

DRAINAGE SYSTEMS ANALYSIS

Drainage System Analysis: Water Quality Topic Area Summary

Technical Memorandum

Water Quality Topic Area Summary

January 16, 2020

Seattle Public Utilities

PHOTO CREDITS from top left:

Salmon in Longfellow Creek, Seattle. Holli Margell, 2009. http://nativelightphoto.com/

Thornton Creek Confluence Restoration, Seattle. Natural Systems Design, 2014. http://naturaldes.com

Flooding in South Park, Seattle. Sheila Harrison, Seattle Public Utlities, 2009.

Lake Union, Seattle. Seattle Public Utilities Photo Archive, date unknown.

Water Quality

Technical Memorandum

Date: January 16, 2020

Deliverable Title: Drainage System Analysis: Water Quality Topic Area Summary Technical Memorandum

Task No.: 3.7

To: Holly Scarlett, SPU Project Manager

From: John Lenth, Water Practice Director, Herrera Environmental Consultants

Copy to: Mike Milne, Brown and Caldwell

Prepared by: ______________________

John Lenth, Water Practice Director
Herrera Environmental Consultants, Inc.

Reviewed by: ______________________

Leslie Webster, Planning Program Manager
Seattle Public Utilities

Table of Contents

Figures

Tables

Appendices

Abbreviations

µg/L	micrograms per liter
BC	Brown and Caldwell
B-IBI	Benthic Index of Biotic Integrity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
City	City of Seattle
DSA	Drainage System Analysis
HEC	Herrera Environmental Consultants
IP	Integrated Plan
ISP	Integrated System Plan
mL	milliliter
MS4	municipal separate storm sewer system
MTCA	Model Toxics Control Act
SOTW	State of the Waters
SPU	Seattle Public Utilities
TM	technical memorandum
TMDL	total maximum daily load
TSS	total suspended solids
WQI	water quality index

1. Introduction

This Water Quality Topic Area Summary Technical Memorandum updates known water quality data from the 2007 State of the Waters (SOTW) Report and summarizes the City of Seattle's (City) evaluation of receiving water bodies and stormwater basins to determine priorities for structural stormwater retrofit projects, which was done during development of the Integrated Plan (IP) (Seattle Public Utilities [SPU] 2015).

SPU's original scope for the DSA Water Quality Topic Area also contained a task to create a crosswalk of water quality actions (e.g. source control, bioretention) to pollutants, land use, system type and receiving water impairments; however, this part of the task was not completed due to budget constraints. SPU has deferred work related to the Creek Hydrologic Flashiness Metric analysis. SPU may update this TM in the future to include the results of the hydrologic flashiness analysis once it is completed.

To support the development of the Integrated System Plan (ISP), this technical memorandum (TM) provides a high-level summary of information compiled through the DSA for the Water Quality and Flow Control Topic Area (Water Quality Topic Area), including information developed in separate analyses for the Pollutant Summary and Structural Stormwater Control Priorities. Information compiled for the Future Conditions analysis is also presented directly within this TM. This TM also identifies sources for more detailed information. The information documented in the TM provides a baseline of information for water quality information that can be used in the ISP to help guide potential future capital improvement projects. For example, the Pollutant Summary shows that Fauntleroy Creek has better water quality than other City creeks and is a middle priority for structural stormwater controls as compared to the other creek basins.

This TM is organized to include a section with background information on the need for the DSA. It then summarizes information from the analyses identified above under separate sections. The key documents that provide the foundation for these analyses are also reproduced in separate appendices to this TM.

2. Background

SPU manages stormwater citywide through 460 miles of drainage pipes, open ditches and culverts, green stormwater infrastructure, and other flow and water quality facilities. Stormwater runoff collected through this system contributes a wide range of pollutants to the city's water bodies that can impact their quality and uses. Seattle is also served by a combined sewer system that handles both stormwater runoff and wastewater generated by businesses and residents. Heavy rains can overwhelm the sewers and cause combined sewer overflows, or CSOs. These sewage discharge events can also contribute pollutants to surrounding water bodies.

Seattle's extensive urban development over the past 150 years has drastically altered the city's watersheds. Previously forested areas and wetlands have largely been converted to residential, industrial, and commercial land uses, with only limited areas of open space. While urban development has created a livable environment for humans, it has brought a decline in the health of the City's watersheds, the water bodies that drain them, and their non-human inhabitants. Common causes of water resource degradation from urbanization include poor water and sediment quality, loss of riparian and aquatic habitat, and stream channel erosion. In combination, these urbanization impacts can disrupt the ecological function of a water body that causes sensitive aquatic life to decline in abundance or disappear completely.

The goal of this TM is to provide an up-to-date understanding of the uses, water quality, regulatory structure, and other information that will help drive key decisions about what parts of SPU's drainage infrastructure are a priority for future plans. This document provides an overview of Seattle's receiving waters. Note that the information provided in this TM is based on water quality information and data from a variety of sources, and given there have been very few recent water quality studies in Seattle, much of the information and data is from older sources that have limited numbers of samples.

3. Pollutant Summary

To assess the level of degradation stemming from urban development and evaluate the effectiveness of ongoing preservation and restoration efforts, SPU periodically documents the health of water bodies in its major watersheds. For example, SPU began mapping and evaluating conditions in the following five salmonid-bearing streams starting in 1993–Fauntleroy Creek, Longfellow Creek, Piper's Creek, Taylor Creek, and Thornton Creek. SPU's Comprehensive Drainage Plan from 2004 also summarized flow- and water-quality-related impacts to public and aquatic health in major water bodies, such as the Lower Duwamish Waterway, Lake Washington, and major creeks. In the 2007 SOTW (SPU 2007a, 2007b, 2007c), SPU summarized water quality and habitat conditions in the five salmonid-bearing streams identified above, several smaller creeks, the city's three small lakes.

Building on these previous assessments, the Pollutant Summary analysis for the DSA involved a review of monitoring data, studies, and other relevant information related to Seattle's creeks, small lakes, large lakes, and major water bodies developed since the 2007 SOTW. The specific water bodies evaluated for the analysis are identified in Table 3.1 Figure 3.1 shows the locations of all of the water bodies except the small creeks, which are located throughout the City.

Table 3.1. Water Bodies Evaluated for Pollutant Summary Analysis

Classification	Receiving Waters
Urban Watercourses [a]	Fauntleroy Creek Longfellow Creek Piper's Creek Taylor Creek Thornton Creek
Small Lakes	Bitter Lake Haller Lake Green Lake
Large Lakes and Canals	Lake Washington (offshore Seattle) Lake Union/Ship Canal
Large Water Bodies	Lower Duwamish Waterway [b] Elliott Bay Puget Sound (offshore Seattle)

a. Also includes smaller creeks described in the 2007 SOTW.

b. Includes East and West Waterways.

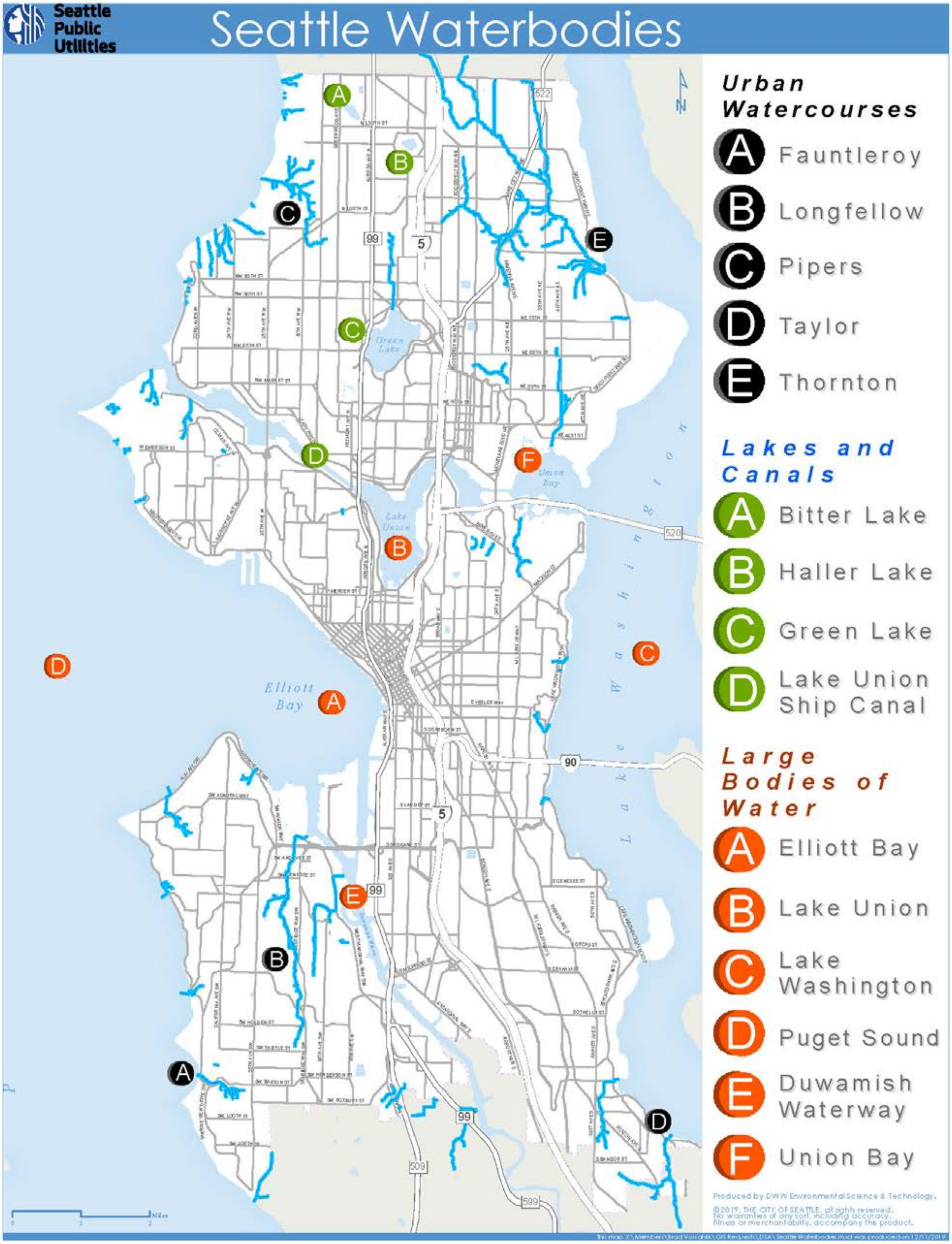


Figure 3.1. Water bodies evaluated for pollutant summary analysis

Based on the information obtained from this review, conditions in each water body were summarized for three categories:

- **Pollutants and Potential Uses**: Quantitative data that provide information on the level of pollutants or other constituents in the water or sediment. Pollutants were grouped according to how they may affect water body uses for recreation, aquatic life, and fish consumption. Table 3.2 summarizes the primary pollutants that were used to evaluate conditions in each water body by use. See subsection 3.1 for more detailed descriptions of the potential uses of each water body.
- **Indicators**: Indices of quantitative data or non-quantitative data that reflect water quality, public health or habitat. See subsection 3.2 below for more detailed descriptions of the indicators used to evaluate conditions in each water body.
- **Regulatory Drivers**: State or federal laws or guidance governing water quality, public health or habitat. See subsection 3.3 for more detailed descriptions of the regulatory drivers that may apply to a specific water body.

Table 3.2. Summary of Pollutants

<table>
<tr><th>Water Body Use</th><th>Pollutant Group</th><th>Pollutants Evaluated</th></tr>
<tr><td>Recreation</td><td>Fecal Indicator Bacteria</td><td>Fecal Coliform, E. coli, Enterococci (173-201A WAC Amendatory Section 2018)</td></tr>
<tr><td rowspan="9">Aquatic Health</td><td>Dissolved Oxygen</td><td>Dissolved oxygen concentration (173-201A WAC 2016)</td></tr>
<tr><td>Flow</td><td>Altered runoff regime</td></tr>
<tr><td>Metals</td><td>Metals with Aquatic Life criteria: Arsenic, Cadmium, Chromium (III), Chromium (VI), Copper, Lead, Mercury, Nickel, Selenium, Silver, Zinc (173-201A WAC 2016).</td></tr>
<tr><td>Nutrients</td><td>Total nitrogen and total phosphorus (173-201A WAC 2016)</td></tr>
<tr><td>Organics</td><td>All organic chemicals listed in Table 240 of the Water Quality Standards (173-201A WAC 2016) with aquatic health criteria</td></tr>
<tr><td>pH</td><td>pH (173-201A WAC 2016)</td></tr>
<tr><td>Sediment Quality</td><td>All pollutants in Table 1 of the Sediment Management Standards (173-204 WAC 2013)</td></tr>
<tr><td>Temperature</td><td>Temperature (173-201A WAC 2016)</td></tr>
<tr><td>Turbidity/Clarity</td><td>Turbidity (173-201A WAC 2016), Trophic State Index - Secchi (Carlson 1977)</td></tr>
<tr><td rowspan="2">Fish Consumption</td><td>Fecal Indicator Bacteria</td><td>Fecal Coliform (173-201A WAC 2016)</td></tr>
<tr><td>Toxics</td><td>All chemicals listed in Table 240 of the Water Quality Standards (173-201A WAC 2016) with human health criteria</td></tr>
</table>

Conditions in each water body for these categories were subsequently documented in a report (Geosyntec 2019a) titled the *DSA Water Quality & Flow Control Pollutant Summary*, which is included in Appendix A for reference. This report:

- Identifies the pollutants that are sources of impairment for each water body based on comparisons to applicable state and federal water quality criteria.
- Provides tabular and graphical summaries for the quantitative pollutant and indicator data.

- Identifies temporal trends for specific pollutants or indicators where enough data are available to facilitate their detection.

The *DSA Water Quality & Flow Control Pollutant Summary* report is intended to provide detailed information on current conditions in the City's water bodies for technical audiences involved in developing the ISP. It also provides a reference point for documenting these conditions for use in assessing future improvements following ISP implementation.

The information from the *DSA Water Quality & Flow Control Pollutant Summary* report (Appendix A) was subsequently used to develop Figures 3.2, 3.3, and 3.4, which respectively summarize conditions in the three categories (potential uses, indicators, and regulatory drivers) in each water body. Sections 3.1 through 3.3 explain how to interpret the information in these summary figures.

3.1 Potential Uses

Figure 3.2 rates each water body based on its ability to support potential recreation, aquatic life, and fish consumption uses.

The ratings for "Recreation" indicate the potential risk of people becoming sick through activities such as swimming, wading, or diving in water bodies contaminated by fecal matter. The ratings are based on comparisons of fecal bacteria concentrations measured in the water body to the state water quality criteria. A "good" rating indicates that the water body has generally met the state water quality criteria for fecal bacteria, indicating low risk of illness for recreational users. A "poor" rating indicates that fecal bacteria concentrations in the water body have exceeded the state criteria, indicating higher risk of illness.

Aquatic health can be affected by water and sediment pollution. In addition, channel erosion, loss of tree cover, and changes in streamflow patterns can affect aquatic health in urban creeks. Figure 3.2 presents water bodies ratings for a range of chemical and physical criteria related to aquatic health. A "good" rating means the water body has generally met the criteria or benchmark for protecting aquatic life. A "poor" rating indicates the water body has not met the criteria or benchmark for water quality, sediment quality, or erosive creek flows. The resultant poor habitat conditions could potentially impact the water body's ability to support salmonids and other sensitive aquatic life.

Finally, the ratings for fish consumption indicate whether it is generally safe to catch and consume fish or shellfish without short or longer-term risks to human health from contaminants present in the tissue of the fish. A "good" rating indicates that there are no fish/shellfish consumption warnings. A "fair" rating indicates that there are fish/shellfish consumption warnings for some portions of the population. A "poor" rating indicates that no fish/shellfish should be consumed from these waters.

The water body ratings in Figure 3.2 are intended to provide a quick snapshot for assessing the ability of the water body to support one or more of the potential uses. The ratings are based on limited water quality monitoring. Additional monitoring and analysis would be needed to make firm conclusions regarding current compliance with state water quality standards.

Seattle Waterbodies: Potential Uses

	Receving Water	Recreation	Aquatic Health									Fish Consumption	
		Fecal Bacteria	Dissolved Oxygen	pH	Temperature	Turbidity & Clarity	Metals	Organcis	Nutrients	Sediment Quality	Flow	Toxics	Fecal Bacteria
Creeks	Fauntleroy Creek	Poor	Good	Good	Good	Good	Fair		Poor				Not Applicable
Creeks	Longfellow Creek	Poor	Good	Good	Fair	Fair	Good	Fair	Poor			Good	Not Applicable
Creeks	Pipers Creek	Poor	Fair	Good	Good	Good	Fair	Good	Poor			Fair	Not Applicable
Creeks	Taylor Creek	Poor											Not Applicable
Creeks	Thornton Creek	Poor	Poor	Good	Poor	Good	Fair	Fair	Poor	Fair		Fair	Not Applicable
Creeks	Small Creeks												Not Applicable
Small Lakes	Bitter Lake	Good			Poor	Fair	Good		Fair		Not Applicable	Good	Not Applicable
Small Lakes	Haller Lake	Good			Fair	Fair	Good		Fair		Not Applicable		Not Applicable
Small Lakes	Green Lake	Good	Good		Poor	Fair	Good		Good	Fair	Not Applicable	Fair	Not Applicable
Large Lakes	Lake Washington (Seattle offshore)	Good	Fair	Good	Fair	Fair			Good	Poor	Not Applicable	Poor	Not Applicable
Large Lakes	Lake Union/Ship Canal	Fair	Fair	Good	Fair	Fair	Good	Fair	Good	Poor	Not Applicable	Fair	Not Applicable
	Duwamish Waterway	Poor	Fair	Good	Fair		Good	Fair		Poor	Not Applicable	Poor	Poor
	Elliott Bay	Fair	Fair	Fair	Fair		Fair	Fair	Fair	Poor	Not Applicable	Fair	Fair
	Puget Sound (Seattle offshore)	Good	Fair	Good	Good		Good		Fair	Fair	Not Applicable	Fair	Good

Key

Good | Fair | Poor | No Data (blank) | Not Applicable

Figure 3.2. Ratings for potential uses by water body

3.2 Water Quality Indicators

The ratings for each water body within the "Indicator" category are presented in Figure 3.3 below. The individual criteria under this category provide a broad assessment of watershed health based on these aquatic life and human health-related indicators:

- The Water Quality Index (WQI) uses data from eight water quality measurements to compute a single score ranging from 0 to 100 that is useful for making broad assessments of water quality in streams. The WQI is a unitless number ranging from 1 to 100, with higher numbers indicating better water quality. WQI scores of 80 and above are considered "good," scores 40 to 80 are considered "fair," and scores below 40 are considered "poor."
- The Benthic Index of Biotic Integrity (B-IBI) integrates data from sampling of insects and other organisms living in or on the bottom of streams to compute a single score ranging from 0 to 100 that is useful for making broad assessments of stream health. Higher values represent benthic communities that reflect higher stream health. B-IBI scores of 80-100 are considered "excellent," scores of 60-80 are "good," scores of 40-60 are "fair," scores of 20-40 are "poor," and scores below 20 are "very poor"
- Coho pre-spawn mortality is a phenomenon where adult Coho salmon die before spawning when returning to freshwater streams to spawn. This phenomenon has been observed in streams impacted by urban development and is closely associated with the roads and traffic in these areas. Streams with coho pre-spawn mortalities (i.e., percentage of females that die before spawning) less than 10 percent are considered "good," between 10 percent and 40 percent are considered "fair," and greater than 40 percent are considered "poor."
- The Trophic State Index uses data from different water quality measurements to compute a single score ranging from 0 to 100 that is useful for assessing the biological productivity of lakes. Runoff with high concentrations of nutrients can increase the biological productivity of lakes and harm sensitive aquatic life. Scores less than 40 represent oligotrophic lakes, with high water clarity and low biological activity; scores between 40 and 50 represent mesotrophic lakes, with moderate water clarity and medium biological activity; and scores greater than 50 represent eutrophic lakes, which have low water clarity and high biological activity. Scores are based on Secchi depth, total phosphorus concentrations, and chlorophyll-a in the lake's surface layer (upper 10 meters or less) of water measured from June through September.
- Toxic algal blooms that can harm people and animals are often stimulated by runoff from urban development with high concentrations of nutrients. Washington State Department of Health recommends a three-tiered approach using recreational guidance values of six micrograms per liter (µg/L) microcystin and one µg/L anatoxin-a for determining significant toxic algal blooms in Washington lakes.
- Beach closures occur when monitoring performed by state and local health authorities determine there is a potential risk of becoming sick from fecal contamination or toxic algal blooms for people that come in direct contact with the water. Marine beaches are closed for swimming if either of the following criteria is exceeded:
  - Geometric mean exceeds 35 enterococci/100 milliliters (mL), based on results from a minimum of five weekly samples
  - Statistical threshold value exceeds 276 enterococci/100 mL.

- If bacteria levels exceed 104 enterococci/100 mL, a beach advisory is issued. Shellfish bed closures occur when monitoring performed by state and local health authorities determine there is a potential risk of becoming sick by consuming shellfish with fecal or toxic algal contamination. All shellfish beds in the waters in and around Seattle are closed to recreational and commercial shellfish harvesting.

The water body ratings in Figure 3.3 are based on limited data. Nevertheless, looking at the ratings in combination provides a quick snapshot for identifying significant problems in a water body that could guide the prioritization of restoration efforts.

Seattle Waterbodies: Indicators

	Receving Water	Water Quality Index	Benthic Index of Biotic Integrity	Coho Pre-spawn Mortality	Trophic State Index	Toxic Algal Blooms	Beach Closures	Shellfish Bed Closures
Creeks	Fauntleroy Creek		Fair	Fair	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Creeks	Longfellow Creek	Poor	Poor	Poor	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Creeks	Pipers Creek	Fair	Poor	Poor	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Creeks	Taylor Creek		Poor	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Creeks	Thornton Creek	Poor	Poor	Poor	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Creeks	Small Creeks		Poor		Not Applicable	Not Applicable	Not Applicable	Not Applicable
Small Lakes	Bitter Lake	Not Applicable	Not Applicable	Not Applicable	Good	Good	Not Applicable	Not Applicable
Small Lakes	Haller Lake	Not Applicable	Not Applicable	Not Applicable	Good	Fair	Not Applicable	Not Applicable
Small Lakes	Green Lake	Not Applicable	Not Applicable	Not Applicable	Good	Fair	Fair	Not Applicable
Large Lakes	Lake Washington (Seattle offshore)	Not Applicable	Not Applicable	Not Applicable	Good	Fair	Good	Not Applicable
Large Lakes	Lake Union/Ship Canal	Not Applicable	Not Applicable	Not Applicable	Fair	Fair	Not Applicable	Not Applicable
Lower Duwamish Waterway					Not Applicable	Not Applicable	Not Applicable	
Elliott Bay		Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Good	Poor
Puget Sound (Seattle offshore)		Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Poor	

Key

Good	Fair	Poor	No Data	Not Applicable
●	◉	○	(blank)	⃠

Figure 3.3. Ratings for indicators by water body

3.3 Regulatory Drivers

Figure 3.4 identifies water bodies that are subject to the following state and federal regulations for improving water or sediment quality:

- Water bodies are placed on the federal Clean Water Act Section 303(d) list when monitoring data indicate water or sediment quality impairment is preventing their beneficial use for activities such as drinking, recreation, aquatic habitat, and industrial processes.
- The federal Clean Water Act requires that Total Maximum Daily Load (TMDL) must be developed for water bodies on the 303(d) list. A TMDL first identifies the maximum amount of a pollutant the water body can receive while still meeting water quality standards. The TMDL then determines how much the pollutant load(s) will need to be reduced to meet standards. Once implemented, a TMDL establishes strict limitations on the amount of a pollutant that can be discharged to a water body from different sources.
- Discharges of stormwater to a water body from the City's municipal separate storm sewer system (MS4) are regulated by a Phase I Municipal Stormwater Permit issued by the state. Section S4.F of this permit requires the City to notify the state if there is knowledge that discharges from the MS4 are causing or contributing to a violation of water quality standards. An outcome of S4.F is that the City may be required to develop an adaptive management response if additional actions beyond the permit requirements are required to address the discharge. As shown in Figure 3.4, adaptive management for S4.F is currently required for MS4 discharges to the Duwamish Waterway.
- The state established the Model Toxics Control Act (MTCA) to fund the investigation and cleanup of sites that are contaminated with hazardous substances. The federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) was established to achieve the same objectives. Figure 3.4 identifies water bodies with contaminated sediment sites that are subject to ongoing cleanup efforts through either MTCA or CERCLA.

At a minimum, the City must meet legal obligations for improving conditions in a water body stemming from these regulatory requirements.

Seattle Waterbodies: Regulatory Drivers

	Receving Water	Impaired Water (303d listed)*	Existing Water Quality Improvement Project (TMDL)	Potential TMDLs in Development	Toxic Sediment Cleanup Sites (MTCA/ CERCLA)	Adaptive Management Plan (S4.F)
Creeks	Fauntleroy Creek	✓	✓			
	Longfellow Creek	✓				
	Piper's Creek	✓	✓			
	Taylor Creek	✓				
	Thornton Creek	✓				
	Small Creeks	✓				
Small Lakes	Bitter Lake					
	Haller Lake					
	Green Lake	✓				
Large Lakes	Lake Washington (Seattle offshore)	✓				
	Lake Union/Ship Canal	✓			✓	
Duwamish Waterway		✓	✓	✓	✓	✓
Elliott Bay		✓		✓		
Puget Sound (Seattle offshore)		✓		✓		

* *Refer to DSA Regulatory Summary for complete 303d listings.*

Figure 3.4. Regulatory drivers by water body

4. Future Conditions

This section provides a qualitative summary of how future conditions may affect water quality and flow (aquatic life) in Seattle's receiving waters to guide the ISP planning effort. This summary builds on unpublished information compiled by Herrera Environmental Consultants (HEC) (2019) through a separate planning effort to support the development of King County's Clean Water Plan (King County 2019). Section 4.1 summarizes potential future trends that are directly related to climate change and have a relatively high level of certainty. Section 4.2 summarizes potential future trends that are related to other factors and have a relatively low level of certainty.

4.1 Climate Change Impacts

Climate change could have significant impacts on water quality in Seattle. The potential climate-related trends summarized below are generally derived from analyses identified in the University of Washington *State of Knowledge: Climate Change in Puget Sound* (2015) unless noted otherwise.

- Changes in precipitation patterns and, therefore, instream flows will continue to occur. Seattle's urban watersheds are rain dominated, and heavy rain events are projected to become more intense due to climate change. As the rainfall pattern changes, streamflow is projected to increase in winter and decrease in spring and summer, and the timing of peak flows is projected to shift earlier.
- Warmer air temperatures and lower stream flows will contribute to warmer water temperatures that impact aquatic habitats. This may be the most critically important water quality trend because of the profound impact it will have on species that are adapted to these habitats:
  - Regional-scale changes in the aquatic food web can be expected as aquatic species and habitat conditions change.
  - Concentrations of dissolved oxygen will decrease in some water bodies because warm water holds less dissolved oxygen than cool water, which will further influence habitat change.
  - New invasive aquatic species in both fresh and marine waters are likely to appear as climate and habitat conditions change. Common invasive species include tunicates, oyster drills, and cordgrass.
- pH will likely continue to decrease in marine waters of Puget Sound as a result of rising carbon dioxide levels in the atmosphere. These changes in ocean chemistry may adversely affect organisms at the base of the marine food web and ultimately shellfish and fish populations.
- Rising sea levels will continue to rise and contribute to increased erosion and wetland flooding that will degrade important shoreline habitats that cause shifts in the distribution of aquatic organisms and birds.

4.2 Other Impacts

- Large-scale changes in aquatic habitat that are driven by climate change and human population increases may alter the regional food web. These changes could impact threatened or endangered species that are an integral part of this food web. Food web changes could also impact commercial species and affect food supply and commerce. Finally, changes in the food web and changes in water quality could negatively impact human health. For example, new species may be hazardous themselves, such as a more toxic stinging jellyfish, or changing conditions may result in more frequent toxic algae blooms.
- Impacts from some contaminants may decrease due to ongoing management efforts. For example, the rates of bioaccumulation of organic contaminants in tissue could decrease over the long term as a result of continued source control and cleanup efforts. Contaminant levels in sediments are likely to continue to decrease (over a long period) if efforts to remove contaminated sediments and reduce recontamination are continued. The quantity of plastics found on beaches and in water samples may start to decline due to bag bans and other local actions to reduce plastics in the environment.
- Our understanding of organics and newly emerging contaminants of concern (e.g., microplastics and pharmaceuticals) will continue to improve. This may result in new standards to be met and/or the adoption of new treatment technologies.
- Land development and increased traffic density from projected population increases will result in increased loading of contaminants; whether this results in increased loading to receiving waters will depend on the effectiveness of water quality protection programs.
- Water scarcity may become an issue due to climate-change-driven decreases in winter snowpack coupled with increased human consumption stemming from population growth. This could drive the need to manage all water (precipitation, streamflow, stormwater, groundwater, drinking water, wastewater, marine water) as one resource. This could result in an increased emphasis on water quality protection and conservation of all these sources.

5. Structural Stormwater Control Priorities

SPU ranked receiving water bodies and stormwater basins to determine priorities for structural stormwater retrofit projects during development of the IP (SPU 2015). The methods and results are described in detail in the *Integrated Plan – Stormwater Priority Basins Technical Memorandum* (SPU 2012). The DSA included development of the *Structural Stormwater Control Priorities Technical Memorandum* (Geosyntec 2019b) to summarize the prioritization method and criteria (see Appendix B). The steps SPU used in the ranking process are summarized below.

- Step 1: Prioritize receiving waters based on three factors—beneficial uses, impairments, and regulatory drivers. These factors were combined and weighted equally into an overall receiving water priority score. Slightly different criteria were used to evaluate water bodies and watercourses (Figures 5.1 and 5.2, respectively). In the IP, watercourses were defined as creeks whereas water bodies were defined as non-creek receiving waters (e.g., lakes and the Puget Sound basins).
- Step 2: Evaluate individual MS4 basins based on their potential to pollute downstream receiving waters. Basins with a drainage area greater than 100 acres were included in the analysis. A total of 57 individual basins were analyzed, representing about 36,000 acres of drainage area or about 90 percent of the City's drainage area. SPU evaluated the stormwater basin pollution potential for basins draining to water bodies based on their estimated total suspended solids (TSS) loads. SPU evaluated the stormwater pollution potential of basins draining to watercourses based on two factors: 1) TSS normalized load and 2) the "2-year storm event factor" (see description in Appendix B).
- Step 3: For each stormwater basin, the water body or watercourse priority and the stormwater basin pollution potential score were combined, and equally weighted, to arrive at the overall stormwater basin priority (Low, Moderate, High).

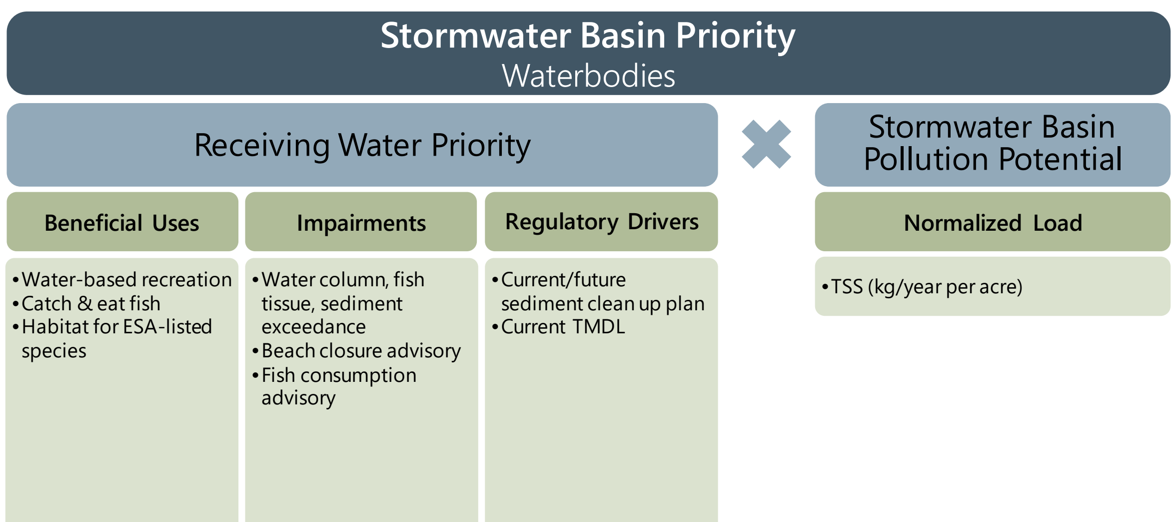


Figure 5.1. Stormwater basin prioritization framework for waterbodies

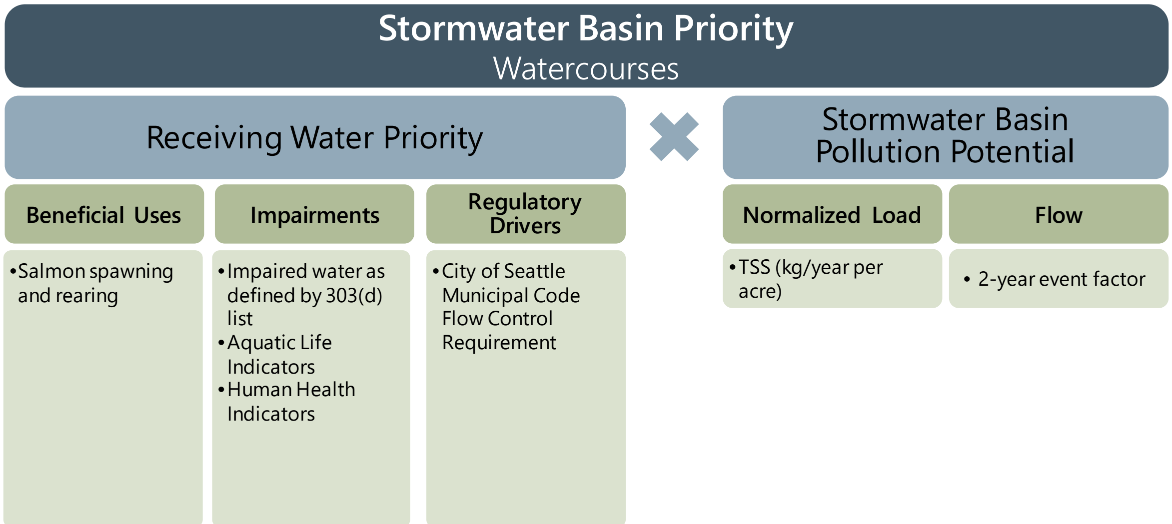


Figure 5.2. Stormwater basin prioritization framework for watercourses

The resultant stormwater basin priorities for water bodies and watercourses are summarized in Figure 5.3 and Figure 5.4, respectively. These stormwater basin priorities are provided to inform the ISP planning process when identifying areas for structural stormwater retrofits to address water quality and flow control needs.

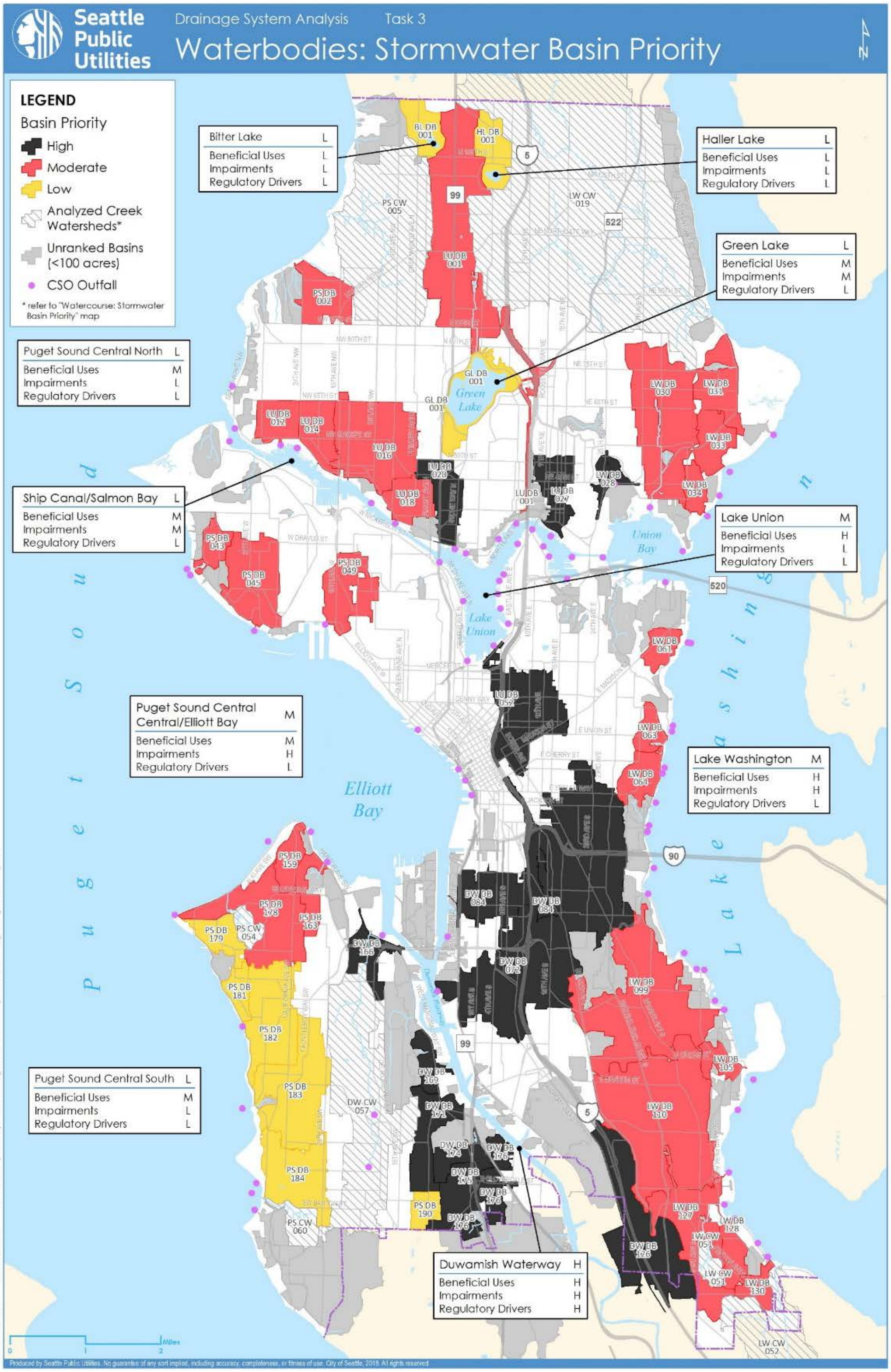


Figure 5.3. Stormwater basin priorities for water bodies

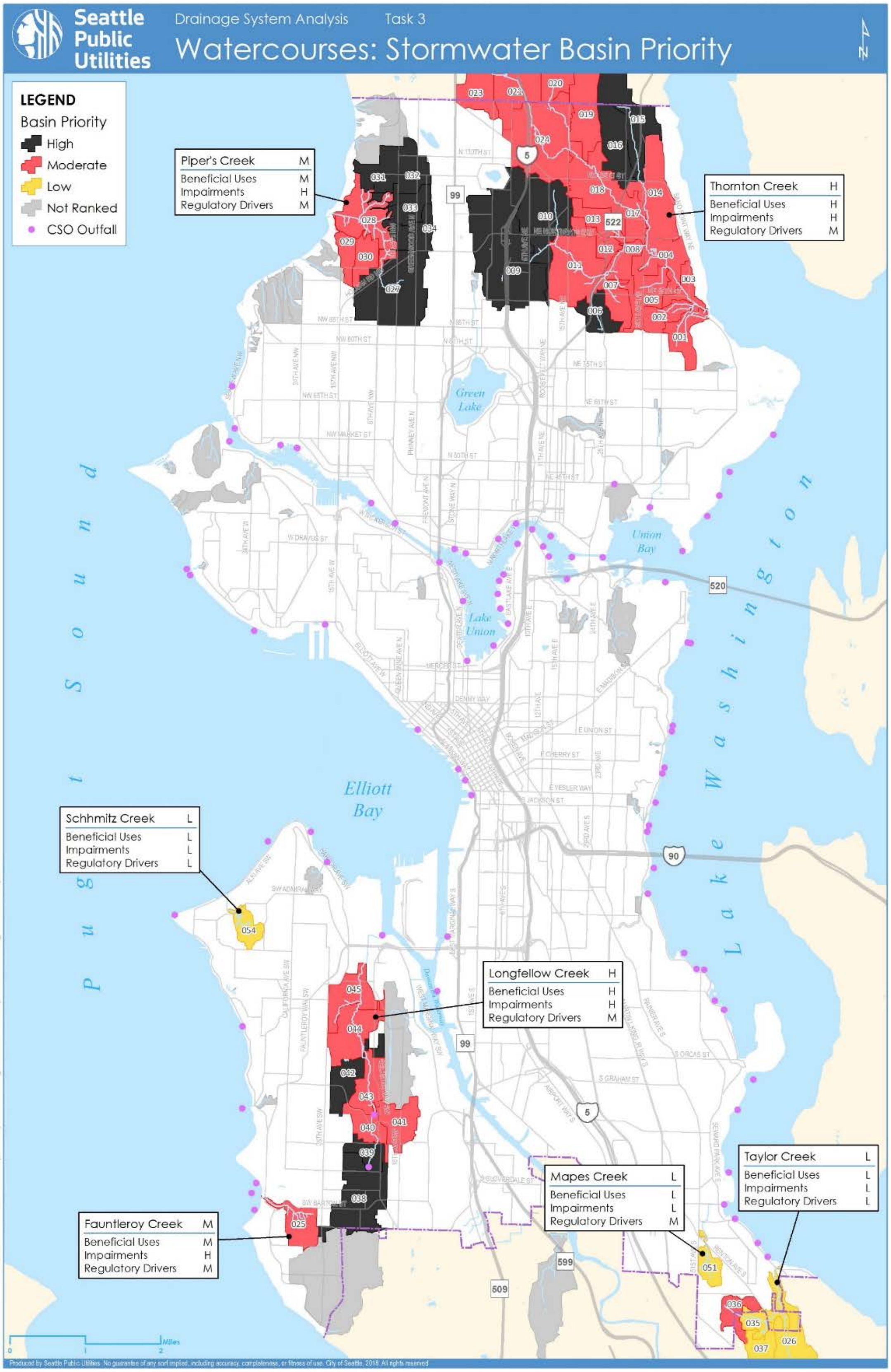


Figure 5.4. Stormwater basin priorities for watercourses

References

Geosyntec. 2019a. DSA Water Quality & Flow Control Pollutant Summary. Prepared for Seattle Public Utilities by Geosyntec Consultants.

Geosyntec. 2019b. Structural Stormwater Control Priorities Technical Memorandum. Prepared for Seattle Public Utilities by Geosyntec Consultants. February.

Herrera Environmental Consultants. 2019. Future Trends Topic Papers: Water Quality. Draft. Prepared for King County by Herrera Environmental Consultants. March.

King County. 2019. Clean Water Plan Fact Sheet. King County, Department of Natural Resources and Parks. Accessed December 26, 2019. <https://www.kingcounty.gov/~/media/depts/dnrp/wtd/capital-projects/system-planning/clean-water-plan/docs/1903_Clean-Water-Fact-Sheet.ashx?la=en>.

Seattle Public Utilities. 2007a. City of Seattle State of the Waters 2007. Executive Summary. Volume I: Seattle Watercourses.

Seattle Public Utilities. 2007b. City of Seattle State of the Waters 2007. Volume I: Seattle Watercourses.

Seattle Public Utilities. 2007c. City of Seattle State of the Waters 2007. Volume III: Seattle Small Lakes.

Seattle Public Utilities. 2012. Integrated Plan (Draft Review): Stormwater Priority Basins Technical Memorandum. September.

Seattle Public Utilities. 2015. Integrated Plan (Final). Volume 3 in “Protecting Seattle’s Waterways.” May.

University of Washington. 2015. State of Knowledge: Climate Change in Puget Sound. University of Washington, Climate Impacts Group. November.

Washington Administrative Code (WAC). 2013. Chapter 173-204 WAC. Sediment Management Standards.

Washington Administrative Code (WAC). 2016. Chapter 173-201A WAC. Water Quality Standards for Surface Waters of the State of Washington.

