Cost Analysis, the highest level of treatment short of reverse osmosis (Level 5). The shift from TIN to TN in the 2025 PSNRP would likely require Level 5. Costs increase as the treatment levels increase, as does energy use, chemical use, excess solids residuals generation, and damaging greenhouse gas emissions. Nitrogen removal at these levels requires supplemental carbon addition using dangerous chemicals, such as methanol. Ecology's FCA doesn't account for the costs of these externalities that impact the environment at this level of treatment.

The City requests that Ecology review the EPA Nutrient Lifecycle Guidance to revise the Ecology FCA Guidance to account for more factors to evaluate the balancing point where there are diminishing benefits and disproportionate impacts to the environment and economy. The EPA Nutrient Lifecycle Guidance should also be considered as part of Ecology's decision making moving forward for nutrient removal regulations. The City plans on using the EPA Nutrient Lifecycle Guidance as part of its NRE effort.

1.5.2 Alternative Financial Assessment Options

In the 2025 Draft PSNGP Fact Sheet, Ecology stated "Ecology recommends using EPA's Clean Water Act Financial Capability Assessment (2024) or Ecology's Final Treatment Plant Financial Capability Assessment Guidance (2024) when looking at options for assessing financial capabilities to implement requirements under the Clean Water Act" (page 53). The EPA FCA Guidance from 2021 has continued to evolve and was updated in 2024.

The current 2024 EPA FCA Guidance has two alternatives to consider:

- Alternative 1: Customer Burden Matrix (expanded 1997 EPA approach)
    - The Ecology FCA Guidance has only considered this option.
    - Generally intended for schedule development and negotiation.
- Alternative 2:
    - This alternative provides a more nuanced and specific assessment of local affordability including rate model forecasts with long-term rate impacts. It can account for many competing priorities at a utility including (to name a few examples):
        - Asset management: renewal and replacement of aging infrastructure
        - Increasing operating costs
        - Declining water sales due to water conservation (which can impact utility rate structures that rely on water usage versus fixed rate structures)
        - Utility specific rate structure and other rate limitations
        - This alternative would provide a more accurate financial impact to the City's rate payers than Alternative 1.

In its FCA Guidance, EPA includes Alternative 2 to provide a more realistic representation of financial impacts by including the entire schedule of projects in a cash flow analysis. The intent is to represent realistic wastewater utility bills that are within reasonable bounds when establishing compliance schedules.

In addition to the EPA FCA Guidance, there are other resources and approaches for evaluating and measuring household affordability including:

- Affordability Ratio (AR20): using the basic sewer price as a percentage of disposable income after non-water essential expenses for the 20th income percentile
- Hours worked at minimum wage
- Household Burden Indicator

- Poverty Prevalence Indicator
- Burden After Housing Costs
- Typical Bills by Neighborhood
- Additional Resources:
    - American Water Works Association (AWWA)
    - Water Environment Federation (WEF)
    - University of Washington Self-Sufficiency Standards
    - Massachusetts Institute of Technology (MIT) Living Wage Calculator
    - United States of America Census Public Use Microdata Areas (PUMAs) Statistics

The City has already used the other resources and approaches as part of its initial FCA evaluation. Tacoma has identified that essential expenses currently exceed income at the 20th percentile in the City. As part of the NRE, Tacoma has already started using EPA FCA Guidance Alternative 2 as well as the other metrics and resources shown above. The City's FCA evaluation is ongoing as the NRE components are completed.

1.6 Alternative Rate Structures

Alternative rate structures are not legal under state law or the Washington State Constitution.

Ecology has recognized that the financial impact of the costs of treatment can create an unreasonable burden upon communities served by wastewater treatment plants. See, *Northwest Environmental Advocates v State,* 2021 Wash. App. LEXIS 1558 (2021). Overburdened communities will bear a significant and disproportionate burden of the cost of compliance with the 2025 PSNGP and future cycles of the permit.

While the City appreciates Ecology's effort to address environmental justice by requiring an affordability assessment, the assessment will do nothing to address the disparate impact of the cost burden of the 2025 PSNGP upon communities of color, Tribes, indigenous communities, and low-income populations. State law does not allow dischargers to create rate classifications based upon ability to pay, except as authorized pursuant to RCW 74.38.070 for low-income citizens. See, RCW Chapters 35.67 and 35.92. Tacoma already has a program for rate reductions under this statute. These allowable rate reductions are offset by increased rates for the remaining ratepayers. All other rate classifications must be based upon the cost of service and must be allocated equitably based upon service received. *See generally King County Water Dist. No. 75 v Seattle*, 89 Wn. 2d 890, 903 (1978). A utility has a duty to fix rates that are just and reasonable and not unduly discriminatory. *Faxe v Grandview*, 48 Wn. 2d 342, 347 (1956). Rates must comply with Article 1 § 12 of the State Constitution which requires that rates be non-discriminatory, meaning that rates apply alike to all persons within a class, and that there must be a reasonable ground for creation of different rate classifications. *Faxe,* 89 Wn. 2d at 348. Rate classifications under state law are based upon such factors as cost of service, the character of the service furnished, or the quantity or amount received. *Faxe,* 89 Wn. 2d at 349-350. State law outlines the criteria in Chapter 35.67 and 35.92 RCW. Neither state law nor the state constitution allow rate classifications based upon an affordability assessment with the exception of low income rate reductions authorized under state law and which are already being implemented. Accordingly, the concept of a study and proposal for rate alternatives only serves to create false hope that the enormous impact of funding the cost of treatment can be more equitably distributed. Further, it will not address the reasonableness of the overall costs of compliance to be borne by all of the rate payers.

Questions:

- **In response to comments, can Ecology explain what assessment Ecology has made to address environmental justice impacts from the proposed permit?**
- **In response to comments, can Ecology explain how the requested report will be used to regulate NPDES permits for publicly owned WWTPs?**

1.7 Environmental Justice Considerations

While the EPA FCA Guidance and other industry resources rely on the LQI focused on the 20th percentile of income, it may not be the best or only indicator to understand impacts to our community’s burdened and vulnerable people. Income is only one component of the impact and a more meaningful approach using an equity lens would be to understand what the “living wage” and “cost of living” are in the community. Overall, the financial component of the Environmental Justice evaluation needs to have a holistic approach beyond just income. The City plans on using the other financial resources noted in Section 1.5.2 to address this concern.

1.8 Integrated Planning

As part of the March 2024 Revision to the EPA FCA Guidance, EPA included the following regarding the history of relevant guidance and an integrated planning framework:

> In 2012, EPA developed the Integrated Municipal Stormwater and Wastewater Planning Approach Framework (Integrated Planning Framework) that offers a voluntary opportunity for a municipality to develop an integrated plan to meet multiple [Clean Water Act] CWA requirements. Integrated planning is a process that municipalities can use to achieve clean water and human health goals while addressing aging infrastructure, changing population and precipitation patterns, and competing priorities for funding. With the release of the Integrated Planning Framework, the Agency [EPA] clarified that an FCA could include the following costs: stormwater and wastewater; ongoing asset management or system rehabilitation programs; existing CWA related capital improvement programs; collection systems and treatment facilities; and other CWA obligations required by state or other regulators. On January 14, 2019, the Water Infrastructure Improvement Act (WIIA) (H.R. 7279) added a new section 402(s) to the CWA to include the 2012 Integrated Planning Framework.

The Integrated Planning sections of the EPA FCA Guidance have not been included as part of the Ecology FCA Guidance, despite the added benefits and avoided impacts that come from such an approach. Integrated plans and components would "include a financial strategy and capability assessment that ensures investments are sufficiently funded, operated, maintained and replaced over time and include consideration of current and planned rates and fees." This is relevant and important for Washington State utilities that are facing potential significant upgrades at the same time as robust asset management requirements (aging infrastructure), capacity upgrades, and multiple regulatory requirements. Rate payers will ultimately shoulder the burden of costs from all these significant rate drivers, not just nutrient removal. In addition, an Integrated Planning Framework should be used to inform any viable compliance schedule.

1.9 Lack of Available Funding – Federal and State

The City requests a more comprehensive and centralized analysis by Ecology to identify applicable funding resources for nutrient removal costs and strategies to advocate for new resources, determine eligibility rules (e.g., whether certain programs are available only to specific wastewater utilities), and understand the levels, priorities and competition for available funding. This centralized approach would be more efficient than having individual utilities research eligibility and funding requirements or advocate for funding independently. It would also help regional partners better understand the adequacy or gaps in available funding compared to the estimated costs utilities will assess in their FCAs. Additionally, this would better position Ecology for any funding requests and proposals to the Legislature with coordinated utility support. While Ecology has indicated that an additional $10 million is available for nutrients, it does not provide any meaningful relief for Tacoma ratepayers based on the cost estimates Tacoma provided above, nor other Puget Sound utilities that will be similarly situated.

2.0 Growth

2.1 Moratorium

Permit limits based on 2014 Flow Based TIN loading conflict with Tacoma's obligation to provide wastewater services to the service areas of its facilities under the Growth Management Act.

Ecology has unreasonably based numeric effluent action levels on calculated levels of 2014 Flow Based TIN loading from flow data and nitrogen concentration data. The action levels do not account for inevitable future growth, even though Ecology acknowledges and bases much of its actions under the related 2025 PSNRP on such growth and that more updated flow data is available.

Tacoma is obligated under the Growth Management Act to accept and facilitate growth within the applicable urban growth boundaries. RCW 36.70A.020. The Growth Management Act is intended to ensure public facilities and services necessary to support development are adequate to serve the development without decreasing current service levels. Associated with this obligation is the parallel requirement under the City's individual National Pollutant Discharge Elimination System (NPDES) permits to maintain sufficient capacity to provide wastewater treatment within the service areas of its two facilities. This is a permit condition in both of Tacoma's individual NPDES permits issued by Ecology, the 2025 PSNGP, and a requirement that is reflected in the general facility plans and engineering documents generated by Tacoma under WAC 173-240-050 and WAC 173-240-060.

Ecology is locking in effluent limitations that fail to consider the City's obligations under the Growth Management Act and permitted design flows for its facilities that may be irrevocable under state and federal water quality anti-backsliding regulations. By adopting an effluent limit based on 2014 flow based loading and concentrations, Ecology will be denying Tacoma any ability to provide for anticipated growth or leave the City in violation of its permit until nutrient reduction technology can realistically be implemented. Ecology should instead be considering loading on the same time scale the facilities are regulated under in their facility plans and engineering documents, which account for growth over the next 30-40 years.

Questions:

- **In response to comments, can Ecology explain why it has not considered design flows and the need to maintain treatment capacity in setting effluent limitations in the 2025 PSNGP?**
- **In response to comments, can Ecology explain how it has evaluated the impact of the effluent limitations on the ability to develop low and moderate income housing?**
- **In response to comments, can Ecology explain how it has evaluated the potential environmental justice concerns that will result from reduced access to affordable housing?**
- **In response to comments, can Ecology explain how it has evaluated the applicability of anti-backsliding regulations to the proposed effluent limitations?**
- **In response to comments, can Ecology explain how it has evaluated the potential concerns that will result from little to no growth in the customer base that will be responsible for paying for nutrient reduction upgrades?**

2.2 Corrective Actions = De Facto Moratorium

The 2025 PSNGP sets action levels for TIN loading at historical (initial years prior to 2020) discharge levels for large and moderate-sized facilities and requires the facilities take specific corrective actions if reported TIN levels exceed the action level. When a permittee exceeds the action level, Condition S4.D requires the facility to prepare a strategy, in the form of an engineering report, that identifies treatment options and design alternatives to reduce the annual effluent load by at least 10% below the action level. The required 10% reduction in annual effluent load is essentially a de facto moratorium. By capping TIN levels at historical loading, the action levels laid out in the permit do not account for future growth. As a result, it is almost inevitable that facilities will trigger corrective actions. Based on previous data, current discharge levels demonstrate that many facilities are expected to exceed the draft action levels within the first permit cycle. The 2025 PSNGP requires those exceeding action levels to submit a proposed approach to reduce effluent levels, utilizing solutions that can be "implemented as soon as possible". Planning for and implementing technologies to reduce TIN loading is a long and complicated process which the corrective action provision in the 2025 PSNGP does not take into account.

Further, requiring facilities to submit and implement proposals for 10% reduction will effectively delay any current major capital projects to address nutrient issues at the effluent limits in the 2025 PSNRP. It is also important to note that part of the NRE analysis Tacoma has already conducted did not identify any viable solutions to incrementally reduce nutrient loading by 10%; to effectively reduce loading, decisions would need to be made farther in advance to account for more significant improvement projects. In fact, the next step for implementing any nutrient reduction technology at CTP, Tacoma's largest WWTP, would be side stream treatment that could achieve approximately 20% reduction, but would cost $30 – 60 million and take 12 to 15 years to be operational. In addition, Tacoma had already identified a solids project that would relocate CTP's solids system ($325 to $650 million) to the other side of the plant and would strand any side stream process near the existing solids system. The timeline for the solids project is still being evaluated and will likely occur after the 12 to 15 years from today. In summary, efforts to implement the corrective actions will divert funds and personnel from ongoing planning of capital projects and other measures that are already in progress to reduce nutrient loading and likely result in significant stranded costs.

Interim limits should be based on current discharge levels that include design capacity and anticipated growth. The Ecology Permit Writer's Manual states that the agency has, "observed over the years that it takes municipalities several years to plan and fund expansions of the wastewater treatment plant," and therefore permit writers should, "note the population growth of a municipality when redrafting their wastewater discharge permit."4 The Permit Writer's Manual also states that the capacity outlined in a plan, "must be sufficient to achieve the effluent limitations and other conditions of [the] permit."5 When parties appealed the 2022 PSNGP, Ecology had agreed to a partial stay that included staying the permit conditions related to corrective actions, due to the various issues outlined above. It is inappropriate and unreasonable

[4] Washington State Department of Ecology, Water Quality Program Permit Writer's Manual (July 2018), pg. 156.

[5] *Id.* at 157.

to retain these provisions in the 2025 PSNGP. Imposing corrective actions under the general permit will potentially result in lost capital expenses and deflect resources that should be focused on completing the NRE process and long-term solutions for nutrient loading.

2.3 Conflicting Deadlines for Corrective Action Versus Other Project Implementations

Condition S4.D of the 2025 PSNGP outlines corrective actions facilities must take if reported TIN loading exceeds the permit action levels. The 2025 PSNGP requires facilities that exceed their action level to submit to Ecology for review a proposed approach to reduce the annual effluent load by at least 10% below the action level and be implemented "as soon as possible." The proposed approach must be submitted in the form of an "engineering report or technical memo" unless Ecology has already approved a design document with the same proposed solution. This engineering document must include much of the same information Tacoma has submitted or is preparing and planning to submit in similar reports as part of its comprehensive sewer planning and facility planning required under state law. Tacoma is unaware whether Ecology has even begun to review the reports the City has already submitted. The corrective actions required under the 2025 PSNGP directly conflict with timelines set out in other planning documents the City is required to submit per state law.