Washington Administrative Code (WAC). 2018. Chapter 173-201A WAC. Amendatory Section to Water Quality Standards for Surface Waters of the State of Washington.

Appendix A: DSA Water Quality and Flow Control Pollutant Summary



DRAINAGE SYSTEMS ANALYSIS

Water Quality & Flow Control (Aquatic Health)

Pollutant Summary

December 13, 2019

Water Quality & Flow Control (Aquatic Health)

Technical Memorandum

Date: January 23, 2019; Revised December 13, 2019

Deliverable title: Water Quality & Flow Control (Aquatic Health) Pollutant Summary

Task No.: 3.2

To: Kevin Buckley, Topic Area Lead

Prepared by: Christian Nilsen, Senior Engineer
Geosyntec Consultants

John Lenth, Herrera Environmental Consultants

Reviewed by: Eric Strecker, Geosyntec Consultants
Mike Milne, Brown and Caldwell

Table of Contents

Figures

Tables

x

Abbreviations

7-DADMax	Seven-day average of the daily maximum temperature
B-IBI	Benthic Index of Biological Integrity
BEACH	Beach Environmental Assessment, Communication & Health Program
BOD	Biochemical Oxygen Demand
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFU	Coliform Forming Units
City	City of Seattle
CSL	Cleanup Screening Level
CSO	Combined Sewer Overflow
CWA	Clean Water Act
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DSA	Drainage System Analysis
DW	Dry Weight
EPA	United States Environmental Protection Agency
EW	East Waterway
FDA	United States Food and Drug Agency
FOD	Frequency of Detection
LDW	Lower Duwamish Waterway
MDL	Method Detection Limit
MPN	Most Probable Number
MWCI	Marine Water Condition Index
MTCA	Model Toxics Control Act
NA	Not Applicable
NOAA	National Oceanic and Atmospheric Administration
NTU	Nephelometric Turbidity Unit
PAH	Polycyclic Aromatic Hydrocarbon
PSM	Prespawn Mortality
RM	River Mile
ROD	Record of Decision

SCO	Sediment Cleanup Objective

Abbreviations (continued)

SMC	Seattle Municipal Code
SOTW	State of the Waters
SPU	Seattle Public Utilities
SQS	Sediment Quality Standard
TM	Technical Memorandum
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TPH	Total Petroleum Hydrocarbons
TPN	Total Persulfate Nitrogen
TSI	Trophic State Index
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington State Department of Fish and Wildlife
WDoH	Washington State Department of Health
WQI	Water Quality Index
WQS	Water Quality Standards
WW	West Waterway

1. Introduction

Seattle Public Utilities (SPU) owns and maintains over 1,400 miles of storm drains and combined sewers. SPU works to protect and improve the quality of Seattle's marine and freshwater receiving water bodies.

This document provides an overview of the current understanding of Seattle's receiving waters. It first discusses the background and methods used to develop this summary. The remainder of the document provides a review of the relevant monitoring data, assessments, and regulations for each receiving water.

2. Background

In 1993, SPU began mapping and evaluating conditions in Seattle's five salmonid-bearing streams (i.e., Fauntleroy Creek, Longfellow Creek, Taylor Creek, Thornton Creek, and Piper's Creek). The Comprehensive Drainage Plan (Seattle Public Utilities 2004) summarized evaluated flow and water quality related impacts to public and aquatic health in major water bodies such as the Lower Duwamish Waterway and Lake Washington as well as the creeks. In the 2007 State of the Waters (SOTW) Report (SPU 2007b, 2007c), SPU provided a detailed review of water quality data and habitat conditions in Seattle's creeks and small lakes. There were no updates to major water bodies in the SOTW.

This technical document reviews monitoring data, studies, and other relevant information developed since the 2007 SOTW report related to Seattle's creeks, small lakes, large lakes, and major water bodies. Where applicable, the methodology used in the SOTW report is used in this study to evaluate receiving water condition.[1]

[1] Not all pollutants, indicators or regulatory drivers were addressed in the SOTW. In these cases, data prior to 2007 have been incorporated into this document.

3. Methods

3.1 Receiving Waters

For this TM, Seattle's receiving waters are divided into the categories defined below:

- Creeks: Natural streams that drain into lakes and other water bodies.
- Large and small lakes: Seattle's lakes classified based on size.
- Water bodies: Large receiving waters adjacent to Seattle.

Receiving waters are summarized in Table 3.1 and displayed on Figure 3.1

Table 3.1. Seattle's Receiving Waters

Classification	Receiving Waters
Creeks	Fauntleroy Creek Longfellow Creek Piper's Creek Taylor Creek Thornton Creek Small Creeks
Small Lakes	Bitter Lake Haller Lake Green Lake
Large Lakes	Lake Washington (offshore Seattle) Lake Union/ Ship Canal
Water bodies	Lower Duwamish Waterway[1] Elliott Bay Puget Sound (offshore Seattle)

[1] Includes East and West Waterways.

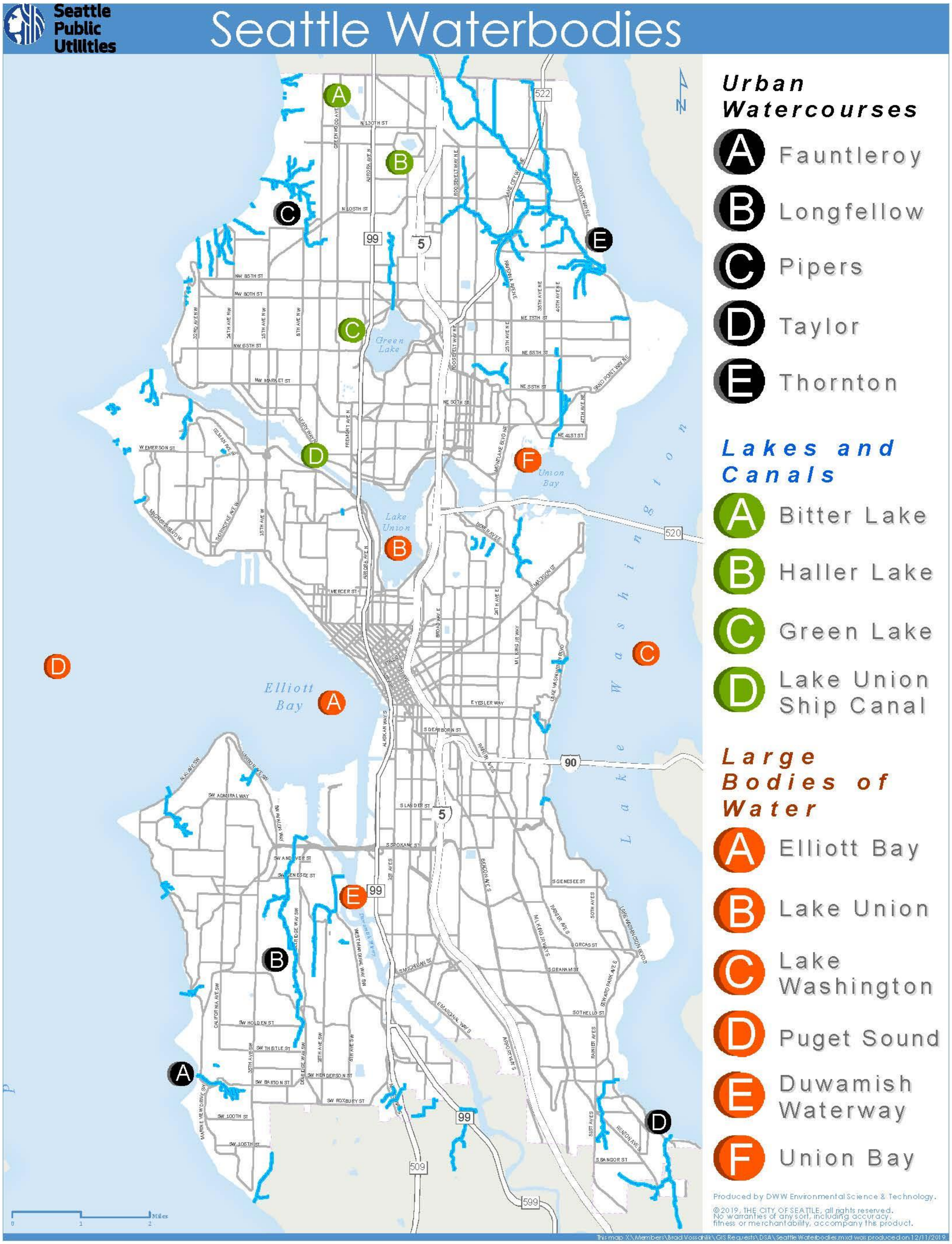


Figure 3-1. Seattle Waterbodies

3.2 Categories and Criteria

In this TM, receiving water conditions are summarized based on three categories:

- Pollutants: Quantitative data that provide information on the level of pollutants or other constituents in the water or sediment. Pollutants are grouped according to how they may affect recreation, aquatic life, and fish consumption.
- Indicators: Indices of quantitative data or non-quantitative data that reflect water quality, public health or habitat.
- Regulatory Drivers: State or Federal laws or guidance governing water quality, public health or habitat.

The Water Quality Standards for Surface Waters of the State of Washington (WQS) (173-201A WAC 2016), identifies the designated uses of all surface waters in the state. The designated uses of the freshwater and marine water bodies studied in this TM are identified and further discussed in the DSA Regulatory Summary.

At the time of preparation of the TM, Ecology is proposing updates to the WQS related to water contact recreation. See Section 3.2.1.1.1 for more information regarding that process.

3.2.1 Pollutants

The available data for pollutants associated with each designated use were reviewed to assess the condition of each water body. Table 3.2 summarizes use categories, pollutant groups, and the primary pollutants used to evaluate the receiving water condition. These pollutants are then discussed in more detail in the following sections.

Table 3.2. Summary of Pollutants		
Category	**Pollutant Group**	**Pollutants Evaluated**
Recreation	Fecal Indicator Bacteria	Fecal Coliform, *E. coli*, Enterococci (173-201A WAC Amendatory Section 2018)
Aquatic Health	Dissolved Oxygen	Dissolved oxygen concentration (173-201A WAC 2016)
	Flow	Altered runoff regime
	Metals	Metals with Aquatic Life criteria: Arsenic, Cadmium, Chromium (III), Chromium (VI), Copper, Lead, Mercury, Nickel, Selenium, Silver, Zinc (173-201A WAC 2016).
	Nutrients	Total nitrogen and total phosphorus (173-201A WAC 2016)
	Organics	All organic chemicals listed in Table 240 of the Water Quality Standards (173-201A WAC 2016) with aquatic health criteria
	pH	pH (173-201A WAC 2016)
	Sediment Quality	All pollutants in Table 1 of the Sediment Management Standards (173-204 WAC 2013)
	Temperature	Temperature (173-201A WAC 2016)
	Turbidity/Clarity	Turbidity (173-201A WAC 2016), Trophic State Index - Secchi (Carlson 1977)
Fish Harvesting	Fecal Indicator Bacteria	Fecal Coliform (173-201A WAC 2016)
	Toxics	All chemicals listed in Table 240 of the Water Quality Standards (173-201A WAC 2016) with human health criteria

3.2.1.1 Recreation

3.2.1.1.1 Fecal Bacteria

Enteric pathogens, such as viruses, bacteria, and protozoa, in receiving waters can negatively affect human health through swimming exposure and other contact. Fecal bacteria indicators, such as fecal coliform, Escherichia coli (E. coli), and Enterococcus species (enterococci), are used to estimate the presence of pathogens that may pose risks to human health. Fecal bacteria and other pathogens may enter receiving waters through leaking sewer systems, sewer overflows, failing septic systems and direct human, pet, and wildlife wastes.

Washington currently applies fecal bacteria criteria to freshwater and marine waters according to the level of recreational use (173-201A WAC 2016). The current standard uses fecal coliform as the fecal indicator bacteria for regulatory purposes as shown in Table 3.3 and Table 3.4.

Table 3.3. Current (2018) Water Contact Bacteria Criteria for Freshwater	
Category	**Fecal Bacteria Indicator**
Extraordinary Primary Contact Recreation	• Geometric Mean Value: ≤ 50 colonies/100 mL • Geometric Mean for the Maximum Ten Percent of Samples: ≤100 colonies/100 mL
Primary Contact Recreation	• Geometric Mean Value: ≤ 100 colonies/100 mL • Geometric Mean for the Maximum Ten Percent of Samples: ≤200 colonies/100 mL
Secondary Contact Recreation	• Geometric Mean Value: ≤ 200 colonies/100 mL • Geometric Mean for the Maximum Ten Percent of Samples: ≤400 colonies/100 mL

Source: (173-201A WAC 2016)

Table 3.4. Current (2018) Water Contact Bacteria Criteria for Marine Waters	
Category	**Fecal Bacteria Indicator**
Primary Contact Recreation	• Geometric Mean Value: ≤ 14 colonies/100 mL • Geometric Mean for the Maximum Ten Percent of Samples: ≤43 colonies/100 mL
Secondary Contact Recreation	• Geometric Mean Value: ≤ 70 colonies/100 mL • Geometric Mean for the Maximum Ten Percent of Samples: ≤208 colonies/100 mL

Source: (173-201A WAC 2016)

Ecology recently revised the water quality criteria for protection of recreational uses. These are explained in more detail the DSA Regulatory Summary and are summarized in Table 3.5 and Table 3.6.

Table 3.5. Proposed Water Contact Bacteria Criteria for Freshwater	
Bacterial Indicator	**Criteria**
E. coli	• Geometric Mean Value: ≤ 100 CFU (MPN/100 mL) • Geometric Mean for the Maximum Ten Percent of Samples: ≤ 320 CFU (MPN/100 mL)
Fecal Coliform (expires 12/31/2020)	• Geometric Mean Value: ≤ 100 CFU (MPN/100 mL) • Geometric Mean for the Maximum Ten Percent of Samples: ≤ 200 CFU (MPN/100 mL)

Source: (173-201A WAC 2019)
Note: Criteria are based on sampling with an averaging period

Table 3.6. Proposed Water Contact Bacteria Criteria for Marine Water	
Bacterial Indicator	**Criteria**
Enterococci	• Geometric Mean Value: ≤ 30 CFU (MPN/100 mL) • Geometric Mean for the Maximum Ten Percent of Samples: ≤ 110 CFU (MPN/100 mL)
Fecal Coliform (expires 12/31/2020)	• Geometric Mean Value: ≤ 14 CFU (MPN/100 mL) • Geometric Mean for the Maximum Ten Percent of Samples: ≤ 43 CFU (MPN/100 mL)

Source: (173-201A WAC Amendatory Section 2018)
Note: Criteria are based on sampling with an averaging period

Agencies that oversee public uses of freshwater beaches and swimming areas use a different metric called the "Ten-State Standard" to make decisions about human exposure to pathogens from water contact and when to issues health advisories. Under this standard, the geometric mean of the five most recent samples cannot exceed 200 CFU/100mL (colony forming units per 100 milliliters) for fecal coliform and no single sample can exceed 1000 CFU/100mL.

In marine swimming beaches, the state Department of Health evaluates human health exposure to fecal contamination based on the EPA's Ambient Water Quality Criteria for Bacteria (EPA 1986). This standard uses a maximum geometric mean of 35 enterococci/100 mL, based on results from a minimum of five weekly samples with a maximum single sample threshold of 276 enterococci/100 mL.

3.2.1.2 Aquatic Health

3.2.1.2.1 Dissolved Oxygen

DO criteria are based on the lowest 1-day minimum concentration. If low DO conditions naturally exist, human actions may not cause a 0.2 mg/L decrease (or more) in concentrations. Concentrations should not fall below established criteria DO concentrations more than once every 10 years. Aquatic life DO criteria for freshwater and marine water are shown in Table 3.7 and Table 3.8, respectively. Only categories relevant to Seattle's receiving waters are shown.

Table 3.7. Aquatic Life Dissolved Oxygen Criteria in Freshwater	
Category	**Lowest 1-day minimum**
Core Summer Salmonid Habitat	9.5 mg/L
Salmonid Spawning, Rearing, and Migration	8.0 mg/L

Source: (173-201A WAC 2016)

Table 3.8. Aquatic Life Dissolved Oxygen Criteria in Marine Water	
Category	**Lowest 1-day minimum**
Extraordinary quality	7.0 mg/L
Excellent quality	6.0 mg/L

Source: (173-201A WAC 2016)

3.2.1.2.2 pH

pH indicates the relative acidity or alkalinity of water. It is expressed as the negative logarithm of hydrogen ion concentration. Table 3.9 and Table 3.10 show the aquatic life pH criteria for freshwater and marine waters, respectively.

Table 3.9. Aquatic Life pH Criteria in Freshwater

Use Category	pH Units
Char Spawning and Rearing and Core Salmonid Habitat	• Range: 6.5 – 8.5 • Human-Caused Variation: 0.2 units
Salmonid Spawning, Rearing, and Migration	• Range: 6.5 – 8.5 • Human-Caused Variation: 0.5 units

Source: (173-201A WAC 2016)

Table 3.10. Aquatic Life pH Criteria in Marine Water

Use Category	pH Units
Extraordinary quality	• Range: 7.0 – 8.5 • Human-Caused Variation: 0.2 units
Excellent quality, good quality	• Range: 7.0 – 8.5 • Human-Caused Variation: 0.5 units
Fair quality	• Range: 6.5 – 9.0 • Human-Caused Variation: 0.5 units

Source: (173-201A WAC 2016)

3.2.1.2.3 Temperature

Temperature criteria in freshwater are based on the 7-day average of the daily maximum temperatures (7-DADMax). Temperature criteria in marine water are based on the 1-day maximum temperature (1-DMax). Table 3.11 shows temperature criteria in freshwater, while Table 3.12 shows temperature criteria in marine water. Only categories relevant to Seattle's receiving waters are shown.

Table 3.11. Aquatic Life Temperature Criteria in Freshwater

Use Category	Highest 7-DADMax
Core Summer Salmonid Habitat	16°C (60.8°F)
Salmonid Spawning, Rearing, and Migration	17.5°C (63.5°F)

Source: (173-201A WAC 2016)

Note: Some streams (e.g. Thornton Creek) have a more stringent temperature criterion that is applied seasonally to further protect salmonid spawning and egg incubation.

Table 3.12. Aquatic Life Temperature Criteria in Marine Water

Category	Highest 1-DMax
Extraordinary quality	13°C (55.4°F)
Excellent quality	16°C (60.8°F)

Source: (173-201A WAC 2016)

3.2.1.2.4 Turbidity and Clarity

In creeks and rivers, Ecology has established criteria to assess turbidity based on a comparison with background turbidity levels. The state water quality criteria includes that no more than a 5 Nephelometric Turbidity Unit (NTU) increase above background level is allowed when the background is 50 NTU or less. When the background turbidity level is above 50 NTU, then no more than a 10 percent increase in turbidity over background is permitted.

This standard can only be applied when concurrent "background" turbidity data are available. However, it is not useful for assessing the long-term condition of a receiving water compared to other waters. Therefore, for purposes of assessing the receiving water condition related to turbidity in this document, the turbidity component of Ecology's Water Quality Index (Ecology 2002), expressed as average monthly turbidity with Good, Fair, and Poor ranges, has been used. See Section 3.2.2.1 for a description of the Water Quality Index. The turbidity range thresholds for the Puget Sound region are shown in Table 3.13 were used to assess turbidity conditions.

Table 3.13. Average monthly turbidity ranges used to assess stream condition

Range	Good	Fair	Poor
June - October	< 17 NTU	17-123 NTU	>123 NTU
November - May	< 8 NTU	8-65 NTU	> 65 NTU

Water clarity in lakes is measured visually using a Secchi Disk, an 8-inch disk with alternating black and white quadrants. The water quality parameter reported is called Secchi depth, which is the depth below the water surface at which the disk just becomes no longer visible. Secchi depth is a measure of water clarity with higher values indicating better clarity or transparency in the lake. There is variability in this depth due to both the light conditions when it is taken and individual differences in the visual assessment.

Clarity criteria are assessed by calculating the Trophic State Index (TSI) based on Secchi depth measurements (Carlson 1977), referred to as TSI-Secchi. TSI-Secchi is calculated from *Equation 1,* where the Secchi depth is reported in meters.

$$TSI_{Secchi} = 10(6 - \frac{\ln(Secchi\ Depth)}{\ln(2)}$$

Equation 1

TSI-Secchi values less than 40 are classified as good, between 40 and 50 are classified as fair, and greater than 50 are classified as poor.

3.2.1.2.5 Metals

Water quality standards specify acute and chronic water quality criteria for 11 metals as shown in Table 3.14. For most metals, the water quality criteria apply to the dissolved fraction only. Exceptions are the acute and chronic criteria for chromium-IV, the chronic criteria for mercury, and the freshwater criteria for selenium; these criteria are based on the total amount present rather than the dissolved fraction.

The Washington State criteria for cadmium, chromium-III, copper, lead, nickel, silver, and zinc are calculated based on water hardness, however, hardness measurements are not always available at the same time as metals concentrations are collected. The 2007 SOTW assumed a typical hardness value for non-storm conditions relating to chronic exposure (70 mg/L hardness as CaCO3) and a value for storm conditions relating to acute exposure (40 mg/L hardness as CaCO3), (SPU 2007b) in its evaluations. The same methodology is used in this TM.

Table 3.14. Metals Criteria for Aquatic Life

Parameter (µg/L)	Freshwater		Marine	
	Acute	Chronic	Acute	Chronic
Dissolved Fraction[a]				
Arsenic	360	190	69	36.0
Cadmium	1.4[d]	0.79[b]	42	9.3
Chromium (III)[d]	264[c]	132.9[b]	1,100.00	50
Copper	7.4[c]	8.37[b]	4.8	3.1
Lead	16[c]	0.47[b]	210	8.1
Mercury	2.1	--	1.8	--
Nickel	670[c]	116[b]	74	8.2
Selenium	--	--	290	71
Silver[e]	0.683[c]	--	1.9	--
Zinc	51.5[c]	47.1[b]	90	81
Total Fraction				
Chromium (VI)[d]	15	10	--	--
Mercury	--	0.012	--	0.025
Selenium	20	5	--	

Source: (*Water Quality Standards for Surface Waters of the State of Washington* 2016)

a. The criteria for arsenic, cadmium, chromium VI, copper, mercury (acute), nickel, selenium (marine only), silver, and zinc correspond to the dissolved fraction of metals.

b. The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. The value given here corresponds to the 15th percentile hardness (70 mg/L as CaCO3) for non-storm flow conditions from the SOTW report.

c. The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. The value given here corresponds to the 15th percentile hardness (40 mg/L as CaCO3) for storm flow conditions from the SOTW report.

d. Due to difficulty meeting holding times and method detection limits, chromium, total measured as dissolved, is used as a surrogate for chromium (VI) and chromium (III). Should chromium, total measured as dissolved, exceed 10 µg/L, additional analysis may be required.

e. An instantaneous concentration not to be exceeded at any time.

3.2.1.2.6 Organics

Urban runoff can contain toxic organic compounds such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), phthalates, and organochlorine and organophosphate compounds. Sources of organic compounds include petroleum products, asphalt sealants, pesticides, transformers, and plastics. Many of these organic compounds are hydrophobic, so they attach to organic matter and settle in bed material. Some organic compounds bioaccumulate, meaning that concentrations increase from lower to higher trophic levels as smaller species are consumed by larger ones. Some compounds, such as PCBs and organochlorine pesticides (e.g., DDT, chlordane), are very persistent and can remain in bottom sediments for many years. Consequently, aquatic and marine sediments, as well as fish tissues, can contain elevated concentrations of some compounds many years after they were regulated or removed from production.

Water quality criteria have been developed for 113 different organic compounds (173-201A WAC 2016). Many compounds are difficult and expensive to analyze, especially at concentrations specified in the water quality criteria, and known toxicity thresholds often approach or are below the detection limits of available analytical technology.

3.2.1.2.7 Nutrients

Excessive levels of phosphorus and/or nitrogen can lead to excess plant and algae growth in receiving waters. Some algae can produce neurotoxins that are harmful to aquatic organisms, pets, and humans. Algal and plant decomposition consumes oxygen in the water column as does respiration of live vegetative materials, leading to reduced DO, especially during nighttime. Ammonia nitrogen can directly remove oxygen from a water body when the ammonia is oxidized to nitrate. In addition, ammonia can be toxic to aquatic organisms when pH and temperature are elevated. Typical anthropogenic sources of nutrients include fertilizers, human and animal wastes, organic matter, and some detergents.

Washington State has not established numerical criteria for nitrogen and phosphorus. In the absence of numerical criteria, regional monitoring efforts undertaken by the regional Stormwater Action Monitoring (SAM) Program (King County 2018g) have adopted metrics for total nitrogen and total phosphorus concentrations from the scientific literature (Hausmann et al. 2016). These metrics are derived from studies of nutrient-sensitive diatom groups that are indicators of stream condition. In the Puget Sound region, these metrics are applied to low-flow conditions only (August – October).

Table 3.15. Freshwater nutrient metrics used to determine condition

Parameter	Good	Fair	Poor
Total Phosphorus [a] (mg/L)	>0.050	>0.041 and <0.050	<0.041
Total Nitrogen [a] (mg/L)	>0.862	>0.459 and <0.862	<0.459

Source: (173-201A WAC 2016)

a. Only low-flow conditions (August – October) are used to evaluate condition.

Eutrophication in lakes is usually driven by excessive phosphorus levels, which is typically the limiting factor for photosynthesis of algae. Ecology has established action-values for total phosphorus concentrations, and an exceedance of these values indicates a suspected problem and need for a lake-specific study to determine if a nutrient problem exists (173-201A WAC 2016).

Table 3.16. Trophic-state action values for establishing nutrient criteria in lakes

Trophic State	If Ambient TP (µg/l) Range of Lake is:	Then criteria should be set at:
Ultra-oligotrophic	0-4	4 or less
Oligotrophic	>4-10	10 or less
Lower mesotrophic	>10-20	20 or less
Action Value > 20	>20	lake specific study may be initiated.

Source: (173-201A WAC 2016)

In contrast to lakes, photosynthesis in marine waters is usually limited by nitrogen. Ecology has identified nitrogen enrichment as a major concern for the Puget Sound. While no established criteria exist for nitrogen concentrations in marine receiving waters, Ecology has developed the marine water condition index to evaluate the condition of marine waters. One component of this index is the Eutrophication Index, which summarizes nutrient-specific conditions. This index draws on a 10-year subset of nutrient conditions in Puget Sound (1999-2008) to describe the likelihood of human-caused eutrophication from nutrients.

3.2.1.2.8 Sediment Quality

Sediments in urban waters can contain elevated levels of toxic metals, organics, and nutrients from stormwater discharges and other sources. As noted above, urban runoff can contain toxic substances in particulate forms that settle to the bottom of receiving water bodies where they can adversely affect benthic organisms. Contaminated sediments that are toxic to benthic organisms can reduce the food supply for fish. Some sediment contaminants (e.g., PCBs) can enter the food chain and bioaccumulate in fish, marine mammals, and birds. Contaminated sediments can also lead to pollutant exceedances in the water column under certain conditions, such as high-flow events that resuspend bed sediments. Ecology established the Sediment Management Standards (SMS; 173-204 WAC 2013) to reduce and ultimately eliminate adverse effects on biological resources and significant threats to human health from surface sediment contamination. The SMS address sediment in freshwater and marine water bodies.

In the cleanup standards portion of the SMS (Part V Sediment Cleanup Standards) sediment cleanup objectives and cleanup screening levels are established for contaminants for protection of the benthic community in marine and low salinity sediments. The sediment cleanup objectives establish a no adverse effects level, including no acute or chronic health effects to the benthic community. The cleanup screening levels include a minor adverse effects level, including acute or chronic effects to the benthic community. Table 3.17 lists the sediment cleanup objectives and cleanup screening levels for marine sediments. Biological effects criteria are also established for marine sediments to evaluate toxicity to the benthic invertebrate community.

Freshwater sediment criteria for benthic community protection in lakes are established as (i) sediment cleanup objectives, which represent the contaminant concentrations that cause no adverse effect, and (ii) sediment cleanup screening levels, which if exceeded, can cause minor adverse effects in the benthic community (173-204 WAC 2013). Sediment cleanup standards for metals, organics, and other contaminants in freshwater are shown in Table 3.18. Biological criteria for freshwater sediments are also established in the SMS.

Table 3.17. Marine Sediment Cleanup Standards Chemical Criteria		
Chemical Parameter	Sediment Cleanup Objective	Cleanup Screening Level

Table 3.17. Marine Sediment Cleanup Standards Chemical Criteria

Chemical Parameter	Sediment Cleanup Objective	Cleanup Screening Level
Metals	mg/kg dry weight	mg/kg dry weight
Arsenic	57	93
Cadmium	5.1	6.7
Chromium	260	270
Copper	390	390
Lead	450	530
Mercury	0.41	0.59
Silver	6.1	6.1
Zinc	410	960
Lipophilic Organics	mg/kg organic carbon	mg/kg organic carbon
LPAH	370	780
Naphthalene	99	170
Acenaphthylene	66	66
Acenaphthene	16	57
Fluorene	23	79
Phenanthrene	100	480
Anthracene	220	1200
2-Methylnaphthalene	38	64
HPAH	960	5300
Fluoranthene	160	1200
Pyrene	1000	1400
Benz(a)anthracene	110	270
Chrysene	110	460
Total Benzofluoranthenes	230	450
Benzo(a)pyrene	99	210
Indeno(1,2,3-c,d)pyrene	34	88
Dibenzo(a,h) anthracene	12	33
Benzo(g,h,i) perylene	31	78
1,2-Dichlorobenzene	2.3	2.3
1,4-Dichlorobenzene	3.1	9
1,2,4-Trichlorobenzene	0.81	1.8
Hexachlorobenzene	0.38	2.3
Dimethyl phthalate	53	53

Table 3.17. Marine Sediment Cleanup Standards Chemical Criteria		
Chemical Parameter	Sediment Cleanup Objective	Cleanup Screening Level
Diethyl phthalate	61	110
Di-n-butyl phthalate	220	1700
Dibenzofuran	15	58
Hexachlorobutadiene	3.9	6.2
N-Nitrosodiphenylamine	11	11
Total PCBs	12	65
Hydrophilic Organics	ug/kg dry weight	ug/kg dry weight
Phenol	420	1200
2-Methylphenol	63	63
4-Methylphenol	670	670
2,4-Dimethylphenol	29	29
Pentachlorophenol	360	690
Benzyl alcohol	57	73
Benzoic acid	650	650

Source: (173-204 WAC 2013)

Table 3.18. Freshwater Sediment Cleanup Standards Chemical Criteria

Chemical Parameter	Sediment Cleanup Objective	Cleanup Screening Level
Conventional Chemicals	mg/kg dry weight	mg/kg dry weight
Ammonia	230	300
Total sulfides	39	61
Metals	mg/kg dry weight	mg/kg dry weight
Arsenic	14	120
Cadmium	2.1	5.4
Chromium	72	88
Copper	400	1200
Lead	360	>1300
Mercury	0.66	0.8
Nickel	26	110
Selenium	11	>20
Silver	0.57	1.7
Zinc	3200	>4200
Organic chemicals	ug/kg dry weight	ug/kg dry weight
4-Methylphenol	260	2000
Benzoic acid	2900	3800
Beta-Hexachlorocyclohexane	7.2	11
Bis(2-ethylhexyl)phthalate	500	22000
Carbazole	900	1100
Dibenzofuran	200	680
Dibutyltin	910	130000
Dieldrin	4.9	9.3
Di-n-butyl phthalate	380	1000
Di-n-octyl phthalate	39	>1100
Endrin ketone	8.5	>8.5
Monobutyltin	540	>4800
Pentachlorophenol	1200	>1200
Phenol	120	210
Tetrabutyltin	97	>97
Total PCBs	110	2500
Total DDDs	310	860
Total DDEs	21	33

Table 3.18. Freshwater Sediment Cleanup Standards Chemical Criteria		
Chemical Parameter	Sediment Cleanup Objective	Cleanup Screening Level
Total PAHs	17000	30000
Tributyltin	47	320
Bulk Petroleum Hydrocarbons	mg/kg dry weight	mg/kg dry weight
TPH-Diesel	340	510
TPH-Residual	3600	4400

Source: (173-204 WAC 2013)

3.2.1.3 Fish Consumption

3.2.1.3.1 Toxics

Water quality for fish consumption can be evaluated by observing certain metal and organic compounds in the water column. Specific metals used to evaluate receiving water condition with respect to fish consumption and human health impacts are shown in Table 3.19.

Table 3.19. Metals with Human Health Criteria (Water and Organism)	
Parameter	**Criteria (ug/L)**
Antimony	12
Arsenic	10
Copper	1300
Cyanide	19
Nickel	150
Selenium	120
Zinc	2300

In addition to metals, human health criteria have been developed for the presence of 88 organic compounds in fish intended for human consumption. A number of water bodies near Seattle are on the 303(d)-list due to elevated concentrations of toxic organic compounds (e.g., PCBs, HPAHs, dioxin, organochlorine pesticides) in fish tissue.

In 2016, EPA reviewed proposed WQS for human health criteria relating to toxics. In this review, the EPA specified the human health criteria to be used for CWA purposes. This is explained in further detail in the DSA Regulatory Summary. For the purposes of this document, the WQS adopted by Ecology are used to evaluate conditions with respect to human health. In most cases, application of the EPA criteria would not result in a different assessment, although some parameters (e.g. PCBs) have significantly more stringent federal criteria.

3.2.1.3.2 Fecal Bacteria

Filter-feeding shellfish, such as clams, mussels, and oysters, can accumulate human-borne pathogens that pose a risk to human health. To protect shellfish harvesting, the state has adopted the Food and Drug Administration's (FDA) National Shellfish Sanitation Program criteria (FDA 2015) for fecal coliform as an indicator of potential health effects. In areas of shellfish harvesting, the fecal coliform criteria are a maximum geometric mean value of 14 colonies/100 mL, with no more than 10 percent of all samples exceeding 43 colonies/100 mL.

3.2.2 Indicators

There are many different systems to summarize water quality of different aquatic environments in Washington State. The Water Quality Index, Benthic Index of Biotic Integrity, and Coho Pre-spawn Mortality analyze the quality of river water; the Trophic State Index and Toxic Algal Blooms analyze the quality of lake water; and Beach and Shellfish Bed Closures can be used to analyze the health of ocean water. These metrics are described in detail below.

3.2.2.1 Water Quality Index (WQI)

Ecology established the Water Quality Index (WQI) as a general indicator of freshwater quality. The WQI for a given location is calculated based on measurements of temperature, pH, fecal coliform bacteria, DO, TSS, turbidity, total phosphorus, and total nitrogen. The WQI is a unitless number ranging from 1 to 100, with higher numbers indicating better water quality. WQI scores of 80 and above are considered "good," scores 40 to 80 are considered "fair," and scores below 40 are considered "poor."

3.2.2.2 Benthic Index of Biotic Integrity (B-IBI)

The Puget Lowland benthic index of biotic integrity (B-IBI) is a regionally used indicator of overall stream health. B-IBI scores are calculated based on the types and numbers of benthic macroinvertebrates found in the stream. B-IBI is expressed as a score between 0 and 100, where the total metric is determined by the sum of 10 individual categories that are indicative of benthic community health. The categories are total, mayfly, stonefly, caddisfly, intolerant, clinger, and long-lived taxa richness as well as percent tolerant, predator, and dominance. Higher values represent benthic communities that reflect higher stream health. B-IBI scores of 80-100 are considered "excellent," scores of 60-80 are "good," scores of 40-60 are "fair," scores of 20-40 are "poor," and scores below 20 are "very poor" (King County 2014). B-IBI impaired water listings are discussed separately under regulatory drivers.

3.2.2.3 Coho Pre-spawn Mortality (PSM)

Coho (*Oncorhynchus kisutch*) returning to spawn in some Puget Sound creeks have been observed to suffer lethal and sublethal effects. Sublethal effects include erratic surface swimming, gaping, fin splaying, and loss of orientation and equilibrium (Scholz et al. 2011). Lethal effects were observed to occur within hours of exposure to surface waters. Beginning in 2002, surveys were conducted in part to identify water quality and spawner condition factors that lead to coho pre-spawn mortality. Fish condition, pathogens, and exposure to known pollutants (i.e., conventionals, metals, and organics) were not found to correlate with pre-spawn mortality. Evidence suggests that returning coho are vulnerable to an unidentified toxic contaminant (or contaminant mixture) in urban runoff (Feist et al. 2017). Streams with coho pre-spawn mortalities less than 10% (unsuccessful females/successful females) are considered "good," between 10% and 40% are considered "fair," and greater than 40% are considered "poor."

3.2.2.4 Trophic State Index (TSI)

The Trophic State Index (Carlson 1977) is a unitless index corresponding to biological activity in lakes. Lower values represent lower biological activity, with an increase of 10 points representing a doubling of algal biovolume. Scores less than 40 represent oligotrophic lakes, with high water clarity and low biological activity; scores between 40 and 50 represent mesotrophic lakes, with moderate water clarity and medium biological activity, and scores greater than 50 represent eutrophic lakes, which have low water clarity and high biological activity. Scores are based on Secchi depth, total phosphorus concentrations, and chlorophyll-a in the lake's surface layer (upper 10 meters or less) of water measured from June through September.

3.2.2.5 Toxic Algal Blooms

High nutrient concentrations (most often phosphorus, but sometimes nitrogen) can trigger algal growth in several Seattle lakes. Both nitrogen and phosphorus can be found in sewage, stormwater runoff, fertilizers, and even rainfall. An algal bloom is the visible appearance of millions of algal cells in water. Some algae species produce toxins and their blooms can present potential health risks to humans and animals. The Washington State Toxic Algae Program (Ecology 2018e) provides identification and toxicity testing services to citizens and groups concerned about algal blooms (King County 2018i).

Bluegreen algae or cyanobacteria produce toxins that are potentially lethal to people and animals. King County monitors cyanotoxins routinely as part of its Swimming Beach Monitoring Program. Washington State Department of Health (WDoH) recommends a three-tiered approach using recreational guidance values of six µg/L microcystin and one µg/L anatoxin-a for determining significant toxic algal blooms in Washington lakes (King County 2018i).

3.2.2.6 Beach Closures

Swimming beaches are managed for contact recreation using different standards than the state WQS. Public agencies monitor and manage swimming beaches for fecal indicator bacteria and toxic algae using guidance for human health. The King County Swimming Beach Monitoring Program follows the Ten State Standard for freshwater beach closures. The Ten State Standard states that the geometric mean of fecal coliform samples should not exceed 200 cfu/100 mL with no single sample exceeding 1000 cfu/100 mL. WDoH recommends an additional approach for swimming beach closure based on microcystin and anatoxin-a levels. When toxins are detected above guidance levels, as listed in Section 3.2.2.5, King County and State departments of health determine public health implications and convey them to the beach managers, who post public health advisories based on their recommendation (King County 2018i)

Decisions to close saltwater beaches to swimming are based on the concentration of enterococci bacteria in the water that indicates human or animal feces are present. Marine beaches are closed for swimming if either of the following criteria is exceeded:

Geometric mean exceeding 35 enterococci/100 mL, based on results from a minimum of five weekly samples; or

Statistical threshold value exceeding 276 enterococci/ 100 mL.

If bacteria levels exceed 104 enterococci/ 100 mL, then a beach advisory is issued.

3.2.2.7 Shellfish Bed Closures

Marine biotoxins are poisons produced by certain toxic algae, which are naturally present in marine waters. A combination of warm temperatures, sunlight, and nutrient-rich waters can cause rapid plankton reproduction, or blooms, which results in increases in toxin-producing algae. Molluscan shellfish (such as oysters, clams, and mussels) feed on toxin-producing algae, and these toxins can concentrate in their tissue. Biotoxins don't harm shellfish but can accumulate in shellfish to levels that can cause death or illness in humans who eat them (Ecology 2018a).

WDoH coordinates with local departments of health and maintains a central database of beach closures for recreational and commercial shellfish harvesting (Washington State Department of Health 2018b).

3.2.3 Regulatory Drivers

Regulatory drivers include the various governmental controls implemented to help monitor and address water quality in Washington state freshwater and marine water bodies. Regulatory drivers used to assess receiving water conditions are discussed below. More detail about specific regulatory drivers is included the DSA Regulatory Summary (SPU 2019).

3.2.3.1 Impaired Waters

Under the Clean Water Action, every two years to categorize surface water bodies in relation to applicable water quality standards. Receiving waters categorized as Category 5 (303(d) listing) or Category 4 (Impaired) were included as impaired waters in this assessment.

Categories are assigned based on the level of impairment. Category 5 is used for water bodies that are impaired (i.e., do not meet the applicable state water quality standards) and need a Total Maximum Daily Load (TMDL) or similar clean-up plan to achieve compliance. Category 5 constitutes the Clean Water Act Section 303(d) list for Washington State. Category 4(b) in Washington's WQA contains impaired water bodies that have an approved TMDL or similar clean-up plan. Category 4(c) includes waters that are impaired due to low flow, dams, or other factors that can't be addressed through a clean-up plan.

3.2.3.2 TMDLs

TMDLs are pollutant load limits set for waterways that are intended to return waterways to an unimpaired state. A TMDL requires a study to determine the appropriate pollutant loading limit(s) for a given waterway and support development of an implementation plan. After EPA approves the TMDL, the requirements must be incorporated into NPDES permits and other regulatory authorizations and orders. If there are non-point sources, then these are addressed via other programs, some of which may be voluntary.

3.2.3.3 Model Toxics Control Act (MTCA)/Comprehensive Environmental Response Compensation and Liability Act (CERCLA)

CERCLA, more commonly known as the Superfund program, is a federal program to clean up uncontrolled or abandoned hazardous-waste sites. CERCLA provides a means to establish liability, including clean-up requirements, for persons responsible for creating hazardous waste and establishes a fund to clean up sites where no persons or other legal entities can be established as liable for the contamination.

The State of Washington has its own cleanup regulations (Chapter 173-340 WAC), which were promulgated under the Model Toxics Control Act (MTCA). In Washington, MTCA helps raise additional funding to prevent future contamination of sites that are a concern for human and/or environmental health.

4. Conditions in Creeks

4.1 Fauntleroy Creek

Fauntleroy Creek is an urban watercourse located in West Seattle, about four miles south of Alki Point. At approximately 1.6 miles in length with a 149-acre watershed, it is the smallest of Seattle's major watercourses. Monthly sampling data collected through the Statewide River and Stream Ambient Monitoring Program is available through 2006. Monthly samples of select parameters are available from July 2007 through October 2007 from the South Puget Sound Dissolved Oxygen study (Ecology 2008). Because data available for Fauntleroy Creek are more than 10-years old, conclusions about conditions are not current and are provided for reference.

4.1.1 Recreation

4.1.1.1 Fecal Bacteria

Based on available data (last sampled in 2006), Fauntleroy Creek is considered in good condition for fecal indicator bacteria. The most recent (2006) data showed that seven of 12 samples exceeded applicable criteria with a geometric mean of 84.4 cfu. Table 4.1 summarizes the fecal coliform sampling data collected in water year 2006. Summary statistics that indicate a potential exceedance of WQS are shaded red.

Table 4.1. Fauntleroy Creek Fecal Coliform Data (cfu/100 mL)

Water Year	Number of Samples	Geometric Mean	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	12	84.4	16	27	115	235	410

Source: (Ecology 2018c)

4.1.2 Aquatic Health

4.1.2.1 Dissolved Oxygen

Based on available data, Fauntleroy Creek is considered in good condition for DO. DO in Fauntleroy Creek was measured between 2004 and 2007 by the Statewide River and Stream Ambient Monitoring Program (Ecology 2018c)(Ecology 2018d) and the South Puget Sound Dissolved Oxygen Study (Ecology 2008). All samples taken as part of these studies show DO levels above the minimum standard. Table 4.2 summarizes the seasonal trend in DO concentrations in Fauntleroy Creek between 2004 and 2007.

Table 4.2. Fauntleroy Creek Dissolved Oxygen Data (mg/L)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

2004										10.7	11	11.4
2005	11.3	12.4	11.2	12.1	11.1	10.8	9.8	9.81	10.4	10.19	11.7	12.1
2006	11.7	12	12	11.6	10.6	10.7	10.7	10.5	10.4			

Source: (Ecology 2018d)

4.1.2.2 pH

Based on available data, Fauntleroy Creek is considered in good condition for pH. pH in Fauntleroy Creek was measured in 2006 by the Statewide River and Stream Ambient Monitoring Program (Ecology 2018d) and in 2007 by the South Puget Sound Dissolved Oxygen Study (Ecology 2008). Measurements of pH ranged from 7.8 to 8.1 with a median of 7.8. All samples have met water quality criteria. Available pH data are shown Table 4.3.