When constructing or modifying domestic wastewater facilities, engineering reports and plans and specifications for the project must be submitted to and approved by Ecology before implementation. WAC 173-240-030. This requirement and related timeline are separate from what Ecology is proposing be required under the 2025 PSNGP. The corrective action required under Condition S4.D would effectively impede facility efforts to submit other similar reports as required under state law. It is unreasonable and unlawful to impose deadlines for corrective actions that conflict with these other requirements. The engineering document required under Condition S4.D is thus not allowed under state administrative code, as Ecology does not have the authority to require a utility to violate state law. WAC 173-06-120(8).

3.0 Desire for Collaboration/Partnership

3.1 Significant Reviews with Limited Time and Missed Opportunities for Collaboration

The City appreciates that Ecology has provided meetings and opportunities for public comment. However, our experience has been that these opportunities often come after key decisions have already been made, limiting the ability to influence outcomes in a meaningful way. While procedural requirements for public engagement may be met, the spirit of true collaboration and engagement has too often been absent. As a result, opportunities to explore viable, cost-effective alternatives are being lost. The City has consistently requested more meaningful collaboration to address the complex challenges of nutrient reduction.

By way of more recent examples, Ecology staff indicated during the March 2025 Nutrient Forum that Ecology intends to issue the finalized 2025 PSNGP and 2025 Reduction Plan by the end of the year (2025). However, we did not receive any further details until the draft documents were issued for public comment in June 2025. This compressed timeline has significantly limited the opportunity for transparent, substantive engagement on critical issues raised in this comment letter.

Moreover, from mid-June through August 27, Ecology released a large volume of documents, totaling thousands of pages, for review. The scale and pace of this review process have placed a substantial burden on stakeholders. The City was disappointed that Ecology declined to extend the review period, a mere four weeks, despite the complexity and significance of the materials.

In light of these concerns, the City respectfully requests that Ecology commit to a more robust, transparent, and collaborative stakeholder process. Specifically, we urge Ecology to engage regularly, at least monthly, with all partners prior to finalizing the 2025 PSNGP and the 2025 PSNRP. This approach will help ensure that the final plan and permit reflect the best, most achievable path forward, developed in partnership with the communities and utilities most affected and integral to its success.

3.2 Technical Advisory Committee

Appendix H of the 2025 PSNRP outlines the formation of a Technical Advisory Committee (TAC) and emphasizes the importance of stakeholder input in making key decisions. The City requests that Ecology convene the TAC promptly and before finalizing the PSNRP. Given the limited opportunities for input during the draft phase, establishing the TAC now in a collaborative environment would allow for meaningful contributions and result in a more robust final PSNRP. This approach would demonstrate Ecology's genuine interest in feedback from dischargers and better understanding the opportunities and challenges on the ground for implementing such significant upgrades to facilities region-wide. Finalizing the document without this critical input and only convening the TAC after the 2025 loads and timeline are set would diminish the TAC's effectiveness and ultimately, the 2025 PSNRP's effectiveness. Tacoma requests to be a member of the TAC and looks forward to hearing from Ecology about it. Additionally, Tacoma requests that the TAC be facilitated by an independent facilitator to ensure meaningful engagement.

Questions:

- **When will Ecology convene the Technical Advisory Committee?**
- **What are Ecology's goals for the Technical Advisory Committee?**
- **When will Ecology provide more information about the Technical Advisory Committee?**
- **Will independent and unbiased facilitation be available for the Technical Advisory Committee?**

3.3 Power Impacts and Regional Energy Considerations

As part of its NRE effort, the City assessed the anticipated increase in power demand resulting from nutrient treatment upgrades needed to meet the proposed concentration limits of 3/5/8 mg/L TIN for hot, warm, and cool seasons, along with a year-round CBOD limit of 8 mg/L. The analysis indicates that these upgrades would increase power consumption by approximately 2.8 times at the CTP and 3.6 times at the NETP. These are substantial increases that will place significant additional demand on the local power grid.

Preliminary discussions with Tacoma Power revealed that local power utilities were not fully aware of the scale of these projected increases. This highlights a critical gap in coordination between regulatory planning and utility infrastructure readiness. With over 50 wastewater treatment plants expected to implement similar upgrades by 2050 under the 2025 PSNRP, the cumulative regional power demand could be considerable. Similar to wastewater utilities, power utilities face complex regulatory and long-term planning processes to implement significant capacity or other upgrades to the local and regional power grid.

This issue is further compounded by the broader context of increasing demand for electricity across the Puget Sound region. The transition to electrification in transportation, heating, and industry, along with the need to support data centers, housing growth, and climate resilience means that power utilities are already facing mounting pressure to expand generation capacity and grid reliability. Adding large, uncoordinated loads from wastewater treatment upgrades could strain the system and lead to unintended consequences, including delays, increased costs, or reliability concerns.

Given these intersecting challenges, the City strongly urges Ecology to proactively engage with regional power providers, including Tacoma Power and other public and private power utilities, to assess and plan for the cumulative energy impacts of nutrient reduction requirements. A coordinated approach is essential to ensure that power infrastructure can support these upgrades without compromising other critical energy needs in the region.

The City also recommends that Ecology:

- **Conduct a regional energy impact assessment in collaboration with utilities and stakeholders.**
- **Integrate power demand considerations into the planning and phasing of nutrient reduction requirements.**
- **Explore opportunities for energy efficiency, resource recovery, and renewable energy integration as part of the upgrade strategies.**

3.4 Nitrogen Removal Operations at Wastewater Treatment Facilities

The operational frameworks presented in the 2025 PSNRP are based on seasonal concentration limits of 3/5/8 mg/L TIN for hot, warm, and cool seasons, respectively, along with a year-round CBOD limit of 8 mg/L (with some variation for some dischargers, e.g. 3/3/8 mg/L TIN at CTP). Appendix E translates these concentration-based frameworks into monthly load targets for each facility, using 2014 flow conditions as a baseline.

However, this approach does not reflect the operational realities of biological nutrient removal at wastewater treatment facilities. Nitrification and denitrification processes rely on the development and maintenance of a stable microbial biomass, which is highly sensitive to fluctuations in flow, load, and environmental conditions. These biological systems cannot be turned on or off on a monthly, or even seasonal, basis without risking significant process instability. Even minor changes in influent characteristics or operational parameters can result in biomass loss (through die-off or washout), requiring days or weeks to reestablish the microbial populations necessary for effective nutrient removal.

The current framework assumes a level of operational flexibility that is neither technically feasible nor advisable for maintaining consistent and reliable treatment performance. While Appendix H suggests that annual or concentration-based load compliance may be possible, the structure and assumptions embedded in Appendix E do not align with that approach. The monthly load targets derived from seasonal concentration limits do not account for the need for operational stability and continuity in biological treatment processes.

The City respectfully requests that Ecology revise Appendix E to better reflect the realities of treatment plant operations. Specifically, we recommend that Ecology:

- Rerun the SSM using an annual average load or concentration framework that aligns with how facilities can realistically operate.
- Provide flexibility in compliance structures that allow for stable, year-round operations rather than rigid monthly or seasonal shifts.
- Engage with operators and engineers to ensure that regulatory frameworks are grounded in practical, science-based understanding of biological treatment systems.

This adjustment would support more reliable compliance, reduce operational risk, and better align regulatory expectations with the technical capabilities of treatment facilities.

3.5 Timelines and Planning Uncertainty

The 2025 PSNGP NRE requires utilities to provide "viable implementation timelines that include funding, design, and construction for meeting both the AKART and seasonal average 3 mg/L TIN preferred alternatives" (pages 20 and 28 of the 2025 PSNGP Permit document). However, Ecology's FCA Guidance states:

"We also emphasize that [FCA] results, for the purpose of the Nutrient Permit, are not intended for schedule negotiation."

This statement is deeply concerning and appears to directly contradict the NRE requirement. If utilities are expected to propose viable implementation timelines, then affordability and schedule development must be inherently linked. The FCA spreadsheet tool, which Ecology notes aligns with the 2023 EPA FCA Guidance (pg. 34), is designed to evaluate the economic impact of water quality decisions. It is not reasonable to separate affordability from implementation timelines when both are essential to determining what is feasible for each utility.

Additionally, the 2025 PSNRP proposes a regional implementation target of 2050. This date was not discussed with utilities prior to its inclusion, nor was it informed by the results of the NREs, which are still underway. This top-down approach undermines the collaborative planning process and fails to account for the diverse financial, technical, and logistical realities faced by individual utilities.

Compounding this issue, the 2025 PSNGP reintroduces the Corrective Action requirement, which mandates upgrades to reduce effluent TIN by 10% below the Action Level. This requirement, reinstated after being stayed in the 2022 PSNGP, creates significant planning challenges. Requiring two separate upgrades for the same parameter within overlapping timeframes introduces confusion, inefficiency, and potential duplication of effort in design and construction.

Planning around the evolving limits remains a significant challenge due to the shifting regulatory, financial, and strategic landscape. Each iteration introduces new constraints or priorities that can alter other City project scopes, timelines, and resource allocations. This fluidity makes it difficult to establish long-term plans with confidence, as assumptions made under one framework may no longer hold under the next.

The City respectfully requests that Ecology:

- Clarify the role of the FCA in informing implementation timelines and acknowledge that affordability and scheduling are inseparable.
- Explain the rationale for setting a 2050 implementation target without prior consultation with utilities.
- Consider removing the Corrective Action requirement due to its timing relative to the broader nutrient reduction planning process.
- Commit to aligning regulatory timelines with the outcomes of the NREs to ensure that implementation schedules are grounded in real-world feasibility.

Questions:

- **Why does the NRE require an implementation timeline when Ecology has proposed a 2050 target in the 2025 PSNRP?**
- **Why was the 2050 timeline not discussed with utilities prior to its inclusion?**
- **Why did Ecology not wait for the completion of the NREs to better understand viable corrective actions and feasible timelines for each WWTP and utility?**

3.6 Regional Capacity Constraints for Nutrient Removal Upgrades

Requiring over 50 wastewater utilities in Washington to upgrade for nutrient removal within the same 25-year period (compliance target in 2025 PSNRP) presents a significant logistical and workforce challenge that the regional engineering and construction sectors are not equipped to handle. The scale and complexity of these upgrades, which involve advanced treatment technologies, will place unprecedented demand on a limited pool of qualified engineers, consultants, equipment suppliers, and construction contractors. This situation is reminiscent of the transition to secondary treatment under the Clean Water Act, which took several decades to implement across the state due to similar capacity and funding constraints.

3.7 Examples of Robust Collaboration

Successful collaborations are based upon transparency, mutual trust, a shared mission, sustained participation among stakeholders, and a capacity to take action. There are examples of successful collaborations on watershed nutrient management, such as San Francisco Bay where the Bay Area Clean Water Agencies (BACWA wastewater dischargers) and the San Francisco Regional Water Quality Control Board (RWQCB regulatory agency) collaborated on the nutrient watershed permit for the Bay over 3 permit cycles. Under the watershed permit, members work together to fund nutrient monitoring programs, support load response modeling, and conduct studies to better understand treatment plant optimization opportunities and upgrade needs to achieve nutrient removal. The collaborative nature of the BACWA Watershed Permit has gained national attention as evidenced by their 2019 NACWA Platinum Award for Partnerships (National Association of Clean Water Agencies). Beyond the overall partnership, there are numerous collaborative efforts to advance the nutrient management strategy, such as the nutrient management strategy group that is led by San Francisco Estuary Institute (SFEI) which focuses on the science. The EPA Regional Office have been strong supporters of this effort by annually speaking at the BACWA Annual Conference and financially sponsoring regional grants, specifically on side-stream treatment and a Nature Based Solution (NbS) demonstration facility (Water Research Foundation (WRF 2023)[6].

Partnerships are one of the foundational aspects of collaborations to develop effective nutrient management strategies and achieve equitable water quality improvements. Watershed partnerships need to address complex environmental problems that span organizational and jurisdictional boundaries. For these reasons, the traditional bureaucratic approaches to environmental management and partnerships may be ineffective and could be a hinderance to producing effective environmental outcomes (Biddle 2017[7]). Effective watershed partnerships are based upon establishing principled engagement, shared motivation, and a capacity for joint action within partnerships. Each of these elements include key subcomponents that are critical to producing outcomes, such as mission consensus, mutual trust, and sustained participation.

3.8 PSNGP Appeal Issues

Ecology has not adequately addressed utility concerns raised during the development of the previous 2022 PSNGP and the 2025 PSNGP, despite these issues being brought forward during the Advisory Committee process and again in over 40 separate issues raised during the 2022 PSNGP appeals process. Notably, the PCHB did not review these utility-specific concerns in its February 2025 ruling, which focused instead on broader legal questions such as the mandatory nature of the permit. Utilities have consistently expressed that the permit imposes significant obligations without providing the necessary regulatory clarity, updated science, technical guidance, or financial support. Key unresolved concerns include:

- Implementation of action levels or caps based on historical discharge data, which do not account for variability in influent quality, seasonal flows, or operational constraints.

[6] Clark, D.L., Stober, J.T., Falk, M., Holmberg, H., and Vanrolleghem, P. (2023). Holistic Approach to Improved Nutrient Management. WRF4974

[7] Biddle, J. 2017. *Improving the Effectiveness of Collaborative Governance Regimes: Lessons from Watershed Partnerships*. *Journal of Water Resources Planning and Management.* 143(9) September 2017.

- Mandatory corrective actions requiring 10 percent reductions in nutrient loads, which would trigger costly infrastructure upgrades without guaranteed funding or realistic implementation timelines.
- Unclear application of AKART (All Known, Available, and Reasonable methods of prevention, control, and treatment), leaving utilities uncertain about compliance expectations and enforcement risks.
- Insufficient consideration of affordability and ratepayer impacts, particularly for smaller or financially constrained utilities.
- Absence of a phased or adaptive management approach, which could allow for more flexible, science-based implementation as monitoring data becomes available.
- No clear pathway for permittees to demonstrate compliance through non-capital strategies, such as optimization or source control, which could be more cost-effective and timely.
- Concerns about how Ecology applied the DO water quality standard, including reliance on outdated or overly conservative modeling assumptions that may not reflect current conditions in Puget Sound.
- The need for updated science and site-specific data, particularly regarding nutrient impacts on DO levels, to ensure that regulatory decisions are based on the best available evidence and tailored to actual environmental risks.
- Failure to conduct a cost-benefit analysis, leaving utilities without a clear understanding of the economic implications of the permit’s requirements relative to the anticipated environmental benefits.
- Inadequate SEPA (State Environmental Policy Act) analysis, which did not fully evaluate the environmental, economic, and social impacts of the permit or consider reasonable alternatives.