Table 4.3. pH Measured in Fauntleroy Creek

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004										8.18	8.23	8.09
2005	7.97	8.17	8.21	8.03	8.25	8.34	8.11	8.24	8.18	8.14	8.05	8.13
2006	7.95	7.95	8.02	8.25	8.12	8.12	8.11	8.21	8.2			
2007							7.9	8.1	7.8	7.8		

Source: (Ecology 2018d, 2008)

4.1.2.3 Temperature

Based on available data, Fauntleroy Creek is considered in good condition for temperature. Ecology collected continuous temperature data at 30-minute intervals at the Fauntleroy Creek station in the summer months of 2005 and 2006. Figure 4-1 shows temperature monitoring results collected during summer of 2006. The 7-DADmax temperature exceeded criteria one time in July 2006 with a value of 16.1°C.

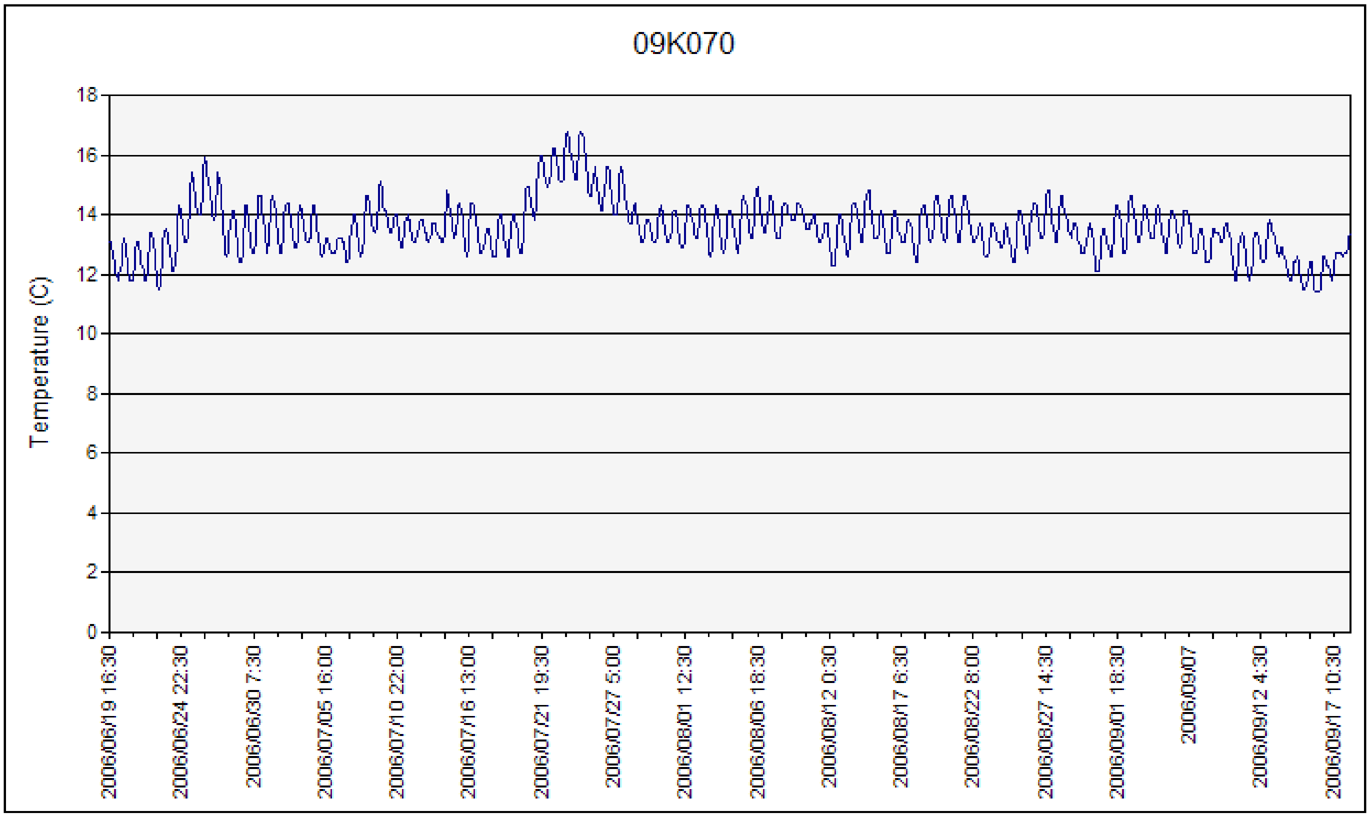


Figure 4-1. Fauntleroy Creek (Ecology Station 09K070) continuous temperature monitoring results, Summer 2006.

Source: (Ecology 2018d)

4.1.2.4 Turbidity

Based on available data, Fauntleroy Creek is considered to be in good condition with respect to turbidity. Ecology monitored turbidity levels in the creek in water years 2005 and 2006. Applicable criteria were not exceeded in any of the reported values. Table 4.4 the available turbidity data for the creek.

Table 4.4. Turbidity Measurements in Fauntleroy Creek (NTU)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004										5.1	3.3	6.8
2005	5.2	4	9.3	6.7	7.6	8.6	19	10	1.5	1.5	2.1	2.9
2006	6.5	7.1	5.8	6.8	11	12	12	9.1	7.1			

Source: (Ecology 2018d)

4.1.2.5 Metals

Based on available data, the metals conditions in Fauntleroy Creek are rated as fair. 2006 Ecology sampling found that dissolved copper and lead were never detected above chronic toxicity standards for aquatic life. Mercury exceeded the chronic criterion once, with a concentration of 0.014 µg/L compared to a criterion of

0.012 µg/L. Arsenic human health standards were frequently exceeded, but aquatic life criteria were seldom exceeded.

4.1.2.6 Organics

There is not sufficient data available to comment on organic contaminant concentrations or trends in Fauntleroy Creek.

4.1.2.7 Nutrients

Based on available data, Fauntleroy Creek is considered to be in poor condition with respect to nutrients. Fauntleroy Creek was monitored by the South Puget Sound Dissolved Oxygen Study (Ecology 2008) and Ecology's River and Stream Monitoring Program in water years 2005 and 2006 (Ecology 2018d). The South Puget Sound study reported a TP range of 0.052-0.074 mg/L with an average of 0.062 mg/L. TN ranged from 0.97-1.2 mg/L with an average of 0.98 mg/L. Ecology's reported data for TP ranged from 0.047 to 0.864 mg/L and concentrations of TN ranged from 0.82 to 1.66 mg/L. Both parameters exceed nutrient benchmarks for stream health. Available data for phosphorus are shown in Table 4.5, while available data for nitrogen are shown in Table 4.6. Measurements above nutrient benchmarks are shaded red. Benchmarks are set for low-flow conditions ranging from August to October. Blank values indicate no data.

Table 4.5. Maximum total phosphorus measured in Fauntleroy Creek (mg/L)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004										0.06	0.05	0.05
2005	0.05	0.05	0.05	0.05	0.07	0.07	0.09	0.86	0.07	0.06	0.05	0.05
2006	0.05	0.05	0.04	0.05	0.06	0.08	0.07	0.07	0.06			
2007	0.08	0.07	0.07	0.06								

Source: (Ecology 2018d)

Table 4.6. Maximum total Nitrogen measured in Fauntleroy Creek (mg/L)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004										0.91	0.89	1.35
2005	1.31	1.14	1.42	1.21	1.08	0.99	0.90	0.89	0.88	0.82	1.09	1.00
2006	1.66	1.48	1.34	1.20	1.12	1.05	1.03	0.97	0.91			
2007	1.2	1.0	1.0	1.0								

Source: (Ecology 2018d)

4.1.2.8 Sediment

No data are available to assess the sediment condition in Fauntleroy Creek.

4.1.2.9 Flow

[flow will be assessed after flow metrics have been calculated based on the DSA modeling results]

4.1.3 Indicators

4.1.3.1 Water Quality Index

Routine monitoring has not been performed in Fauntleroy Creek to collect data for computing the Water Quality Index.

4.1.3.2 B-IBI

Fauntleroy Creek is rated as fair based on the available data for the Benthic Index of Biotic Integrity indicator. Seattle Public Utilities has conducted benthic invertebrate monitoring at three stations on Fauntleroy Creek to obtain data for computing B-IBI scores. Stations FA01 and FAMA0851 are located just downstream of Fauntleroy Park while station FA02 is located near the mouth of the creek. Monitoring was performed at one or more of these stations from 1994 through 2016; data are available for 13 of the 23 years in this period.

The SOTW (Seattle 2007) indicated that Fauntleroy Creek is among the healthiest creeks in Seattle based on B-IBI scores showing poor to fair aquatic habitat condition. More recent B-IBI scores from 2006 through 2016 indicate that aquatic habitat conditions remain in poor to fair condition; B-IBI scores from this period range from 24.7 to 52.2 with a mean of 40.3. However, a plot of B-IBI scores from all stations over time (Figure 4-2.) shows a pronounced increase in the scores over the entire monitoring period.

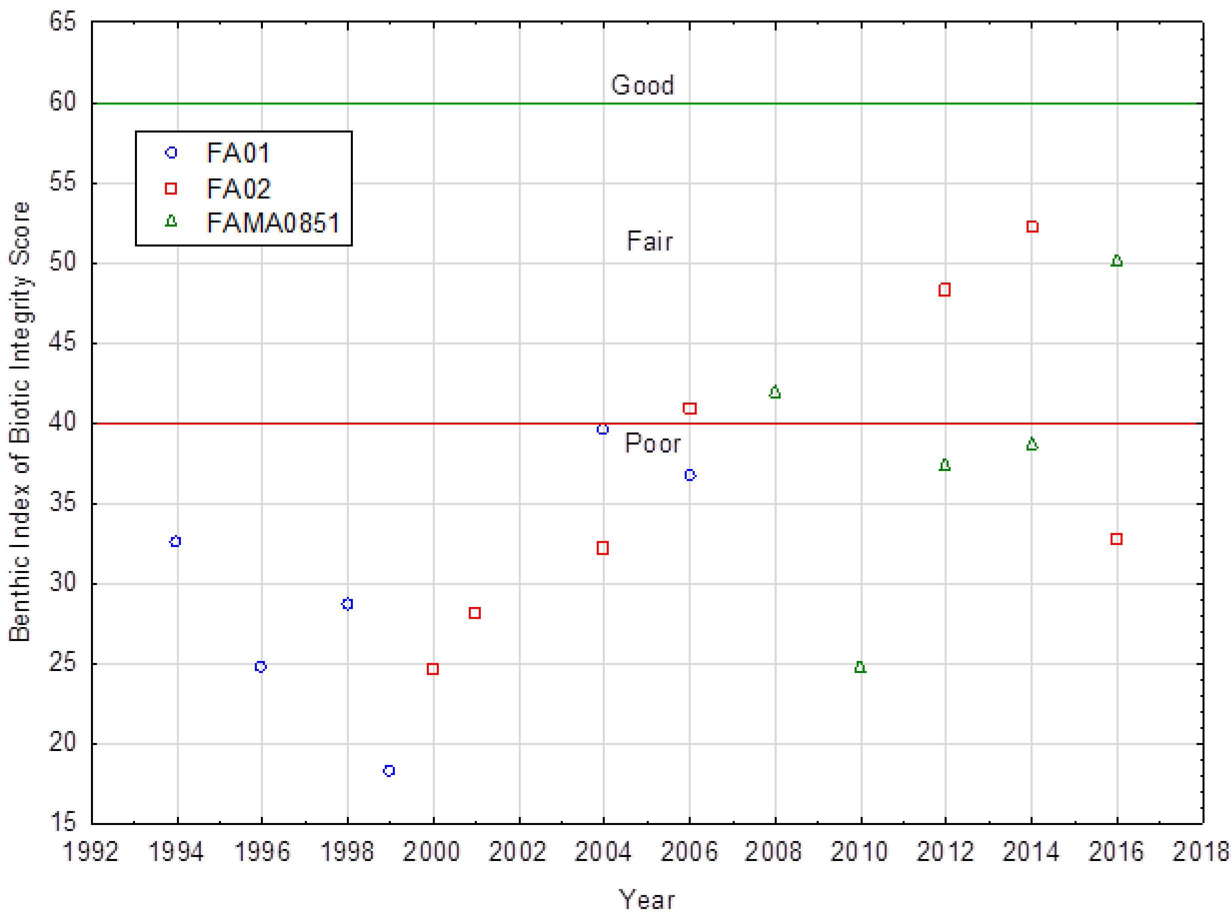


Figure 4-2. Benthic index of biotic integrity scores from monitoring stations in Fauntleroy Creek between 1994 and 2016.

Source: (King County 2018d)

4.1.3.3 Coho Pre-spawn Mortality

Based on available studies, Fauntleroy Creek is considered in fair condition for Coho pre-spawn mortality. For the five years of available spawning data, the average pre-spawn mortality rate is 37% as summarized in Table 4.8. Years considered to be in fair condition are shaded yellow and years in poor condition are shaded red.

Table 4.7. Coho spawning data in Fauntleroy Creek

Year	Confirmed female pre-spawn mortalities	Total female spawners	Pre-spawn mortality
2000	3	12	25%
2001	2	9	22%
2002	0	1	0%
2005	3	4	75%
2007	3	4	75%
Total	11	30	37%

Source: (Scholz et al. 2011)

4.1.4 Regulatory Drivers

Fauntleroy Creek is listed as a Category 4(a) impaired water body under EPA's CWA section 303(d) for fecal coliform. The Fauntleroy Creek Fecal Coliform TMDL was approved by EPA in 2007. (Ecology 2018f).

4.2 Longfellow Creek

Seattle's second-largest watershed, the Longfellow Creek basin, is located in West Seattle. The Longfellow watershed covers 1,729 acres, or 2.7 square miles, with 4.6 miles of watercourse length (City of Seattle, 2007). Historically, the watershed area was approximately 4.4 square miles, but development reduced the drainage area by redirecting flows. The structure of Longfellow Creek is very different from the other major Seattle watercourses; the watercourse is dominated by a single channel with a few short tributaries. The watercourse includes 3.9 miles of main channel, one-third of which (6,350 feet) is piped, and 0.7 miles of tributaries. The watercourse discharges to the Lower Duwamish Waterway through a 3,250-foot-long culvert (SPU 2007b).

Total land use is almost entirely developed. Development ranges from low to high intensity, medium intensity being the most common, and open space. Some forest land exists and is mostly deciduous. Less than 1% of the land is (woody) wetlands. There is no agriculture, scrub, or other land use (such as grassland or barren land) (King County 2018h).

4.2.1 Recreation (fecal bacteria)

Based on available data, Longfellow Creek is considered in poor condition for fecal indicator bacteria.

Fecal coliform is routinely measured by King County (King County 2018h). Samples collected from 2006 to 2017, frequently exceeded the fecal coliform criteria. Monitoring results are summarized in Table 4.8. Summary statistics that indicate fecal coliform concentrations above 100 cfu/100 mL are shaded in yellow, and summary statistics greater than 200 cfu/100 mL are shaded in red. Geometric means have not been calculated.

Table 4.8. Longfellow Creek Fecal Coliform Data (cfu/100 mL)

Year	Number of Samples	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	28	59	90	220	450	21000
2007	24	26	68	160	340	2900
2008	24	17	65	98	145	480
2013	11	21	62	85	210	1800
2014	12	25	148	180	420	7200
2015	11	75	80	120	305	640
2016	13	23	54	110	280	790
2017	12	32	125	215	395	900

E. coli was measured by King County (King County 2018h) between 2006 and 2008. During that period, *E. coli* concentrations frequently exceeded proposed contact recreation standards (173-201A WAC Amendatory Section 2018). Monitoring results are summarized in Table 4.9.. *E. coli* summary statistics above 100 cfu/mL are shaded in yellow. *E. coli* summary statistics above 320 cfu/mL are shaded in red.

Table 4.9. Longfellow Creek *E. coli* Data (cfu/100 mL)

Year	Number of Samples	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	28	30	69	135	430	12000
2007	24	18	65	140	415	3700
2008	24	11	76	145	220	540

4.2.2 Aquatic Health

4.2.2.1 Dissolved Oxygen

Based on available data, Longfellow Creek is considered in good condition for DO. DO is routinely measured by King County (King County 2018h), and between 2006 and 2017, all samples show DO levels above the minimum standard of 8.0 mg/L. Table 4.10 shows summary statistics for DO measurements in Longfellow Creek, and Table 4.11 shows the minimum monthly measurements since 2006.

Table 4.10. Dissolved Oxygen Statistics for Longfellow Creek (mg/L)							
Year	**Number of Samples**	**Mean**	**Minimum**	**25th Percentile**	**Median**	**75th Percentile**	**Maximum**
2006	25	19.7	17.1	17.8	19.6	21.1	23.0
2007	24	19.6	16.4	17.7	19.4	21.6	23.8
2008	24	20.1	16.2	18.5	20.1	21.8	23.9
2013	11	9.9	8.2	9.0	9.9	10.4	11.8
2014	12	10.0	8.6	8.9	10.0	11.4	11.8
2015	12	10.2	8.6	9.3	10.3	11.1	12.0
2016	13	10.5	9.1	9.6	10.5	11.5	12.4
2017	12	10.8	9.3	9.9	10.9	11.4	12.8

Source: (King County 2018h)

Table 4.11. Minimum Monthly Dissolved Oxygen Measured in Longfellow Creek (mg/L)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006		11.4	11.4	9.8	9.5	8.4	8.4	8.7	8.7	10.0	10.1	10.9
2007	11.0	10.4	10.7	10.6	8.9	9.0	8.1	8.4	8.3	9.2	9.6	11.5
2008	11.1	11.2	11.7	10.7	9.7	9.3	8.2	8.0	8.8	9.4	10.0	10.1
2009			11.6	10.5	9.8	9.0	8.8	9.1	9.5			
2010			11.0	10.4	10.2	9.9	9.2	9.5	9.6			
2011			11.6	11.0	10.3	9.8	9.6	9.4	9.9			
2012			11.4	10.9	9.9	10.0	9.5	9.3	9.8			
2013		10.1	11.3	10.7	9.4	9.2	8.2	8.8	8.7	9.9	10.1	11.8
2014	11.3	11.5	10.9	10.3	9.7	9.0	8.6	8.7	8.8	8.6	11.8	10.2
2015	12.0	11.2	11.0	11.4	10.0	9.1	8.9	8.6	9.4	9.7	10.6	11.0
2016	11.9	11.5	11.6	10.8	10.2	10.1	9.2	9.1	9.6	10.6	10.5	12.4
2017	12.8	11.6	11.3	11.1	10.5	10.0	9.6	9.3	9.4	10.6	11.3	12.5

Source: (King County 2018h)

4.2.2.2 pH

Based on available data, Longfellow Creek is considered in good condition for pH. Available studies include the State's Surface Water Monitoring Program for Pesticides in Salmonid-Bearing Streams Program (Washington State Departments of Ecology and Agriculture 2013b) and King County's routine monitoring program (King County 2018h). Out of a total of 212 available measurements, one measurement exceeded criteria. Table 4.12 provides the summary of pH measurements in Longfellow Creek between 2006 and 2017.

Table 4.12. pH Measurements in Longfellow Creek (mg/L)							
Year	**Number of Samples**	**Mean**	**Minimum**	**25th Percentile**	**Median**	**75th Percentile**	**Maximum**
2006	25	7.6	7.3	7.5	7.5	7.8	8.0
2007	24	7.5	7.2	7.5	7.6	7.6	7.8
2008	24	7.5	7.3	7.4	7.6	7.7	7.7
2009	26	7.9	7.1	7.8	7.9	8.0	8.7
2010	26	8.0	7.4	8.0	8.0	8.1	8.2
2011	27	8.0	7.7	7.9	8.0	8.0	8.4
2013	11	7.8	7.4	7.7	7.8	7.8	8.1
2014	12	7.5	7.2	7.4	7.5	7.7	7.8
2015	12	7.6	7.1	7.5	7.7	7.8	7.9
2016	13	7.6	7.2	7.5	7.7	7.7	7.9
2017	12	7.6	7.3	7.4	7.8	7.9	7.9

Source: (King County 2018h; Washington State Departments of Ecology and Agriculture 2013b)

4.2.2.3 Temperature

Based on available data, Longfellow Creek is considered in fair condition for temperature. Temperature in Longfellow Creek was measured between 2009 and 2014 by the Pesticides in Salmon Bearing Streams Study and monthly by King County. A maximum temperature of 20.3°C was measured in July 2009. Maximum temperature measurements in Longfellow Creek are shown in Table 4.13. Measurements that exceed 17.5°C are shaded in red, although the 7-DADmax value has not been calculated.

Table 4.13. Maximum Temperature Measured in Longfellow Creek (°C)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006		5.0	8.0	10.4	10.6	14.7	15.2	14.9	14.4	10.1	9.8	8.3
2007	6.4	8.4	9.9	9.4	12.5	13.1	16.5	16.0	16.3	12.4	9.6	6.1
2008	5.7	5.9	6.7	7.6	10.9	11.8	16.0	16.1	13.6	11.3	8.6	9.3
2009			8.6	13.1	15.1	19.1	20.3	18.0	15.5			
2010			9.9	12.2	13.4	15.3	17.7	17.7	15.5			
2011			8.1	11.5	13.1	15.2	15.9	17.4	15.3			
2012			8.9	11.2	14.9	15.4	16.7	17.3	14.5			
2013		8.3	9.4	11.2	14.0	15.0	18.6	17.0	16.7	12.2	9.4	5.6
2014	6.8	6.4	10.0	10.8	13.7	15.0	17.9	17.9	15.6	13.9	4.3	10.5
2015	5.9	9.0	9.6	8.8	12.2	15.5	17.0	17.3	13.2	12.7	9.0	10.3
2016	7.5	7.9	8.0	10.8	12.5	12.4	16.3	16.1	13.2	9.6	10.8	4.5
2017	3.3	7.7	9.1	10.2	12.7	13.1	15.2	16.3	15.1	10.2	9.3	5.0

Source: (King County 2018h)

4.2.2.4 Turbidity

Based on available data, Longfellow Creek is considered in fair condition for turbidity. King County routinely monitors two locations in Longfellow Creek. Average monthly turbidity measured since 2006 is shown in Table 4.14. Months when average turbidity is considered fair are shaded in yellow, and months when average turbidity is considered poor are shaded in red.

Table 4.14. Average Monthly Turbidity Measured in Longfellow Creek

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006		5.9	3.1	2.6	3.9	3	2.7	2.2	2.8	4	21.5	26.8
2007	8.1	5.1	12.6	3.3	3.2	3.4	3.8	2.1	2.7	2	1.3	2.3
2008	10.8	7.7	2	8	2	3	1.8	2.8	2	8.7	4.7	3.4
2013		5.3	5.3	3.3	3.7	5.5	5.7	9.1	8.4	10.2	5.7	6.5
2014	9.9	13.3	24.9	5.3	7.6	4.7	3.3	22	6.5	22.8	4	15.9
2015	4.3	7.2	3.1	4.8	3.9	5.7	3.5	3.1	5.8	4.9	3.5	27.7
2016	122	12.1	8.7	4.8	6.4	4.8	5	3.4	4.5	3.3	6.6	6.1
2017	18.4	64.9	104	38.3	6	7.6	5	4.2	5.7	8.9	18	4.1

4.2.2.5 Metals

Available data suggest that metals in Longfellow Creek are in good condition.

In 2012, copper and copper-related compounds were measured in Longfellow Creek (Department of Ecology and Department of Agriculture 2013). Maximum monthly copper concentrations and associated hardness values are shown in Table 4.15. Copper toxicity is hardness dependent. The summary statistics shown in Table 4.15 indicate that Longfellow Creek was likely below acute and chronic copper criteria during the sampling period.

Table 4.15. Maximum Monthly Copper Measured in Longfellow Creek (µg/L)

Year	Parameter	Number of Samples	Minimum	25th Percentile	Median	75th Percentile	Maximum
2012	Dissolved Copper (µg/L)	14	0.83	1.06	1.23	1.96	2.55
	Hardness, Total as CaCO3 (mg/L)	14	92.6	125.5	132.5	137.8	140.0

Source: (Department of Ecology and Department of Agriculture 2013)

Various studies performed by King County, Ecology, and SPU on metals prior to 2006 showed no exceedances of chronic or acute criteria for any metal during both storm and non-storm events. However, the human health standard for arsenic was exceeded in all samples (SPU 2007b).

4.2.2.6 Organics

Based on available data, Longfellow Creek is considered in fair condition for organics. The Surface Water Monitoring Program for Pesticides in Salmonid-Bearing Streams (Washington State Departments of Ecology and Agriculture 2013a) detected 17 organic compounds related to pesticides in Longfellow Creek: 2,4,6-trichlorophenol, 2,4-d, 3,5-dichlorobenzoic acid, 4-nitrophenol, boscalid, carbaryl, chlorothalonil (daconil), diazinon, dicamba, dichlobenil, diuron, imidacloprid, mcpa, mecoprop, methiocarb, prometon, and triclopyr. Early March 2009 detections of the insecticide methiocarb exceeded the chronic water quality criteria. All other detected organics were below water quality criteria.

The SOTW report (SPU 2007b) described a NOAA, USGS, and SPU coho prespawn mortality investigation that detected 18 different semi-volatile organic compounds, including phthalates, PAHs, and insecticides. Only bis(2-ethylhexyl) phthalate was detected above aquatic life toxicity criteria.

4.2.2.7 Nutrients

Based on available data, Longfellow Creek is considered in poor condition for nutrients.

Longfellow Creek is routinely monitored by King County (King County 2018h) for nutrients. Since 2006, total phosphorus ranged from 0.06-0.17 mg/L with an average of 0.09 mg/L. Total nitrogen ranged from 0.01-2.08 mg/L with an average of 1.05 mg/L. Maximum monthly total phosphorus concentrations since 2006 are shown in Table 4.16. Maximum monthly total nitrogen concentrations are shown in Table 4.17. Measurements above nutrient benchmarks are shaded red. Blank values indicate no data.

Table 4.16. Maximum monthly total phosphorus measured in Longfellow Creek (mg/L)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006		0.06	0.06	0.05	0.07	0.10	0.10	0.10	0.09	0.08	0.09	0.14
2007	0.06	0.06	0.13	0.05	0.09	0.09	0.11	0.09	0.09	0.07	0.06	0.06
2008	0.06	0.06	0.04	0.06	0.06	0.08	0.09	0.09	0.08	0.08	0.08	0.07
2013		0.05	0.05	0.05	0.07			0.09	0.09	0.08	0.06	0.07
2014	0.07	0.08	0.09	0.07	0.08	0.09	0.09	0.17	0.10	0.16		0.09
2015	0.06	0.06	0.06	0.06	0.08	0.11	0.10		0.11	0.09	0.07	0.17
2016	0.31	0.08	0.06	0.07	0.09	0.09	0.11	0.10	0.11	0.09	0.08	0.06
2017	0.09	0.18	0.26	0.12	0.07	0.08	0.08	0.08	0.14	0.08	0.10	0.07

Table 4.17. Maximum monthly total nitrogen measured in Longfellow Creek (mg/L)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006		1.47	1.35	0.97	1.31	1.28	1.10	0.89	0.91	1.13	1.71	1.92
2007	1.30	1.34	1.11	1.10	1.14	1.19	1.08	0.89	0.73	0.95	1.05	1.68
2008	1.27	1.13	1.18	0.97	1.18	1.02	1.11	1.07	1.11	0.94	1.26	1.10
2013		1.40	1.15	1.32	1.36		1.28	1.24	1.25	1.41	0.77	1.22
2014	1.86	1.94	1.27	1.01	1.36	1.23	1.08	1.46	1.10	0.97	1.27	1.74
2015	1.35	2.01	1.38	1.10	1.45	1.15	0.93	0.81	1.00	0.99	1.83	3.14
2016	1.61	1.62	1.47	1.26	1.24	1.20	0.91	0.91	0.98	0.93	1.44	1.26
2017	1.33	1.32	1.29	0.89	1.35	1.36	1.30	1.16	2.08	1.31	0.97	0.94

4.2.2.8 Sediment Quality

No data are available to assess sediment quality in Longfellow Creek.

4.2.2.9 Flow

[flow will be assessed after flow metrics have been calculated based on the DSA modeling results]

4.2.3 Indicators

4.2.3.1 Water Quality Index

King County Department of Natural Resources and Parks conducts monitoring at two stations on Longfellow Creek to obtain data for computing water quality index scores. Monitoring at station C370 near the mouth of Longfellow Creek has occurred between water year 2003 (WY2003) and WY2008 as well as between WY2014 and WY2017 (a water year is defined as the 12-month period from October 1 for any given year through September 30 of the following year). Monitoring at station J370 where Longfellow Creek crosses SW Brandon Street has occurred over the period spanning between WY2003 and WY2008. Water quality index scores are computed for each individual water year over these periods of monitoring. Water quality index scores from this monitoring were not summarized in the SOTW (SPU 2007b).

Water quality index scores indicate that Longfellow Creek is in poor condition for water quality with scores at both stations from all water years ranging from 29 to 67 with a mean of 48. However, water quality conditions appear to be deteriorating based on comparisons of scores from the two periods of monitoring at station C730. For example, the mean of water quality index scores spanning the period from WY2003 through WY2008 was 53, which indicated fair conditions. In comparison, the mean for the period spanning WY2014 through WY2017 was 36, which indicated poor conditions. This trend can be observed in Figure 4-3. Based on an analysis of the individual scores for the eight water quality parameters used to compute the water quality index, the primary sources of water quality impairment in Longfellow Creek are elevated concentrations of fecal coliform bacteria and total phosphorus.

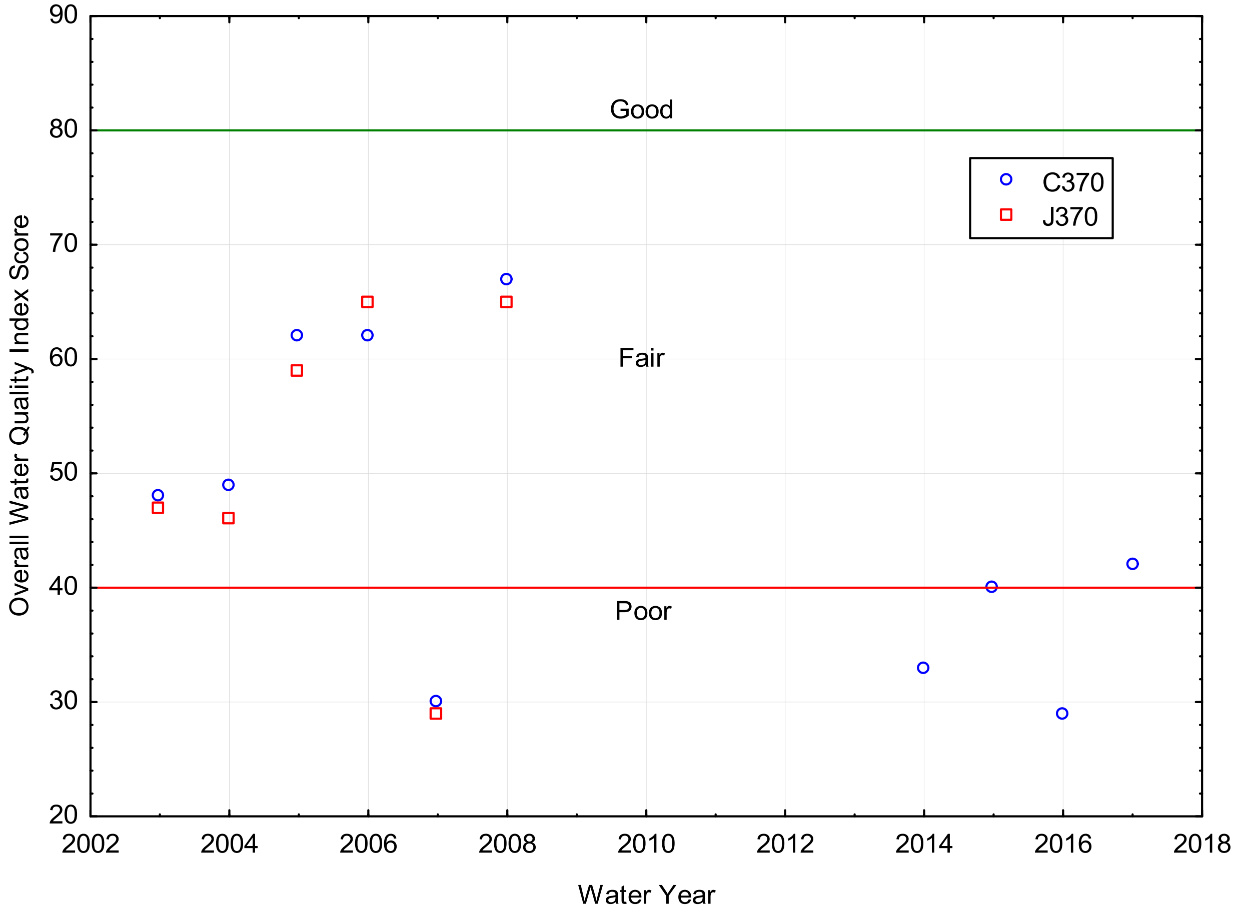


Figure 4-3. Water quality index scores from monitoring stations in Longfellow Creek between 2003 and 2017.
Source: (King County 2018d)

4.2.3.2 B-IBI

SPU has conducted benthic invertebrate monitoring at nine stations on Longfellow Creek to obtain data to compute B-IBI scores. Stations LF05, LF04, LFMA3490, LFMA3396, and LF01 are in the lower reaches of the creek within or just downstream of the West Seattle Golf Course. Stations LFMA2559 and LF03 are in the middle reaches of the creek whereas stations LFMA0954 and LF02 are in the upper reaches. King County Department of Natural Resources and Parks also conducts monitoring at station C370 in the lower reaches of the creek while the Washington State Department of Ecology conducts monitoring at station RSM06600-011399 in the middle reaches. Monitoring at one or more of these stations has occurred on a regular basis between 1996 and 2016 with data available for 12 of the 21 years.

The SOTW (SPU 2007b) indicated that aquatic habitat in Longfellow Creek was in very poor condition based on B-IBI scores from monitoring conducted between1996 and 2004. More recent B-IBI scores from monitoring conducted between 2006 and 2016 indicate that aquatic habitat remains in very poor condition; B-IBI scores from this period range from 0 to 13.8 with a mean of 5.7. A plot of B-IBI scores for all stations over the entire period of monitoring shows no obvious increasing or decreasing trends (Figure 4-4.).

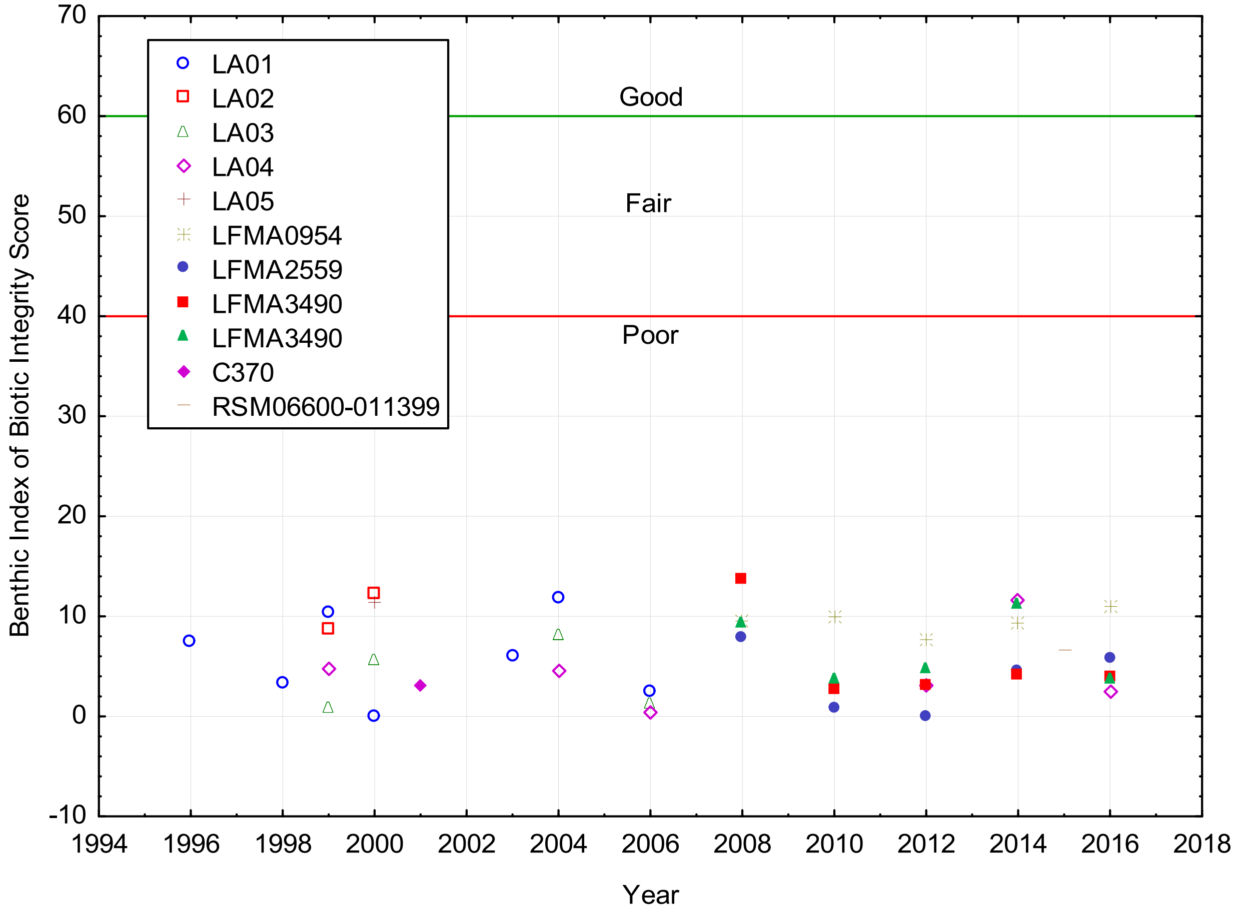


Figure 4-4. Benthic index of biotic integrity scores from monitoring stations in Longfellow Creek between 1996 and 2016.

Source: (King County 2018d)

4.2.3.3 Coho Pre-spawn Mortality

Based on available studies, Longfellow Creek is considered in poor condition for Coho pre-spawn mortality. For the 10 years of available Coho spawning data, the average pre-spawn mortality rate is 73% as summarized in Table 4.18. Years considered to be in poor condition are shaded red.

Table 4.18. Coho spawning data in Fauntleroy Creek			
Year	**Confirmed female pre-spawn mortalities**	**Total female spawners**	**Pre-spawn mortality**
2000	100	135	74%
2001	68	111	61%
2002	49	57	86%
2003	12	18	67%
2004	8	9	89%
2005	57	75	76%
2006	4	4	100%
2007	30	41	73%
2008	8	12	67%
2009	28	36	78%
Total	**364**	**498**	**73%**

Source: (Scholz et al. 2011)

4.2.4 Regulatory Drivers

Longfellow Creek is listed as a Category 5 impaired water body under EPA's CWA section 303(d) for temperature, DO, and fecal coliform. TMDLs or other approved water quality improvement projects are required for water bodies under this category (Ecology 2018f).

4.3 Piper's Creek

The Piper's Creek watershed, in northwest Seattle, is approximately 2.5 square miles. The main stem is approximately two miles long with an additional three miles of tributaries. Major tributaries are Venema and Mohlendorph Creeks. Piper's Creek and most of its tributaries flow in a northwesterly direction, before flowing west and draining into Puget Sound.

The upper portion of the Piper's Creek watershed is primarily occupied by single-family residences with some small businesses and multifamily housing. The upper watershed makes up roughly 80% of the Piper's Creek drainage area. In the lower 20% of the watershed, the majority of the creek runs within Carkeek Park. Steep ravines, covered with second growth forest, characterize the park; the stream in the park is heavily shaded. There are relatively little forest and wetlands and no agriculture or scrub (King County 2018h) outside the park boundaries.

4.3.1 Recreation (fecal bacteria)

Based on available data, Piper's Creek is considered in poor condition for fecal indicator bacteria. Piper's Creek is routinely sampled for fecal bacteria by King County as part of the Routine Ambient and Wet Weather Monitoring Program.

Fecal coliform is routinely measured by King County (King County 2018h). Between 2006 and 2017, fecal coliform concentrations frequently exceeded standards. Monitoring results are summarized in Table 4.19. Summary statistics that indicate fecal coliform concentrations above 50 cfu/100 mL are shaded in yellow, and summary statistics greater than 100 cfu/100 mL are shaded in red. Geometric means have not been calculated.

Table 4.19. Fecal Coliform in Piper's Creek (cfu/100 mL)

Year	Number of Samples	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	37	33	150	230	320	2000
2007	36	6	42	65	91	1000
2008	36	5	44	68	105	4100
2009	12	7	49	60	125	370
2010	12	17	59	75	448	6800
2011	4	5	12	38	62	66
2012	3	82	91	100	280	460
2013	23	3	8	35	52	500
2014	27	5	31	80	425	9900
2015	36	8	26	75	388	7400
2016	50	2	19	59	155	1200
2017	46	5	34	90	330	1700
2018	13	16	28	66	230	620

Source: (King County 2018h)

E. coli was measured by King County (King County 2018h) between 2006 and 2008. During that period, E. coli concentrations frequently exceeded proposed contact recreation standards (173-201A WAC Amendatory Section 2018). Monitoring results are shown in Table 4.20. E. coli concentrations above 100 cfu/100 mL are shaded in yellow and concentrations above 320 cfu/100 mL are shaded in red.

Table 4.20. Maximum Monthly *E. coli* in Piper's Creek (cfu/100 mL)

Year	Number of Samples	Mean	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	37	311	16	100	200	340	2500
2007	36	126	7	34	64	130	1000
2008	36	396	5	58	75	225	5600

Source: (King County 2018h)

4.3.2 Aquatic Health

4.3.2.1 Dissolved Oxygen

Based on available data, Piper's Creek is considered in fair condition for DO. DO in Pipers Creek is routinely by measured by King County (King County 2018h). Since 2006, nine measurements have been below the minimum criteria. Minimum monthly DO measurements between 2006 and 2018 are shown in Table 4.21.

Table 4.21. Minimum Dissolved Oxygen Measured in Piper's Creek (mg/L)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	10.9	11.3	12.0	10.7	10.7	10.3	9.9	10.2	10.5	11.0	10.1	10.7
2007	11.5	11.6	11.1	11.5	11.1	10.4	10.1	9.9	9.4	10.1	10.7	11.1
2008	11.4	11.9	11.1	11.3	10.9	10.7	9.9	9.3	10.3	10.2	10.4	10.1
2009		11.4	11.6	11.4		10.3	11.1	9.2	10.0	10.5	10.8	12.8
2010	11.5	11.0	11.1	11.2	10.9	10.2	9.9	9.3	9.4	10.3	10.5	11.6
2011	12.6	11.4	11.5	10.9								
2012										10.8	10.0	10.3
2013	11.4	10.6	11.8	11.3	10.2	10.0	9.4	10.0	9.0	9.9	10.3	11.8
2014	11.0	10.7	10.4	10.2	10.2	10.0	9.5	8.6	9.5	8.3	11.4	9.6
2015	11.7	11.0	10.8	11.1	10.4	10.1	10.0	9.8	10.2	10.4	10.7	10.8
2016	11.5	11.2	11.2	10.9	10.3	10.3	10.1	10.0	10.1	10.6	10.6	11.6
2017	12.2	11.2	11.1	10.8	10.4	10.4	10.1	9.9	10.1	10.5	10.6	11.4
2018	11.2	11.6	11.1	10.9	10.1	10.4	10.3	9.9	10.1	10.6	10.6	

Source: (King County 2018h)

4.3.2.2 pH

Based on available data, Piper's Creek is considered in good condition for pH. King County (King County 2018h) routinely measures pH in Pipers Creek, and all measurements since 2006 have met criteria. Table 4.22 summarizes pH measurements in Piper's Creek.