These concerns reflect a broader frustration that the permit imposes significant obligations without providing the necessary regulatory clarity, technical guidance, or financial support to ensure successful implementation.

4.0 Science

4.1 Dissolved Oxygen Standard and Requirement to Use Sound Science

Under Section 303(c) of the Clean Water Act (CWA) and federal implementing regulations at 40 CFR § 131.4, states and authorized tribes have the primary responsibility for reviewing, establishing, and revising water quality standards, which consist primarily of the designated uses of a waterbody or waterbody segment, the water quality criteria that protect those designated uses, and an antidegradation policy to protect high quality waters. The Washington State surface water quality standards are established under WAC 173-201A.

The dissolved oxygen criteria Ecology uses to determine whether a water body is "impaired" do not meet federal requirements of 40 CFR 131.11. EPA's Water Quality Standards Regulation requires states to adopt water quality criteria using "sound scientific rationale". § 131.11(a). The law also requires criteria be established based on federal guidance or "other scientifically defensible methods." 40 CFR 131.11(b)(1). The state's DO criteria fail to meet both of these standards, as they are not biologically-based and there is no evidence of the criteria being established according to any sound federal guidance or scientifically-defensible methods.

The state first adopted marine DO numeric criteria in 1967, and these criteria continue to be the applicable water quality standards despite being 58 years old. Ecology reports have claimed that the marine water quality standards were developed under the CWA framework, specifically 40 CFR 131.11, but that is a factually impossible statement, since the 1967 criteria were adopted before the CWA even existed. Ecology searched through historical archival records in an attempt to find the origin of the current marine DO numeric criteria. Finding no definitive records, Ecology determined that, "little information exists in general regarding the water quality standards."[8] Ecology admitted it could find no basis for the criteria in the state's archives and does not have supporting information on the technical basis for the existing criteria.[9]

In 2018, Ecology claimed to have found the basis for the DO criteria, asserting unambiguously that the basis lies in a Department of Interior (DOI) water quality criteria document published in 1968. The 1968 DOI report states that, "surface dissolved oxygen concentrations in coastal waters shall not be less than 5.0 mg/l, except when natural phenomena cause this value to be

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[8] *Id*.

[9] Letter from Mark Hicks to Lincoln Loehr (July 8, 1998).

depressed," and, "dissolved oxygen concentrations in estuaries and tidal tributaries shall not be less than 4.0 mg/l at any time or place except in dystrophic waters or where natural conditions cause this value to be depressed."[10] The report's recommendations of 5 and 4 mg/l do not resemble the marine DO criteria of 7, 6, 5 and 4 mg/l adopted by Washington in 1967. Further, directly after these statements, the report cautions, "[t]he [National Technical Advisory Committee] would like to stress the fact that, due to a lack of fundamental information on the DO requirements of marine and estuarine organisms, these requirements are tentative and should be changed when additional data indicate that they are inadequate."[11] Based on the lack of knowledge or materials supporting Ecology's current DO criteria, paired with the fact that the 1968 DOI report (the one piece of documentation Ecology asserts as a basis for its criteria) explicitly admits to this lack of knowledge and instead speaks to the need for updated standards, it is clear there is no supporting evidence to claim the current DO criteria Ecology uses for the state DO water quality standards is based on "sound scientific rationale" or is based on a "scientifically-defensible method".

The DO criteria also fail to meet the requirements in Chapter 2 of the state's Water Quality Policy 1-11: "Ensuring Credible Data for Water Quality Management". State law requires that Ecology use credible data when determining whether a water body is impaired or whether any surface water of the state is supporting its designated use. RCW 90.48.570 - 90.48.590. With no historical record or evidence of the current DO criteria being based on credible data, the standard cannot be used to determine impairment of water bodies based on DO, nor can it drive permitting requirements or other related nutrient reduction actions.

Apart from there being no supporting materials for how the current criteria were established or that they were established using credible data, there is supporting information showing the criteria do not accurately reflect the needs or behavior of the local aquatic species. For example, marine waters with 5 mg/l DO in many deep-water basins are considered noncompliant under the current standards, when in fact the oxygen level poses no threat to organisms the standards are intended to protect. A study was conducted to identify where oxygen falls below critical levels for certain species in areas of Puget Sound.[12] Results showed that environmental conditions for

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[10] Department of the Interior Federal Water Pollution Control Administration, Water Quality Criteria Report (April 1968), pg. 70.

[11] *Id*.

[12] University of Washington Puget Sound Institute, Presentation on Temperature Dependent Oxygen Thresholds for Marine Life (Aug. 15, 2025).

Dungeness Crab remained above the threshold oxygen level in all but three distinct areas of Puget Sound. Where DO was lowest, in Southern Hood Canal, it was only below the oxygen threshold for one month out of the year (November 2014); spatial variability was only impacted in Southern Hood Canal for that one month as well. The study showed the same results for Chinook Salmon in Southern Hood Canal, but the impact was further limited to only the deeper layers of the water column, where the Dungeness Crab exist as well, whereas DO in the upper layers remained at sufficient levels. Further, for the Chinook Salmon, a map of where oxygen fell below the threshold level was even more confined than that for Dungeness Crab, showing almost an absence of impact on a wider scale across Puget Sound. This initial analysis confirmed that DO impacts for these local species are limited to certain Puget Sound areas and specific periods of the year.

Additional studies have expounded on the fact that marine life may be more resilient than the current standard assumes.[13,14] For example, fish were found at lower DO levels, as low as 1.3 mg/L for herring and 2.06 mg/L for Chinook salmon, even when DO levels higher in the water column were greater than 6 mg/L.[15] Maintaining adequate levels of DO is critical for the survival and well-being of marine organisms, but accurately predicting responses and impacts on aquatic species can be difficult. The current scientific understanding and ability to predict habitat and species shifts due to changes in oxygen supply and demand are limited by a lack of available knowledge on Salish Sea species' vulnerability to the combined impacts of low DO and warming waters.[16]

Additionally, the current criteria allow for no less than 6 or 7 milligrams of DO per liter, but studies have surmised most of Puget Sound has never met those standards, even in pre-anthropogenic times. Simply stated, the current DO criteria Ecology uses to determine whether a

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[13] Puget Sound Institute Nutrient Discussion (Jun 6, 2025); Genoa Sullaway & Tim Essington, Biological sensitivity of Salish Sea taxa to low oxygen levels: determining observed metabolic demand thresholds of key taxa based on concomitantly measuring abundance, oxygen, and temperature (Feb. 2025) ("Salish Sea Species Sensitivity Report").

[14] Salish Sea Species Sensitivity Report at 1.

[15] Salish Sea Sensitivity Report at 1.

[16] *Id*. at 1-2.

water body is "impaired" are not biologically based and therefore do not meet federal requirements of 40 CFR 131.11.17.

Before using a new Natural Conditions Rule and associated performance-based approach – both of which have yet to be approved by EPA – to develop water quality standards, Ecology should first develop biologically based DO criteria. Ecology has ignored inputs from EPA, multiple municipalities, Tribes, and other parties urging the adoption of such a standard.[18] Ecology is already in the process of updating its freshwater criteria. There is no reason it cannot begin to do the same for marine water.

4.2 *Natural Conditions Rule has not received EPA approval and cannot be used in water cleanup plans.*

Ecology adopted amendments to Chapter 173-201A WAC on November 14, 2024. The amendments include a new section in the Code and definition to describe and reference a "performance-based approach" that Ecology plans to apply when determining natural conditions criteria. Ecology is still reviewing comments on the guidance document for the performance-based approach, and neither the Natural Conditions Rule nor the associated performance-based approach have been approved by EPA. Ecology plans to submit both as a package to EPA in December 2025. When the first iteration of the PSNGP was originally issued, Washington had a natural conditions rule in place; that is not the case now. In 2021, EPA disapproved sections of the previously approved natural condition provisions in the state's Surface Water Quality Standards and has not yet approved the new Natural Conditions Rule adopted by Ecology in November 2024.

The Natural Conditions Rule and performance-based approach cannot be applied to the 2025 PSNGP or PSNRP until they have been approved by EPA. Under section 303(c) of the Clean Water Act, EPA must review and approve or disapprove state-adopted water quality standards. CFR §131.5. The CR-103 filing for the Natural Conditions Rule states that the Natural Conditions Rule, "goes into effect for Clean Water Act purposes, such as for the Water Quality

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[17] Ecology has acknowledged it has no documentation as to the scientific basis for the marine DO standards adopted by a predecessor agency in 1967.

[18] Letter from Sara Thitipraserth, Director, Stillaguamish Tribe Natural Resources Department to EPA (May 26, 2023); Letter from EPA to Vince McGowan, Water Quality Program Manager, Washington State Department of Ecology (Nov. 19, 2021); City of Tacoma, Comment Letter on the Department of Ecology's draft Puget Sound Nutrient General Permit and draft Fact Sheet (Aug. 16, 2021); Email from Chad Brown to Ronald L. Lavigne (Nov. 21, 2022); Michael Connor and William Stelle, *Elements of a Comprehensive Puget Sound Nutrients Program*; Petition to the Department of Ecology from Tad Shimazu and Lincoln Loehr (Jul. 17, 1998).

Assessment and water quality permits, after it has been approved by the EPA." The filing also states that, until Ecology receives EPA approval, it "will not be able to use the performance-based approach document for site-specific criteria under the Clean Water Act, 'such as for water clean up plans (alternate restoration plans and Total Maximum Daily Loads).'" Further, Ecology included in its response to comments on its 2022 Water Quality Assessment and 303(d) list ("2022 Assessment") that Policy 1-11, Chapter 1 was updated for the 2022 Assessment in March 2023 with a note stating, "Ecology will not utilize the following Natural Conditions methodology for waterbodies relevant to the disapproved provisions until a new natural conditions provision has been adopted into our Surface Water Quality Standards and approved by EPA." Ecology has clearly acknowledged it may not apply its Natural Conditions Rule or associated performance-based approach to water quality permits or alternate restoration plans until obtaining EPA approval; yet, Ecology states that it is applying the newly adopted natural conditions to its modeling scenarios for the purpose of developing nutrient targets under the PSNRP: "Ecology targets the applicable numeric and natural conditions water quality criteria in its modeling scenarios [and] considers results acceptable where DO concentrations are above the numeric criteria or where local and regional sources do not cause more than a 0.2 mg/L decrease in DO below the natural condition."[19] Additionally, there is no guarantee that EPA will approve the rule shortly after submission. Before approving the rule, EPA must also consult with US Fish and Wildlife Service and the National Marine Fisheries Service to determine if the rule adequately protects endangered species. Given the time that has already passed and the steps still left to go, it could take years for EPA to approve the Natural Conditions Rule. Therefore, it is certainly not appropriate for Ecology to use this rule and related methods to base permitting and nutrient limits that require immediate action and compliance.

Ecology has itself acknowledged it cannot use the Natural Conditions Rule or associated methods such as the performance-based approach for alternate restoration plans, which includes the proposed PSNRP. Given the new proposed natural conditions provisions have not been approved by the EPA ("only EPA approved natural conditions provisions can be used for CWA purposes such as the Assessment"), please explain how the PSNRP is a valid approach.

[19] Washington State Department of Ecology, Draft Puget Sound Nutrient Reduction Plan, pg. 30.

4.3 The draft narrative water quality-based effluent limits ("WQBELs") do not control discharges as necessary to meet applicable water quality standards for dissolved oxygen.

As Ecology admits, it does not have the data to determine if the 2025 PSNGP will control discharges in a manner that will result in meeting water quality standards. Ecology has further determined that current levels of TIN in WWTP effluent are causing or contributing to violations of the DO standards in Puget Sound. See Fact Sheet, Page 32. Ecology has not proposed a monitoring program that adequately measures DO in the "impaired" water bodies. Without this data there is no way to tell whether the proposed actions in the 2025 PSNGP have any impact on DO.

Questions:

- **In response to comments, can Ecology explain whether discharges from a facility at or below the total inorganic nitrogen action levels in Condition S4.B will cause or contribute to a violation of water quality standards?**
- **In response to comments, can Ecology explain how the proposed permit narrative effluent limits will meet water quality standards for dissolved oxygen?**
- **In response to comments, can Ecology explain whether a facility in full compliance with the permit and discharging total inorganic nitrogen at or below action levels in Condition S4.B will be meeting water quality standards for dissolved oxygen? Can Ecology explain the basis for its answer to this question?**

4.4 Binding Nature of Nitrogen Targets and SSM Assumptions

Ecology states in its PSNRP that it has utilized the SSM to develop nitrogen targets. These targets are included as basin-wide TN targets, generated from SSM scenario runs using 2014 data. The PSNRP asserts the TN targets are the "basis for calculating water quality based effluent limits ("WQBELs") in future reissuances of NPDES permits for domestic WWTPs."[20] Specifically, "the marine point source nitrogen targets will be translated into WQBELs in the future reissuance of the General Permit, individual domestic WWTP permits and industrial permits," and although WQBELs in future permits do not need to be "identical" to the targets in the PSNRP, they must be "consistent" with the targets set by the Plan.[21] The City would like

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[20] Washington State Department of Ecology, Draft Puget Sound Nutrient Reduction Plan (June 2025), pg. 36.

[21] *Id*. at 41.

confirmation whether future permit writers will be obligated to apply the assumptions produced by the Salish Sea Model to develop effluent limits in future permits.

Questions:

- **In response to comments, can Ecology explain whether permit writers will be required to implement the assumptions from the updated Salish Sea Model as though they are Waste Load Allocations?**
- **The PSNRP lays out that the City of Tacoma will need to achieve 3/3/8 mg/L; will a permit writer issuing future iterations of general or individual NPDES permits have discretion to choose different levels of loading, or are these levels binding? If the former, what other considerations will permit writers take into account other than these stated values?**
- **Will the Waste Load Allocations produced using the SSM be the applicable Waste Load Allocations the City of Tacoma will need to meet for compliance with future permits?**
- **Is the science complete with respect to using current criteria and modeling to produce Waste Load Allocations? If not, is there additional science facilities can provide showing other pathways to achieving Water Quality Standards?**
- **Is meeting the seasonal average loading limits listed in the draft voluntary permit a binding obligation?**
- **Will Ecology consider alternative modeling scenarios that achieve the similar results to the nutrient loading targets in the PSNRP?**

4.5 Ecology has not Provided Adequate Information for a Meaningful Comment on the Reasonable Potential Analysis that Forms the Basis for the General Permit

EPA and Ecology regulations require sufficient information to evaluate and comment on the basis for a NPDES permit. In the case of the 2025 PSNGP, Ecology has relied entirely on the 2019 Bounding Scenarios Report, Optimization Scenarios Phase 1 and 2, and the SSM model runs described therein. The Bounding Scenarios Reports (Phase 1 and 2) suggest that Ecology did not conduct a facility specific or watershed level assessment to determine whether each WWTP has a reasonable potential to cause or contribute to DO impairment – whether through nearfield or farfield impacts. Federal regulation (40 CFR 122.44(d)(1)(iii)) requires that a Reasonable Potential Analysis account for "the variability of the pollutant or pollutant parameter in the effluent." For TIN, variability cannot be accurately determined from the limited 2014 monthly, quarterly, or annual nutrient data available from WWTPs. Despite requiring Puget Sound WWTPs to collect expanded monitoring data since 2022, Ecology has not incorporated this more robust dataset into its current regulatory approach. This omission undermines both the precision and defensibility of the proposed limits, and underscores the need for a targeted, data driven Reasonable Potential Analysis before advancing new requirements. Given these deficiencies, there is not enough information for Tacoma to comment on the reasonable potential determination.