Table 4.22. pH Measurements in Piper's Creek							
Year	**Number of Samples**	**Mean**	**Minimum**	**25th Percentile**	**Median**	**75th Percentile**	**Maximum**
2006	34	7.8	7.3	7.7	7.8	8.0	8.1
2007	36	7.8	7.5	7.7	7.8	8.0	8.2
2008	39	7.9	7.5	7.8	7.9	8.0	8.1
2009	12	7.7	7.4	7.6	7.7	7.8	7.9
2010	12	7.6	7.2	7.6	7.7	7.8	7.9
2011	4	7.6	7.5	7.5	7.6	7.6	7.7
2012	3	7.6	7.4	7.6	7.7	7.7	7.8
2013	23	7.9	7.5	7.8	7.9	8.0	8.2
2014	27	7.8	7.4	7.7	7.8	7.9	8.1
2015	36	8.0	7.5	7.9	8.0	8.0	8.1
2016	50	7.9	7.3	7.8	8.0	8.0	8.2
2017	46	7.9	7.4	7.7	8.0	8.1	8.1

Source: (King County 2018h)

4.3.2.3 Temperature

Based on available data, Piper's Creek is considered in good condition for temperature. Temperature is routinely measured by King County as part of the Routine Ambient and Wet Weather Monitoring Program (King County 2018h). Since 2006, only one month (August 2014) had a measurement above 16°C. Maximum monthly temperatures are shown in Table 4.23. Months exceeding temperature criteria are shaded in red.

Table 4.23. Maximum monthly temperature in Piper's Creek (°C)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006	8.3	8.7	7.6	9.9	10.1	12.5	13.5	13.5	12.2	11.2	9.9	8.8
2007	8.3	8.5	9.4	8.2	11.8	13.1	13.4	13.9	14.4	11.3	9.2	7.0
2008	7.3	7.0	8.5	8.7	10.5	11.3	12.6	12.8	12.4	12.3	11.5	10.9
2009	6.7	6.8	8.4	8.0	10.4	11.9	13.8	14.1	13.0	10.1	9.2	3.3
2010	7.3	8.0	8.8	8.7	10.1	11.4	12.9	13.1	14.0	11.9	11.0	7.0
2011	5.2	7.9	6.6	8.5								
2012										11.2	12.4	9.1
2013		9.1	8.5	11.1	12.5	13.4	14.9	14.2	15.2	12.3	10.5	7.1
2014		8.2	9.2	11.0	12.7	12.9	14.6	16.3	13.4	13.7	7.8	11.3
2015		10.6	11.0	10.5	11.9	14.1	14.9	14.8	12.7	12.3	10.5	10.7
2016		10.2	10.4	11.9	13.5	13.0	14.5	14.3	13.5	11.4	11.6	7.7
2017		8.9	9.9	11.4	13.0	12.8	14.5	14.9	13.9	12.0	10.4	9.3

Source: (King County 2018h)

4.3.2.4 Turbidity

Based on available data, Piper's Creek is considered in good condition for turbidity. King County (King County 2018h) routinely monitors three locations within Piper's Creek. Average monthly turbidity measured since 2006 is shown in Table 4.24, and months when average turbidity is considered fair are shaded in yellow and no shading considered good.

Table 4.24. Average Monthly Turbidity Measured in Piper's Creek (NTU)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	10.6	9.4	1.3	1.2	3.0	3.8	3.9	2.8	3.0	2.9	5.8	33.8
2007	1.9	1.5	3.5	1.1	2.6	3.9	3.0	2.1	5.4	1.6	1.0	2.9
2008	2.8	1.4	1.2	0.9	0.8	1.1	0.9	1.9	0.8	0.9	3.5	1.6
2013										2.2	3.2	9.5
2014	24.3	1.8	2.8	1.1	1.6	2.4	2.2	2.7	4.4	7.7	1.2	1.0
2015	5.7	2.2	7.9	1.1	1.8	4.9	1.2	6.4	2.0	2.2	1.5	16.0
2016	2.3	1.7	1.1	1.7	5.2	2.8	2.4	2.5	1.2	1.3	1.3	6.7
2017	10.5	26.0	2.9	1.3	3.0	2.8	2.0	1.8	2.0	1.6	2.4	4.2

4.3.2.5 Metals

Metals in Piper's Creek are in fair condition, with occasional exceedances of the Aquatic Life Freshwater Criteria for copper, lead, and zinc.

King County (King County 2018h) monitored metals in Piper's Creek between 2006 and 2008. A summary of 10 metal concentrations and hardness in the creek over that period are shown in Table 4.25. Summary statistics above chronic criteria are shaded in yellow, and summary statistics above acute criteria are shaded in red.

Table 4.25. Metals and Hardness Concentrations in Piper's Creek						
Parameter	**Number of Samples**	**Minimum**	**25th Percentile**	**Median**	**75th Percentile**	**Maximum**
Arsenic	20	1.420	2.355	2.475	2.645	8.230
Cadmium	19	0.010	0.010	0.010	0.010	0.369
Chromium	20	0.670	0.832	0.968	1.193	32.2
Copper	20	0.555	0.886	1.145	1.600	38.1
Hardness, Total as CaCO3	10	61	100	104	109	114
Lead	20	0.025	0.050	0.309	0.395	42.0
Mercury	12	0.001	0.001	0.001	0.002	0.050
Nickel	20	0.631	0.855	1.007	1.263	44.3
Selenium	19	0.500	0.500	0.500	0.500	1.5
Silver	19	0.010	0.018	0.025	0.025	0.2
Zinc	22	1.200	2.100	2.730	3.308	142.0

Source: (King County 2018h)

Note: All metals concentrations are in ug/L, hardness concentrations are in mg/L.

4.3.2.6 Organics

There is not sufficient available data to produce a rating for organics quality in Piper's Creek. In 2006, King County sampled Piper's Creek for certain phenols, phthalates, and pesticides, but none were detected above reporting limits. More recent data are not available.

4.3.2.7 Nutrients

Based on available data, Pipers Creek is considered in poor condition for nutrients.

Piper's Creek has been monitored by King County (King County 2018h) for nutrients since 2004. Since 2007, 89 low-flow samples were collected for total phosphorus and 53 low-flow samples were collected for total Nitrogen. Total phosphorus ranged from 0.053 – 0.19 mg/L with an average of 0.08 mg/L. Total nitrogen ranged from 0.1-2.0 mg/L with an average of 1.4 mg/L. Both parameters exceed nutrient thresholds for stream health. Maximum monthly total phosphorus measured since 2006 is shown in Table 4.26. Maximum monthly total nitrogen measured since 2006 is shown in Table 4.27. Measurements above thresholds are shaded red.

Table 4.26. Maximum monthly total phosphorus measured in Piper's Creek (mg/L)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006	0.08	0.10	0.08	0.08	0.08	0.10	0.10	0.10	0.10	0.09	0.08	0.15
2007	0.06	0.07	0.08	0.07	0.09	0.09	0.09	0.09	0.12	0.07	0.07	0.07
2008	0.06	0.07	0.07	0.06	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.07
2009	0.07	0.06	0.07	0.06	0.06	0.08	0.07	0.09	0.07	0.07	0.06	0.05
2010	0.31	0.06	0.06	0.06	0.07	0.09	0.08	0.08	0.19	0.07	0.35	0.06
2011	0.07	0.06	0.07	0.05								
2012										0.07	0.07	0.06
2013	0.13	0.06	0.06	0.07	0.07			0.07	0.08	0.12	0.06	0.07
2014	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2015	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2016	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2017	1.8	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Source: (King County 2018h)

Table 4.27. Maximum monthly total nitrogen measured in Piper's Creek (mg/L)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006	1.70	2.18	2.04	1.84	1.99	1.99	1.92	1.77	1.68	1.73	3.09	1.53
2007	2.26	1.93	1.93	1.95	1.82	1.81	1.80	1.82	1.78	1.54	1.61	2.13
2008	1.95	1.89	1.79	1.73	1.67	1.63	1.57	1.68	1.61	1.62	1.10	1.59
2009	1.85	1.62	1.22	2.16	1.46	1.79	1.36	1.69	1.51	1.55	1.52	1.75
2010	1.05	1.87	1.76	1.68	1.67	1.68	1.69	1.75	1.60	1.50	1.31	1.61
2011	1.92	1.80	2.00	1.84								
2012										1.78	1.53	1.76
2013	1.68	1.83	1.71	1.73	1.71		1.81	1.89	1.60	1.65	1.54	1.72
2014	1.8	1.9	1.6	1.6	1.7	2.0	1.6	1.7	1.6	1.5	1.9	2.4
2015	1.8	2.3	1.8	1.8	1.8	1.8	1.7	1.7	1.9	1.8	2.2	3.3
2016	1.5	2.0	2.0	1.8	1.8	1.8	1.7	1.9	1.6	1.7	1.9	1.8
2017	1.8	1.7	1.3	1.2	1.8	1.8	1.8	1.7	1.7	1.9	2.2	1.9

Source: (King County 2018h)

4.3.2.8 Sediment Quality

No data are available to assess sediment quality in Piper's Creek.

4.3.2.9 Flow

[flow will be assessed after flow metrics have been calculated based on the DSA modeling results]

4.3.3 Indicators

4.3.3.1 Water Quality Index

King County Department of Natural Resources and Parks conducts monitoring at two stations on Piper's Creek and one station on Venema Creek, a major tributary of Piper's Creek, to obtain data for computing water quality index scores. Monitoring at station KSHZ06 near the mouth of Piper's Creek has occurred over the period spanning from WY2000 through WY2017. Monitoring at station KTAH02 on Piper's Creek, upstream of its confluence with Venema Creek, has occurred over the periods spanning from WY2000 through WY2008 and WY2015 through WY2017. Monitoring at station KTAH03 on Venema Creek has occurred over the periods spanning from WY2000 through WY2008 and WY2014 through WY2017. Water quality index scores are computed for each individual water year over these monitoring periods. Water quality index scores from this monitoring were not summarized previously in the SOTW (SPU 2007b).

Water quality index scores indicate that Piper's Creek is in fair condition for water quality with scores across all stations and all water years ranging from 20 to 77 with a mean of 46. The scores from station KTAH03 on Venema Creek were generally higher (mean = 56) than those from stations KTHZ06 and KTAH02 on Piper's Creek (mean = 43). A plot of water quality index scores for all three stations over the entire period of monitoring shows no obvious increasing or decreasing trends (Figure 4-9.). Based on an analysis of the individual scores for the eight water quality parameters that are used to compute the water quality index, the primary sources of water quality impairment in Piper's Creek are low dissolved oxygen concentrations and elevated concentrations of fecal coliform bacteria and total phosphorus.

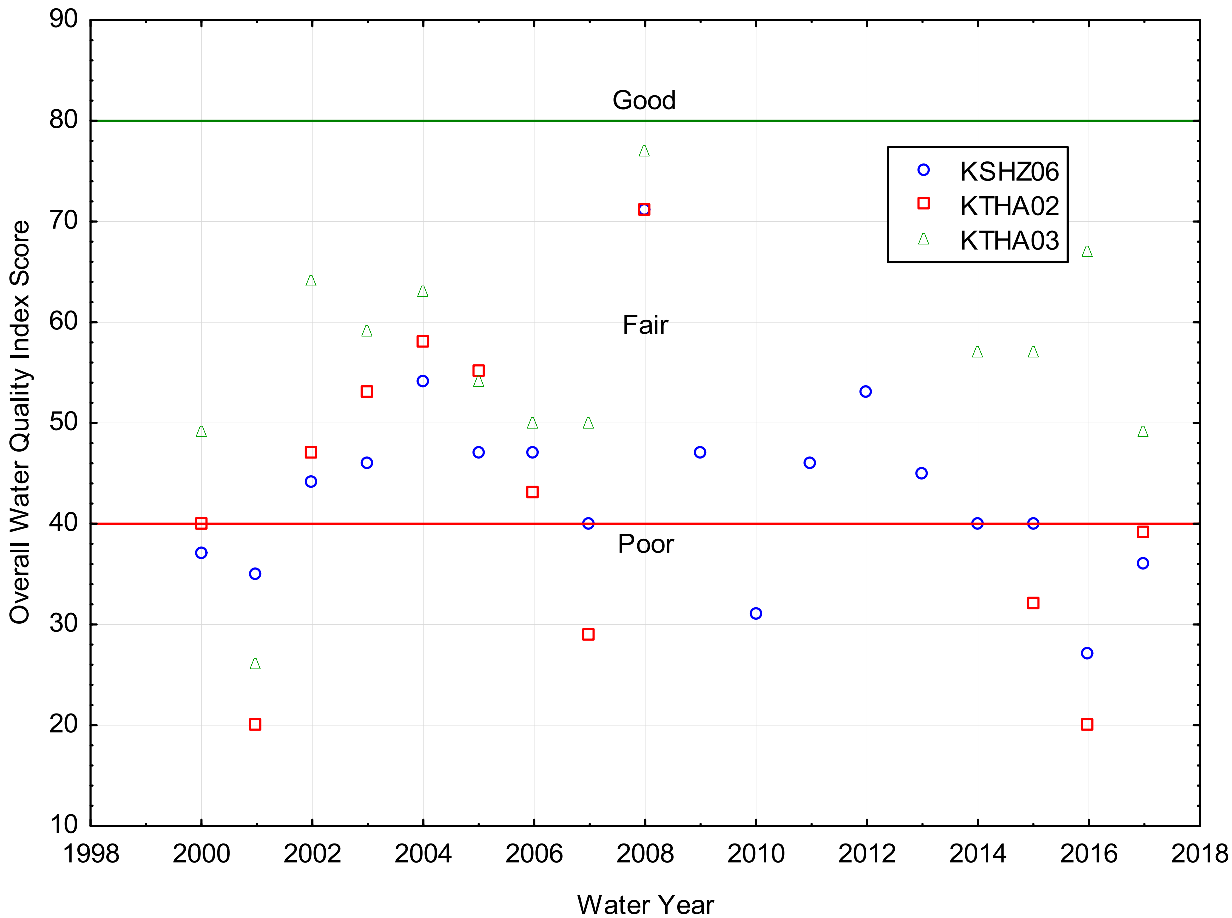


Figure 4-5. Water quality index scores from monitoring stations in Piper's Creek and Venema Creek between 2000 and 2017.

4.3.3.2 B-IBI

Based on available data for Piper's Creek, the B-IBI rating is considered poor. Seattle Public Utilities has conducted benthic invertebrate monitoring at seven stations on Piper's Creek to obtain data for computing B-IBI scores. Stations PI01, PI04, PI05, and PIMA6462 are in the middle reaches of the creek whereas stations PI02, PI03, and PIMA7729 are in the upper reaches. King County Department of Natural Resources and Parks also conducts monitoring at stations KTHA03 and WAM06600-063831 in the middle reaches of the creek. Monitoring at one or more of these stations has occurred on a regular basis over the period spanning from 1996 through 2017 with data available for 15 of the 22 years in this period.

The SOTW (SPU 2007b) indicated that the condition of aquatic habitat in Piper's Creek varied substantially among different reaches based on B-IBI scores from monitoring that was conducted between 1996 and 2005. In general, aquatic habitat in the lower reaches was in very poor condition and improved in the upper reaches. More recent B-IBI scores from monitoring that was conducted over the period from 2007 through 2017 indicate that aquatic habitat was generally in poor condition throughout all creek reaches. B-IBI scores from this period range from 1.2 to 25.8 with a mean of 13.1. A plot of B-IBI scores for all stations over the entire period of monitoring shows no obvious increasing or decreasing trends (Figure 4-6.).

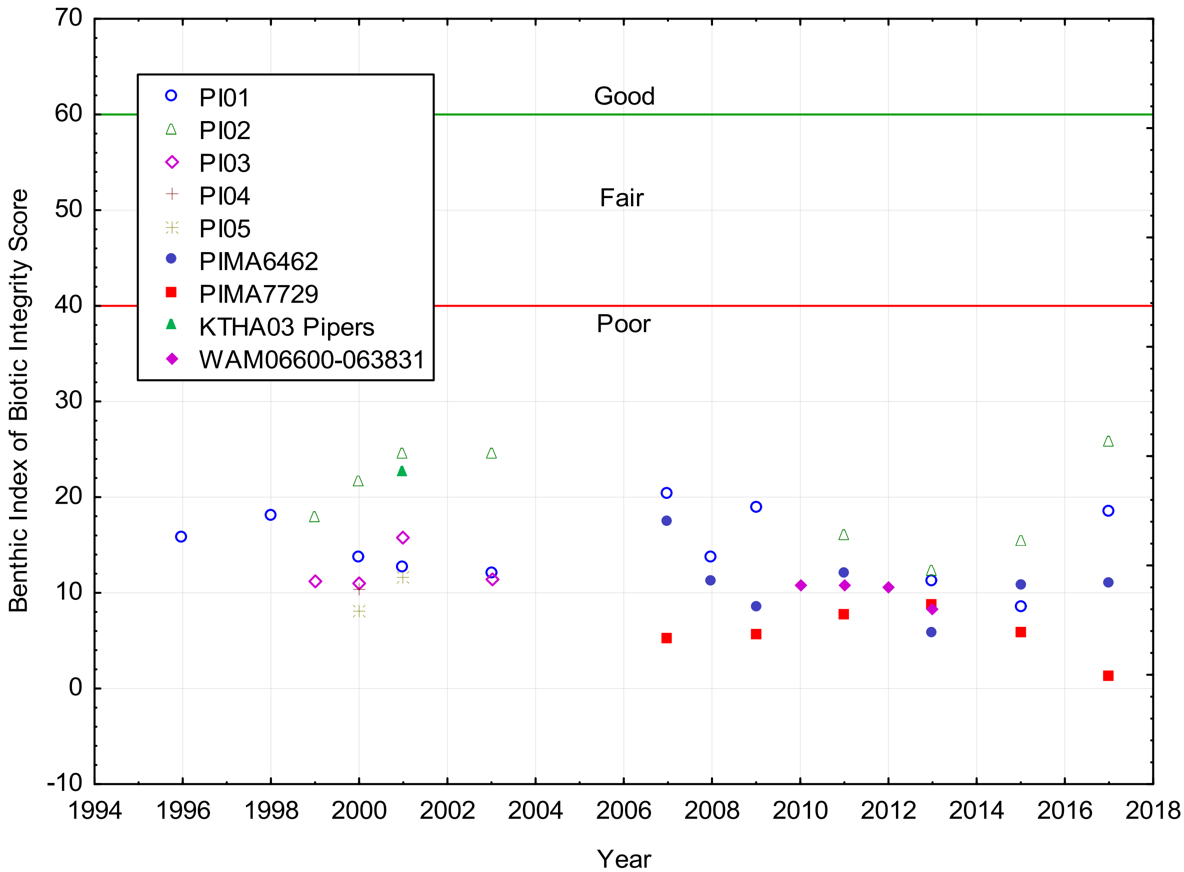


Figure 4-6. Benthic index of biotic integrity scores from monitoring stations in Piper's Creek and Venema Creek over time between 1996 and 2017.

Source: (King County 2018d)

4.3.3.3 Coho Pre-spawn Mortality

Based on available studies, Piper's Creek is considered in poor condition for Coho pre-spawn mortality. For the 10 years of available Coho spawning data, the average pre-spawn mortality rate is 54% as summarized in Table 4.28. Years considered to be in poor condition are shaded red.

Table 4.28. Coho spawning data in Piper's Creek

Year	Confirmed female pre-spawn mortalities	Total female spawners	Pre-spawn mortality
2000	3	135	2%
2001	68	111	61%
2002	49	57	86%
2003	12	18	67%
2004	8	9	89%
2005	57	75	76%
2006	4	4	100%

2007	30	41	73%
2008	8	12	67%
2009	28	36	78%
Total	**267**	**498**	**54%**

Source: (Scholz et al. 2011)

4.3.4 Regulatory Drivers

Piper's Creek is listed as a Category 5 impaired water body under EPA's CWA section 303(d) for DO. The creek is also listed as a Category 4(a) impaired water body for fecal coliform, along with six minor tributaries and sections of major tributary, Venema Creek (Ecology 2018f).

4.4 Taylor Creek

Taylor Creek is a small watershed with an area of one square mile in southeastern Seattle. The creek is 2.7 miles long with a mainstem of two miles. It has three distinct segments: an upper plateau area, a steep forested ravine (Lakeridge Park), and a flat lower plain. The mainstem of Taylor Creek flows through Lakeridge Park before discharging to Lake Washington. No recent water quality data are available for this watercourse(SPU 2007b).

4.4.1 Recreation (fecal bacteria)

Based on previously assessed data, Taylor Creek is considered in poor condition for fecal indicator bacteria. No recent information regarding Taylor Creek Fecal Indicator Bacteria levels is available since the 2007 State of the Waters Study, which found fecal indicator bacteria conditions were poor.

4.4.2 Aquatic Health

4.4.2.1 Dissolved Oxygen

No data are available to assess DO conditions in Taylor Creek.

4.4.2.2 pH

No data are available to assess pH conditions in Taylor Creek.

4.4.2.3 Temperature

No data are available to assess temperature conditions in Taylor Creek.

4.4.2.4 Turbidity

No data are available to assess turbidity in Taylor Creek.

4.4.2.5 Metals

No data are available to assess metals in Taylor Creek.

4.4.2.6 Organics

No data are available to assess organic chemicals in Taylor Creek.

4.4.2.7 Nutrients

No data are available to assess nutrients in Taylor Creek.

4.4.2.8 Sediment Quality

No data are available to assess sediment quality in Taylor Creek.

4.4.2.9 Flow

[flow will be assessed after flow metrics have been calculated based on the DSA modeling results]

4.4.3 Indicators

4.4.3.1 Water Quality Index

Routine monitoring has not been performed in Fauntleroy Creek to collect data for computing the Water Quality Index.

4.4.3.2 B-IBI

Seattle Public Utilities has conducted benthic invertebrate monitoring at seven stations on Taylor Creek to obtain data for computing B-IBI scores. Stations TAMA_MOUTH and TA03 are in the lower reaches of the creek; stations TA01 and TAMA7468 are in the middle reaches; and stations TA02, TAEF6250, and TAWF4847 are in the upper reaches. King County Department of Natural Resources and Parks also conducts monitoring at stations 08WES1340 and WAM06600-065043 in the middle reaches of the creek. Monitoring at one or more of these stations has occurred on a regular basis over the period spanning from 1994 through 2018 with data available for 22 of the 25 years in this period.

The SOTW (SPU 2007b) indicated that aquatic habitat in Taylor Creek was in poor condition based on B-IBI scores from monitoring that was conducted between 1994 and 2004. More recent B-IBI scores from monitoring that was conducted over the period from 2005 through 2018 indicate that aquatic habitat remains in poor condition; B-IBI scores from this period range from 11.3 to 28.9 with a mean of 19.0. A plot of B-IBI scores for all stations over the entire period of monitoring shows no obvious increasing or decreasing trends (Figure 4-7.).

4.4.3.3 Coho Pre-Spawn Mortality

No data are available to assess coho pre-spawn mortality in Taylor Creek.

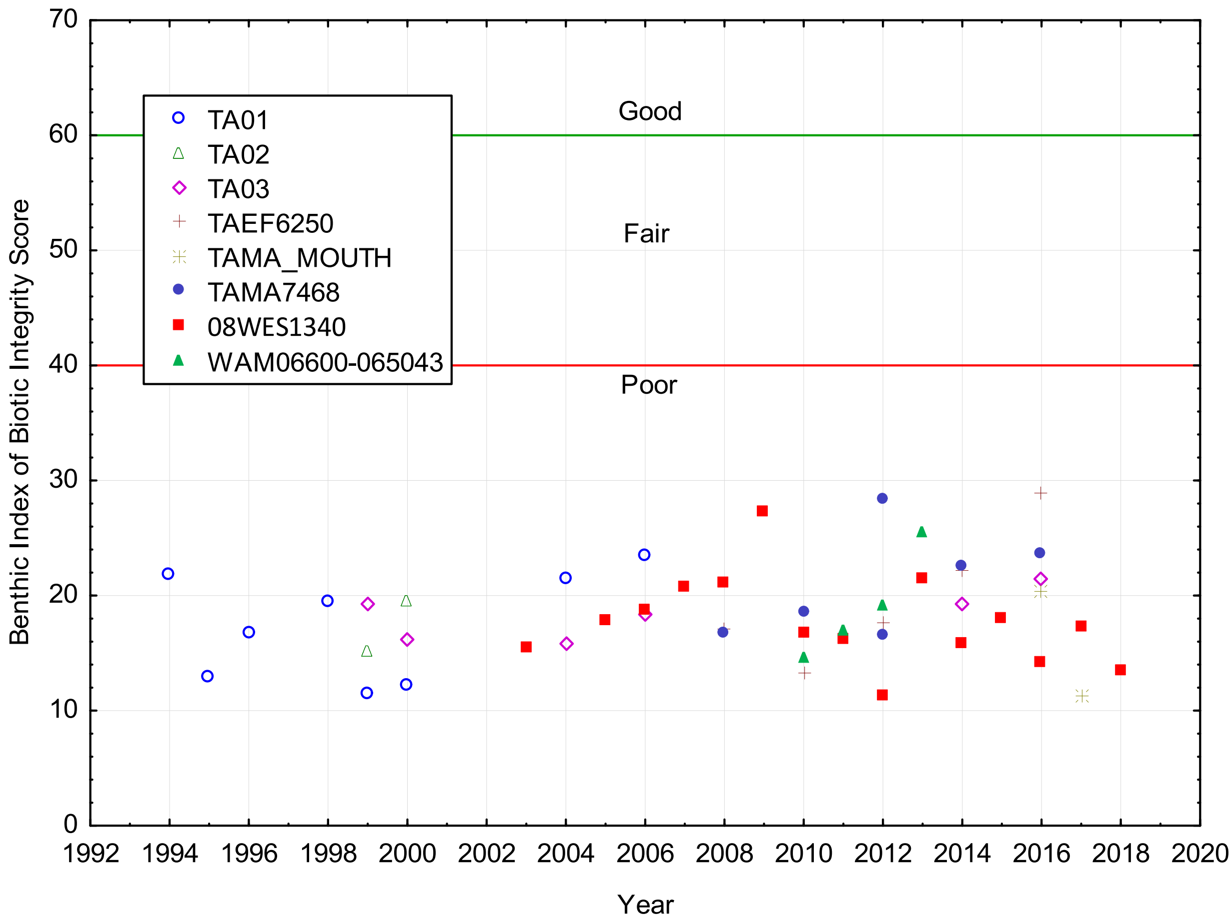


Figure 4-7. Benthic index of biotic integrity scores from monitoring stations in Taylor Creek between 1994 and 2018.

Source: (King County 2018d)

4.4.4 Regulatory Drivers

Taylor Creek is listed as a Category 5 impaired water body under EPA's CWA section 303(d) for biological integrity, as measured by B-IBI scores (Ecology 2018f).

4.5 Thornton Creek

Thornton Creek and its many tributaries flow through the northeast part of Seattle, forming the city's largest watershed. The watercourse is the longest in Seattle with nearly 20 miles of main stream channel and 20 tributaries (Seattle Public Utilities 2015).

Subbasins of Thornton Creek include the mainstem, North Branch, and South Branch (Maple Leaf Creek). The headwaters of the North Branch originate near Ronald Bog, which along with Twin Ponds one mile downstream, were ponds created in the 1950s when peat deposits were mined from the area. The North Branch drains approximately 4,446 acres of the Cities of Shoreline and Seattle, Washington. The South Branch originates west of Interstate-5 near North Seattle Community College and drains approximately

2,333 acres of the City of Seattle. The creek and its tributaries flow over 15 miles and drain approximately 7,402 acres before entering the northern end of Lake Washington at Matthews Beach Park (King County 2018h).

Land use in the Thornton Creek basin consists almost entirely of developed land. Developed land ranges from low to high intensity and open space, although about half is low intensity. The remaining land use consists of forest, scrub, wetlands, and other (open water). There is no agriculture in the basin (King County 2018h).

Flooding is an issue in this watershed where much of the development took place prior to the promulgation of flood and pollutant control regulations. Most stormwater enters the creek either through storm drains along busy streets and commercial districts or through open ditches in residential areas.

4.5.1 Recreation (fecal bacteria)

Thornton Creek is in poor condition with respect to fecal bacteria.

Fecal coliform is routinely measured by King County (King County 2018h). Between 2006 and 2017, fecal coliform concentrations frequently exceeded standards. Monitoring results are summarized in Table 4.29. Summary statistics that indicate fecal coliform concentrations above 100 cfu/100 mL are shaded in yellow, and summary statistics greater than 200 cfu/100 mL are shaded in red. Geometric means have not been calculated.

Table 4.29. Fecal Coliform in Thornton Creek (cfu/100 mL)

Year	No of Samples	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	12	65	360	505	865	1600
2007	12	94	118	250	455	10000
2008	12	110	213	280	393	700
2009	12	32	193	320	583	1600
2010	12	18	65	230	720	3500
2011	4	53	96	135	290	680
2012	3	350	460	570	685	800
2013	12	56	183	340	435	2300
2014	12	46	153	205	468	12000
2015	12	42	64	160	313	2500
2016	12	22	98	190	298	1000
2017	13	32	48	420	460	660

Source: (King County 2018h)

E. coli was measured by King County (King County 2018h) between 2006 and 2008. During that period, *E. coli* concentrations frequently exceeded proposed contact recreation standards (173-201A WAC Amendatory Section 2018). Monitoring results are shown in **Error! Reference source not found.** *E. coli* concentrations above 100 cfu/100 mL are shaded in yellow and concentrations above 320 cfu/100 mL are shaded in yellow.

Table 4.30. E. Coli in Thornton Creek (cfu/100 mL)						
Year	**No. of Samples**	**Minimum**	**25th Percentile**	**Median**	**75th Percentile**	**Maximum**
2006	32	52	335	560	773	4400
2007	12	64	150	195	603	9800
2008	12	120	200	280	378	590

Source: (King County 2018h)

4.5.2 Aquatic Health

4.5.2.1 Dissolved Oxygen

Based on available data, Thornton Creek is considered in poor condition for DO. Several data sources are available on DO levels in Thornton Creek (King County 2018h; Voss and Embrey 2000; Ecology 2018d; SPU 2013b; Washington State Departments of Ecology and Agriculture 2013b). Since 2007, 29 out of 151 available samples have shown DO levels below the minimum criterion with a minimum level of 7.8 mg/L in July 2012. Thornton Creek has not met the DO standard for an entire year in each year that data are available. Minimum monthly DO measurements in Thornton Creek are shown in Table 4.31. Months when DO levels were below the criterion are shaded in red.

Table 4.31. Minimum Monthly Dissolved Oxygen Measured in Thornton Creek (mg/L)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006	11.0	10.7	13.2	11.0	11.1	9.1	8.6	8.5	9.7	10.0	10.4	11.4
2007	11.4	10.9	11.3	11.2	10.3	9.6	8.9	8.5	8.6	10.0	10.7	12.3
2008	11.6	11.4	10.9	10.2	9.2	9.6	9.1	8.7	9.4	9.9	9.5	10.2
2009		11.8	11.5	10.8	9.7	9.0	8.7	8.5	9.5	10.9	10.8	12.7
2010	11.2	10.9	10.9	9.9	9.9	9.6	8.3	8.5	9.0	9.8	10.1	12.3
2011	12.9	11.3	11.1	10.6	10.1	9.4	9.1	9.2	9.3			
2012			11.2	10.4	9.1	9.4	7.8	9.1	9.6	10.5	9.8	11.5
2013	11.4	11.4	11.4	10.5	9.6	8.4	8.6	8.4	8.5	10.1	10.4	10.4
2014	12.4	10.8	10.9	10.5	9.3	9.2	8.7	8.1	9.2	8.9	10.1	9.2
2015	11.7	10.7	11.0	11.0	9.4	9.1	9.4	8.6	9.4	9.6	10.6	10.6
2016	11.4	10.8	11.1	10.3	9.6	9.6	9.5	9.4	9.7	10.6	10.4	12.0
2017	12.5	11.2	10.9	10.8	9.8	9.9	9.5	8.8	9.6	10.4	10.4	11.9

Source: (King County 2018h)

4.5.2.2 pH

Based on available data, Thornton Creek is considered in good condition for pH. Several studies have measured pH in Thornton Creek since 2006 (SPU 2013b; King County 2018h; Clinton et al. 2016). The average pH from these studies is 7.8, and out of 337 available samples, only two samples were above the pH criterion. Summary statistics for pH measurements in Thornton Creek are shown in Table 4.32, with values that fall outside of the applicable criterion shaded in red.

Table 4.32. pH measurements in Thornton Creek

Year	Number of Samples	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	46	7.0	7.5	7.8	7.9	8.3
2007	58	7.0	7.5	7.7	7.8	8.3
2008	55	6.8	7.6	7.7	8.0	8.7
2009	38	7.4	7.6	7.8	7.9	8.7
2010	38	7.2	7.6	7.8	7.9	8.0
2011	35	7.4	7.7	7.9	8.0	8.1
2012	34	7.2	7.7	7.9	8.1	8.3
2013	43	7.4	7.7	7.8	7.9	8.1
2014	41	7.1	7.5	7.7	7.7	7.9
2015	16	7.2	7.6	7.7	7.8	8.0
2016	17	5.5	7.7	7.8	7.9	8.0
2017	13	7.3	7.4	7.7	7.8	7.9

Sources: (SPU 2013; King County 2018e; Clinton et al. 2016)

4.5.2.3 Temperature

Based on available data, Thornton Creek is considered in poor condition for temperature.

Continuous data has been collected by King County (King County 2018h) and can be used to evaluate the 7-DADMax. Maximum monthly temperature measurements are shown in Table 4.33. Maximum monthly values of rolling 7-DAD Max data are shown in Table 4.34. Months when temperature exceeded criteria are shown in red.

Table 4.33. Maximum Monthly Temperature in Thornton Creek (°C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	8.0	7.7	5.7	11.6	14.7	19.6	20.9	20.4	17.7	11.6	9.0	8.0
2007	7.4	8.5	10.6	11.5	16.7	15.9	19.9	17.6	17.6	11.6	8.7	5.5
2008	5.9	5.9	7.5	12.3	15.6	13.6	18.1	18.0	15.5	12.8	11.1	10.7
2009	5.5	6.0	8.4	12.5	15.0	18.1	20.2	18.3	16.1	9.8	9.1	2.6
2010	7.4	7.6	10.2	12.8	14.6	15.3	19.9	19.3	16.8	13.2	11.3	5.9
2011	3.6	7.7	8.4	10.6	14.1	15.5	15.3	17.9	16.9			
2012			9.3	11.9	15.2	15.8	19.0	18.5	15.7	11.9	13.2	8.6
2013	7.7	8.6	9.4	11.2	15.1	16.3	18.5	18.8	17.7	13.2	9.0	8.0
2014	4.7	6.5	9.6	12.4	14.8	16.2	18.1	18.8	16.7	15.8	12.7	10.3
2015	6.8	10.0	9.7	14.0	15.5	17.5	18.2	18.0	16.3	13.7	9.7	10.2
2016	7.7	8.8	9.5	17.0	14.8	17.8	16.7	16.8	14.7	14.5	10.8	5.3
2017	4.0	8.3	10.0	10.2	15.1	14.0	16.6	16.6	15.1	11.7	9.4	6.3

Source: (King County 2018h)

Table 4.34. Maximum Monthly Values from the 7-Day Average of the Daily Maximum Temperatures in Thornton Creek (°C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013								19.5	19.2	14.2	10.8	8.6
2014	8.4	7.9	10.9	13.2	15.8	17.7	19.8	19.7	18.6	16.1	13.3	10.1
2015	10.1	11.0	13.3	13.7	16.9	20.1	21.2	19.9	17.8	15.3	13.3	9.7
2016	9.2	10.4	11.7	15.7	15.9	18.4	19.5	19.4	17.5	14.9	13.0	10.0
2017	7.3	8.7	10.8	13.0	17.0	17.8	18.5	19.0	17.9	15.2	11.4	9.9

Source: (King County 2018h)

4.5.2.4 Turbidity

Based on available data, Thornton Creek is considered in good condition for turbidity.

King County routinely monitors turbidity within Thornton Creek. Average monthly turbidity measured since 2006 is shown in Table 4.35. Months when average turbidity is considered fair are shaded in yellow.

Table 4.35. Average Monthly Turbidity Measured in Thornton Creek												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006	10.8	8.3	1.8	1.6	3.2	4.7	5.3	4.7	3.3	4.3	6.0	24.0
2007	3.1	2.4	3.5	3.0	4.7	4.9	16.9	6.8	24.6	3.7	2.5	2.5
2008	4.5	2.4	1.6	1.9	2.6	2.5	1.4	1.8	1.3	1.2	5.2	3.8
2013										2.7	4.5	13.4
2014	14.3	4.8	4.3	3.3	3.5	2.6	3.2	2.3	3.3	2.9	2.1	7.1
2015	2.9	5.2	13.2	2.1	3.4	5.8	1.8	23.2	3.1	8.8	3.2	7.4
2016	2.7	3.8	2.4	1.9	3.8	2.8	2.3	5.8	1.9	3.5	3.6	6.6
2017	13.7	16.5	2.8	3.4	2.6	4.0	2.5	2.0	2.0	2.6	3.9	5.0

Source: (King County 2018h)

4.5.2.5 Metals

Based on available data, Thornton Creek is considered in fair condition for metals.

King County (King County 2018h) monitored metals in Thornton Creek between 2006 and 2009. Summary statistics of metals concentrations over that period are shown in Table 4.36. Summary statistics above chronic criteria are shaded in yellow, and summary statistics above acute criteria are shaded in red.

Table 4.36. Metals and Hardness Concentrations in Thornton Creek						
Parameter	**Number of Samples**	**Minimum**	**25th Percentile**	**Median**	**75th Percentile**	**Maximum**
Arsenic	20	0.920	1.333	1.590	1.883	4.210
Cadmium	19	0.010	0.010	0.010	0.017	0.215
Chromium	20	0.378	0.526	0.630	0.932	11.2
Copper	40	0.948	2.053	3.175	6.223	36.5
Hardness, Total as $CaCO_3$	20	28	57	84	94	104
Lead	20	0.120	0.230	0.843	1.488	28.2
Mercury	12	0.001	0.002	0.002	0.006	0.050
Nickel	20	0.822	0.963	1.085	1.318	11.6
Selenium	19	0.500	0.500	0.500	0.500	1.5
Silver	19	0.010	0.018	0.025	0.025	0.2
Zinc	22	2.200	4.128	6.620	10.588	87.1

Source: (King County 2018h)
Note: All metals concentrations are in µg/L. Hardness as CaCO3 is reported in mg/L.

4.5.2.6 Organics

Based on available data, Thornton Creek is considered in fair condition for organics. Although select organic pesticides were monitored as part of the Surface Water Monitoring Program for Pesticides in Salmonid-Bearing Streams (Washington State Departments of Ecology and Agriculture 2013a), none of the chemicals detected have established water quality criteria for aquatic life. The study detected 39 organic compounds related to pesticides in Thornton Creek above reporting limits.

4.5.2.7 Nutrients

Based on available data, Thornton Creek is considered in poor condition for nutrients.

Thornton Creek has been monitored by King County for nutrients since 2004 (King County 2018h). Since 2007, 29 low-flow samples were collected for total Phosphorus and 26 low-flow samples were collected for total nitrogen. Total phosphorus ranged from 0.06 – 0.275 mg/L with an average of 0.09 mg/L. Total nitrogen ranged from 0.68 – 1.78 mg/L with an average of 1.2 mg/L. Both parameters exceeded nutrient thresholds for stream health. Maximum monthly total phosphorus measured since 2006 is shown in Table 4.37. Maximum monthly total nitrogen measured since 2006 is shown in Table 4.38. Months when values exceeded nutrient criteria are shaded in red.

Table 4.37. Maximum Monthly total phosphorus in Thornton Creek

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	0.06	0.07	0.04	0.05	0.06	0.10	0.10	0.11	0.09	0.09	0.06	0.10
2007	0.05	0.05	0.05	0.05	0.08	0.09	0.22	0.12	0.28	0.07	0.05	0.05
2008	0.05	0.06	0.04	0.04	0.04	0.08	0.08	0.07	0.07	0.07	0.08	0.06
2009	0.08	0.05	0.08	0.05	0.04	0.08	0.09	0.10	0.07	0.07	0.05	0.05
2010	0.18	0.05	0.04	0.04	0.07	0.06	0.07	0.07	0.14	0.11	0.23	0.05
2011	0.05	0.04	0.04	0.05								
2012										0.07	0.06	0.06
2013	0.09	0.05	0.04	0.04	0.06	0.06		0.07	0.07	0.06	0.05	0.09
2014	0.1	0.1	0.1		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2015	0.1	0.1	0.1		0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
2016	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2017	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Source: (King County 2018h)

Table 4.38. Maximum Monthly total nitrogen in Thornton Creek												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006	1.06	1.71	1.51	1.38	1.46	1.61	1.52	1.41	1.22	1.39	1.49	1.11
2007	1.56	1.64	1.56	1.47	1.44	1.46	1.62	1.37	1.78	1.07	1.24	1.76
2008	1.28	1.56	1.33	1.18	1.18	1.31	1.37	1.14	1.24	1.13	0.89	1.26
2009	1.29	1.41	0.98	1.59	1.01	1.39	1.29	1.18	0.97	1.14	1.16	1.46
2010	1.12	1.48	1.15	1.18	1.19	1.18	1.36	1.17	1.26	1.21	1.08	1.41
2011	1.55	1.26	1.41	1.36								
2012										1.16	0.85	0.93
2013	1.26	1.43	1.22	1.27	1.20	1.25	1.23	1.23	0.98	1.14	1.01	1.41
2014	1.4	1.3	1.0	1.2	1.2	1.2	1.2	1.2	1.1	0.9	1.3	1.1
2015	1.3	1.5	1.4	1.1	1.5	1.2	1.0	1.6	0.9	1.1	1.2	1.9
2016	0.9	1.6	1.3	1.3	1.3	1.3	1.0	1.0	1.1	1.3	1.1	1.3
2017	1.3	1.0	0.9	0.8	1.1	1.2	1.1	0.9	1.1	1.0	0.8	1.3

Source: (King County 2018h)

4.5.2.8 Sediment Quality

Based on limited data, sediment quality in Thornton Creek is considered fair.

Thornton Creek sediment data were collected, compiled, and analyzed as part of the Stream Sediment Monitoring Program from 1987 through 2002. Results indicate that sediments in the Thornton Creek basin exceeded the Sediment Cleanup Objective for nickel at three sites (0434, A434 and WW434). Concentrations of bis(2-ethylhexyl)phthalate exceeded the Cleanup Objective at two sites (A434 and VV434). Concentrations of 4,4`-DDE (a degradation by-product of the pesticide DDT) and dieldrin (an organochlorine pesticide) were above the Cleanup Objectives at site A434 (King County 2018e).

The SOTW report (SPU 2007b) reported that several classes of compounds have been detected in Thornton Creek sediments. These included pesticides, phthalates, and high molecular weight PAHs. Table 4.39 shows metals and nutrient concentrations detected in Thornton Creek sediments, and Table 4.39 shows organic compound concentrations detected in the sediments. Values exceeding Sediment Cleanup Objectives for freshwater (WAC 173-204-563, Table VI) are shaded red.

Table 4.39. Ammonia and Metals detected in Thornton Creek Sediments (μg/Kg)				
Parameter	**Number of Samples**	**Minimum**	**Median**	**Maximum**
Ammonia as N (mg/Kg)	5	44.9	54.5	125.4
Arsenic	5	9.4	10.7	15.0
Cadmium	5	0.2	0.6	1.0
Chromium	5	36.1	40.8	51.4
Copper	5	34.6	41.5	59.9
Lead	5	58.3	75.8	91.5
Mercury	5	0.1	0.1	0.1
Nickel	5	36.8	40.6	57.1
Silver	5	0.2	0.2	0.2
Zinc	5	221.1	323.8	372.9

Source: (King County 2018e)

Red Shading: Detected concentrations of ammonia and metals exceeded sediment cleanup objectives (Table 3.18)

Table 4.40. Organic Compounds detected in Thornton Creek Sediments (μg/Kg)				
Parameter	**Number of Samples**	**Minimum**	**Median**	**Maximum**
Benzoic Acid	5	742	1065	4130
Carbazole	5	7	43	62
Di-N-Octyl Phthalate	5	11	16	23
Dibenzofuran	5	7	9	11
Dibutyl phthalate	5	37	42	51
Dieldrin	5	2.11	8.16	9.07
Total PAH	1	394	2163	3931
Phenol	5	11	16	588
PCB, Sum of Aroclors	3	60	76	144
4,4'-DDE	5	8.3	31.4	42.9
4,4'-DDT	5	5.5	15.4	29.0

Source: (King County 2018e)

Red Shading: Detected concentrations of organics exceeded human health criteria (consumption of water plus organism)

4.5.2.9 Flow

[flow will be assessed after flow metrics have been calculated based on the DSA modeling results]

4.5.3 Indicators

4.5.3.1 Water Quality Index

King County Department of Natural Resources and Parks conducts monitoring at one station on Thornton Creek to obtain data for computing WQI scores. Monitoring at station 0434 near the mouth of Thornton Creek has occurred over the period spanning from WY2000 through WY2017. Water quality index scores are computed for each individual water year over this period of monitoring. Water quality index scores from this monitoring were not summarized previously in the SOTW (SPU 2007b).

Water quality index scores indicate that Thornton Creek is in poor condition for water quality with scores across all water years ranging from seven to 59 with a mean of 33. However, a plot of water quality index scores over time (Figure 4-8.) shows a modest increasing trend with scores for WY2008, WY2013, WY2016, and WY2017 all showing fair conditions. Based on an analysis of the individual scores for the eight water quality parameters used to compute the water quality index, the primary sources of water quality impairment in Thornton Creek are elevated concentrations of fecal coliform bacteria and total phosphorus.

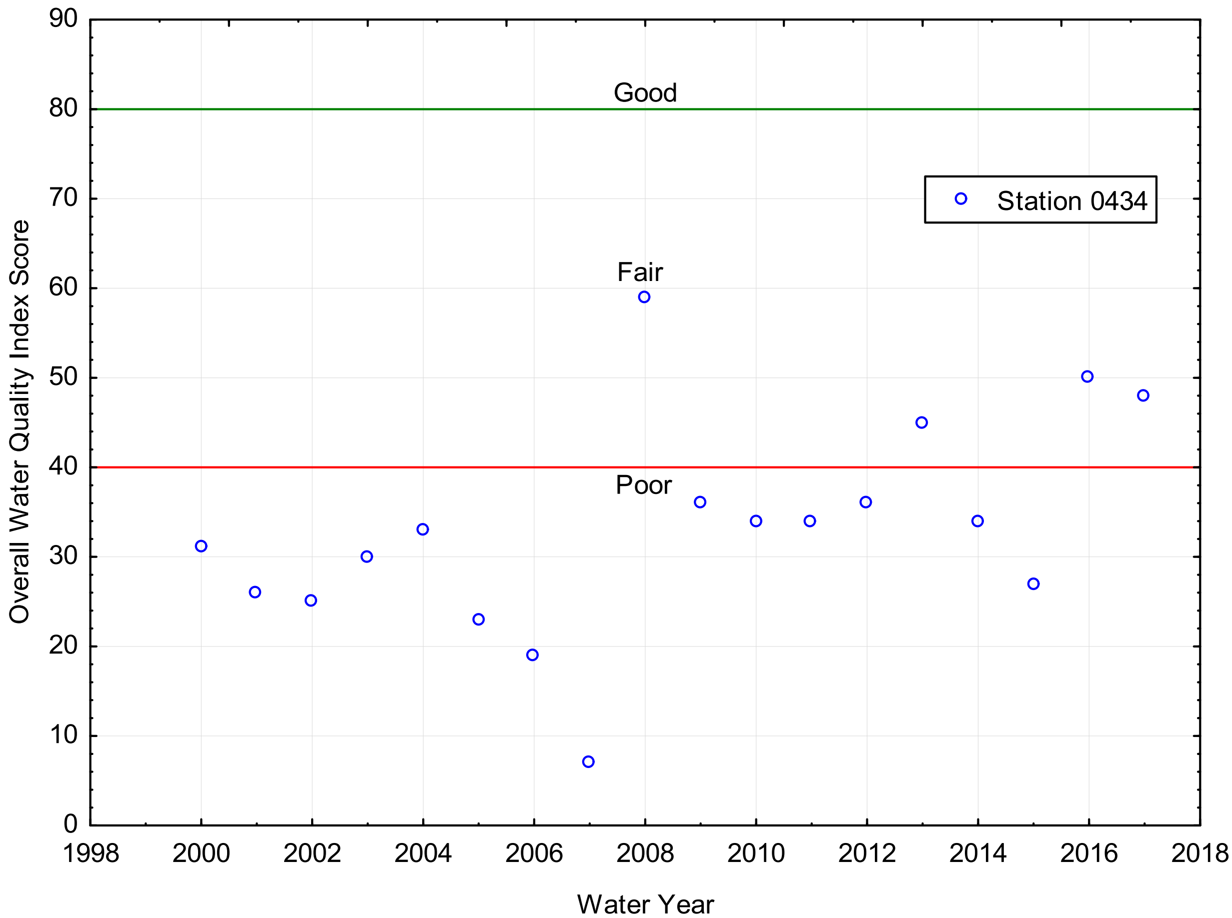


Figure 4-8. Water quality index scores from monitoring stations in Thornton Creek between 2000 and 2017.
Source: (King County 2018d)

4.5.3.2 B-IBI

Seattle Public Utilities, King County Department of Natural Resources and Parks, City of Shoreline, and the University of Washington have all conducted Benthic invertebrate monitoring in Thornton Creek to obtain data for computing B-IBI scores. Collectively, this monitoring has occurred at a total of 35 stations with nine of these stations located on the mainstem of Thornton Creek, 11 stations on the North Branch, and 15 stations on the South Branch. Monitoring at one or more of these stations has occurred on a regular basis from 1994 through 2017 with data available for 19 of the 24 years in this period.

The SOTW (SPU 2007b) indicated that aquatic habitat in Thornton Creek was in poor condition based on B-IBI scores from monitoring that was conducted between 1994 and 2005. B-IBI scores from monitoring that was conducted from 2005 through 2018 indicate that aquatic habitat remains in poor condition. B-IBI scores across all stations from this period range from 0 to 19.1 with a mean of 7.6. Mean scores for stations on the Mainstem, North Branch, and South Branch were 9.5, 8.5, and 5.9, respectively. A plot of B-IBI scores for all stations over the entire monitoring period shows no obvious increasing or decreasing trends (Figure 4-9.).

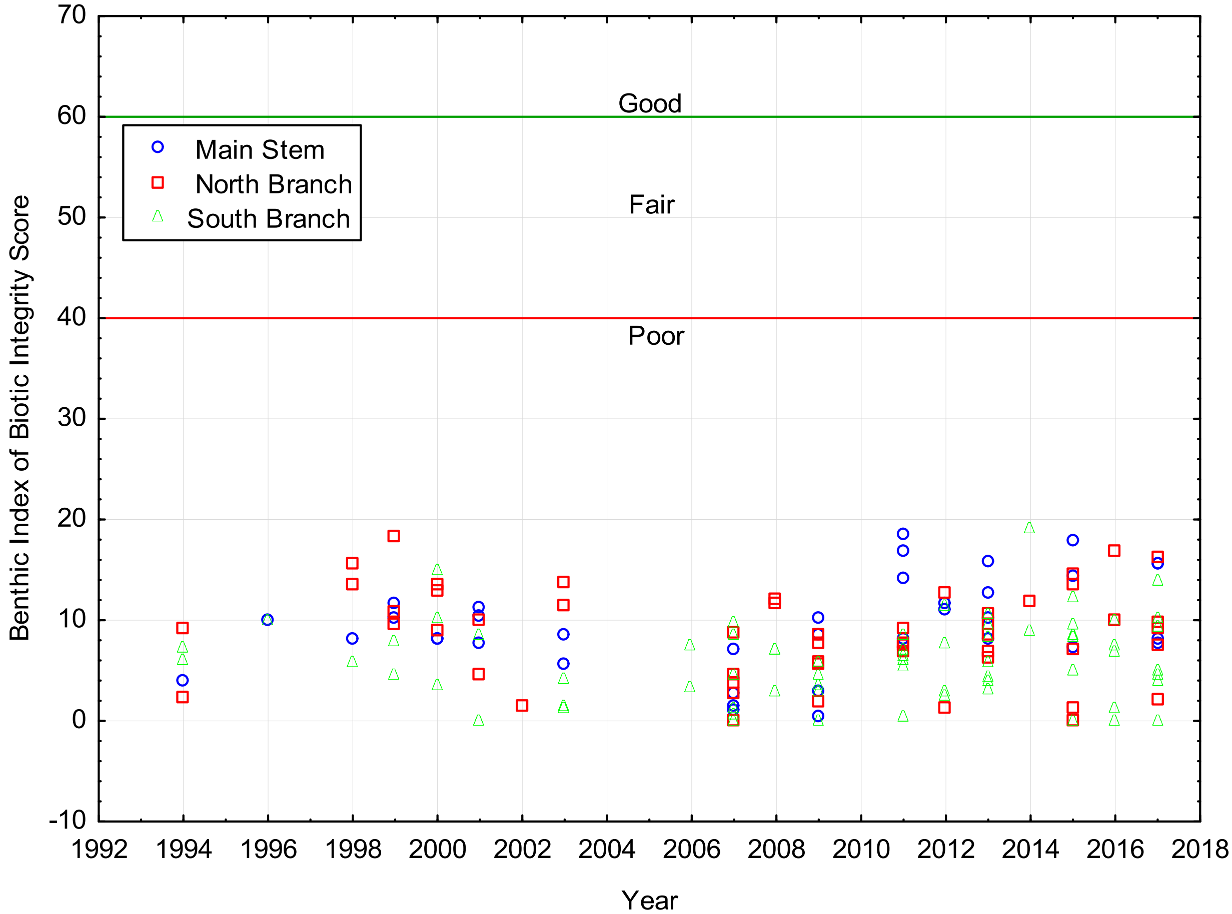


Figure 4-9. Benthic index of biotic integrity scores from monitoring stations in Thornton Creek between 1994 and 2017.

Source: (King County 2018d)

4.5.3.3 Coho Pre-spawn Mortality

Based on available studies, Thornton Creek is considered in poor condition for Coho pre-spawn mortality. For the nine years of available Coho spawning data, the average pre-spawn mortality rate is 83% as summarized in Table 4.28.

Table 4.41. Coho spawning data in Piper's Creek			
Year	**Confirmed female pre-spawn mortalities**	**Total female spawners**	**Pre-spawn mortality**
2000	29	33	88%
2001	9	11	82%

2002	4	5	80%
2003	2	2	100%
2004	1	1	100%
2005	4	8	50%
2006	4	4	100%
2007	4	5	80%
2008	2	2	100%
Total	**59**	**71**	**83%**

Source: (Scholz et al. 2011)

Red Shading: Years rated poor condition based on pre-spawn mortality.

4.5.4 Regulatory Drivers

The upper and lower branches of Thornton Creek are listed as Category 5 impaired water bodies under EPA's CWA section 303(d) for DO, temperature, and fecal coliform. A portion of the Southern branch of the creek (between 5th Avenue NE and 35th Avenue NE) is listed as a Category 5 water body for fecal coliform, temperature, and biological integrity (measured by B-IBI scores). A tributary discharging to the creek's Northern branch is listed as a Category 5 water body for fecal coliform, and a tributary discharging to the Southern branch is listed as a Category 5 water body for fecal coliform and temperature (Ecology 2018f).

4.6 Small Creeks

In addition to Seattle's five major watercourses, there are a number of small watercourses that do not support anadromous salmonid populations. These watercourses include Mapes, Seola Beach, Puget, Yesler, Fairmount, Madrona, Frink, Washington Park, Wolfe, Blue Ridge, Ravenna, and Schmitz creeks as well as Lincton Springs.

In general, there is limited information on these small watercourses.

4.6.1 Indicators

4.6.1.1 B-IBI

Seattle Public Utilities has conducted benthic invertebrate monitoring in the following small creeks within Seattle to obtain data for computing B-IBI scores: Mapes Creek, Maple Leaf Creek, Mohlendorph Creek (a tributary to Venema Creek), Puget Creek, Ravenna Creek, Schmitz Creek, and Willow Creek. This monitoring has occurred over the period spanning from 1994 through 2017 with data available for one or more of these creeks in 18 of the 24 years in this period.

The SOTW (SPU 2007b) indicated that aquatic habitat in Seattle's small creeks (i.e., Maple Creek, Puget Creek, Washington Park/Arboretum Creek, Ravenna Creek, and Schmitz Creek) was in very poor to fair condition based on B-IBI scores from monitoring that was conducted between 1994 and 2004. More recent B-IBI scores from monitoring that was conducted from 2006 through 2017 indicates that aquatic habitat in these creeks was also in poor to fair condition with B-IBI scores ranging from 6.3 to 43.9 and a mean of 23.6. B-IBI scores were highest in Schmitz Creek with a mean of 29.3 and lowest in Ravenna Creek with a mean of 11.9. A plot of B-IBI scores for all creeks over the entire period of monitoring shows no obvious increasing or decreasing trends (Figure 4-10.).

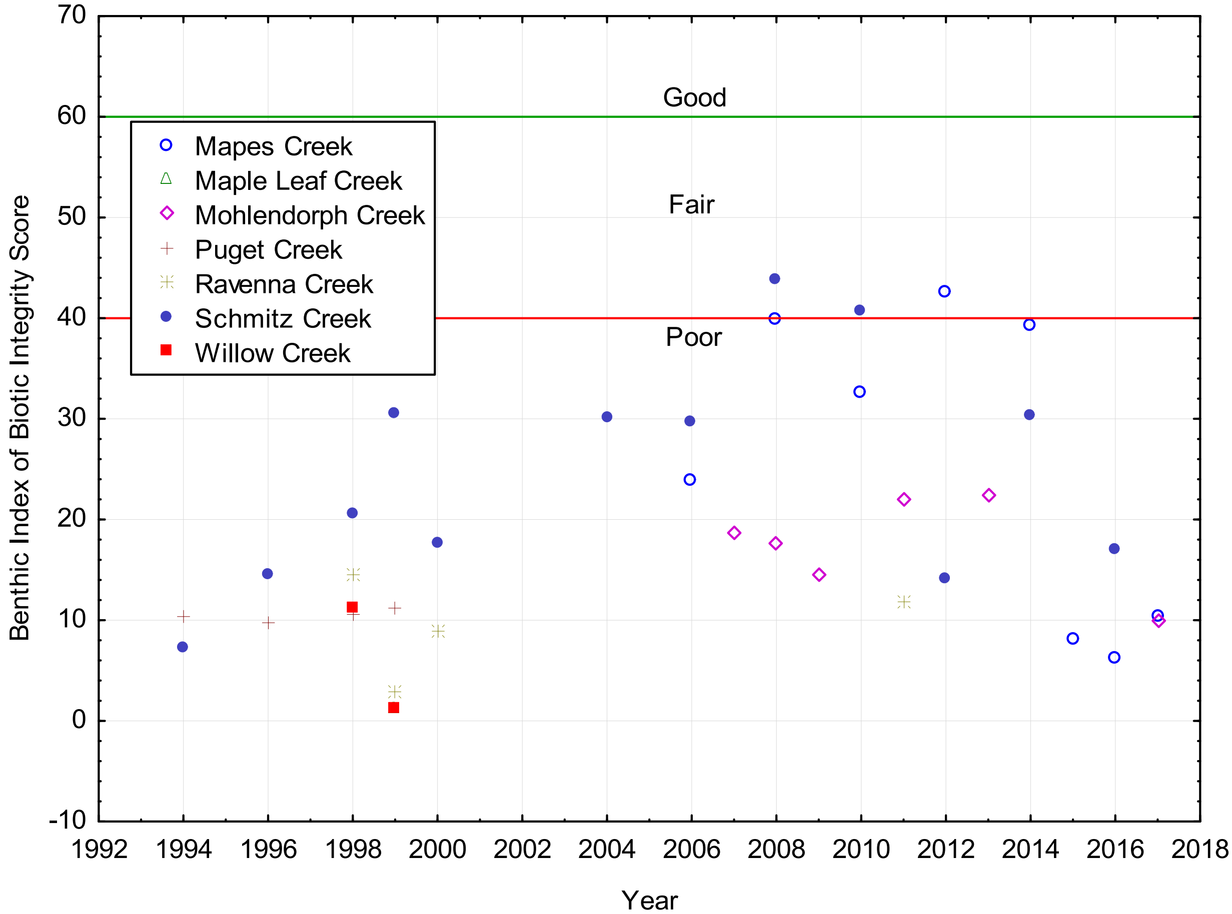


Figure 4-10. Benthic index of biotic integrity scores from monitoring stations in small creeks between 1994 and 2017.

Source: (King County 2018d)

4.6.2 Regulatory Drivers

Mapes Creek and Ravenna Creek are listed as Category 5 impaired water bodies under Ecology's 303(d) list for biological integrity, as measured by B-IBI scores. Mohlendorph Creek is listed as a Category 5 stream for Fecal Coliform.

5. Conditions in Small Lakes

5.1 Bitter Lake

Bitter Lake is an 18.4-acre lake in north-central Seattle with a mean depth of 16 feet and a maximum depth of 31 feet (SPU 2007c). Current land use in the basin is a mixture of single-family and multifamily residential development. Surface water runoff from the approximate 159-acre basin is the primary source of inflow to

Bitter Lake. At its southeastern end, Bitter Lake drains through a piped outlet that runs through small ditches and culverts before entering the Densmore storm drain system. Volunteers for the King County small lakes program monitored water quality in Bitter Lake from 1986 through 2008. Water samples were collected twice each month between May and October. Data collected under the King County small lakes program indicated that Bitter Lake was nearly color free and moderate in primary productivity (mesotrophic) with good water quality and that these indicators remained stable over time (King County 2018f).

5.1.1 Recreation (fecal bacteria)

Based on previously assessed data, Bitter Lake is considered in good condition for fecal bacteria. The SOTW Report (SPU 2007c) reported that while elevated levels of fecal coliform bacteria were measured in 1998, no exceedances since have been reported.

5.1.2 Aquatic Health

The habitat of Bitter Lake has not been well studied, although the water quality studies indicate that the lake is moderately productive and able to support a variety of fish and wildlife species. The Washington Department of Fish and Wildlife (WDFW) has stocked the lake with rainbow trout and warm-water fish species (WDFW 2005a, 2005b).

5.1.2.1 Dissolved Oxygen

No recent data are available to assess the condition of Bitter Lake with respect to DO.

5.1.2.2 pH

No recent data are available to assess the condition of Bitter Lake with respect to pH.

5.1.2.3 Temperature

Based on available data, Bitter Lake is considered in poor condition with respect to temperature. King County measured temperature in Bitter Lake until 2008 as part of the Small Lakes Monitoring Program (King County 2018f). From 2006-2008, temperatures frequently exceeded criteria thresholds (7-DADMax of 16°C)

Use Category	Highest 7-DADMax
Core Summer Salmonid Habitat	16°C (60.8°F)
Salmonid Spawning, Rearing, and Migration	17.5°C (63.5°F)

during the summer months. Table 5.1 summarizes lake temperatures at one-meter depth. Measurements that exceed 20°C are shaded in red. Water quality standards are based on the 7-DADMax temperature, which cannot be calculated from existing data.

Table 5.1. Water Temperatures in Bitter Lake (°C), 1-meter depth, 2006-2008					
Month	**Number of Samples**	**Mean**	**Minimum**	**Median**	**Maximum**
May	6	15.2	14.0	14.5	18.0
June	7	19.1	17.0	18.0	23.0
July	5	23.8	22.0	23.0	28.0
August	6	20.3	20.0	20.0	21.0
September	5	17.5	15.0	18.0	19.0
October	6	13.1	11.5	13.0	15.0

Source: (King County 2018f)

5.1.2.4 Clarity

Clarity in Bitter Lake is classified as fair. Secchi depth was monitored by King County (King County 2018a). Maximum monthly values for TSI-Secchi are shown in Table 5.2. Values classified as fair are shaded yellow, and values classified as poor are shaded red.

Table 5.2. Maximum Monthly TSI-Secchi in Bitter Lake						
Year	**May**	**June**	**July**	**August**	**September**	**October**
2006	40.0	50.0	50.0	46.2	45.7	46.2
2007	46.2	48.0	46.8	48.0	51.5	54.2
2008	41.1	46.2	45.7	50.0	48.6	48.0

Source: (King County 2018f)

5.1.2.5 Organics

Based on previously assessed data, Bitter Lake is considered in good condition for organics. Organics were tested in the Seattle Lakes Alliance sampling event in 2000 and summarized in the SOTW (SPU 2007c). Naphthalene, bis(2-ethylhexyl)phthalate, and heptachlor were the only organic compounds detected in the samples. Concentrations were low and generally near the reporting limits. Naphthalene and bis(2-ethylhexyl)phthalate results are qualified as these chemicals were also detected in method or equipment blanks. Detected concentrations of Heptachlor exceeded the 24-hour average chronic concentration limit.

5.1.2.6 Metals

Based on previously assessed data, Bitter Lake is considered in good condition for metals. The SOTW (SPU 2007c) summarized monitoring efforts where arsenic, chromium, copper, lead, and zinc were detected in water samples. Detected concentrations of all metals were below the aquatic life criteria for freshwater.

5.1.2.7 Nutrients

Trophic State	If Ambient TP (µg/l) Range of Lake is:	Then criteria should be set at:
Ultra-oligotrophic	0-4	4 or less
Oligotrophic	>4-10	10 or less
Lower mesotrophic	>10-20	20 or less
Action Value > 20	>20	lake specific study may be initiated.

Based on available data, Bitter Lake is considered in fair condition with respect to nutrients. Total phosphorus (TP) measured at a depth of one meter below the lake's surface exceeded thresholds (20 µg/l) 10 times in the period from 2006-2008 years of monitoring (King County 2018f). No lake-specific nutrient criteria have been established for Bitter Lake. Average monthly values for TP are shown in Table 5.3. Summer mean values above the TP action level of 0.02 mg/L are shaded red.

Table 5.3. Mean Monthly TP in Bitter Lake (mg/L)

Year	May	June	July	August	September	October	Summer Mean[a]
2006	0.02	0.01	0.01	0.02	0.02	0.02	0.02
2007	0.05	0.01	0.01	0.15	0.02	0.04	0.07
2008	0.04	0.01	0.01	0.12	0.02	0.02	0.06

a. June – September
Source: (King County 2018f)

5.1.2.8 Sediment Quality

Based on previously assessed data, Bitter Lake is considered in fair condition for sediment quality (SPU 2007c).. Metals and organics were tested in sediment samples collected offshore of four major outfalls as part of the 2000 Seattle Lakes Alliance study. Arsenic, cadmium, chromium, copper, lead, mercury, selenium, silver, and zinc were detected in the collected samples. Several samples exceeded the sediment cleanup objective for cadmium, and at least one sample exceeded the cadmium cleanup screening level. All other metals were well below sediment cleanup objectives and screening levels. Total detected concentrations of high and low molecular weight polynuclear aromatic hydrocarbons (PAHs) exceeded the total PAHs sediment cleanup objective. Diesel and motor oil were also detected in the samples but were orders of magnitude below the sediment cleanup objectives (SPU 2007c).

5.1.3 Fish Consumption

To analyze water quality standards related to fish consumption in Bitter Lake, the levels for many toxic chemicals were measured and the findings are reported below. Fecal coliform levels are not discussed as Bitter Lake has no shellfish.

5.1.3.1 Toxics

Based on previously assessed data, Bitter Lake is considered in good condition for toxics related to fish consumption. Organic compounds detected during the Seattle Lakes Alliance sampling program in 2000 were compared to the applicable criteria. The detected concentration of bis(2-ethylhexyl)phthalate exceeded the criteria limit. However, the compound was also detected in the equipment blank for that sampling event, and the reported concentration is qualified (SPU 2007c).

5.1.4 Indicators

5.1.4.1 Trophic State Index

Bitter Lake is classified as mesotrophic based on biological activity, and water quality conditions are fair. TSI indicators predict the biological activity of the lake based on water clarity (Secchi) and TP and chlorophyll a (Chlor) concentrations. TSI for Bitter Lake between 1986 and 2008 ranged from 39 to 52, with an average of approximately 47 (King County 2018f).

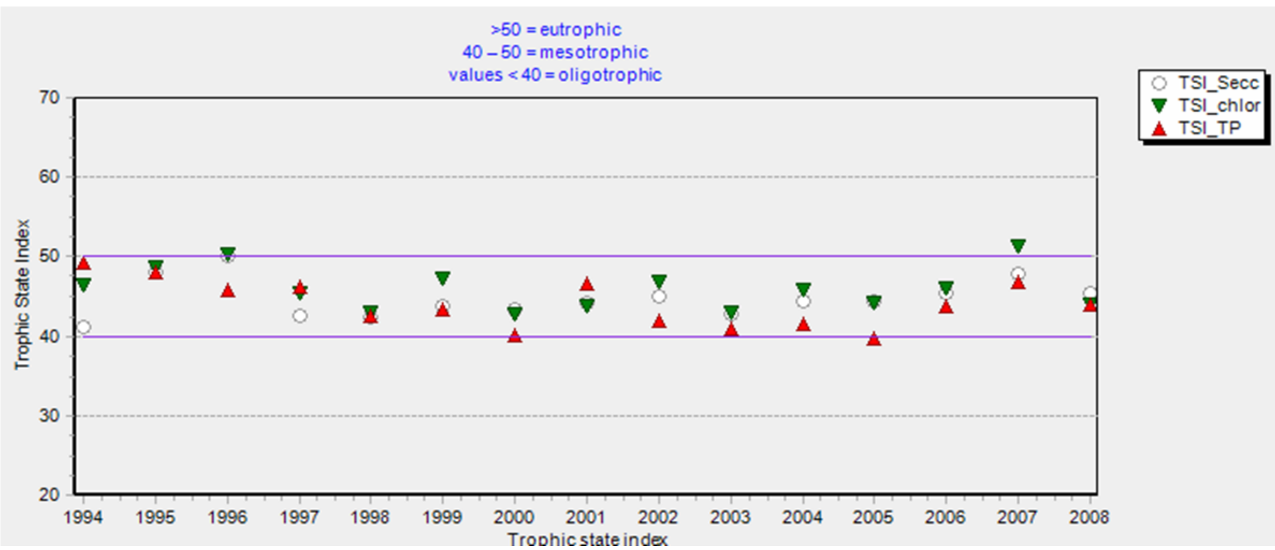


Figure 5-1. Trophic state indices for Bitter Lake between 1994 and 2008.

(reference)

5.1.4.2 Toxic Algal Blooms

The lack of algae scum sampling and guideline exceedance since 2007 in Bitter Lake indicate good conditions. Only two algae scum samples have been collected from the shore of Bitter Lake and tested for cyanobacteria toxins since the conception of the Washington State Toxic Algae Program (Ecology 2018e) in 2007 (Figure 5-2. Toxic algae bloom test results for Bitter Lake since 2007.). One sample was collected in May 2012 and the other was collected in August 2017. Microcystin was not detected in either sample. Anatoxin-a was detected at a low level (0.02 ug/L) in the August 2017 sample, which is well below the state guideline of one ug/L.

Figure 5-2. Toxic algae bloom test results for Bitter Lake since 2007.

(Ecology 2018e)

5.1.4.3 Beach Closures

Bitter Lake does not have any monitored swimming beaches.

5.2 Haller Lake

Haller Lake is located in north-central Seattle. It covers approximately 15 acres, with a maximum depth of 36 feet. The area draining to Haller Lake is primarily residential, with limited public access points at the ends of Meridian Avenue North and North 125th Street. The lake receives stormwater runoff from a drainage area of about 260 acres and discharges through an outlet control structure on the western side of the lake, draining to Lake Union via the Densmore storm drain system (SPU 2007c). Volunteer monitoring under the King County small lakes program began in 1997 and was discontinued in 2008. Water samples were collected twice a month from May through October (King County 2018f).

Data collected under the King County small lakes program indicated that Haller Lake was lightly colored and moderate in primary productivity (mesotrophic) with good water quality that remained steady over time (King County 2018f). The wildlife habitat of Haller Lake has not been well studied (SPU 2007c). Fish species inhabiting the lake include rainbow trout, largemouth bass, yellow perch, brown bullhead, and black crappie (WDFW 2005a, 2005b). The WDFW stocks the lake with rainbow trout each year.

5.2.1 Recreation (fecal bacteria)

Based on previous assessments of available data, conditions in Haller Lake with respect to fecal bacteria are good. The SOTW report cited that only one sample for fecal coliform bacteria was collected in Haller Lake in 1998, and the reported value of 29 CFU/100 mL was below the established standard (SPU 2007c).

5.2.2 Aquatic Health

5.2.2.1 Dissolved Oxygen

No data are available to assess the condition of Haller Lake with respect to DO.

5.2.2.2 pH

No data are available to assess the condition of Haller Lake with respect to pH.

5.2.2.3 Temperature

Based on available data, Haller Lake is considered in fair condition with respect to temperature. King County measured temperature in Haller Lake until 2008 as part of the Small Lakes Monitoring Program (King County 2018f). Between 2006 and 2008, temperatures frequently exceeded criteria during the summer months. Table 5.4 summarizes lake temperatures at one-meter depth. Measurements exceeding 20°C are shaded in red. Water quality standards are based on the 7-DADMax temperature, which cannot be calculated from existing data.

Table 5.4. Water Temperatures in Haller Lake (°C), 1-meter depth, 2006-2008

Month	Number of Samples	Mean	Minimum	Median	Maximum
May	5	16.8	14.0	17.0	20.0
June	7	19.7	17.5	19.5	23.0
July	5	23.6	22.0	24.0	25.0
August	6	22.0	21.0	22.0	23.0
September	6	19.5	18.0	19.0	22.0
October	6	14.5	12.0	14.5	17.0

Source: (King County 2018d)

5.2.2.4 Clarity

Based on available data, Conditions in Haller Lake with respect to clarity are fair. Secchi depth was monitored by King County (King County 2018a). Maximum monthly values for TSI-Secchi are shown in Table 5.5. Values classified as fair are shaded yellow.

Table 5.5. Maximum Monthly TSI-Secchi in Haller Lake						
Year	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
2006	42			47		
2007	39	42	44	47	44	44
2008	40	40	44	47		47

Source: (King County 2018a)

5.2.2.5 Metals

Based on available data, conditions in Haller Lake with respect to metals are good. In 2001, students of Seattle University collected a composite sample from the Meridian Avenue North storm drain, the largest storm drain discharging into Haller Lake, as part of a drainage improvement evaluation. Dissolved copper and lead were not detected in the sample and dissolved zinc was detected below the aquatic life freshwater criteria (SPU 2007c).

5.2.2.6 Organics

No data are available to assess the condition of Haller Lake with respect to organics.

5.2.2.7 Nutrients

Based on available data, Haller Lake is considered in fair condition for nutrients. TP, ammonia, total nitrogen, and nitrate concentrations in the lake were monitored and reported by King County (King County 2018f). Concentrations of ammonia in Haller Lake were monitored from 2005 through 2008 at varying depths. No lake-specific nutrient criteria have been developed for Haller Lake. Average monthly values for TP are shown in in Table 5.6. Summer mean values above the TP action level of 0.2 mg/L are shaded red.

Table 5.6. Mean Monthly TP in Haller Lake (mg/L)							
Year	**May**	**June**	**July**	**August**	**September**	**October**	**Summer Mean[a]**
2006	0.03	0.01	0.02	0.10	0.02	0.02	0.05
2007	0.10	0.02	0.02	0.11	0.02	0.04	0.05
2008	0.15	0.01	0.01	0.13	0.02	0.01	0.06

a. June – September
Source: (King County 2018f)

5.2.2.8 Sediment Quality

No data are available to assess the condition of Haller Lake with respect to sediment quality.

5.2.3 Fish Consumption

While the levels of toxic chemicals are relevant to fish health and human consumption, the fecal levels are not relevant in this water body as no shellfish are present.

5.2.3.1 Toxics

No data are available to assess the condition of Haller Lake with respect to toxics related to fish consumption.

5.2.4 Indicators

5.2.4.1 Trophic State Index

Haller Lake can be classified as mesotrophic based on biological activity, and water quality conditions are considered fair. TSI for Haller Lake between 1986 and 2008 ranged from 37 to 54, with an average of approximately 44 (King County 2018f).

TSIs of Haller Lake for total phosphorus, chlorophyll a, and Secchi depth are presented in Figure 5-3. for the King County monitoring period of record from 1997 through 2008. The trophic state of Haller Lake has been mesotrophic (TSI ranging from 40 to 50) based on each of these parameters throughout this period.

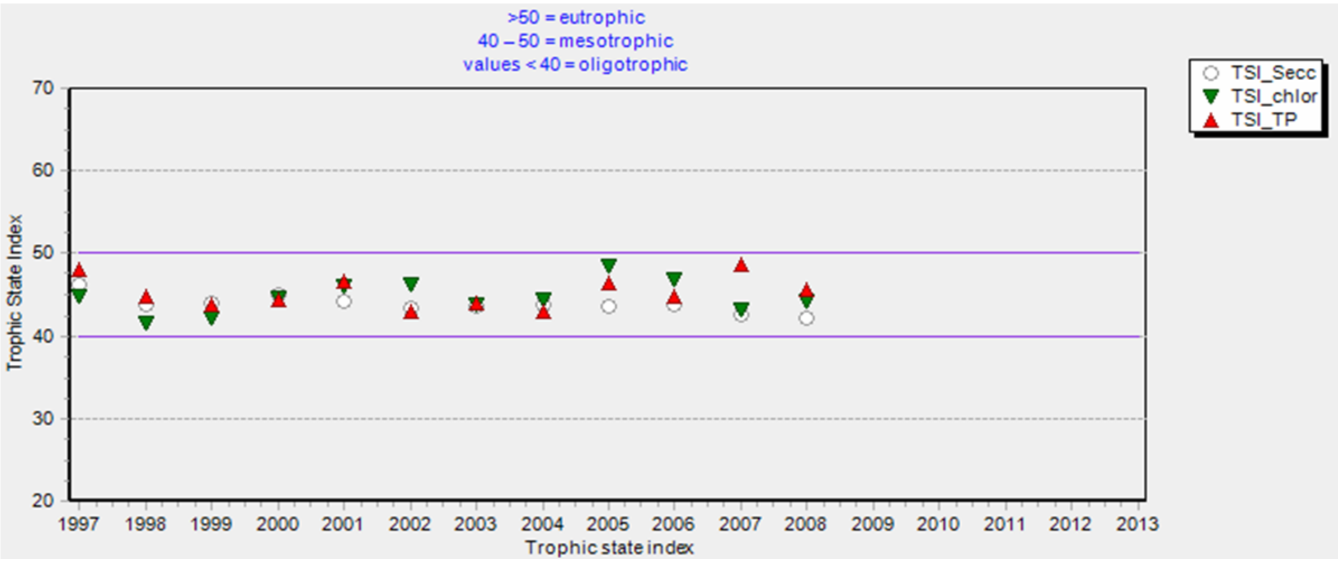


Figure 5-3. Trophic state indices for Haller Lake between 1997 and 2008.

(King County 2018f)

5.2.4.2 Toxic Algal Blooms

Available data on toxic algae blooms indicates fair conditions, and there is no indication that the blooms are worsening. A total of 17 algae scum samples have been collected from the shore of Haller Lake and tested for cyanobacteria toxins since the conception of the Washington State Toxic Algae Program in 2007 (Ecology 2018e) (Figure 5-4.). Microcystin exceeded the state guideline of 6 ug/L in eight of the 12 samples collected in 2013, but not in the samples collected in 2015, 2017, or 2018. Anatoxin-a was not detected above the guideline (1 ug/L) in any of the four samples tested in those years.

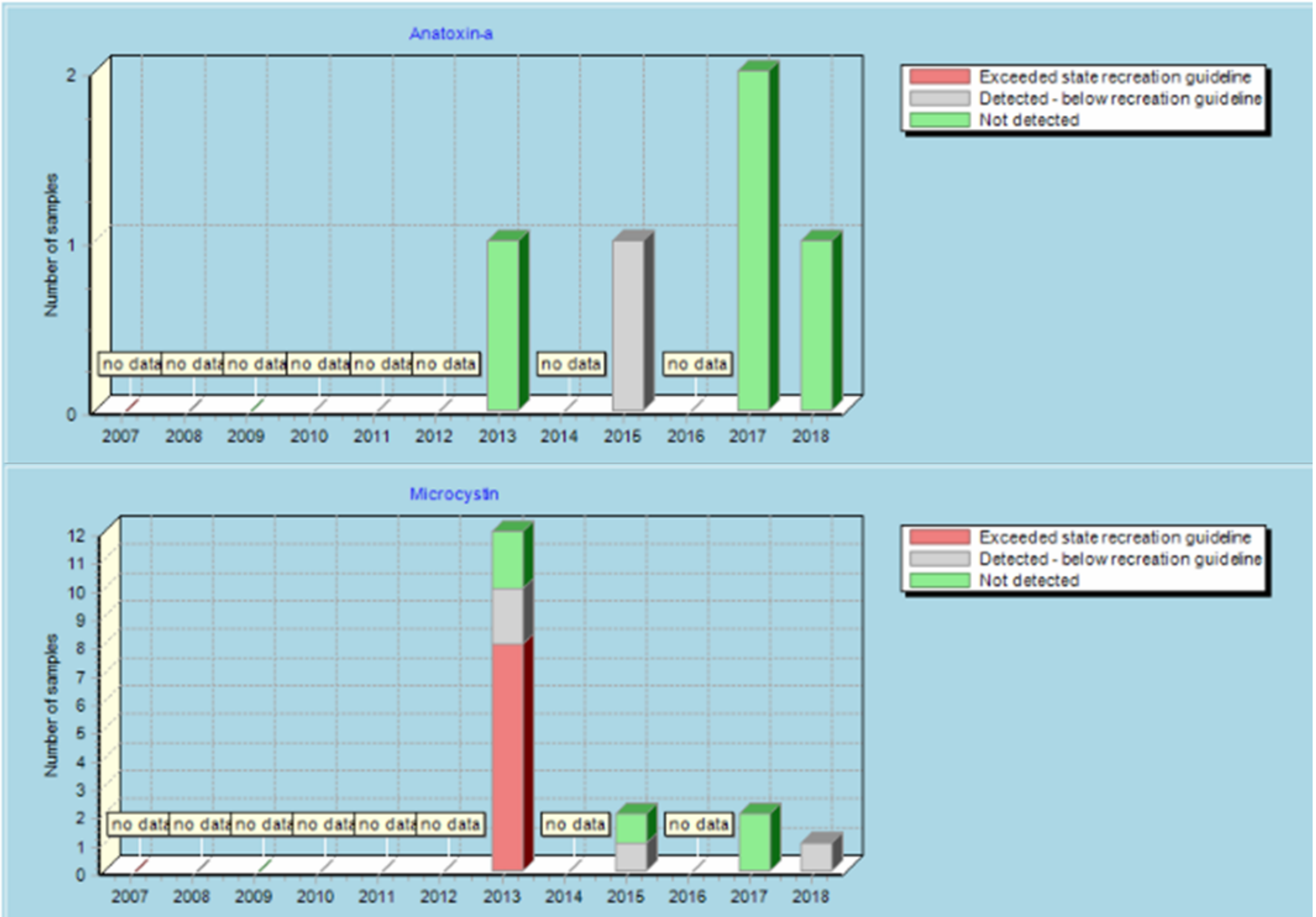


Figure 5-4. Toxic algae bloom test results for Haller Lake since 2007.

(Ecology 2018e)

5.2.4.3 Beach Closures

Haller Lake does not have any monitored swimming beaches.

5.3 Green Lake

Green Lake is located north of Lake Union between Aurora Avenue N and East Green Lake Way, covering approximately 259 acres. The lake is relatively shallow, with a mean depth of about 13 feet and a maximum depth of approximately 30 feet. Major sources of water for Green Lake are rainfall, direct stormwater runoff from lands adjacent to the lake, and overflows from Densmore Avenue storm drain. The lake discharges into Lake Union through a single outlet located near Meridian Avenue North.

Green Lake has been treated with aluminum sulfate (alum) multiple times since 1991 to inactivate phosphorus in the lake sediment, thereby reducing internal phosphorus loading and availability to blue-green algae. Other solutions implemented for water quality improvement in the lake include aquatic plant harvesting, control of the local geese population, dilution with excess drinking water from SPU, stormwater treatment facilities, and diversion of stormwater discharge away from the lake (SPU 2007c).

5.3.1 Recreation (fecal bacteria)

Water quality in Green Lake with respect to fecal bacteria for recreational use is considered good. Fecal coliform bacteria in Green Lake are monitored between May and September under King County's swimming beach monitoring program, which began in 1996 (King County 2018f). Between 2014 and 2018, a total of 190 samples were collected, out of which five individual samples exceeded 200 CFU/100 mL and one reported geometric mean exceeded 100 CFU/100 mL (King County 2018i). The swim beach monitoring program considers individual samples of fecal coliform less than 200 cfu/100 mL to be of low concern, 200-1000 cfu/100 mL to be of moderate concern, and above 1000 cfu/100 mL to be of high concern. The swim beach monitoring program also considers a geometric mean above 200 cfu/100 mL to be of high concern. Individual sample results are shown in Table 5.7. Geometric mean samples are shown in Table 5.8. Values that indicate a moderate concern are highlighted in yellow.

Table 5.7. Maximum Monthly Fecal Coliform in Green Lake – individual samples (cfu/100 mL)

Year	May	Jun	Jul	Aug	Sep
2013	77	32	75	55	26
2014	38	62	38	170	70
2015	53	200	22	61	180
2016	8	54	26	200	230
2017	41	40	80	30	190

Table 5.8. Monthly Fecal Coliform in Green Lake – Geometric Means (cfu/100 mL)

Year	Jun	Jul	Aug	Sep
2014	15	18	24	46
2015	24	18	16	44
2016	22	19	37	52
2017	25	30	15	16

5.3.2 Aquatic Health

5.3.2.1 Dissolved Oxygen

Based on existing data, DO conditions in Green Lake are considered good. According to the SOTW (SPU 2007c) water quality data collected in the summer of 2005, following a 2004 alum treatment, reported DO concentrations ranged from 7.5 - 10.3 mg/L, with an average of 9.2 mg/L. Reported data for DO meets the state standard for protection of aquatic health.

5.3.2.2 pH

No data are available to assess the condition of Green Lake with respect to pH.

5.3.2.3 Temperature

Based on available data, Green Lake is considered in poor condition with respect to temperature. King County routinely measures temperature in Green Lake as part of the Small Lakes Monitoring Program (King County 2018f). During the period from 2006-2018, temperatures frequently exceeded the criterion during the summer months. Table 5.9 summarizes lake temperatures at one-meter depth. Measurements exceeding 20°C are shaded in red. Water quality standards are based on the 7-DADMax temperature, which cannot be calculated from existing data.

Table 5.9. Water Temperatures in Green Lake (°C), 1-meter depth, 2006-2018

Month	Number of Samples	Mean	Minimum	Median	Maximum
May	31	16.1	13.0	16.0	19.0
June	38	19.2	15.0	19.5	23.0
July	29	22.1	20.0	22.0	24.0
August	35	22.0	20.0	22.0	26.0
September	31	19.1	14.5	19.5	23.0
October	27	14.0	11.5	14.0	17.0

5.3.2.4 Clarity

Clarity conditions in Green Lake are fair. Aquatic life clarity criteria were applied to Green Lake by calculating a Trophic State Index (TSI) based on Secchi depth measurements. Based on Secchi depth data reported between 2005 and 2018, TSI-Secchi values displayed a range from 33 to 60, with an average of 45 (King County 2018f). Maximum monthly values for TSI-Secchi are shown in Table 5.10. Values classified as fair are shaded yellow, and values classified as poor are shaded red.

Table 5.10. Maximum Monthly TSI-Secchi in Green Lake						
Year	**May**	**June**	**July**	**August**	**September**	**October**
2006	43	44	52	54	51	46
2007	50	43	42	41	45	44
2008	42	49	42	45	43	32
2009	39	47	49	40	43	43
2010	60	51	42	45	43	45
2011	43	52	43	41	44	41
2012	47	44	42	37	40	40
2013	40	41	42	57	54	44
2014	44	48	44	47	49	44
2015	44	43	49	52	50	52
2016	35	39	38	45	41	40
2017	49	42	46	43	44	47
2018	41	46	44	49	48	49

5.3.2.5 Metals

Based on limited data, Green Lake is in good condition with respect to metals. Metals were sampled in July 2013 under the King County Minor Lakes Monitoring Program (King County 2018f). All metals were below applicable aquatic life criteria, except for a single lead sample, which was above the chronic exposure level. Metals data are shown in Table 5.11. Values exceeding chronic exposure limits are highlighted in yellow.