Tacoma has been trying to understand the SSM runs done by Ecology for the Bounding Scenarios Report Phase 1 and 2. Tacoma cannot provide meaningful comments on the reasonable potential analysis forming the basis for the 2025 PSNGP without completing this work.

The input files and post-processing of SSM results should be subject to review.

Questions:

- **In response to comments, can Ecology disclose how it processed it the results from the SSM modeling to make impairment determinations used in its reasonable potential analysis?**
- **In response to comments, can Ecology explain the extent of cells deemed out of compliance with DO standards based solely on model results in the deepest layer of a cell?**
- **In response to comments, can Ecology explain if WQP 1-11 represents the current interpretation and application of the marine DO water quality standard?**

4.6 Collaboration with University of Washington Puget Sound Institute

To strengthen the scientific foundation of nutrient regulation in Puget Sound, it is essential that Ecology actively collaborate with academic institutions such as the University of Washington Puget Sound Institute (UW PSI) and the Washington Academy of Sciences. These organizations bring deep expertise in marine science, ecosystem modeling, and environmental policy, and can provide critical, independent analysis to inform regulatory decisions. Similar collaborations have proven highly effective in other regions. In the San Francisco Bay, the partnership between the San Francisco Estuary Institute (SFEI), regional universities, and the Bay Area Clean Water Agencies (BACWA) has led to adaptive, science-based nutrient management strategies that balance ecological protection with practical implementation timelines. Likewise, in the Chesapeake Bay, long-standing collaboration between the Chesapeake Bay Program, academic institutions, and regulatory agencies has been instrumental in developing nutrient reduction strategies grounded in rigorous science and supported by robust monitoring and modeling. These partnerships have helped ensure that regulatory frameworks are both environmentally effective and operationally feasible. By engaging Washington's academic community in a similar way, Ecology can foster a more transparent, informed, and regionally appropriate approach to nutrient management in Puget Sound.

4.6.1 Available Science That Should Be Considered

For many years, UW PSI has been a leader in advancing the science and modeling of water quality and species health in Puget Sound. This leadership has included organizing a series of scientific workshops and convening an international modeling group to evaluate and improve the performance of the SSM. According to UW PSI in its August 22, 2025 Technical Memorandum, "Review of the 2025 Salish Sea Model Updates and Application to Nutrient Management" (UW PSI August 2025 Memo)[22]:

"In 2023-2024, the Puget Sound Institute convened global experts to advise on how to improve the application of the Salish Sea Model to inform recovery goals and nutrient management decisions in Puget Sound. The Model Evaluation Group included scientists who have led pioneering research and advised regional managers on the application of modeling and monitoring in nutrient management programs in other regions, like the Baltic and Chesapeake Bay. These experts – Bill Dennison, Jacob Carstensen, Jeremy Testa, Kevin Farley, and Peter Vanrolleghem – shared several recommendations to improve confidence in applying the Salish Sea Model to support Puget Sound's recovery goals and regulation (Mazzilli et al., 2024). In Figueroa Kaminsky et al. (2025), the State made significant advances addressing the prior Model Evaluation Group's recommendations."

While Ecology has made progress in refining the model between Phase 1 and Phase 2 of the Bounding Scenarios Report, key challenges remain. Model performance and associated errors still exceed Ecology's proposed human use allowance of 0.2 mg/L dissolved oxygen, as outlined in the draft Natural Conditions Provision. Additionally, Ecology continues to rely on subtracting two model scenarios, a method that does not adequately address the inherent uncertainty in model outputs. As UW PSI further notes in its August 2025 Memo[22]:

"As a result, when compliance is determined by comparing existing and reference scenarios, the true level of uncertainty in the outcome is larger than the model statistics alone suggest and must

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[22] https://www.pugetsoundinstitute.org/wp-content/uploads/2025/08/2025.08.22-Review-of-2025-Salish-Sea-Model-Updates-and-Application-to-Nutrient-Management.pdf

be explicitly considered in regulatory applications. It seems unlikely that any model could reduce uncertainty to the point that it is lower than the current human use allowance of 0.2 mg/L."

UW PSI's 2025 memorandum also includes additional evaluation points regarding Ecology's use of the Salish Sea Model, particularly in relation to nutrient reduction targets and watershed management. These insights are critical to understanding the feasibility and implementation challenges of proposed nutrient reductions. As stated in the same Memo[22]:

"Reducing nutrients from diffuse sources in watersheds is notoriously challenging because actions are often voluntary, require buy-in from thousands of independent landowners, and are frequently undermined by competing agricultural incentives that encourage fertilizer-intensive cropping practices. The proposed reductions range from 53 – 67% in most basins, which exceeds what has been achieved even in the best cases in Denmark and the Chesapeake Bay (Scientific and Technical Advisory Committee (STAC), 2023). Since 1990, Denmark has cut its nitrogen surplus by ~50%, but only through decades of strong political will and strict regulations on livestock, manure, and fertilizer use (Riemann et al., 2016). Implementing the proposed targets will also require a more sophisticated understanding of the watershed sources. Recent modeling by USGS SPARROW, in collaboration with the State, has taken strong initial steps by estimating seasonal loads from both marine point and watershed sources (Schmadel et al., 2025). A helpful next step would be to show watershed sources separately and aligned to the watershed boundaries in the State's Draft Puget Sound Nutrient Reduction Plan. This would allow managers to see how the nutrient sources line up with the watershed-specific targets set in the plan."

Given the depth and breadth of UW PSI's scientific evaluations, Ecology is strongly encouraged to review and condsider this Memorandum along with the many others published by UW PSI. These documents provide critical context, technical recommendations, and real-world examples that can inform more effective and realistic nutrient management strategies. For convenience, the City has included a list (and attached) of some of these available resources at the end of its detailed comments.

4.7 Use Attainability Analysis/Variance Applications

A Use Attainability Analysis is the tool used to evaluate the potential to remove non-existing and non-attainable designated uses, or to establish subcategories of uses. It is a structured scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, biological, and economic factors as described in 40 CFR § 131.10(g). Section 131.10(g) of the federal regulations contains the rules governing the circumstances under which a state can remove a use. Under 40 CFR§ 131.10(g), states may remove a designated use which is not an existing use, or establish subcategories of a use requiring less stringent criteria, if the state can demonstrate that attaining the designated use is not feasible (not an attainable use) because certain conditions exist. Of the six factors to analyze in whether attaining the use is feasible, the following are relevant for addressing how nutrient discharge from a WWTP may exacerbate dissolved oxygen depletion: (1) Naturally occurring pollutant concentrations prevent the attainment of the use; (2) Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use; (5) Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; and (6) Controls more stringent than those required by sections 301(b) and 306 of the Act would result in substantial and widespread economic and social impact. Criteria can also be revised to represent the attainable level of water quality without changing the designated use; this exercise is tied to the application of natural conditions criteria. As it relates to dissolved oxygen and regulating nutrients, has Ecology considered a Use Attainability Analysis required under 40 CFR § 131.2?