Table 5.11. Metals concentrations in Green Lake, July 2013		
Parameter	**Units**	**Value**
Antimony	µg/L	0.3
Arsenic	µg/L	2.42
Thallium	µg/L	0.04
Chromium	µg/L	0.2
Copper	µg/L	1.8
Hardness	mg/L	44.6
Lead	µg/L	1.03
Nickel	µg/L	0.48
Selenium	µg/L	0.5
Silver	µg/L	0.04
Zinc	µg/L	20

5.3.2.6 Organics

No data are available to assess the condition of Green Lake with respect to organics.

5.3.2.7 Nutrients

Water quality in Green Lake with respect to nutrients is considered good, most likely as a result of recent efforts to reduce algae blooms.

Green Lake is a shallow, highly productive lake with high concentrations of nutrients such as nitrogen and phosphorus that promote plant and algae growth. Green Lake has had a history of algae problems and several water-quality improvement programs have been implemented to control the growth of blue-green bacteria and associated human health risks (SPU 2007c). Lake-wide applications of aluminum sulfate (alum) to reduce phosphorus and control algae were performed in 1991 and 2004.

Lake specific TP criteria were first established for Green Lake in 1990. The most recent TP criteria of 0.02 mg/L was established under the 2016 Phosphorus Management Plan (Herrera Environmental Consultants 2016). No lake-specific criteria have been reported for total nitrogen, or ammonia.

TP, ammonia, total nitrogen, and nitrate concentrations in Green Lake were monitored by King County (King County 2018f) between 2005 and 2018. Average monthly values for TP are shown in in Table 5.12. Summer mean values above the TP action level are shaded red.

Table 5.12. Mean Monthly TP in Green Lake (mg/L)

Year	May	June	July	August	September	October	Summer Mean
2006	0.01	0.01	0.01	0.02	0.02	0.02	0.03
2007	0.01	0.01	0.01	0.01	0.01	0.01	0.03
2008	0.01	0.01	0.01	0.01	0.01	0.01	0.04
2009	0.02	0.02	0.01	0.02	0.01	0.02	0.02
2010	0.01	0.01	0.01	0.02	0.01	0.02	0.01
2011	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2012	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2013	0.02	0.01	0.01	0.02	0.02	0.01	0.02
2014	0.01	0.01	0.01	0.02	0.01	0.01	0.02
2015	0.01	0.01	0.02	0.02	0.02	0.03	0.02
2016	0.01	0.01	0.02	0.02	0.02	0.01	0.02
2017	0.01	0.01	0.02	0.01	0.02	0.04	0.01

5.3.2.8 Sediment Quality

Based on previously assessed data, sediment quality in Green Lake is categorized as fair.

Sediment samples were collected by SPU in 2004 from seven locations offshore of the Densmore Avenue N storm drain outfall in Green Lake and analyzed for metals and semi-volatile organic compounds as well as total petroleum hydrocarbons, and PCBs. Metals were frequently detected in most sediment samples. Reported concentrations of arsenic, cadmium, and lead exceeded the sediment cleanup objectives in select samples, and organic compounds were infrequently detected in the sediment samples. Bis(2-ethylhexyl)phthalate and Di-n-octylphthalate were reported at concentrations above existing sediment cleanup objectives in several samples, and Dieldrin was reported above sediment cleanup screening levels (SPU 2007c; 173-204 WAC 2013).

5.3.3 Fish Consumption

Green Lake contains native rainbow trout (stocked) and sculpin, along with nonnative largemouth bass, common carp, tiger musky (stocked), yellow perch, brown bullhead, rock bass, black crappie, pumpkinseed, and channel catfish (WDFW 2005a, 2005b). Fish surveys conducted in the lake since 1993 indicate that common carp and largemouth bass are the dominant species (SPU 2007c).

5.3.3.1 Toxics

Based on available information, water quality in Green Lake with respect to toxics is fair.

Green Lake is under a fish consumption advisory for Common Carp and Rainbow Trout. King County monitored toxic metals in the water column in July 2013. All metals monitored were below applicable human health criteria for consumption except for arsenic. Monitoring results are shown in Table 5.13. Values above the human consumption criteria are shaded red. No water quality data for organics are available, although fish tissue samples have shown accumulation of Chlordane, 4,4′-DDE, 2,3,7,8-TCDD, and PCBs in fish tissue, leading to listing as a 303(d) impaired water body.

Table 5.13. Toxic Metal Concentrations in Green Lake

Year	Parameter	Units	July
2013	Antimony	µg/L	0.3
	Arsenic	µg/L	2.42
	Beryllium	µg/L	0.1
	Hardness, Total as CaCO3	µg/L	44.6
	Selenium	µg/L	0.5
	Thallium	µg/L	0.04

5.3.4 Indicators

5.3.4.1 Trophic State Index

Based on available information, water quality in Green Lake with respect to TSI is fair.

TSIs of Green Lake for total phosphorus, chlorophyll a, and Secchi depth are presented in Figure 5-5. for the King County monitoring period of record from 2005 through 2018. The trophic state of Green Lake generally has been mesotrophic (TSI ranging from 40 to 50) based on each of these parameters throughout this period. Additional data collected by Seattle Parks and Recreation before this period has shown that TSIs were reduced by the three alum treatments in 1994, 2004, and 2016 and generally increased between treatments.

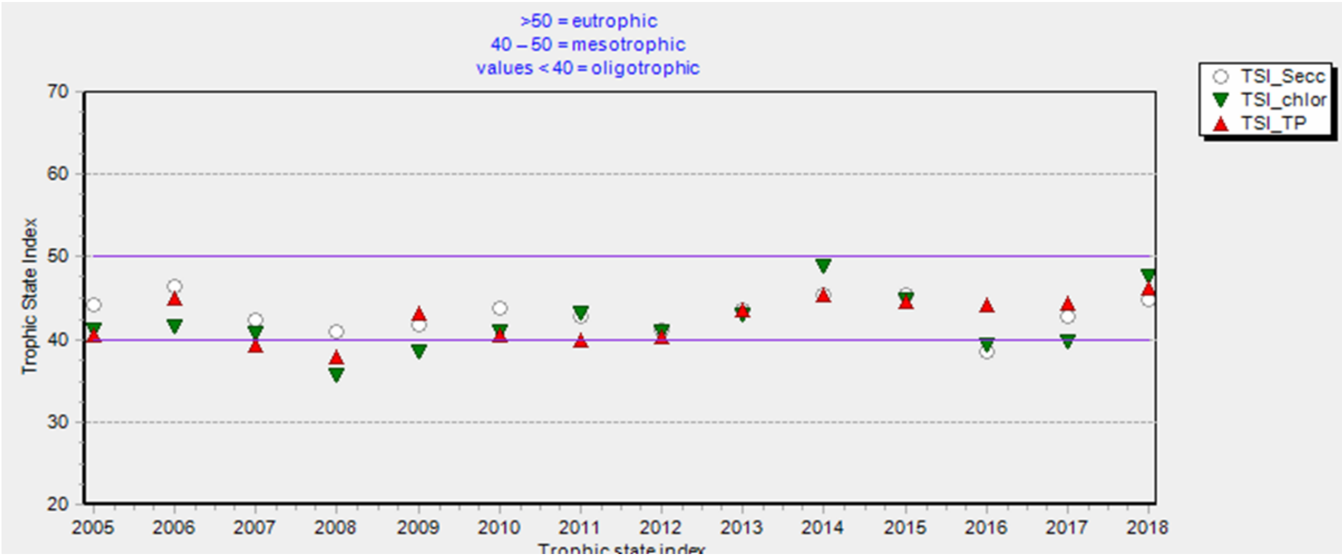


Figure 5-5. Trophic state indices for Green Lake between 2005 and 2018.

5.3.4.2 Toxic Algal Blooms

Water quality in Green Lake is fair with respect to toxic algal blooms. A total of 125 algae scum samples have been collected from the shore of Green Lake and tested for cyanobacteria toxins since the conception of the Washington State Toxic Algae Program in 2007 (Figure 5-6.). Microcystin exceeded the state recreation guideline of six ug/L each year in 2011 through 2015, and toxic algae blooms were most prevalent in 2014. (Note that data in Figure 5-6. does not include samples collected in 2011 through 2015 with undetected or detected results below the guideline.) Anatoxin-a was never detected above the guideline (1 ug/L) in any of the samples tested in those years. Additional weekly toxin testing at the two Green Lake beaches during summer months since 2009 has shown no exceedance of state recreation guidelines except for microcystin in two samples from each beach in 2014.

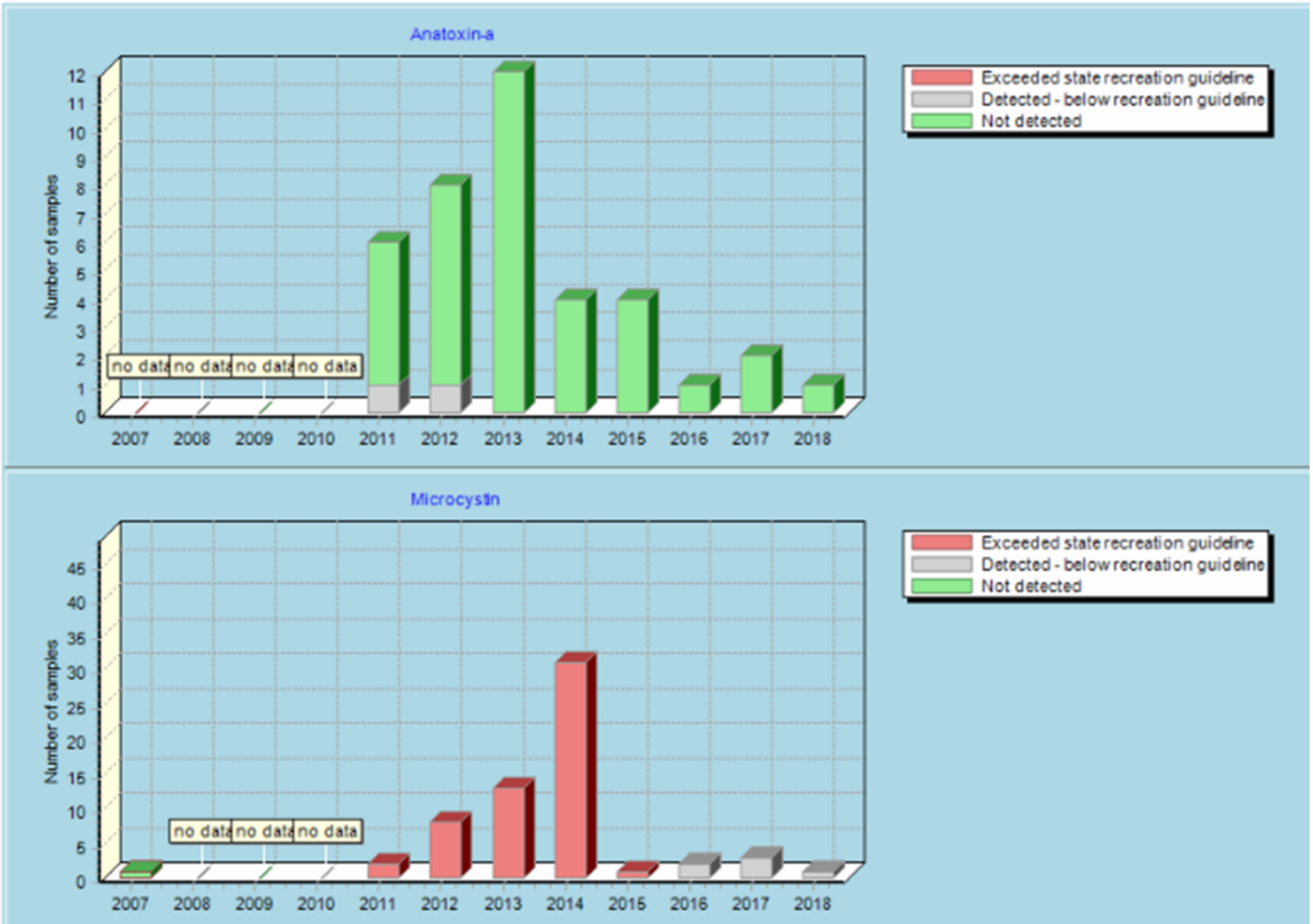


Figure 5-6. Toxic algae bloom test results for Green Lake since 2007.

Table 5.14. Toxic Algae monitoring results in Lake Green Lake 2007-2018			
Constituent	**Samples with no detection**	**Samples with detections below recreation guidelines**	**Samples with detections exceeding recreation guidelines**
Anatoxin-a	36	2	0
Microcystin	19	52	55

5.3.4.3 Beach Closures

Green Lake is considered in fair condition related to beach closures.

Beach closures occurred in 2002, 2003, 2012, 2013 and 2014 due to microcystin detections above state recreation guidelines (Herrera Environmental Consultants 2016).

5.3.5 Regulatory Drivers

Green Lake is listed as a Category 5 impaired water body under EPA's CWA section 303(d) for Chlordane, 4,4′-DDE, 2,3,7,8-TCDD, and PCBs in fish tissue. The lake is also listed as a Category 4(c) water body for invasive exotic species. Category 4(c) implies that the water quality impairment cannot be addressed through a TMDL (Ecology 2018f).

6. Conditions in Large Lakes

6.1 Lake Washington (offshore Seattle)

Lake Washington is the second-largest natural lake in Washington, with a surface area of 21,500 acres and a watershed of 472 square miles. The lake encloses Mercer island and receives inflows from the Sammamish and Cedar Rivers as well as Ravenna, Thornton, Kelsey, Juanita, and Coal Creeks and small local storm drains. Lake Washington's primary discharge is through Lake Union and the Lake Washington Ship Canal into Puget Sound. This assessment focuses on the portion of Lake Washington offshore of Seattle, which is the lake's central east shoreline. Union Bay, located near the eastern end of the Ship Canal, is considered part of Lake Washington for this assessment.

6.1.1 Recreation (fecal bacteria)

Based on available data, Lake Washington offshore of Seattle is in good condition with respect to fecal bacteria.

The King County Routine Major Lakes Ambient Monitoring Program monitored fecal bacteria in Lake Washington until 2008. Data were collected at three locations offshore of Seattle: just south of the 520 Bridge (Lake Washington Buoy, Site-0852), about 3,000 feet offshore of Stan Sayres Memorial Park (Site-0890, and approximately 300 feet offshore of Beer Sheva Park (Site-4903).

Table 6.1 summarizes fecal coliform concentrations offshore of Seattle. Fecal coliform measurements above 50 cfu/100ml are shaded yellow, and measurements above 100 cfu/100 ml are shaded red. Geometric means of samples have not been calculated, and these values do not indicate a violation of the water quality criteria.

Table 6.1. Fecal Coliform Measurements in Lake Washington (cfu/ml)

Year	Number of Samples	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	45	0	0	2	9	520
2007	37	1	1	4	12	490
2008	39	1	1	3	9	90

Table 6.2 summarizes E. coli concentrations offshore of Seattle. E. coli measurements above 100 cfu/100ml are shaded yellow, and measurements above 320 cfu/100 ml are shaded red. Geometric means of samples have not been calculated, and these values do not indicate a violation of the proposed water quality criteria.

Table 6.2. *E. coli* Measurements in Lake Washington (cfu/ml)

Year	Number of Samples	Mean	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	46	37	0	0	2	7	880
2007	37	19	1	1	2	10	320
2008	39	6	1	1	1	8	52

6.1.2 Aquatic Health

6.1.2.1 Dissolved Oxygen

DO in Lake Washington is considered in fair condition. DO concentrations are currently measured at one site offshore of north Seattle (Lake Washington – 0852) and have historically been measured at a site offshore of south Seattle (Lake Washington – 0890).

Table 6.3 summarizes dissolved oxygen measurements in the upper 10 meters of the water column for the period from 2006-2018. Measurements that were below the water quality criterion for minimum DO are shaded red. DO concentrations consistently fall below water quality criteria in late summer throughout the water column. However, DO concentrations rarely fall into ranges that threaten salmonid survival (King County 2018a).

Table 6.3. Dissolved Oxygen Measurements in Lake Washington 2006-2018, 0-10 m (mg/L)

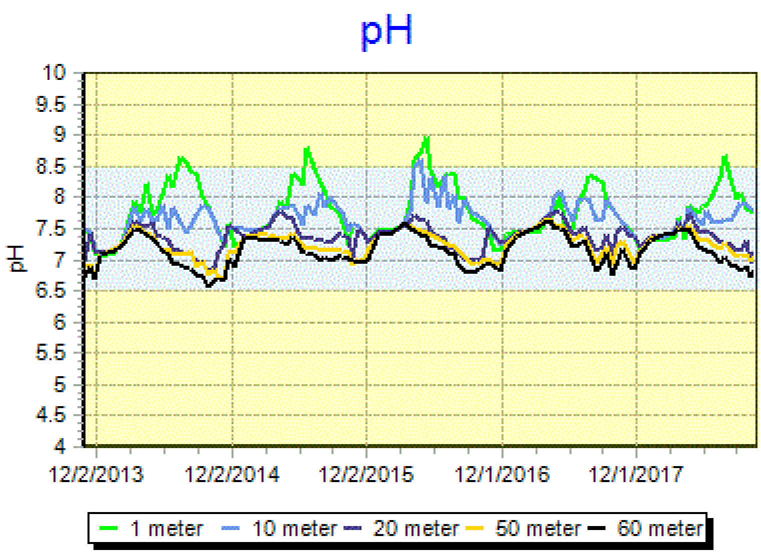
Year	Number of Samples	Mean	Minimum	Median	Maximum
January	228	10.4	9.7	10.4	10.8
February	228	11.1	10.6	11.1	12.5
March	472	11.7	10.7	11.7	12.8
April	483	11.8	10.5	11.7	13.5
May	451	10.9	9.6	11.0	12.5
June	478	9.9	8.9	9.9	10.8
July	441	9.2	7.0	9.2	10.4
August	488	8.6	6.6	8.7	9.5
September	487	8.7	7.0	8.8	9.4
October	469	9.1	8.1	9.1	10.0
November	354	9.4	8.6	9.4	10.0
December	217	9.3	8.9	9.3	10.2

6.1.2.2 pH

Lake Washington is considered in good condition for pH.

pH concentrations are currently measured at one site offshore of north Seattle (Lake Washington – 0852) and have historically been measured at a site offshore of south Seattle (Lake Washington – 0890). Lake

Washington has seen a trend of high pH values that occasionally exceed the upper pH criteria limit during the late summer months (Figure 6-1) (King County 2018a). These high pH values are likely due to a long-term trend of increasing alkalinity in the lake that is not well-understood (King County 2016).



Note: State water quality standards for pH thresholds are indicated by color changes.

6.5 = the lower threshold, and 8.5 = the upper threshold of the Washington Aquatic Life Criteria.

Figure 6-1. Measurements at Lake Washington (0852) Monitoring Station 2013 - 2018.

(King County 2018a)

6.1.2.3 Temperature

Lake Washington is considered in fair condition for temperature based on available data.

Lake Washington is currently monitored offshore of Seattle by the Washington buoy. Data from the Washington buoy show that temperature criteria are consistently exceeded in the summer months, from late May or early June through late September or early October.

Table 6.4. Water Temperatures in Lake Washington (°C), 1-meter depth, 2005-2017												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2005	8.6	7.8	9.0	9.6	14.4	18.6	21.6	23.5	21.0	16.9	12.3	9.6
2006		7.7	7.5	8.7	14.1	18.6	20.9	21.9	21.1	18.6	13.0	9.0
2007	7.8	6.9	7.9	11.0	16.2	17.4	21.5	20.9	20.6	16.7	11.6	8.9
2008	7.2	6.2	7.6	9.2	15.3	16.5	21.0	20.5	19.7	15.1	12.4	10.2
2009	7.5	6.6	6.5	11.1	11.6	18.2	18.3	21.4	19.3	14.3	12.1	8.2
2010	7.7	7.8	8.3	11.1	13.8	17.1	22.0	21.0	18.2	16.5	12.7	9.4
2011	7.9	7.4	7.3	8.5	13.1	18.3	18.2	20.9	20.8	16.2	11.8	8.9
2012	8.1	7.1	7.3	12.4	15.3	16.1	19.9	22.6	19.8	17.4	13.5	9.7
2013	7.7	7.2	7.9	10.1	14.6	18.6	22.9	22.8	21.9	15.4	11.7	8.9
2014	7.9	6.9	8.0	11.3	17.3	19.1	23.8	23.7	20.8	18.3	13.9	9.9
2015	8.8	8.6	9.6	12.4	19.0	21.3	23.1	22.6	18.8	16.7	13.9	10.1
2016	8.4	8.1	8.9	13.6	16.2	19.8	21.8	22.1	19.9	16.4	13.3	9.6
2017	7.7	6.5	7.1	9.8	12.2	19.2	22.3	22.5	21.5	16.9	11.2	9.1

Table 6.5. Water Temperatures in Lake Washington (°C), 10-meter depth, 2005-2017												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2005	8.6	7.7	8.4	8.7	13.7	15.5	18.5	19.6	20.7	16.9	12.3	9.6
2006		7.6	7.3	8.7	12.2	17.4	17.9	21.0	20.4	18.3	0.0	9.0
2007	7.8	6.7	7.7	9.7	12.5	16.9	18.4	20.4	20.4	16.7	11.5	8.9
2008	7.2	6.2	7.0	8.6	11.2	13.8	17.7	19.5	19.0	15.1	12.4	0.0
2009	7.4	6.6	6.5	9.9	10.3	14.1	0.0	0.0	18.9	14.3	12.1	0.0
2010	7.6	7.6	8.1	8.9	13.1	15.4	15.0	20.4	18.1	16.5	12.7	9.4
2011	7.9	7.4	7.3	8.4	10.7	14.5	14.6	20.1	19.7	16.0	11.8	9.0
2012	8.1	0.0	7.1	9.8	13.7	14.8	18.2	20.0	19.7	17.3	13.5	9.7
2013	7.7	7.2	7.8	9.7	13.9	17.3	18.1	20.4	21.2	15.1	11.7	8.9
2014	7.8	0.0	7.7	9.9	15.7	17.1	17.7	21.2	20.4	18.3	13.8	0.0
2015	0.0	8.5	9.5	12.2	13.8	17.4	18.7	21.4	18.5	16.7	13.9	10.1
2016	8.4	7.9	8.8	12.7	15.7	17.7	19.0	21.8	19.7	16.4	13.2	0.0
2017	0.0	6.4	7.1	9.5	12.3	17.5	19.0	20.4	21.2	16.9	10.0	9.1

6.1.2.4 Clarity

Conditions in Lake Washington with respect to clarity are fair. Secchi depth was monitored by King County (King County 2018a). Maximum monthly values for TSI-Secchi are shown in Table 6.6. Values classified as fair are shaded yellow.

Table 6.6. Maximum monthly TSI-Secchi in Lake Washington, 2005-2009												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2005	35.1	29.1	40.0	36.8	47.4	37.4	40.0	35.9	36.8	36.8	36.2	33.0
2006	31.5	40.0	37.4	43.2	44.2	40.4	38.3	38.3	34.2	35.4	35.4	38.3
2007	40.0	35.9	39.3	40.0	50.0	44.6	41.9	36.8	37.1	35.9	34.2	38.3
2008	36.8	36.2	43.2	44.2	40.0	36.2	37.4	39.6	35.9	34.2	33.9	36.2
2009	35.9	40.0	42.3	41.9	46.8	46.2	39.0	36.2	36.8	31.5	37.4	35.4

6.1.2.5 Metals

No data are available to assess metals in Lake Washington.

6.1.2.6 Organics

No data are available to assess organics in Lake Washington.

6.1.2.7 Nutrients

Lake Washington is considered to be in good condition with respect to nutrients. Nutrient concentrations (i.e., total nitrogen, nitrate/nitrite nitrogen, ammonia nitrogen, total phosphorus, and ortho phosphorus) are currently measured at one site offshore of north Seattle (Lake Washington – 0852) and have historically been measured at a site offshore of south Seattle (Lake Washington – 0890). Ammonia concentrations tend to be greatest at the surface, while total nitrogen and total phosphorus tend to be greatest at depth. Spikes in surface ammonia concentration are generally seen twice a year – once around late spring / early summer, and once in fall (Figure 6-2.). Total nitrogen at depth shows a weak decrease in concentration in spring, while surface total nitrogen is highest in spring and lowest in fall (Figure 6-3. Total Nitrogen Measurements at Lake Washington (0852) Monitoring Station, (2013-2018)). Total phosphorus concentrations in the deep water samples are generally higher than a concentrations in samples collected at the surface during fall and winter (Figure 6-1) (King County 2018a).

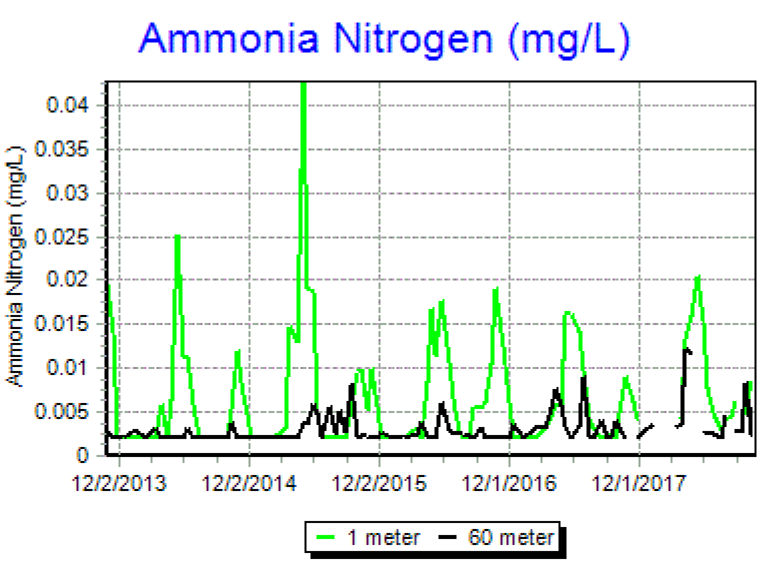


Figure 6-2. Ammonia Nitrogen Measurements at Lake Washington (0852) Monitoring Station, (2013-2018)

(King County 2018a)

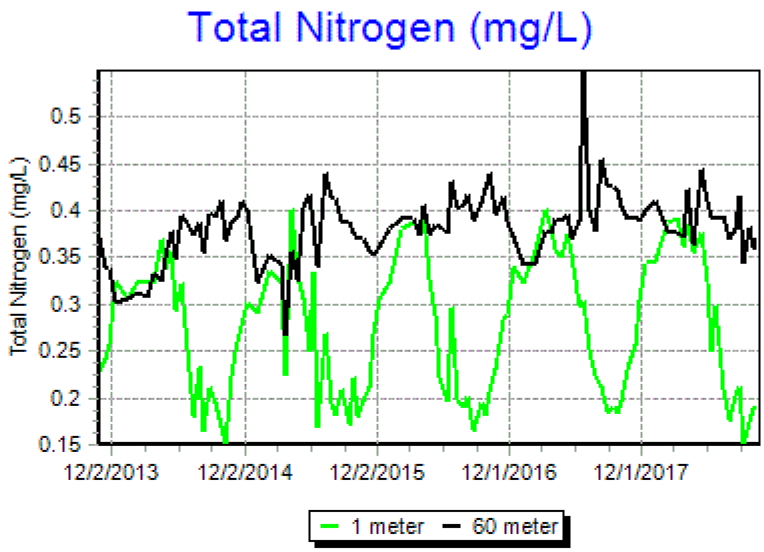


Figure 6-3. Total Nitrogen Measurements at Lake Washington (0852) Monitoring Station, (2013-2018)

(King County 2018a)

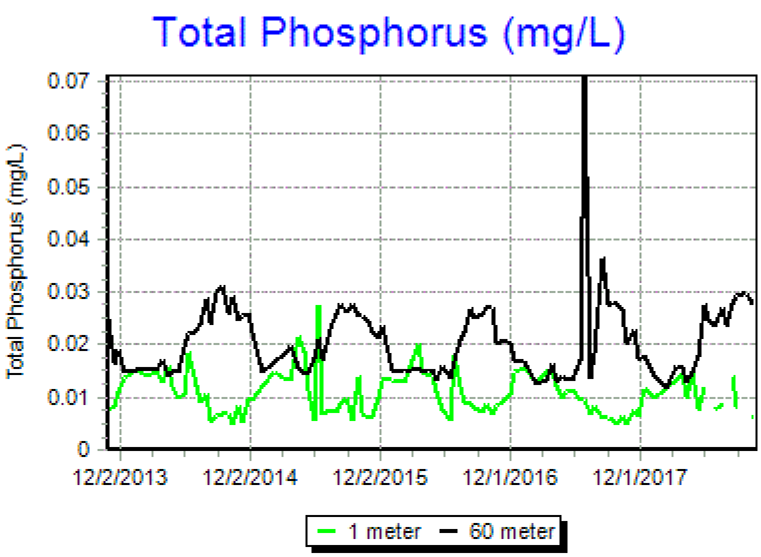


Figure 6-4. Total Phosphorus Measurements at Lake Washington (0852) Monitoring Station, (2013-2018)

(King County 2018a)

6.1.2.8 Sediment Quality

Lake Washington is considered to be in poor condition with respect to sediment quality.

Sediment data in Lake Washington is available in a 2004 King County study on Lake Sammamish, Lake Washington and Lake Union sediments (Moshenberg 2004). Based on floating percentile statistics, Sediment

Quality Guidelines at the time of study were exceeded at 10% of sites in Lake Washington for tributyltin , 34% for phthalates, 28% for metals, and 97% for PCBs. Based on Threshold Effects Levels, 34% of sites exceeded guidelines for DDT, 17% for PAHs, 76% for metals, and 100% for PCBs. These assessments were based on criteria in effect at the time of the study and do not reflect current criteria. Note that these data are for all of Lake Washington rather than just sites offshore of Seattle.

6.1.3 Fish Consumption

6.1.3.1 Toxics

Lake Washington is considered to be in poor condition with respect to toxic substances in fish tissue. consumption advisories exist for common carp, cutthroat trout, northern pikeminnow, and yellow perch, with recommendations for no consumption of common carp or northern pikeminnow (Washington State Department of Health 2018a).

6.1.4 Indicators

6.1.4.1 Trophic State Index

Lake Washington is in good condition with respect to TSI. TSIs of Lake Washington for total phosphorus, chlorophyll a, and Secchi depth are presented in Figure 6-5 for the King County monitoring period of record from 1994 through 2014. The trophic state of Lake Washington generally has been oligotrophic (TSI less than 40) with mesotrophic status (TSI ranging from 40 to 50) for some parameters in the early and most recent years of this period. TSIs calculated for 2015 through 2018 from King County's website, which are not presented in Figure 6-5, show oligotrophic status for all three parameters. Additional years of consistent mesotrophic status would be needed to determine if the trophic state index for Lake Washington has increased from oligotrophic status.

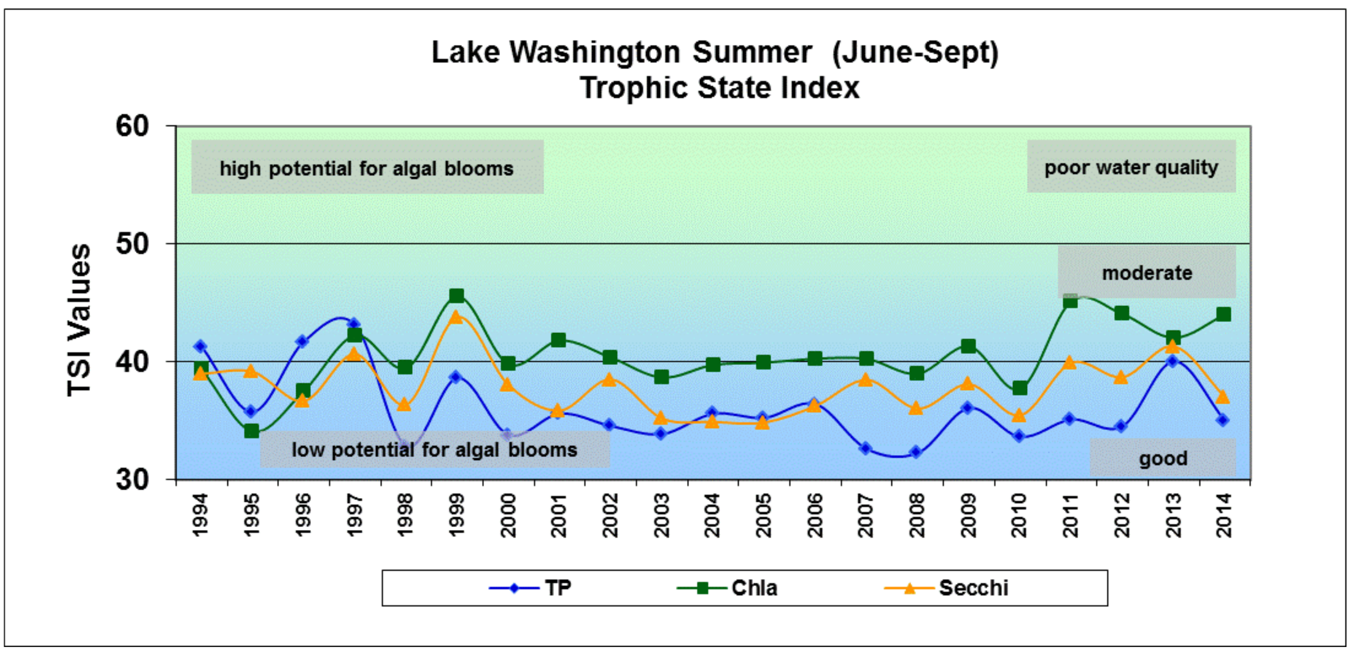


Figure 6-5. Lake Washington summer trophic state indices between 1994 and 2014.

(reference)

6.1.4.2 Toxic Algal Blooms

Lake Washington is considered in fair condition with respect to toxic algal blooms. A total of 61 algae scum samples have been collected from non-beach areas of Lake Washington and tested for cyanobacteria toxins since conception of the Washington State Toxic Algae Program in 2007 (Figure 6-6). Microcystin exceeded the state recreation guideline of six ug/L each year in 2014 through 2016, and toxic algae blooms were most prevalent in 2015. (Note that data in Figure 6-6 does not include samples collected in 2015 through 2016 with undetected or detected results below the guideline.) Anatoxin-a was never detected above the guideline (1 ug/L) in any of the samples tested in those years. Additional weekly toxin testing at seven Lake Washington beaches in Seattle during summer months since 2009 has shown no exceedances of state recreation guidelines at Madrona Beach, Magnuson Beach, Seward Park Beach, or Pritchard Island Beach. Only one sample from three different beaches exceeded the microcystin guideline of six ug/L; Matthews Beach in 2015, Mount Baker Beach in 2010, and the off-leash area of Magnuson Beach in 2015.

Table 6.7. Anatoxin-a monitoring results in Lake Washington 2006-2018

Beach	Samples with no detection	Samples with detections below recreation guidelines	Samples with detections exceeding recreation guidelines
Andrews Bay, Seward Park	108	10	0
Madison Park Beach	102	15	0
Magnuson Park Off-leash Area	114	6	0
Matthews Beach	117	2	0
Mount Baker Beach	112	5	0
Pritchard Island Beach	115	1	0

Table 6.8. Microcystin monitoring results in Lake Washington 2006-2018

Beach	Samples with no detection	Samples with detections below recreation guidelines	Samples with detections exceeding recreation guidelines
Andrews Bay, Seward Park	227	3	0
Madison Park Beach	218	6	0
Magnuson Park Off-leash Area	206	20	1
Matthews Beach	215	12	1
Mount Baker Beach	218	7	1
Pritchard Island Beach	222	7	0

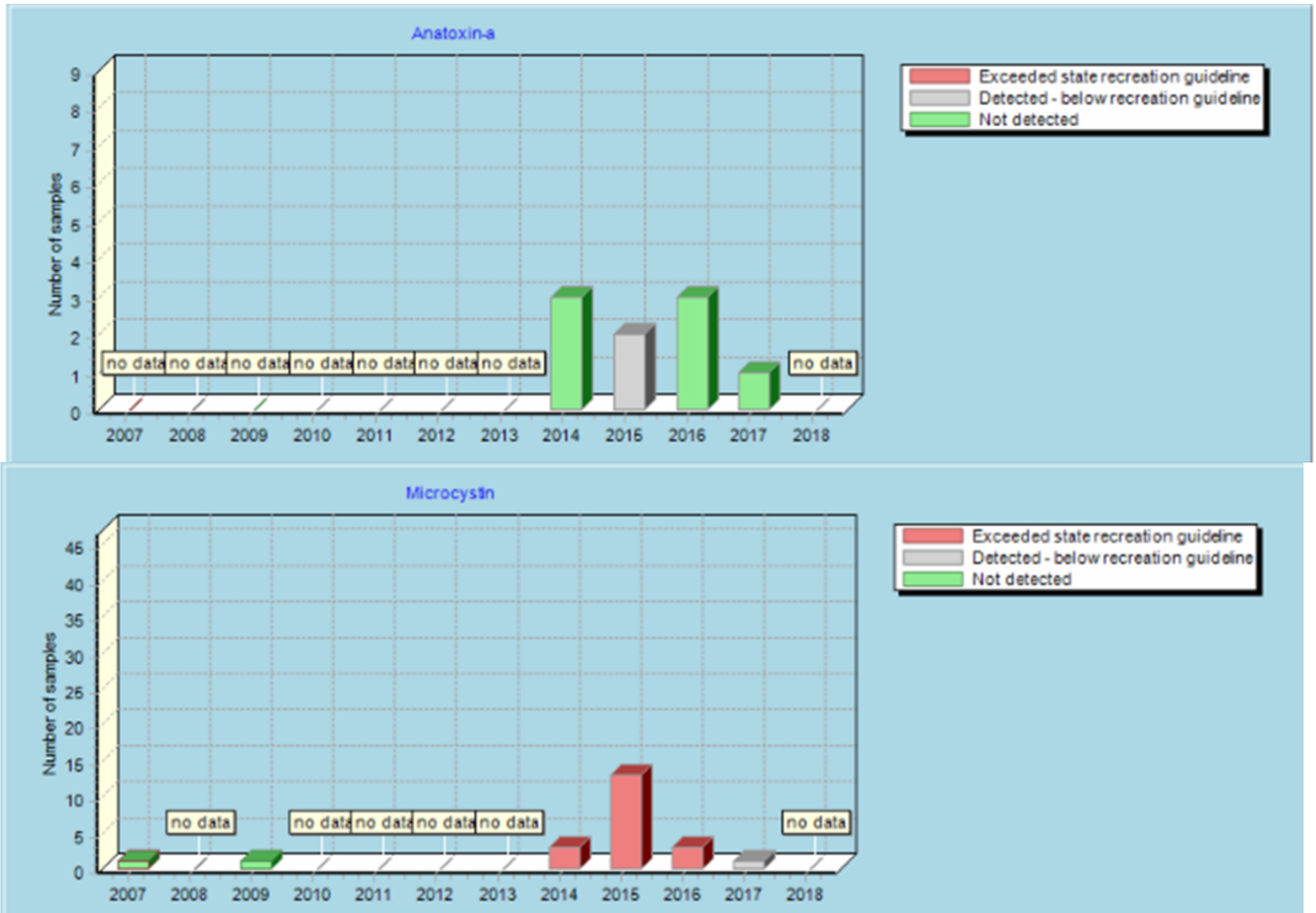


Figure 6-6. Toxic algae bloom test results for non-beach areas of Lake Washington since 2007.

6.1.4.3 Beach Closures

Lake Washington is considered in good condition with respect to beach closures. King County monitors fecal bacteria concentrations at swimming beaches throughout the county. Sampling is usually done once a week from mid-May to mid-September, with cyanotoxin sampling occurring in June through October. The six monitored beach sites in Seattle are Matthews Beach, the Magnuson Park off-leash area, Magnuson Beach, Madison Park Beach, Mount Baker Beach, and Pritchard Island Beach.

Between 2008 and 2017, several exceedances of the Ten State Standard occurred, but all exceedances were short-lived and never resulted in beach closures. Madison Park beach exceeded the standard in 2011, 2013, 2016, and 2017; the other two beaches never exceeded the Ten State Standard (King County 2018i). Only one beach closure has been reported since 2008. Matthews Beach was closed for one weekend in 2014 due to high fecal coliform.

6.1.5 Regulatory Drivers

Lake Washington waters adjacent to Seattle Shoreline are listed as Category 5 impaired waters under CWA Section 303(d) for fecal coliform in water, and Chlordane, Dieldrin, 4,4'-DDE, 2,3,7,8-TCDD, and PCBs in fish tissue. Lake water adjacent to Seattle shoreline is also listed as a Category 4(c) water body for invasive exotic species (Ecology 2018f).

6.2 Lake Union/Ship Canal

The Lake Union/Lake Washington Ship Canal system is an 8.6-mile-long, man-made navigable waterway connecting Shilshole Bay in Puget Sound to Union Bay in Lake Washington in Seattle. This system includes several interconnected waterways: the Hiram M. Chittenden Locks, Salmon Bay, Salmon Bay Waterway, Fremont Cut, Lake Union, Portage Bay, and Montlake Cut. Lake Union is a freshwater lake and receives most of its inflow from Lake Washington via the Montlake Cut and Portage Bay. Lake Union is approximately 581 acres in area with an average depth of 32 feet and a maximum depth of 50 feet.

Gas Works Park, a City of Seattle park, is located on the north shore of Lake Union and is listed by Ecology as a MTCA site (Ecology, 2013b). It is the former location of a plant that converted coal and oil into manufactured gas. The sediments offshore of Gas Works Park contain polycyclic aromatic hydrocarbons (PAHs) and are currently being studied to determine the best cleanup remedy.

Lake Union and the Ship Canal are monitored as part of the King County Major Lakes Monitoring Program (King County 2018b). King County routinely measures water quality at five sites, summarized in Table 6.9. The water quality of Lake Union and the Ship Canal were reviewed comprehensively by the King County Department of Natural Resources and Parks in 2017 (King County Department of Natural Resources and Parks 2017a). This section summarizes findings from that study.

Table 6.9. King County Monitoring Locations in Lake Union/Ship Canal

Location ID	Name and Description	Maximum Depth at Site (meters)	Depths Sampled	Years Sampled
0512	Locks–Salmon Bay	8	1, 5	1975-present
0518	Fremont–NW Lake Union	11	1, 9	1974-2009
A522	Dexter–SW Lake Union	16	1, 5, 10, 14	1979-present
0536	NE Lake Union–Portage	9	1, 3	1975-2008
0540	Montlake Cut	11	1, 8	1975-2008

6.2.1 Recreation (fecal bacteria)

Based on available data, Lake Union and the Lake Washington Ship Canal are considered in fair condition for fecal bacteria.

King County performed monthly fecal coliform sampling at five sites at one-meter depth in Lake Union and the Ship Canal from 1970 to the present. Concentrations were significantly higher from one site to the next site downstream; only the sites at the upstream end and the southwest area of Lake Union were not significantly different from each other. This is consistent with the understanding that fecal coliform bacteria largely enter Lake Union via CSOs and direct runoff from streets and an observed correlation between fecal coliform bacteria concentrations and observed 3-day rainfall (King County 2017c). During the monitoring period, this standard was not violated at the upstream two King County monitoring locations. It was violated occasionally at the southwest Lake Union and Fremont Channel sites and was violated frequently at the Ballard Locks site.

All five sites showed long-term decreases in fecal coliform bacteria concentrations and frequency of exceedance of the water quality standard. Table 6.10 shows measurements of fecal coliform in Lake Union and the Ship Canal. Fecal coliform measurements higher than 50 cfu/100mL are shaded yellow; measurements higher than 100 cfu/100 mL are shaded red.

Table 6.10. Lake Union/Ship Canal Fecal Coliform Data (cfu/mL)

Year	Number of Samples	Mean	Minimum	25th Percentile	Median	75th Percentile	Maximum
2006	69	64	1	8	15	33	1700
2007	60	43	2	6	13	30	420
2008	60	15	1	5	9	19	75
2009	61	19	1	2	8	23	140
2010	60	46	1	3	7	18	670
2011	46	31	1	3	5	17	610
2012	42	12	1	2	5	21	60
2013	42	17	1	2	9	17	180
2014	42	15	1	3	8	23	100
2015	42	20	1	2	7	16	210
2016	63	11	1	3	9	17	52
2017	70	13	1	2	5	15	85

Table 6.11 shows E. coli measurements in Lake Union and the Ship Canal. Measurements of E. coli higher than 100 cfu/100mL are shaded yellow; measurements higher than 320 cfu/100 mL are shaded red. Geometric means of samples have not been calculated, and these values do not indicate a violation of the proposed water quality criteria.

Table 6.11. Lake Union/Ship Canal E. Coli Data (cfu/mL)

Year	**Number of Samples**	**Mean**	**Minimum**	**25th Percentile**	**Median**	**75th Percentile**	**Maximum**
2006	69	46	0	5	12	28	1200
2007	60	43	1	5	12	30	410
2008	60	15	1	5	12	17	72

King County calculated geometric means of fecal coliform in Lake Union/Ship Canal using a 12-month moving window between 2004 and 2013 and compared results to water quality standards. The results from this study are summarized in Table 6.12. Summary of Fecal Coliform Monthly Exceedances in Lake Union/Ship Canal 2004-2013 . No exceedances were observed at the Montlake Cut or Lake Union. Fremont and Dexter occasionally exceeded the peak standard but had no geometric mean standard exceedances. The Locks consistently exceeded standards, only meeting them about half the time.

Table 6.12. Summary of Fecal Coliform Monthly Exceedances in Lake Union/Ship Canal 2004-2013

Location	Total Number of Months Sampled	Exceeded Peak Standard Only	Exceeded Geometric Mean Standard Only	Exceeded Both Standards	Met Standards
Locks	120	44	0	13	63
Fremont	60	16	0	0	44
Dexter	120	10	0	0	110
NE Lake Union	60	0	0	0	60
Montlake	120	0	0	0	120

6.2.2 Aquatic Health

6.2.2.1 Dissolved Oxygen

Lake Union/Ship Canal is considered to be in fair condition with respect to DO. Concentrations in Lake Union are primarily influenced by temperature, primary productivity, turbulence, and biochemical oxygen demand. There has not been sufficient analysis to determine if Lake Union DO meets water quality standards or not.

Lake Union naturally stratifies every summer, with stratification lasting for 4-6 months each year. Deep waters regularly register DO measurements below two mg/L during stratified conditions. The effects of stratification on DO can be strengthened by increased nutrients, salinity, and organic matter (King County 2017a). Therefore, the effects of stratification are exacerbated by anthropogenic inputs, lower flows from Lake Washington during the summer, and saltwater inputs caused by the operation of the locks. DO in Lake Union generally ranges from 8-12 mg/L when measured at or above one m in depth, and from 6-12 mg/L when measured at or below five m in depth.

No significant trends in DO have been observed with the exception of NE Lake Union, where a statistically significant downward trend has been reported (King County 2017c)

6.2.2.2 pH

Based on available data, Lake Union/Ship Canal is considered in good condition for pH. Nearly all pH measurements in Lake Union and the Ship Channel were between seven and 8. Exceedances of a summer standard of 6.5 to 8.5 occurred six times from 2004 to 2013. Values were highest during the spring phytoplankton bloom.

King County reported a statistically significant increasing trend in volume-weighted pH for Dexter, NE Lake Union, and the Montlake Cut.

6.2.2.3 Temperature

Based on available data, Lake Union/Ship Canal is considered in fair condition for temperature. Lake Union is a warm monomictic lake. The Ship Canal does not stratify due to its shallow depth and flow rate. From 2004 through 2013, summer water temperatures occasionally exceeded the thresholds for both fish migration and fish mortality, which were 17 °C and 21.5°C, respectively. Temperature measurements were summarized by King County at three sites, shown in Figure 6-7. Median surface temperatures were below the water quality standard of 16°C, however, the standard was regularly exceeded in summer months.

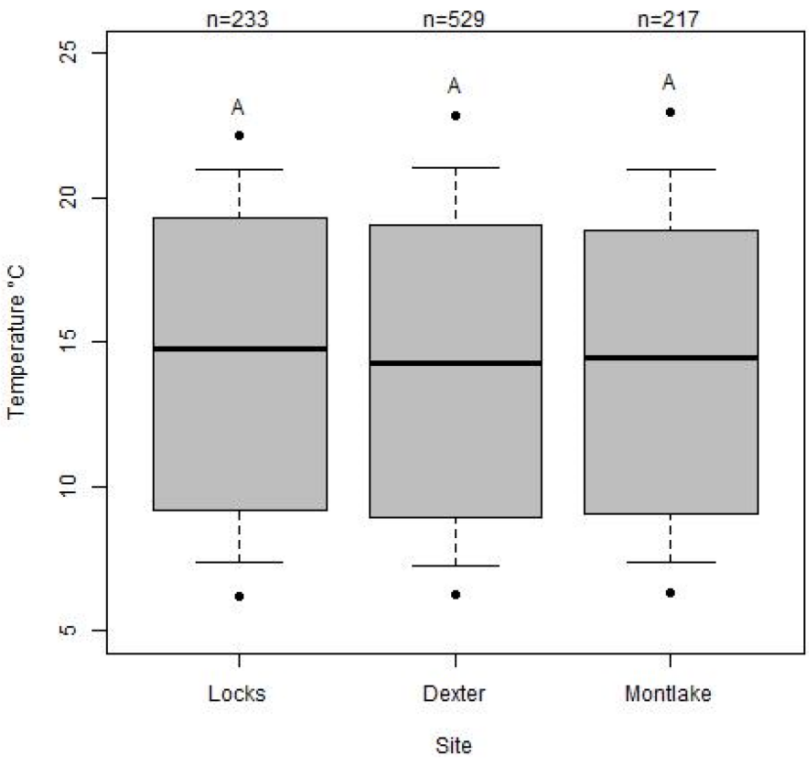


Figure 6-7. Surface temperature in Lake Union/Ship Canal (2009-2013).

Source: (King County 2017c)

Long-term trends indicate steadily increasing temperatures and an increase in the number of days when temperature exceeded the water quality criteria. The hypolimnion of Lake Union grew slightly cooler over that time.

6.2.2.4 Clarity

Based on available data, Lake Union/Ship Canal is considered in fair condition for clarity. Clarity is influenced by phytoplankton biomass, sediment resuspended by ship propellers, particles from stormwater outfalls and CSOs, and surface runoff. Transparency was generally much better than many lakes with a median depth of 3.7 m.

Secchi depth was summarized by King County over the period 2009-2013 and is displayed in Figure 6-8. These depths translate to a TSI-Secchi index that fluctuates between good and fair conditions for lakes.

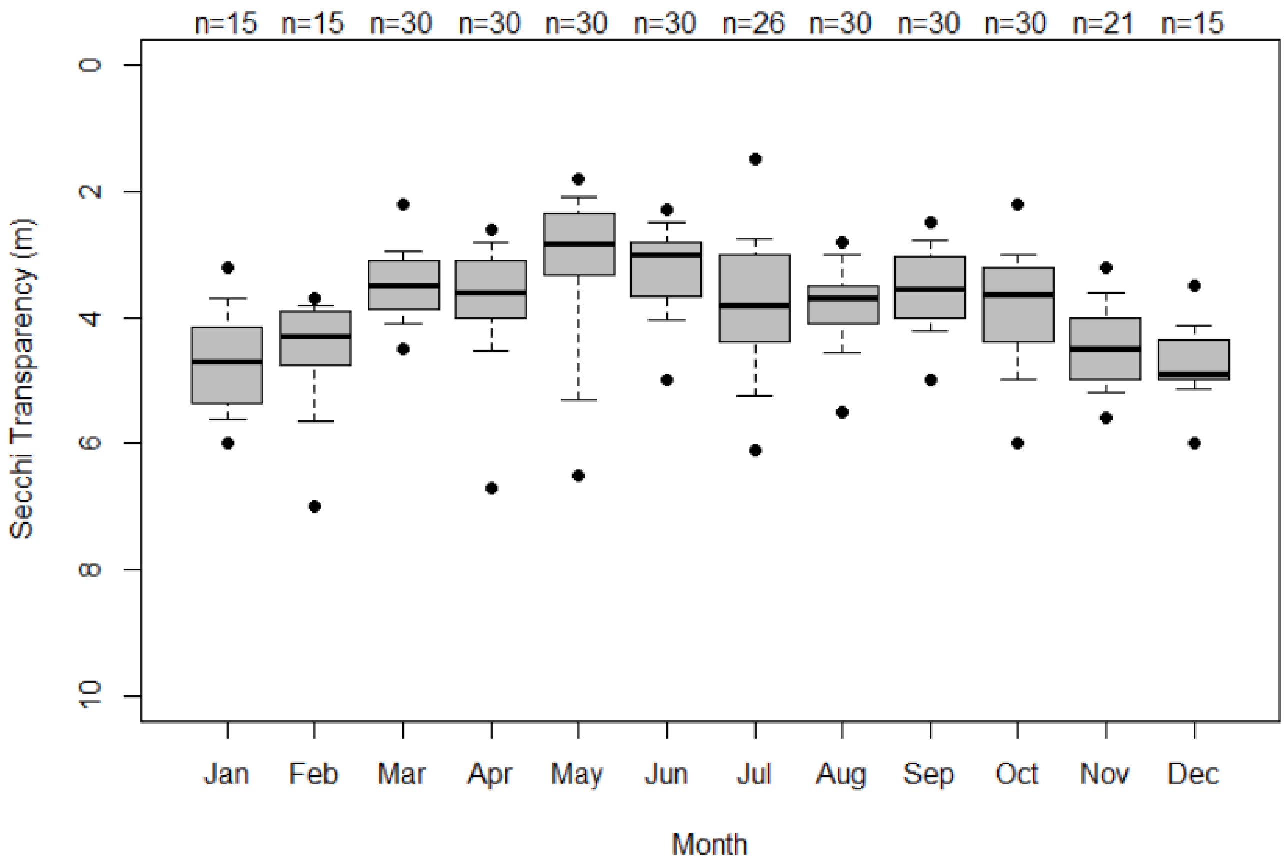


Figure 6-8. Secchi Depth in Lake Union/Ship Canal (2009-2013), all sites.

Source: (King County 2017c)

6.2.2.5 Metals

Lake Union is considered to be in good condition for metals. Metals measurements in Lake Union and the Ship Canal were made quarterly from 2000 through 2008. Arsenic, chromium, copper, lead, mercury, nickel, and zinc were consistently detected, cadmium and selenium were infrequently detected, and silver was never detected. Method detection limits (MDLs) were less than 0.1 ug/l for all metals except for zinc and mercury, whose MDLs were 0.5 µg/L and 0.2 ng/L, respectively. Table 6.13. shows metal concentrations in Lake Union/Ship Canal. Concentrations were higher in the hypolimnion of Lake Union in summertime except for copper, which was higher in the epilimnion. Concentrations were generally higher near the locks.

Table 6.13. Detection frequency and maximum of metals concentrations (µg/L) in Lake Union/Ship Canal

Analyte	FOD	Max. Detect	Highest Site/Depth Mean	Min. MDL	Max. MDL	WA state Aquatic Criteria	
						Acute	Chronic
Arsenic, dissolved	185/185	8.69	1.43	NA	NA	360	190
Cadmium, dissolved	0/187	NA	< MDL	0.01	0.2	1.27c	0.5c
Chromium (III)	—	—	—	—	—	245c	83.9c
Chromium (VI)	—	—	—	—	—	15	10
Chromium, total	167/185	2.8	0.26	0.4	0.4	—	—
Copper, dissolved	176/176	5.69b	2.87	NA	NA	6.74c	4.9c
Lead, dissolved	33/187	0.74	0.0554	0.025	0.2	21.81c	0.85c
Mercury, dissolved	109/137	0.00135	0.000437	0.2	0.2	2.1	
Mercury, total	156/177	0.00503	0.000993	0.0002	0.2	—	0.012
Nickel, dissolved	187/187	2.6	0.609	NA	NA	616c	68.4c
Selenium, dissolved	3/187	1.1	0.616	0.5	25	20	5
Silver, dissolved	0/184	NA	< MDL	0.01	0.5	0.64c	—
Zinc, dissolved	136/141	15	4.32	0.5	0.5	49.8c	45.4c

6.2.2.6 Organics

Based on available data, Lake Union and the Ship Canal are considered in fair condition with respect to organics. Monitoring for organic pollutants in the water column of Lake Union and the Ship Canal has not been systematic, with varying analytes measured at several different sites. Generally, 25% or fewer of analytes were detected. Between 2000 and 2004, the southwest Lake Union site had the highest concentrations of total PAHs with maxima of 2.38 and 5.14 µg/L in the epilimnion and hypolimnion, respectively. All other measured concentrations were <0.2 µg/L. PCBs and PBDEs were not detected between 2000 and 2004, but improved analyses in 2011 and 2012 led to detections at Montlake Cut and Salmon Bay. At these locations, median concentrations were 85 and 201 pg/L, respectively, for total PCBs and 530 and 603 pg/L, respectively, for total PBDEs. Measured concentrations were below state criteria for aquatic life, however, PCB concentrations are considerably higher than EPA fish consumption criteria. Only a few chlorinated herbicides, organophosphate pesticides, endocrine disrupting compounds, PAHs, PCBs, semi-volatile organic compounds, and oils were detected.

6.2.2.7 Nutrients

Based on available data, Lake Union/Ship Canal is considered in good condition for nutrients. For the period 2009 – 2013, median epilimnion total phosphorus (TP) concentrations ranged from 12 µg/L in the Montlake

Cut to 14 µg/L in southwest Lake Union and Salmon Bay. King County monitoring results for this period are summarized in Table 6.14.

Table 6.14. Total phosphorus concentrations (µg/L) in Lake Union/Ship Canal (2009–2013)

Site	Depth	FOD	Min.	Max.	Median	Mean	Min. MDL	Max MDL
Locks–Salmon Bay	Epilimnion	202/202	8	65	14	15	5	5
Dexter–SW Lake Union	Epilimnion	273/273	5	71	14	15	5	5
	Hypolimnion	187/187	6	1350	14	89	5	5
	Volume-weighted	101/101	6	357	15	50	5	5
Montlake Cut	Epilimnion	197/202	< 5	26	12	13	5	5

FOD = frequency of detection; MDL = method detection limit. Source: (King County 2017c)

From 2009 through 2013, nitrate and nitrite concentrations ranged from 0.01 to 0.217 mg/L with elevated values in the hypolimnia during the summer. Overall during the year, however, nitrate and nitrite concentrations reached maxima during the winter and minima during the summer due to uptake by phytoplankton. Nitrogen concentrations decreased during the monitoring period at all five King County monitoring sites.

From 2009 through 2013, ammonia concentrations ranged from 0.002 to 2.09 mg/L with elevated concentrations in anoxic summertime hypolimnia. Aside from these elevated deep-water concentrations, concentrations were lowest in winter and peaked near 0.1 mg/L in late fall.

Total nitrogen (TN) concentrations ranged from 0.161 to 2.01 mg/L, although the maximum can be explained by elevated ammonia in anoxic hypolimnia. In surface water, TN ranged from approximately 0.2 mg/L in the summer to 0.4 mg/L in the winter.

King County analyzed nutrient trends and found that TP concentrations are improving at all monitoring locations. TN concentrations are improving at the Montlake Cut and Salmon Bay. Ammonia concentrations are improving in Salmon Bay, the Montlake Cut, and northwest Lake Union. No locations were found where nutrients concentrations are worsening.

6.2.2.8 Sediment Quality

Based on available data, Lake Union and the Ship Canal are considered to be in poor condition with respect to sediment quality. Sediment in Lake Union and the Ship Canal has been studied by more than 40 sediment sampling programs. Sediment is generally >50% silt and clay and frequently >90% silt and clay. Total organic carbon (TOC) concentrations exceeded 40% at some locations of the Northlake shipyards and near Gas Works Park, although most sediment samples are below 20% TOC. Most measured concentrations exceeded sediment cleanup target concentrations for nickel, TBT, total sulfides, arsenic, PAHs, silver, BEHP, and total PCBs. Lead, cadmium, copper, and several organic chemicals exceeded cleanup standards in at least 5% of samples. PAHs are the most notable contaminant, ranging from 10 to 4,000 times the sediment cleanup objective of 17,000 µg/kg. Sediment near the Northlake shipyard is contaminated with PAHs and metals, and sediment near the Lake Union Steam Plant is contaminated with PCBs.

6.2.3 Fish Consumption

6.2.3.1 Toxics

Based on available data, Lake Union and the Ship Canal are considered to be in fair condition with respect to toxics related to fish consumption. King County monitored metals from 2000-2008, organics from 2000-2004, and PCB/PBDEs from 2011-2012 in surface water. Over those monitoring periods Bis(2-ethylhexyl)phthalate, pentachlorophenol, benzo(b)fluoranthene, and total PCBs (congeners) exceeded Ecology toxic substances human health criteria in at least one sample. PCBs were above the criteria in nearly every sample, except for one sample from the Montlake Cut. Congener analysis from 2011−2012 detected PCBs at levels below the state criteria for aquatic life but above Human Health Criteria. No metals concentrations were reported above Human Health Criteria. Exceedances above the detection limits of organics are shown in Table 6.15..

Table 6.15. Detection frequency and maximum concentrations (µg/L) of toxics in Lake Union/Ship Canal

Analyte	FOD	Max. Detection	Highest Site/ Depth Mean	Min. MDL	Max. MDL	Human Health Criteria for Consumption of Organism Only
Benzo(b)fluoranthene	1/101	0.0471	< MDL	0.0047	0.39	0.031
Total PCBs (pg)	12/12	583	295			170
Bis(2-ethylhexyl)phthalate[a]	23/95	148	15.3	0.0844	3.79	5.9

b. a. Blank contamination present in at least one sample.

6.2.4 Indicators

6.2.4.1 Trophic State Index

Lake Union is in fair condition with respect to the TSI indicator. Trophic state indices (TSIs) of Lake Washington for total phosphorus, chlorophyll a, and Secchi depth are presented in Figure 6-9 for the King County monitoring period of record from 1994 through 2014. The trophic state of Lake Union generally has been mesotrophic (TSI ranging from 40 to 50) with occasional oligotrophic (TSI less than 40) for some parameters. TSIs calculated for 2015 through 2018 from King County's website, which are not presented in Figure 6-9, show mesotrophic status for chlorophyll a, oligotrophic statues for Secchi depth, and either status for total phosphorus. The trophic state of Lake Union appears to have been mesotrophic since 2000.

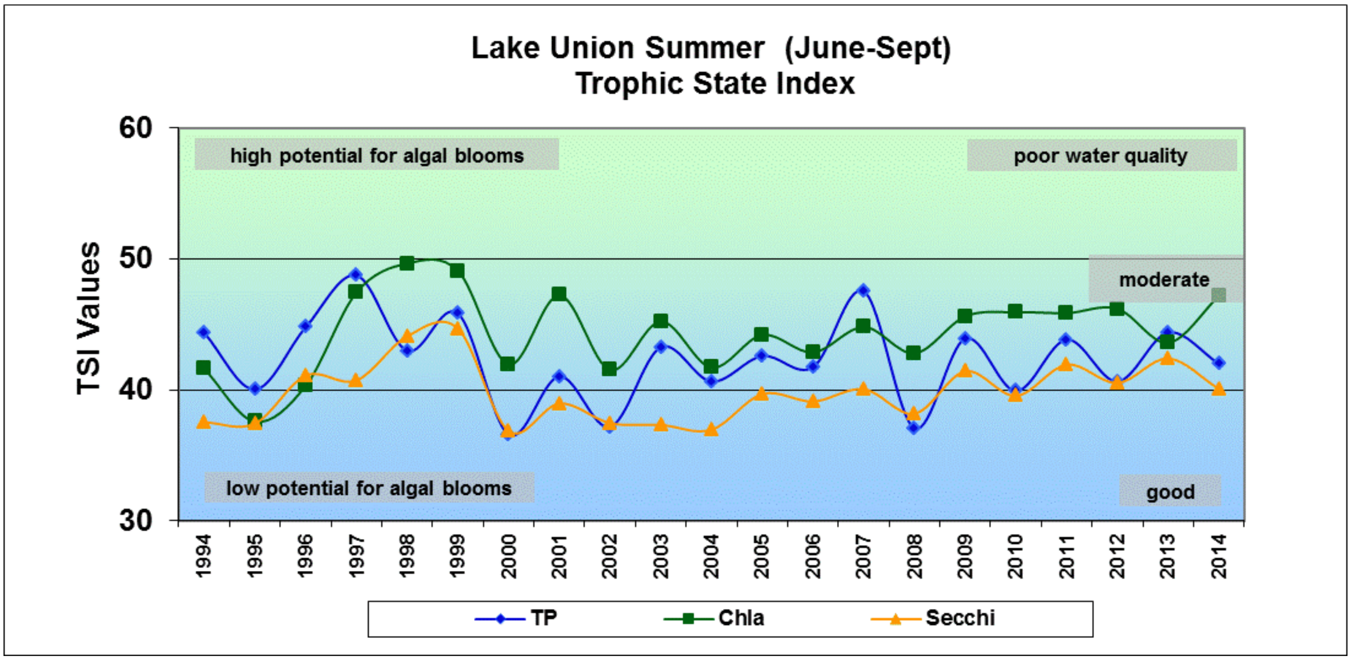


Figure 6-9. Trophic State Indices in Lake Union during Summer Months between 1994 and 2014.

(reference)

6.2.4.2 Toxic Algal Blooms

Based on limited data, Lake Union and the Ship Canal are considered in fair condition with respect to toxic algal blooms. The Washington State Freshwater Algae Bloom Monitoring Program (Ecology 2018e) monitors the cyanobacteria toxins microcystin and anatoxin-a in Lake Union. Data are then compared to recreational guidelines established by the Department of Health. Table 6.16 summarizes microcystin and anatoxin-a results. Over the monitoring period, anatoxin-a was never detected above recreation guidelines. Microcystin was detected twice above recreation guidelines in four samples.

Table 6.16. Toxic Algae monitoring results in Lake Union 2007-2014

Constituent	Samples with no detection	Samples with detections below recreation guidelines	Samples with detections exceeding recreation guidelines
Anatoxin-a	3	0	0
Microcystin	1	1	2

A total of four algae scum samples have been collected from Lake Union and tested for cyanobacteria toxins since conception of the Washington State Toxic Algae Program in 2007 (

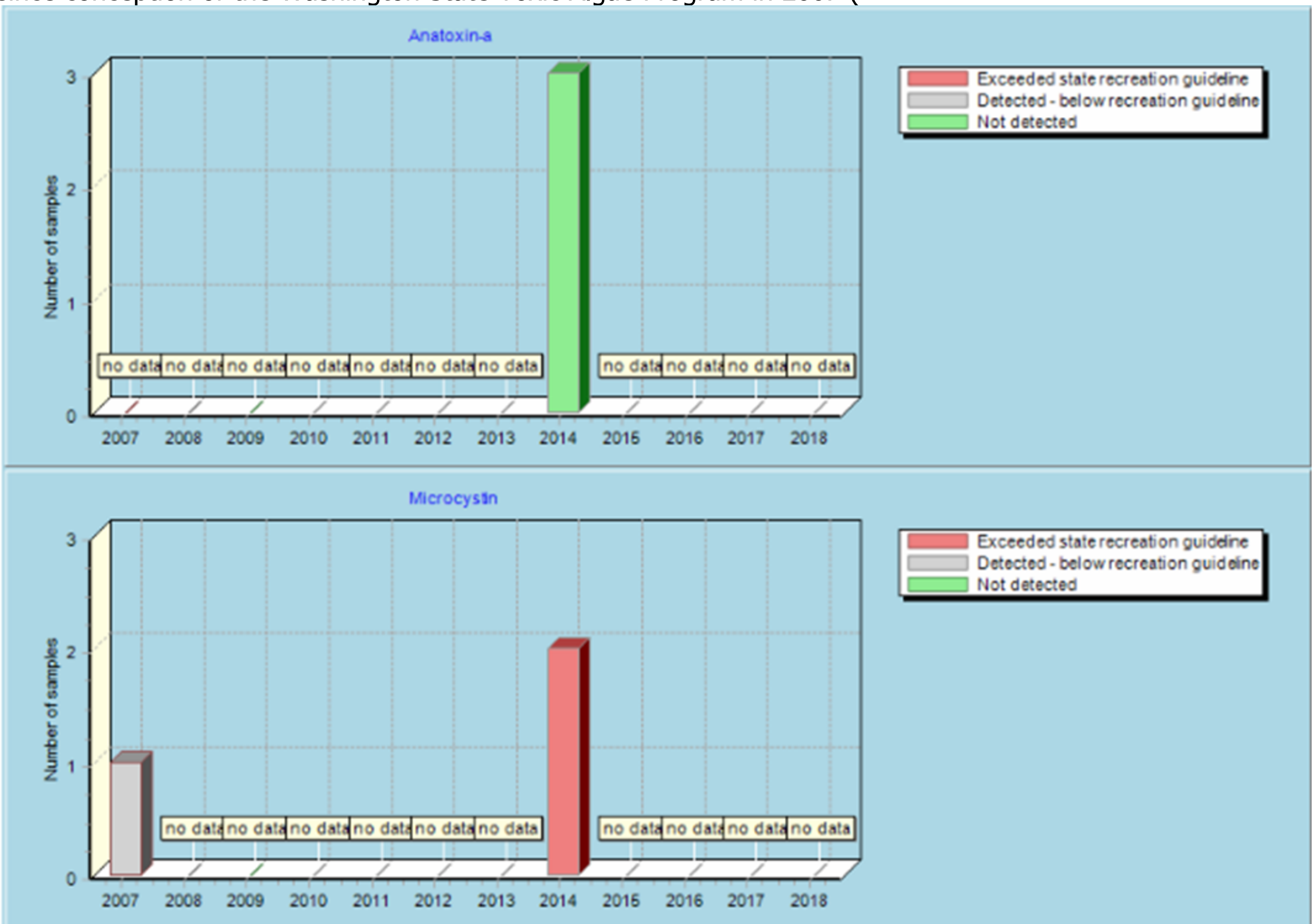


Figure 6-10). Microcystin exceeded the state recreation guideline of six ug/L in one sample collected in December 2014. Anatoxin-a was never detected above the guideline (1 ug/L) in any of the samples tested in those years.

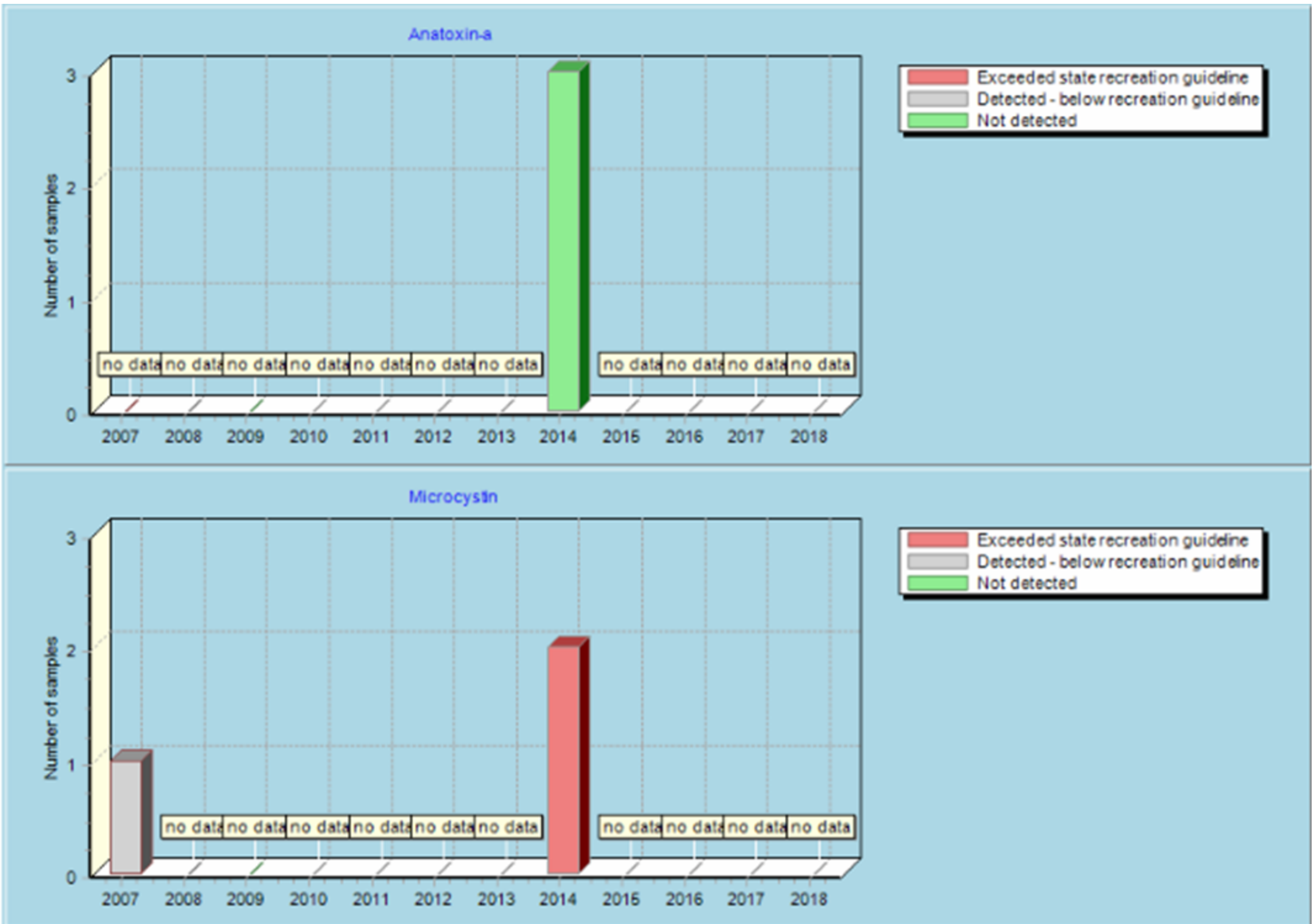


Figure 6-10. Toxic algae bloom test results for Lake Union since 2007.

6.2.4.3 Beach Closures

There are no monitored swimming beaches on the Lake Washington Ship Canal/Lake Union water body. Consequently, there is no information on beach closures.

6.2.5 Regulatory Drivers

Salmon Bay and the section of Ship Canal connecting the Bay to Lake Union are listed as a Category 5 water body for lead, pH, Aldrin, and fecal coliform under EPA's CWA section 303(d). Lake Union and the eastern section of Ship Canal are listed as a Category 5 water body for fecal coliform and temperature. Northern Lake Union sediments adjacent to Gas Works Park are listed as Category 5 under CWA section 303(d) for sediment bioassay (Ecology 2018f).

7. Conditions in the Lower Duwamish Waterway

The Lower Duwamish Waterway originates at the confluence of the Green and Black rivers near Tukwila, Washington, and flows northwest for approximately 12 miles, splitting at the southern end of Harbor Island to form the East and West waterways before discharging into Elliott Bay. The Lower Duwamish Waterway is at the end of the 93-mile long Green-Lower Duwamish Waterway system that drains 483 miles from the Cascade Mountains to Elliott Bay. The lowermost 4.6 miles of the Lower Duwamish Waterway is located within the city of Seattle.

The downstream portion of the Lower Duwamish Waterway is brackish and serves as a major shipping route for bulk and containerized cargo. Most of the shoreline along the Lower Duwamish has been developed for industrial and commercial land uses. A portion of the Lower Duwamish is maintained as a federal navigation channel by the U.S. Army Corps of Engineers (USACE).

This section describes conditions within the portions of the Lower Duwamish Waterway within the City of Seattle (i.e., East Waterway, West Waterway, and Lower Duwamish Waterway). It is based on a 2017 evaluation performed by the King County Department of Natural Resources and Parks (King County 2017d).

King County has performed water quality monitoring in the Lower Duwamish since the 1970s. Table 7.1 summarizes the King County sampling locations within the Seattle city limits.

Table 7.1. Long-term ambient water quality monitoring sites in the Lower Duwamish Water within Seattle				
Site ID	**Description**	**River Mile[a]**	**Depths Sampled**	**Years Sampled**
EW lower	East Waterway – Near South Hanford Street	–	Below 1 m	1996–1997 2008–2013
EW upper	East Waterway – Near South Hanford Street	–	Above 1 m	1996–1997 2008–2013
WW-a lower	West Waterway – Upstream of the Spokane Street Bridge, middle of the channel	–	Below 1 m	2005–2013
WW-a upper	West Waterway – Upstream of the Spokane Street Bridge, middle of the channel	–	Above 1 m	2005–2013
WW-b lower	West Waterway – Upstream of the Spokane Street Bridge, on west side of channel	–	Below 1 m	1970–2004
WW-b upper	West Waterway – Upstream of the Spokane Street Bridge, on west side of channel	–	Above 1 m	1970–2004
LDW-0.1	Lower Duwamish Waterway – At the south end of Harbor Island	0.1	Above 1 m	2003–2004
LDW-3.0	Lower Duwamish Waterway – Duwamish Waterway Park	3	Above 1 m	2007–2010
LDW-3.3 lower	Lower Duwamish Waterway – 16th Ave. S Bridge	3.3	Below 1 m	1970–2013
LDW-3.3 upper	Lower Duwamish Waterway – 16th Ave. S Bridge	3.3	Above 1 m	1970–2013

c. *a. River miles conform to the convention used in the Remedial Investigation/Feasibility Study for the Lower Duwamish Waterway Superfund site. The starting point of River mile 0 is at the southern tip of Harbor Island (Windward Consulting 2010)*

7.1.1 Recreation (fecal bacteria)

Based on available data, the Lower Duwamish Waterway is considered in poor condition for fecal bacteria. The Lower Duwamish Waterway is considered a continuation of Elliott Bay for the purposes of applying marine criteria (US EPA 2014).

King County performs monthly fecal coliform sampling at three sites (EW, WW-a, and LDW-3.3) in the Lower Duwamish Waterway within Seattle through the Routine Marine Ambient Monitoring Program (King County 2018c). Table 7.2 shows maximum monthly detections of fecal coliform in the Lower Duwamish Waterway.

Table 7.2. Fecal coliform bacteria concentrations (CFU/100 mL) in the Lower Duwamish Waterway (2004–2013)

Site	Years Evaluated	FOD[a]	Mean	Standard Deviation	Median	Geometric Mean	Min.	Max.
EW lower	2008–2013	67/71	2.4	5.1	1	0.6	0	26
EW upper	2008–2013	49/71	6.5	12.5	3	2.5	0	88
WW-a lower	2005–2013	99/108	4.8	6.6	3	2.3	0	38
WW-a upper	2005–2013	107/108	36.3	75.6	16	16	0	660
WW-b lower	2004	11/12	31.3	94.2	3	3.6	0	330
WW-b upper	2004	12/12	67.8	119.0	33	36	6	440
LDW-3.0	2007–2010	48/48	134.7	246.9	54	55	1	1,400
LDW-3.3 lower	2004–2013	118/120	19.6	44.2	9	8.9	0	450
LDW-3.3 upper	2004–2013	119/120	64.5	113.8	28.5	27	0	830

a. FOD = Frequency of Detection

King County calculated geometric means of fecal coliform in the Lower Duwamish Waterway using a 12-month moving window between 2004 and 2013 and compared results to water quality standards. The results from this study are summarized in Table 7.3. The West Waterway and the LDW sampling sites frequently did not meet water quality standards.

Table 7.3. Summary of Fecal Coliform Monthly Exceedances in the Lower Duwamish Waterway 2004-2013

Location	Total Number of Months Sampled	Exceeded Peak Standard Only	Exceeded Geometric Mean Standard Only	Exceeded Both Standards	Met Standards
EW	60	0	0	0	60
WW-a	97	13	9	58	17
LDW-3.0	37	0	0	37	0
LDW-3.3	120	0	17	103	0

The WW-b upper and LDW-3.3 upper sites showed a decreasing trend in fecal coliform from 1970-2013 (King County 2017d).

7.1.2 Aquatic Health

7.1.2.1 Dissolved Oxygen

Water quality in the Lower Duwamish Waterway is fair with respect to DO.

DO concentrations in the Lower Duwamish Waterway are primarily influenced by temperature, primary productivity, turbulence, and biochemical oxygen demand (King County 2017e).

King County regularly monitors DO at multiple sites in the LDW and the Lower Duwamish Estuary. Monthly DO concentrations at the four sites within the City of Seattle are shown in Figure 7-1 summarizes DO measurements over the year for the period 2009-2013.

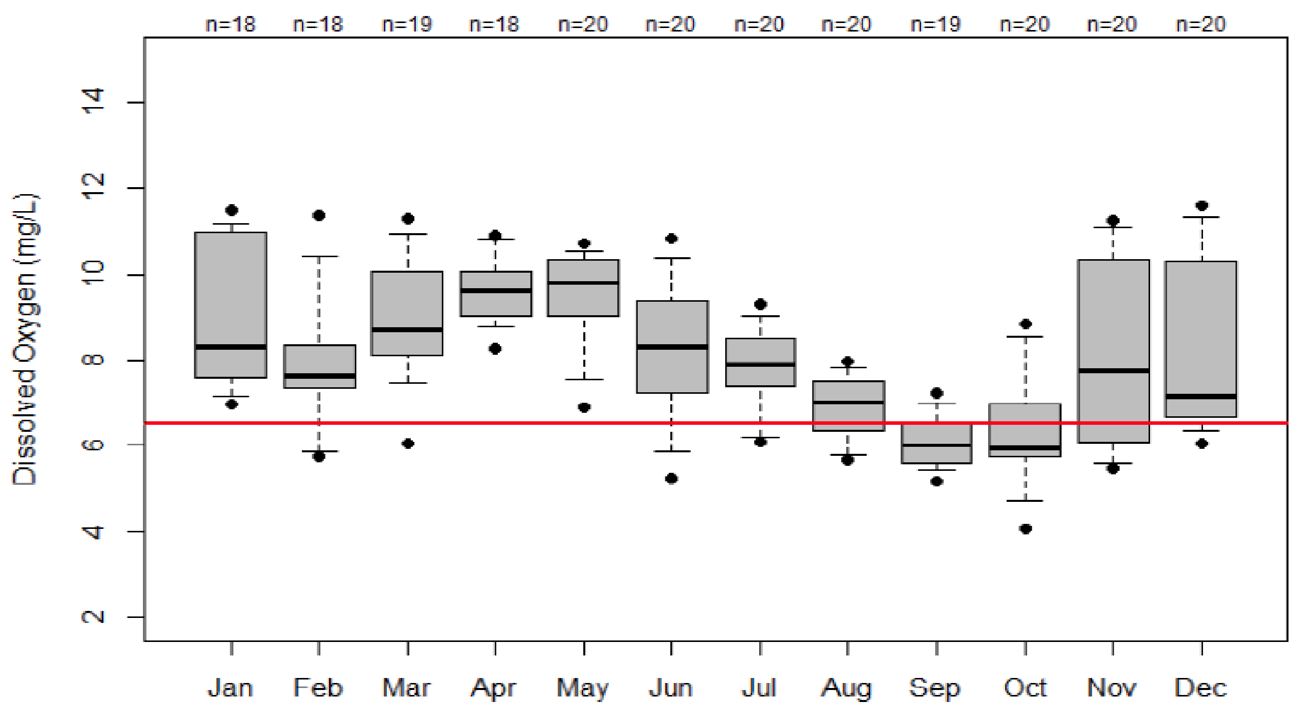


Figure 7-1. Between 2009 and 2013, median DO concentrations generally met the water quality criteria of 6.5 mg/L except during the late summer/early fall. During those months, DO concentrations were approximately 6.0 mg/L with a range between 4 and 9 mg/L. Generally, DO does not meet water quality standards during late summer and fall, when water temperature rises and upwelling of deep water from the Pacific Ocean drives low-DO water into the shallow water column. During the rest of year, DO usually meets water quality criteria, although concentrations occasionally dip below standards (King County 2017e).

Available data for DO in the Lower Duwamish Waterway are summarized in Table 7.4. Values below the water quality criteria are shaded red.

Table 7.4. Dissolved Oxygen Measurements in the Lower Duwamish Waterway, 2009-2013 (mg/L)						
Site	**Depth**	**Number of Samples**	**Mean**	**Median**	**Minimum**	**Maximum**
EW	Upper	60	7.66	7.60	5.3	10.8
	Lower	60	7.31	7.55	5.3	9.3
WW-a	Upper	60	7.89	7.85	4.9	11.1
	Lower	60	7.53	7.70	5.3	10.0
LDW-3.3	Upper	58	7.22	6.70	3.6	11.6
	Lower	58	6.56	6.75	4.7	9.9

Figure 7-1 summarizes DO measurements over the year for the period 2009-2013.

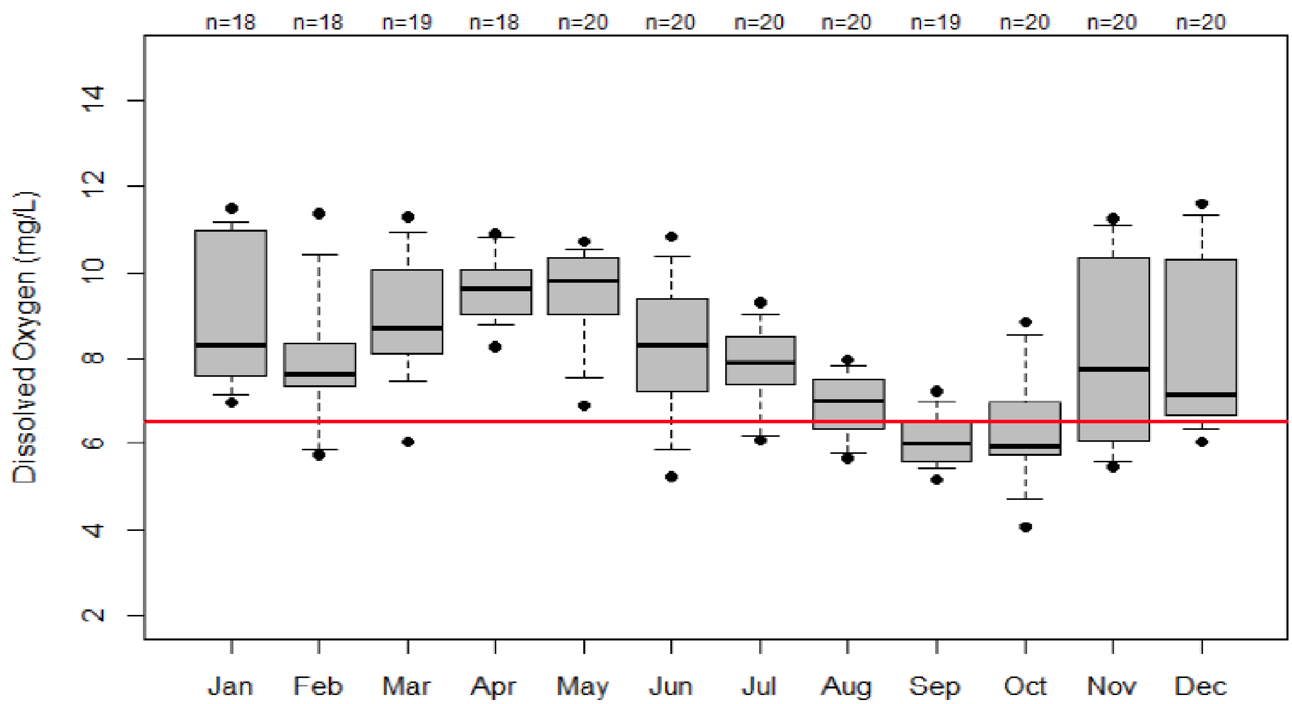


Figure 7-1. Ranges of monthly dissolved oxygen concentrations at sites EW, WW-a, LDW-3.3, and LDW-4.8 in the Lower Duwamish Waterway (2009–2013).

Notes: The red line shows Ecology's minimum daily criterion. Includes one site (LDW-4.8) outside of Seattle.

King County analyzed historic DO concentrations in the Lower Duwamish and found a slightly increasing trend since 1975 for certain locations. This improvement may be due to the diversion of wastewater and other source controls in the watershed (SPU 2010).

7.1.2.2 pH

The Lower Duwamish Waterway is considered to be in good condition with respect to pH.

pH was sampled monthly from 2009 through 2013. No criterion exceedances have occurred in the Lower Duwamish Estuary (Figure 7-2).