Relatedly, as attaining the reduction targets in the PSNRP may not be feasible for a number of WWTPs, Ecology should more seriously consider the option of allowing variances. The PSNRP only mentions variances once, as an additional permitting tool alongside compliance schedules and interim limits, "recognizing the significant nutrient reductions needed from marine point sources." After WWTPs complete NREs, would Ecology be open to variance applications? Especially with the shift from TIN to TN, it is likely that many WWTPs will not be able to attain the target limits without expending a significant amount of time and money, and should therefore be provided alternative means of still working towards nutrient loading reduction without facing the consequences of noncompliance.

5.0 Puget Sound Nutrient General Permit Condition Issues

5.1 Nutrient Reduction Evaluation Deadline

Ecology has extended the due date for the NRE under the draft 2025 PSNGP to June 30, 2026. This is a six-month extension from the original December 31, 2025 deadline established under the 2022 PSNGP. While the extension offers some relief, it may still be insufficient for many utilities. Following the invalidation of the 2022 PSNGP by the PCHB in February 2025 and the introduction of revised nutrient targets during Ecology's March 2025 Nutrient Forum, utilities were left in a prolonged state of uncertainty regarding how to proceed with the NRE. This ambiguity significantly disrupted planning efforts, delayed consultant and contractor engagement, and in some cases, brought engineering and financial evaluations to a standstill.

Many utilities were forced to pause or revise scopes of work while awaiting clarity from Ecology, resulting in lost time and the need for contract amendments. These administrative and logistical setbacks are further compounded by the evolving regulatory landscape. For example, the 2025 PSNRP introduces a shift to a 2014 flow cap, changes the nutrient parameter from TIN to TN, and adds CBOD as a new parameter. These changes require utilities to reevaluate previously completed work and potentially renegotiate consultant contracts to align with the new requirements.

Given these challenges, Tacoma respectfully requests that the NRE deadline be extended to December 31, 2026. This additional time would allow utilities to complete the necessary technical evaluations, secure funding, and amend contracts without compromising the quality or integrity of the NRE. Furthermore, if final effluent limits are aligned with the 2025 PSNRP, all affected utilities will require additional time to revisit and revise their NREs accordingly, ensuring compliance with the updated regulatory framework.

6.0 Additional Available Resources

As part of this review, the City referenced the documents attached to this letter. The City requests that Ecology review and consider these reference documents (and recommendations) as part of the proposed draft 2025 Reduction Plan efforts.

Attachments 1-34:

Attached as Separate Files with Comment Letter (File Names):

1. Modeling_Considerations_Checklist__R10_comments_ (1).docx
2. SEPADNS_NaturalConditions.pdf

Attached as One Combined File Named "Attachments 3-4":

3. Publication no. 11-10-060_Tetra Tech Report on Nutrient Upgrades Costs
4. EPA Life Cycle and Cost Assessments of Nutrient Removal 2021

Attached as One Combined File Named "Attachments 5-6"

5. Ex. A to Petition - 2019 01-15 WDOE Salish Sea Model Bounding Scenarios Report 1903001 4810-7635-6819_1 (copy)
6. 2024.06.26_Salish-Sea-Model-Evaluation-and-Proposed-Actions-to-Improve-Confidence-in-Model-Application

Attached as One Combined File Named "Attachments 7-34":

7. 06.04.21 Loehr Comment on Draft PSNGP
8. 07.17.1998 Everett Petition to Revise DO Standards
9. 08.16.21 Holtgrieve Comment on Draft PSNGP
10. 1998-07-08 Mark Hicks Letter to Loehr re State Standards for Dissolved Oxygen (copy)
11. 2013 12-04 HDR Treatment Technology Review and Assessment 4852-0702-5351_1 (copy)
12. 2021-08-16 City of Tacoma Comment Letter PSNGP (copy)
13. 2021 12-28 King County's Declaration of Christie True (King Cty v. Dept of Ecology 4892-0931-6616_1
14. 2021 12-28 King County's Motion for Stay 4866-0819-2776_1
15. 2022-12-07 Notes on EPA Ecology Discussion of NC Process.msg
16. 2023-02-28 UW Puget Sound Institute - Puget Sound Clean Water Alliance (CWA) Affordability + Modeling Presentation (copy)
17. 2023 05-23 Stillaguamish Tribe of Indians ltr to Ecology re DO Criteria
18. 2024-04-12 Amicus Curiae Brief by Building Industry Association of Washington
19. 2024-04-15 Brief of Amicus Curiae from King County (copy)
20. 2024-04-15 Washington Association of Sewer & Water Districts' Motion for Leave to Join in Amicus Brief Filed by King County (copy)
21. 2024-04-16 Ecology Response to Natural Conditions Criteria Questions by Lincoln Loehr
22. 2410022 - Preliminary Regulatory Analysis
23. BrysonFinch_Marine DO Criteria Presentation 2018
24. Burke_et_al_2023_Wastewater_Affordability_Critical_Analysis_Summary_Report_05.017.23
25. City of Tacoma v. Dep't of Ecology (2023) (copy)
26. Connor & Stelle_Elements of a Comprehensive Puget Sound Nutrient Alternative
27. Ecology Draft Interim Financial Capability Assessment Guidance
28. Environmental Checklist 2023
29. EPA_ActionsNCC_Nov192021
30. Holtgrieve Scheuerell_Detailed Critique of Ahmed et al 2019
31. Holtgrieve & Scheuerell_Appendix
32. Loehr MPB 1986 article re 301(h) in Washington (2)
33. Loehr 2020.02.29 memo to Scott Redman
34. wawqs-action-letter-11-19-2021 (copy)

Attached as One Combined File Named "Attachments 35 - 38":

35. 3-25-25_UW PSI_'Natural Conditions' are at the Center of Disputes Over Dissolved Oxygen Standards
36. 4-2-25_UW PSI_Unpacking Uncertainty - How Experts Recommend Improving Puget Sound Modeling
37. 6-10-25_UW PSI_A Century of Warming has Reduced Dissolved Oxygen in Puget Sound
38. 6-12-25_UW PSI_Low Oxygen Challenge Part 1 -The Debate Over Oxygen in Puget Sound

Attached as One Combined File Named "Attachments 39 - 44":

39. 6-12-25_UW PSI_Low Oxygen Challenge Part 2 - Water-cleanup
40. 6-12-25_UW PSI_Low Oxygen Challenge Part 3 - Computer Models
41. 6-12-25_UW PSI_Low Oxygen Challenge Part 4 - Many Actions
42. 12-20-22_UW PSI_The Quest Continues for a Nutrient Reduction Plan
43. 2025.08.22-Review-of-2025-Salish-Sea-Model-Updates-and-Application-to-Nutrient-Management
44. 2025-Biological_Sensitivy_DO_Final_Report.docx

Attached as One Combined File Named "Attachments 45 - 47":

45. SOG_NB-Technical-Memo
46. EPA nutrient-economics-report-2015
47. EPA Nutrient life-cycle-nutrient-removal-2023-update