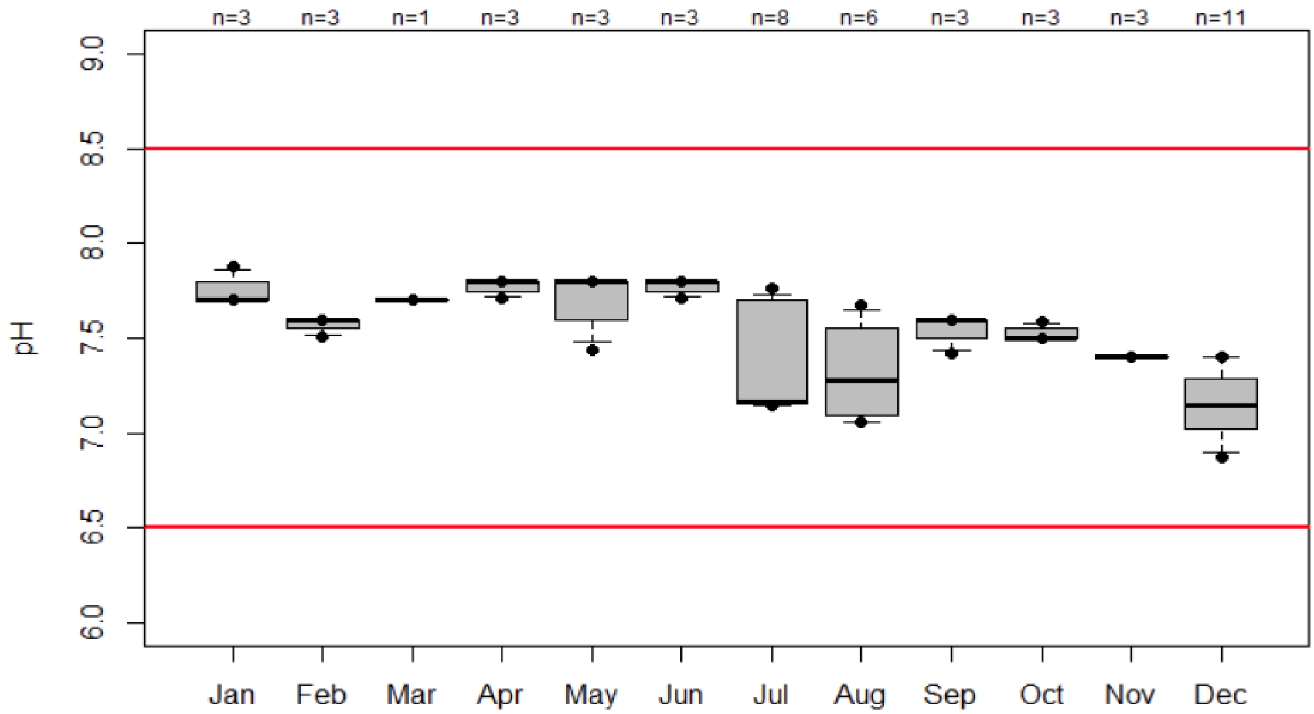


Figure 7-2. Ranges of monthly pH in the Lower Duwamish Estuary (2011-2012). Ecology's criterion range is shown between the red lines.

(King County 2017d)

In general, long-term trends show an increase in pH in the LDW and a few more upstream sites. The remaining sites show no significant trend (King County 2017d).

7.1.2.3 Temperature

Temperature in the Lower Duwamish-Green area is considered to be in fair condition. Available temperature data for the Lower Duwamish Waterway are summarized in Table 7.5. Values above the 7-DADMax criteria are shaded red.

Table 7.5. Water temperatures (°C) in the Lower Duwamish Waterway (2009–2013)						
Site	**Depth**	**Number of Samples**	**Mean**	**Median**	**Minimum**	**Maximum**
EW	Upper	60	10.51	10.43	7.48	14.74
	Lower	60	10.18	10.13	7.52	12.72
WW-a	Upper	60	10.44	10.17	5.78	15.63
	Lower	60	10.30	10.25	7.46	12.9
LDW-3.0[a]	Upper	23	11.44	11.4	3.8	20.4
LDW-3.3	Upper	60	10.32	10.45	4.44	16.76
	Lower	60	10.42	10.26	6.73	16.58

a. Sampled in 2009 and 2010 only.

Temperatures tend to peak in August and are at their lowest in December and January (Figure 7-3). In summer, surface temperatures are slightly higher than lower depth temperatures, while the trend is opposite in late fall and winter. Temperature patterns are also influenced by tides and deeper water circulation in the Lower Duwamish Waterway. Because the available data are monthly samples, direct comparison to criteria is not possible.

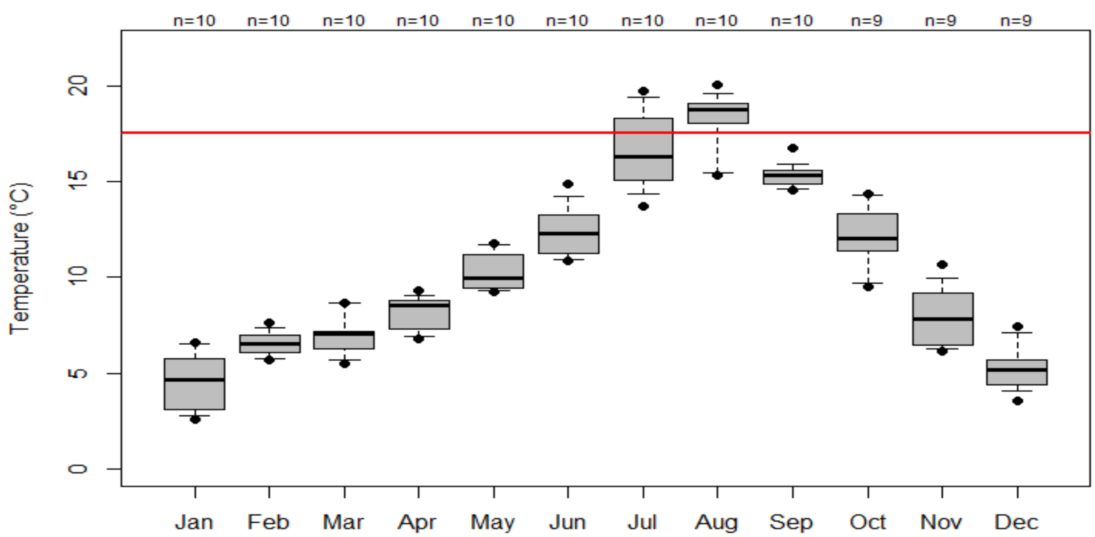


Figure 7-3. Range of monthly surface water (0–1 m) temperatures at sites EW, WW-a, LDW-3.3, and LDW-4.8 in the Lower Duwamish Waterway (2009–2013).

Notes: The red line shows Ecology's 7-DADMax criterion. Includes one site (LDW-4.8) outside of Seattle.

Long-term trends analyzed from 1998 through 2013 at the LDW monitoring stations show a significant reduction in temperature of approximately 0.01°C per year in the lower depths of the Lower Duwamish Waterway site (King County 2017d).

7.1.2.4 Turbidity

No data are available to assess the conditions in the Lower Duwamish Waterway with respect to turbidity. King County monitored four sites on the Green River from 2009-2013, but no recent data are available for the Lower Duwamish Waterway.

7.1.2.5 Metals

Based on available data, the Lower Duwamish Waterway is considered to be in good condition with regard to metals.

Metals data in this area are limited and span a variety of flow regimes and detection limits. Data are available for 14 sites between 2000 and 2013 and include data on around 25 different metals. Only one sample within the City of Seattle exceeded Marine Aquatic Life Criteria. A total mercury concentration of 0.0835 ug/L was reported compared to the chronic criterion of 0.025 ug/L.

7.1.2.6 Organics

Based on available data, the Lower Duwamish Waterway is in fair condition with respect to organics. King County has sampled 135 organic compounds at varying frequencies from 2001-2012. Over this period, no chlorinated pesticides, organophosphorus pesticides, or PCB Aroclors were detected although PCBs were consistently detected by congener analysis. One chlorinated herbicide was detected, and PAHs were commonly detected. No samples exceeded established aquatic life criteria.

7.1.2.7 Nutrients

The condition of the Lower Duwamish Waterway has not been evaluated with respect to nutrients; no marine nutrient water quality criteria or guidelines have been established that are applicable to the Lower Duwamish Waterway. King County routinely monitors nitrate and nitrite, ammonia, TN, and Phosphorus. Data indicate a decreasing long-term trend for nutrients (King County 2017d).

7.1.2.8 Sediment Quality

Sediment quality in the Lower Duwamish Waterway is considered poor. This Lower Duwamish Waterway is on the EPA Superfund National Priorities List due to pollutants found in the sediments in the waterway. The Chemicals of Concern in sediments for the Superfund site are arsenic, lead, zinc, total PCBs, carcinogenic polyaromatic hydrocarbons (cPAHs), dioxins and furans. The contaminated sediments pose human health risks due to contact with sediments or consumption of resident fish and shellfish. The Lower Duwamish Waterway Remedial Investigation report is the primary source for detailed information on sediment quality (Windward, 2010).

Total high and low molecular weight PAHs, sixteen individual PAHs, four phthalates, and four chlorobenzenes have exceeded CSLs in the Lower Duwamish Waterway and East Waterways. PCB CSLs were exceeded in all but four sections of the Lower Duwamish Waterway (totaling only 0.5 river miles without PCB CSL exceedances) (King County 2017d). Sediment toxicity analysis has been performed for 48 locations in the East Waterway and compared to the SMS.

Table 7.6. Sediment toxicity test results in the Lower Duwamish Waterway			
Location	**Percent of samples not exceeding SQS biological effects criteria**	**Percent of samples exceeding SQS biological effects criteria, but not CSL biological effects criteria**	**Percent of samples exceeding CSL biological effects criteria**
Lower Duwamish Waterway	37.5	22.9	39.6
East Waterway	40	39.6	21

Table 7.6 shows that eighteen of the 48 Lower Duwamish Waterway sediment samples (37.5 percent) did not exceed the SQS biological effects criteria, 11 sediment samples (22.9 percent) exceeded the SQS biological effects criteria but not the CSL biological effects criteria, and 19 samples (39.6 percent) exceeded the CSL biological effects criteria (Windward 2010).

7.1.3 Fish Consumption

7.1.3.1 Toxics

The Lower Duwamish Waterway is in poor condition with respect to toxic compounds related to fish consumption. The Lower Duwamish Waterway up to RM 5 is under a "Do not eat" consumption advisory for residential fish, crab, and shellfish.

Data collected for metals with human health criteria are shown in Table 7.7. No metals have been detected above the human health criteria for consumption of organisms only.

Table 7.7. Toxic Metals data for the Lower Duwamish Waterway						
Analyte	**FOD**	**Maximum Detect**	**Highest Site/Depth Mean**	**Minimum MDL**	**Maximum MDL**	**EPA Human Health Criteria (Consumption of Organism Only)**
Antimony, dissolved	53/187	0.153	0.117	0.005	0.5	4,300
Mercury, dissolved	49/195	0.0058	0.00069	0.00015	0.2	0.15
Nickel, dissolved	116/230	7.79	0.425	0.03	0.34	4,600

d.

Total PCB's and Bis(2-ethylhexyl)phthalate have been detected above the Human Health Criteria as shown in Table 7.8. Values above human health criteria for consumption of organisms only are shaded red.

Table 7.8. Organic compounds detected above human health criteria in the Lower Duwamish Waterway.

Analyte	FOD	Maximum Detect	Highest Site/Depth Mean	Minimum MDL	Maximum MDL	Human Health Criteria for Consumption of Organisms Only
Total PCBs (pg/L)	72/72	5,838	2,780	-	-	170
Bis(2-ethylhexyl)phthalate	9/61	12.7	15.3	0.0844	3.79	5.9

7.1.4 Indicators

For the Lower Duwamish Waterway, there are no data for the WQI, B-IBI, and PSM indicators. There is only information on shellfish bed closures.

7.1.4.1 Shellfish Bed Closures

The Lower Duwamish is rated poor with respect to shellfish bed closures. The Lower Duwamish Waterway has been under a Washington State Department of Health Fish Consumption Advisory for fish, crab, and shellfish since 2002 due to exposure to PCBs and other contaminants. A shellfish consumption advisory recommending no consumption due to fecal contamination is also in place (Washington State Department of Health 2018a).

7.1.5 Regulatory Drivers

Several segments of the Lower Duwamish waterway are 303(d) listed for fecal bacteria, DO, and ammonia. The waterway is also listed as Category 5 (impaired) due to elevated concentrations of several inorganic and organic contaminants in sediment and fish tissue (Ecology 2018f).

The Lower Duwamish Waterway is listed as a Superfund Site under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (EPA, 2013a) and as a Model Toxics Control Act (MTCA) site (Ecology, 2013b). The CERCLA and MTCA listings are for bottom sediments that contain elevated concentrations of PCBs carcinogenic PAHs (cPAHs), arsenic (As), dioxins, and furans.

In 2014, EPA published a final cleanup plan for the Lower Duwamish Waterway, also referred to as the Record of Decision (ROD) (US EPA 2014). The ROD identifies areas for cleanup and actions for controlling sources of contamination to the waterway. The West Waterway is under a “No Action” ROD for sediments and that East Waterway is expected to have a cleanup ROD in 2020.

Table 7.9. 303(d) listings in the Lower Duwamish Waterway

Medium	Listed Contaminants	
	Category 5	Category 4 (a,b,c)
Water	• Fecal coliform • DO	• Ammonia-N
Fish Tissue	• PCBs • Benzo[a]pyrene • Benzo[a]anthracene • Benzo[b]fluoranthene • Bis(2-ethylehexyl)phthalate • Benzo[k]fluoroanthene • Chrysene • Dibenzo[a,h]anthracene • Indeno(1,2,3-cd)pyrene • Dieldrin • 2,3,7,8-TCDD • Arsenic (inorganic)	•
Sediment	• Sediment Bioassay • Anthracene • Arsenic • Benzo(a)pyrene • Bis(2-ethylhexyl)phthalate • Cadmium • Chromium • Chrysene • Copper • Dibenzo(a,h)anthracene • Fluoranthene • Indeno(1,23-cd)pyrene • Lead • Mercury • HPAHs • PCBs • Phenol • Pyrene • Silver • Zinc • LPAHs • 4-Methylphenol • Benzo(g,h,i)perylene • Total benzofluoranthenes (b+k+j) • Benzoic acid • Butyl benzyl phthalate • Di-n-octyl phthalate • Phenanthrene	• 1,2- Dichlorobenzene • 1,2,4-Trichlorobenzene • 1,4-Dichlorobenzene • 2,4-Dimethylphenol • Dibenzo(a,h)anthracene • 2-Methylnaphthalene • 2-Methylphenol • Di-n-octyl phthalate • 4-Methylphenol • Pentachlorophenol • Hexachlorobenzene • Hexachlorobutadiene • Acenaphthene • Acenaphthylene • Anthracene • Arsenic • Bis(2-ethylhexyl)phthalate • Benzo(a)anthracene • Benzo(g,h,i)perylene • Butyl benzyl phthalate • Cadmium • Chromium • Chrysene • Copper • Diethyl phthalate • Dibenzofuran • Di-n-butyl phthalate • Dimethyl phthalate • Fluoranthene • Fluorene • HPAHs • Indeno(1,2,3-c,d)pyrene • Lead • LPAHs • Mercury • Naphthalene • N-Nitrosodiphenylamine • PCBs • Phenanthrene • Phenol • Pyrene • Silver • Total Benzofluoranthenes (b+k+j) • Zinc • Sediment Bioassay

8. Conditions in Elliott Bay

Elliott Bay is a deep, partially enclosed embayment, surrounded by urbanized areas of Seattle on the north, east, and south and open to Puget Sound on the west. The eastern shoreline borders the downtown neighborhoods and has been heavily modified from historical development. The southern portion of Elliott Bay is heavily altered through man-made port facilities, including Harbor Island. Elliott Bay is influenced by Green River freshwater flows through the heart of Seattle's industrial area and port facilities, where the Green River becomes the Lower Duwamish Waterway.

For this assessment, Elliott Bay is defined as the portion of Puget Sound east of Fourmile Rock and Alki Point. King County conducted a comprehensive review of receiving water conditions (King County 2017b). This summary draws primarily from that assessment. King County further divided Elliott Bay into Outer Elliott Bay (Elliott Bay west of Duwamish Head and Smith Cove) and Inner Elliott Bay (east of Duwamish Head and Smith Cove). These two areas are grouped together for the purposes of this assessment.

Monthly ambient monitoring is conducted at five locations in Elliott Bay, as summarized in Table 8.1. Additional monitoring is conducted near wastewater treatment plant outfalls, however, those data are not included in this assessment.

Table 8.1. Water quality monitoring sites in Elliott Bay

Locator	Name	Monitoring Agency	Type	Greatest Depth Sampled (m)	Years Sampled
LSGY01	Seacrest Park	King County	Beach	N/A	1997–present
LTEH02	Seattle Waterfront	King County	Beach	N/A	1981–2010
ELB015	SW Elliott Bay	Ecology	Offshore	30	1991–present
LTED04	Central Elliott Bay	King County	Offshore	75	1997–present
SEAQYSI[a]	Seattle Aquarium	King County	Offshore	10	2007–present

a. Mooring station that collects data at 15-minute intervals.

8.1 Recreation (fecal bacteria)

Based on available data, fecal bacteria conditions in Elliott Bay are considered fair. King County performs monthly fecal coliform sampling at four sites (Seacrest Park, Seattle Waterfront, SW Elliott Bay, and Central Elliott Bay). The highest concentrations are seen at the Seattle Waterfront Site, which is near the City of Seattle CSO, several stormwater outfalls, and the mouth of the Lower Duwamish Waterway . All offshore sites met the geometric mean criteria, and all but the Central Elliott Bay site met the 10% criteria.

Bacteria concentrations in Elliott Bay are generally highest during months of high rainfall. Stormwater and CSO discharges are likely sources of fecal coliform.

King County calculated geometric means of fecal coliform in Elliott Bay using a 12-month moving window between 2004 and 2013 and compared results to water quality standards. The results from this study are summarized in Table 8.2, which shows Seacrest Park and the Seattle Waterfront frequently did not meet standards.

Table 8.2. Summary of Fecal Coliform Monthly Exceedances in Elliott Bay 2004-2018

Location	Total Number of Months Sampled	Exceeded Peak Standard Only	Exceeded Geometric Mean Standard Only	Exceeded Both Standards	Met Standards
Seacrest Park	119	24	0	0	95
Seattle Waterfront	85	16	1	56	12
SW Elliott Bay	85	0	0	0	85
Central Elliott Bay	120	12	0	0	108

Ecology monitors swimming beaches in Elliott Bay under the Beach Environmental Assessment, Communication & Health (BEACH) Program. Enterococci levels are measured from Memorial Day through Labor Day each year. Ecology reports geometric means of enterococci measurements as shown in Table 8.3. For all years where data are available, Elliott Bay beaches met saltwater swimming criteria (geometric mean of 35 cfu/100mL based on a minimum of five weekly samples).

Table 8.3. Summary of enterococci monitoring data in Elliott Bay 2004-2018

Location	Years Sampled	Minimum Geometric Mean Reported (cfu/100mL)	Maximum Geometric Mean Reported (cfu/100mL)
Alki Beach Park	2004-2018	<10	21.2
Alki Point Light Station	2004-2006	<10	11.5
Myrtle Edwards Park	2007	<10	<10
Seacrest Park	2004-2011	<10	17

Of the fecal coliform locations with sufficient data to evaluate long-term trends, Seattle Waterfront and Central Elliott Bay show a significant decreasing trend, while SW Elliott Bay shows a significant increasing trend. Seacrest Park shows no significant trend. (King County 2017b).

8.1.1 Aquatic Health

8.1.1.1 Dissolved Oxygen

Based on available data, Elliott Bay is considered in fair condition for DO. DO routinely fails to meet water quality criteria from June through December, however, this is primarily due to the upwelling of deep waters during this time period. Surface samples taken at one m depth typically range from 6-9 mg/L, with the highest DO measured near the surface at times of high phytoplankton concentrations (May and late summer/early fall) (King County 2017b). DO concentrations tend to decrease as depth increases.

Inner Elliott Bay and Outer Elliott Bay are subject to differing water quality criteria. Inner Elliott Bay is classified as an "excellent" marine water body with a minimum DO criterion of 6.0 mg/L, while Outer Elliott Bay is classified as an extraordinary water with a minimum DO criterion of 7.0 mg/L. Over the period from 2004-2013, King County reported 43 monthly samples below DO criteria and 72 samples above criteria (Table 8.4).

Table 8.4. Elliott Bay dissolved oxygen and water quality criteria results (2004–2013)

Site	Number of Samples	Number above criterion	Number below criterion
Central Elliott Bay	115	43	72

Note: The lowest DO concentration measured at discrete sampling depths was compared to WQC.

Long-term trends indicate no significant change in DO concentrations in Elliott Bay at any depth (King County Department of Natural Resources and Parks, 2017b).

8.1.1.2 pH

Based on limited data, Elliott Bay is considered to be in good condition with respect to pH.

Limited data are available from a King County sampling event in 2011, and these data show no exceedances of water quality criteria. pH measured during this event ranged from 7.4-8.0 (King County 2017b).

8.1.1.3 Temperature

Based on available data, temperature conditions in Elliott Bay are considered fair. Similar to DO, Inner Elliott Bay and Outer Elliott Bay are subject to differing water quality criteria. Inner Elliott Bay is regulated as excellent waters with a one-day maximum temperature of 16°C; Outer Elliott Bay is regulated as extraordinary waters with a one-day maximum temperature of 13°C. Over the period from 2004-2013, King County reported only one monthly sample above temperature criteria (Table 8.5), however continuous sampling at the Seattle Aquarium recorded 15 water quality criteria exceedances since 2008.

Table 8.5. Elliott Bay temperature and water quality criteria results (2004–2013)

Location	Total Number of Months Sampled	Above Criteria	Met Criteria
Seacrest Park	116	0	116
Seattle Waterfront	81	1	80
SW Elliott Bay	92	0	92
Central Elliott Bay	119	0	119

Long-term trend analysis shows a significant increase at the Seattle Waterfront and significant decreases in temperature at all depths for both the South Plant Outfall and Central Elliott Bay. All other sites showed no significant trend (King County 2017b).

8.1.1.4 Turbidity

No determination has been made on the condition of Elliott Bay with respect to turbidity. Studies by King County and NOAA indicate that suspended particulate matter in Elliott Bay is most variable near the bottom as the result of tidal activity and that the surface is more influenced by freshwater discharges. Both observations are driven by natural processes, making it difficult to define background turbidity and determine how to apply WQC.

8.1.1.5 Metals

Based on limited data, Elliott Bay is considered in good condition for metals. King County collected four samples at three depths (5, 50, and 75 m) from the Central Elliott Bay site in July and December of 2011 and 2012. Arsenic, cadmium, chromium, copper, and nickel were detected in all samples. Silver, lead, mercury, and zinc were detected in most samples.

Most of King County's metals sampling has been conducted around outfall locations. Beach water samples were collected just below the surface at West Point South and the Magnolia Outfall in August 1999, 2001, and 2002. King County compared sampling results to aquatic life criteria for all sampled sites together (West Point South, Magnolia Outfall, and South Plant Outfall sites). These results are shown in Table 8.6. All samples were below aquatic life criteria.

Table 8.6. Comparison of maximum detected concentrations of metals (µg/L) in Elliott Bay and adjacent Puget Sound (West Point South, Magnolia Outfall, Central Elliott Bay, and South Plant Outfall sites) to marine Water Quality Criteria

Analyte	FOD	Max Detect	WA State Aquatic Life Criteria	
			Acute	Chronic
Arsenic, Dissolved	59/59	1.39	69	36
Cadmium, Dissolved	59/59	0.0763	42	9.3
Copper, Dissolved	59/59	1.23	4.8	3.1
Lead, Dissolved[a]	19/59	0.0276	210	8.1
Mercury, Dissolved	37/51	0.000616	1.8	-
Nickel, Dissolved[a]	56/59	0.545	74	8.2
Selenium, Dissolved	0/47	NA	290	71
Silver, Dissolved	6/59	0.028	1.9	-
Zinc, Dissolved[a]	31/59	2.81	90	81

Offshore samples were collected from Central Elliott Bay in 2011-2012. Arsenic, cadmium, chromium, copper, nickel, thallium, antimony, lead, mercury, and zinc were frequently detected in these samples. At the beach sites, samples were taken in 1999, 2001, and 2002. Antimony, arsenic, cadmium, chromium, copper, lead, nickel, thallium, and zinc were detected in these samples (King County 2017b).

8.1.1.6 Organics

Elliott Bay is considered in fair condition for organics.

Data on organic compounds in Elliott Bay is limited. Since 1999, only 55 samples have been collected in Elliott Bay or adjacent Puget Sound. Samples are available from the South Plant Outfall for 1999-2000, Central Elliott Bay and the Seattle Waterfront for 2003-2004, and for Central Elliott Bay for 2004. None of the tested chlorinated pesticides, herbicides, organophosphorus pesticides, or seven PCB congeners were detected. Five low molecular weight PAHs, seven high molecular weight PAHs, two endocrine-disrupting compounds, several PCB congeners, and all tested phthalates were detected. No PCB samples exceeded the water quality criteria. However, one sample exceeded each of the benzo(a)anthracene, benzo(b)fluoranthene, and benzo(k)fluoranthene criteria at the Seattle Waterfront site, and bis(2-ethylhexyl)phthalate in several samples exceeded the Human Health Criteria (King County 2017b).

8.1.1.7 Nutrients

Elliott Bay is considered in fair condition for nutrients. Although no nutrient-specific water quality criteria apply to Elliott Bay, Ecology has developed the Marine Water Condition Index (MWCI) to measure changes in water quality that are relevant to eutrophication. MWCI uses variables that describe temperature, salinity, nutrient balance, algae biomass, and dissolved oxygen in surface water 0-50 m. The baseline is calculated for the time period 1999 – 2008. Positive values of the index indicate relatively improved marine water quality, and negative values indicate worse marine water quality relative to the baseline. Results for Elliott Bay are shown in Table 8.7. Negative values (below baseline) are shaded red.

Table 8.7. Elliott Bay MWCI 1999-2014

Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Elliott Bay	28	19	5	-3	-9	3	-15	-9	3	4	-8	-5	5	5	8	-2

8.1.1.8 Sediment Quality

Sediment in Elliott Bay is considered to be in poor condition.

Sediment data from a total of 238 sampling sites in Elliott Bay were reviewed. Three sediment monitoring studies were conducted by King County between 2010 and 2013, with various other samples dating back to 1990. These studies yielded a total of 31 samples that were analyzed for conventional parameters (particle size distribution, total organic carbon, and total solids) and for the 47 pollutants listed as part of state sediment management standards (173-204 WAC 2013; King County 2017b).

The sediment chemistry data were compared to sediment management standards, which include two levels of criteria: (1) sediment quality standards or sediment cleanup objectives, and (2) cleanup screening level. For comparison to criteria, dry weight concentrations were used for metals, and concentrations of most organic compounds were normalized to organic carbon content. If organic carbon content at any particular site was below 0.5% or higher than 4% dry weight, then dry weight-normalized results for lipophilic organic compounds were compared to lowest apparent effects threshold or second lowest apparent effects threshold, which relate to benthos toxicity data (EPA 1988). Table 8.8 shows the frequency of detection and exceedances of sediment management standards in Elliott Bay.

Table 8.8. Frequency of Detection and Exceedances of Sediment Management Standards in Elliott Bay (1990-2013)

Analyte	SMS		AETs		Detection Rate		
	SQS	CSL	LAET	2LAET	Detects	≥SQS	≥CSL
Metals	**mg/kg dw**		**mg/kg dw**				
Arsenic	57	93	57	93	223/254	4/254	1/254
Cadmium	5.1	6.7	5.1	6.7	157/228	7/228	1/228
Chromium	260	270	260	270	199/201	2/201	2/201
Copper	390	390	390	390	259/259	5/259	5/259
Lead	450	530	450	530	253/255	2/255	2/255
Mercury	0.41	0.59	0.41	0.59	247/267	71/267	57/267
Silver	6.1	6.1	6.1	6.1	135/217	6/217	6/217
Zinc	410	960	410	960	256/256	13/256	0/256
LPAHs	**mg/kg OC**		**µg/kg dw**				
Naphthalene	99	170	2100	2100	170/274	11/274	6/274
Acenaphthylene	66	66	1300	1300	154/274	5/274	5/274
Acenaphthene	16	57	500	500	176/273	37/273	26/273
Fluorene	23	79	540	540	191/274	39/274	28/274
Phenanthrene	100	480	1500	1500	249/274	49/274	35/274
Anthracene	220	1200	960	960	235/274	26/274	26/274
2-Methylnaphthalene	38	64	670	670	143/274	11/274	8/274
Total LPAHs	370	780	5200	5200	250/274	37/274	28/274
HPAHs	**mg/kg OC**		**µg/kg dw**				
Fluoranthene	160	1200	1700	2500	255/274	53/274	31/274
Pyrene	1000	1400	2600	3300	259/274	35/274	32/274
Benzo(a)anthracene	110	270	1300	1600	112/135	17/135	13/135
Chrysene	110	460	1400	2800	254/274	51/274	29/274
Total Benzofluoranthenes	230	450	3200	3600	60/68	6/68	4/68
Benzo(a)pyrene	99	210	1600	1600	248/274	43/274	35/274
Indeno(1,2,3-c,d)pyrene	34	88	600	690	239/274	47/274	34/274
Dibenzo(a,h)anthracene	12	33	230	230	148/241	48/241	34/241
Benzo(g,h,i)perylene	31	78	670	720	120/167	15/167	10/167
Total HPAHs	960	5300	12000	17000	260/274	51/274	28/274
Chlorobenzenes	**mg/kg OC**		**µg/kg dw**				
1,2,4-Trichlorobenzene	0.81	1.8	31	51	5/231	0/231	0/231
1,2-Dichlorobenzene	2.3	2.3	35	50	14/226	0/226	0/226
1,4-Dichlorobenzene	3.1	9	110	110	45/221	2/221	2/221

Table 8.8. Frequency of Detection and Exceedances of Sediment Management Standards in Elliott Bay (1990-2013)							
Analyte	**SMS**		**AETs**		**Detection Rate**		
	SQS	**CSL**	**LAET**	**2LAET**	**Detects**	**≥SQS**	**≥CSL**
Hexachlorobenzene	0.38	2.3	22	70	2/212	0/212	0/212
Phthalates	**mg/kg OC**		**µg/kg dw**				
Dimethyl phthalate	53	53	71	160	11/224	1/224	1/224
Diethyl phthalate	61	110	200	>200	19/224	0/224	0/224
Di-n-butyl phthalate	220	1700	1400	1400	93/166	1/166	1/166
Benzyl butyl phthalate	4.9	64	63	900	65/230	11/230	0/230
Bis(2-ethylhexyl)phthalate	47	78	1300	1900	108/134	14/134	8/134
Di-n-octyl phthalate	58	4500	6200	6200	1/230	0/230	0/230
Misc. Organics	**mg/kg OC**		**µg/kg dw**				
Dibenzofuran	15	58	540	540	136/249	20/249	13/249
Hexachlorobutadiene	3.9	6.2	11	120	1/212	1/212	1/212
N-Nitrosodiphenylamine	11	11	28	40	1/212	0/212	0/212
Total PCBs	12	65	130	1000	182/246	61/246	11/246
Hydrophilic Organics	**mg/kg OC**		**µg/kg dw**				
Phenol	420	1200	420	1200	68/230	7/230	1/230
2-Methylphenol	63	63	63	63	2/166	0/166	0/166
4-Methylphenol	670	670	670	670	0/33	0/27	0/27
2,4-Dimethylphenol	29	29	29	29	30/220	16/220	16/220
Pentachlorophenol	360	690	360	690	2/196	0/196	0/196
Benzoic acid	650	650	650	650	87/226	7/226	7/226
Benzyl alcohol	57	73	57	73	26/238	8/238	0/238

Notes:

Samples with <0.5% or >4% total organic carbon were compared to Apparent Effects Thresholds (AETs)

mg/kg dw – milligrams per kilogram dry weight; mg/kg OC – milligrams per kilogram organic carbon

SMS – sediment management standards; SQS – sediment quality standards; CSL – cleanup screening level; LAET – lowest apparent effects threshold; 2LAET – second lowest apparent effects threshold

Source – (King County 2017b)

Nearly all analyzed chemicals exceeded at least one of the sediment quality standards or cleanup screening levels, with PCBs, PAHs, and some metals having the most frequent exceedances. The contaminants of highest concern are mercury, PAHs, total PCBs, and bis(2-ethylhexyl)phthalate, which each exceeded sediment management standards at more than 10 percent of sites.

Concentrations of some contaminants seem to be decreasing over time, including mercury, LPAHs, HPAHs, PCBs, and silver. Other contaminants, such as zinc, some LPAHs, bis(2-ethylhexyl)phthalate, arsenic, and cadmium appear to be increasing in some locations (King County 2017b).

8.1.2 Fish Consumption

8.1.2.1 Toxics

Elliott Bay is considered to be in fair condition with respect to toxics related to fish consumption. The Washington State Department of Health has a fish consumption advisory in place due to PCBs and methylmercury. Consumption is not restricted, however, advice is given to limit intake of toxics.

8.1.3 Indicators

8.1.3.1 Beach Closures

Elliott Bay is considered to be in good condition with respect to beach closures. The only reported beach closure in the past decade was Alki Beach Park, which was closed to swimming for two days in 2017 due to a large sewage spill at the West Point Wastewater Treatment Plant .

8.1.3.2 Shellfish Bed Closures

Elliott Bay is closed to shellfish harvesting year-round due to the presence of sewage treatment outfalls and urban stormwater runoff.

8.1.4 Regulatory Drivers

Elliott Bay is listed as a Category 5 impaired water body under EPA's CWA section 303(d) for lead in water and PCBs and 2,3,7,8-TCDD in fish tissue (Ecology 2018f).

9. Conditions in Puget Sound (offshore Seattle)

Puget Sound is an inlet of the Pacific Ocean. It is a fjord-like estuary that consists of four major interconnected basins that stretch from Hood Canal to north of Admiralty Inlet. The four basins include the Main (Admiralty Inlet and the Central Basin), Whidbey, Southern, and Hood Canal basins. Puget Sound has a surface area of approximately 1,000 square miles and drains approximately 12,000 square miles (SPU 2013a). It extends along 30 miles of Seattle's western boundary.

Natural landforms once included coastal bluffs, backshore, sand spits, coastal wetlands, estuaries, and marine riparian zones. Today, most of these natural features are absent from Seattle's shoreline. Surface runoff from regional urban, agricultural or undeveloped land delivers the largest proportion of toxins to Puget Sound (SPU 2013a).

The following sections describe generalized water quality conditions in the portion of Puget Sound offshore of Seattle.

9.1.1 Recreation (fecal bacteria)

Based on available data, fecal bacteria conditions in Puget Sound offshore of Seattle are considered good.

Results from King County monitoring at the three King County ambient sites offshore of Seattle (Table 9.1) have all been below marine contact requirements for fecal coliform.

Table 9.1. Summary of Fecal Coliform Data in Puget Sound 2004-2018 (cfu/100mL)

Location	Total Number of Samples	Maximum	Minimum	Median	
Jefferson Head	178	10	0	1	
Fauntleroy/Vashon	321	5	1	1	
Fauntleroy Cove Offshore	176	3	0	1	

Ecology monitors swimming beaches in Puget Sound under the Beach Environmental Assessment, Communication & Health (BEACH) Program. Enterococci levels are measured from Memorial Day through Labor Day each year. Ecology reports geometric means of enterococci measurements as shown in Table 8.3. For all years where data are available, Puget Sound beaches have met saltwater swimming criteria (geometric mean of 35 cfu/100mL based on a minimum of five weekly samples).

Table 9.2. Summary of enterococci monitoring data in Elliott Bay 2004-2013			
Location	**Years Sampled**	**Minimum Geometric Mean Reported (cfu/100mL)**	**Maximum Geometric Mean Reported (cfu/100mL)**
Carkeek Park	2004-present	<10	14.6
Discovery Park	2004-2006	<10	<10
Golden Gardens	2004-present	<10	23.8
Lincoln Park	2004-present	<10	13.2
Lowman Beach	2004-2006	<10	10.5
Richey Viewpoint	2004-2018	<10	19.8

9.1.2 Aquatic Health

9.1.2.1 Dissolved Oxygen

Based on available data, DO conditions in Puget Sound offshore of Seattle are considered fair. In many locations, low DO is a natural occurrence due to bathymetry, slow flushing rats, and water stratification. Near-surface DO tends to be high, while deep water tends to be lower.

King County collects DO data at multiple locations and depths in Puget Sound as shown in Table 9.3.

Table 9.3. DO Measurements for Puget Sound (mg/L); all depths, 2004-2018							
Location	**Number of Samples**	**Mean**	**Minimum**	**25th Percentile**	**Median**	**75th Percentile**	**Maximum**
Jefferson Head	1612	7.5	4.9	6.4	7.4	8.2	14.9
Fauntleroy/Vashon	336	8.2	5.6	7.1	8.0	8.9	15.0
Fauntleroy Cove Offshore	1520	7.2	4.5	6.2	7.2	8.0	13.4

9.1.2.2 pH

Based on available data, Puget Sound offshore Seattle is considered to be in good condition with respect to pH. King County operates a high-frequency monitoring buoy in Central Puget Sound offshore from Port Williams, north of Lincoln Park. Monitoring data are summarized in Table 9.4. Data show that pH is usually within WQS (7.0-8.5).

Table 9.4. Temperature pH Measurement summary for Puget Sound						
Year	Mean	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile
2015	7.8	7.8	7.8	7.9	7.9	7.9

2016	7.9	7.7	7.8	7.9	8.0	8.3
2017	7.6	6.7	7.7	7.7	7.7	8.1
2018	8.0	7.7	7.9	8.0	8.1	7.8

Notes: 5th and 95th percentiles are shown rather than maxima and minima due to the nature of high-frequency (15-minute) data collected at this site.

No calculated trends are available for pH, however, a decreasing trend can be expected due to global trends in ocean acidification.

9.1.2.3 Temperature

Based on available data, Puget Sound offshore Seattle is considered to be in good condition with respect to temperature.

Table 9.5. Temperature Measurements for Puget Sound (°C); all depths, 2004-2018

Location	Number of Samples	Mean	Minimum	25th Percentile	Median	75th Percentile	Maximum
Jefferson Head	1255	10.5	7.2	9.0	10.4	11.9	15.4
Fauntleroy/Vashon	282	10.9	7.3	9.4	11	12.6	14.2
Fauntleroy Cove Offshore	1189	10.4	7.4	8.9	10.4	12.0	14.1

No calculated trends are available for temperature, however, an increasing trend can be expected due to global trends in ocean warming.

9.1.2.4 Turbidity

No determination has been made on the condition of Puget Sound with respect to turbidity. Like Elliott Bay, suspended particulate matter in Puget Sound is most variable near the bottom as the result of tidal activity and that the surface is more influenced by freshwater discharges. Both observations are driven by natural processes, making it difficult to define background turbidity and determine how to apply WQC.

9.1.2.5 Metals

Based on limited data, Puget Sound is considered to be in good condition with respect to metals. Metals were only collected at ambient sites during one sampling event in the past decade. King County sampled metals intermittently at select outfall sites in 1999-2000 and 2011-2012. All metals concentrations reported were below chronic and acute marine water quality criteria (King County 2017b).

9.1.2.6 Organics

No data are available to assess the condition of Puget Sound offshore of Seattle with respect to organics.

9.1.2.7 Nutrients

Puget Sound is considered in fair condition based on nutrients. Although no nutrient-specific water quality criteria apply to Puget Sound other than for ammonia, Ecology has developed the Marine Water Condition Index (MWCI) to measure changes in water quality that are relevant to eutrophication. Positive values of the index indicate relatively improved marine water quality, and negative values indicate worse marine water quality relative to the baseline. Results for Puget Sound are shown in Table 9.6. Negative values (below baseline) are shaded red.

Table 9.6. Elliott Bay MWCI 1999-2014

Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Central Basin	15	14	12	8	-1	-6	-8	-3	4	1	-7	-10	7	0	1	-1

9.1.2.8 Sediment Quality

Based on available data, Puget Sound sediment quality is considered fair. Ecology sampling results from 2004-2014, referred to as the Second Round survey were compared to results from 1997-2003, referred to as Baseline, as well as results from 10 long-term monitoring sites sampled between 1989 and 2015 (Ecology 2018b).

Total organic carbon content in Puget Sound sediments ranged from <0.1% to 7.2%, with a mean of 1.5%. Many of the concentrations of individual chemicals were qualified as undetected, at or below reporting limits of analytical methods. Chemical classes that were often detected included metals, PAHs, polybrominated diphenylethers (PBDEs), and PCBs. Several of these chemicals had concentrations exceeding their respective sediment quality standards or sediment cleanup objectives. Sites at which one or more of the sediment standards were exceeded represented a relatively small portion (3.9%) of the Puget Sound area (Ecology 2018b).

9.1.3 Fish Consumption

9.1.3.1 Toxics

Puget Sound offshore of Seattle is considered to be in fair condition with respect to toxics related to fish consumption. The Washington State Department of Health has a fish consumption advisory in place due to PCBs and methylmercury in Puget Sound. Consumption is not restricted, , however, advice is given to limit intake of toxics.

9.1.4 Indicators

9.1.4.1 Beach Closures

Puget Sound is considered to be in fair condition with respect to beach closures. There were 13 beach closures in Puget Sound offshore of Seattle for the period of 2004 - 2010 (Ecology 2018a). Golden Gardens beach was closed for 12 days in 2017 due to the West Point sewage spill.

9.1.4.2 Shellfish Bed Closures

Puget Sound offshore of Seattle is considered to be in poor condition with respect to Shellfish Bed Closures due to year-round closures from the presence of sewage treatment outfalls and urban stormwater runoff.

9.1.5 Regulatory Drivers

Puget Sound water adjacent to Seattle shoreline is listed as Category 5 impaired water body under CWA section 303(d) for fecal coliform in water, and PCBs, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, indeno(1,2,3-cd)pyrene, and dibenzo(a,h)anthracene in fish tissue (Ecology 2018f).

10. References

173-201A WAC. 2016. *Water Quality Standards for Surface Waters of the State of Washington*.

173-201A WAC Amendatory Section. 2018. *Amending WSR 16-16-095*. https://ecology.wa.gov/DOE/files/a8/a844d463-8e1c-4236-ba1b-2f32236384ec.pdf.

173-204 WAC. 2013. *Sediment Management Standards*. https://fortress.wa.gov/ecy/publications/documents/173204.pdf.

Carlson, Robert E. 1977. "A Trophic State Index for Lakes." *Limnology and Oceanography* 22 (2): 361–69. https://doi.org/10.4319/lo.1977.22.2.0361.

Clinton, Christopher, Michael Friese, Dave Serdar, and Environmental Assessment Program. 2016. "PBT Trend Monitoring : Measuring Lead in Suspended Particulate Matter , 2014 Results," no. April.

Department of Ecology, State of Washington, and Department of Agriculture. 2013. "Copper in Surface Waters from Urban and Agricultural Watersheds." https://fortress.wa.gov/ecy/publications/documents/1303041.pdf.

Ecology. 2002. "A Water Quality Index for Ecology's Stream Monitoring Program." *Publication No. 02-03-052*. http://www.ecy.wa.gov/biblio/0203052.html.

———. 2008. "South Puget Sound Dissolved Oxygen Study Interim Data Report." Vol. NO. 08-03-. https://doi.org/10.1080/09291016.2017.1299367.

———. 2018a. "Beach Environmental Assessment, Communication and Health (BEACH)." 2018. https://ecology.wa.gov/Water-Shorelines/Water-quality/Saltwater/BEACH-program.

———. 2018b. "Sediment Quality in Puget Sound: Changes in Chemistry, Toxicity, and Benthic Invertebrates at Multiple Geographic Scales, 1989 – 2015." Vol. 0. https://fortress.wa.gov/ecy/publications/documents/1803004.pdf.

———. 2018c. "Washington State Department of Ecology - Water Quality Monitoring." 2018. https://ecology.wa.gov/Research-Data/Monitoring-assessment/River-stream-monitoring/Water-quality-monitoring.

———. 2018d. "Washington State Department of Ecology - Water Quality Monitoring." 2018. https://ecology.wa.gov/Research-Data/Monitoring-assessment/River-stream-monitoring/Water-quality-monitoring.

———. 2018e. "Washington State Toxic Algae Program." 2018. https://www.nwtoxicalgae.org/Program.aspx.

———. 2018f. "Washington State Water Quality Assessment 303(d)/305(b) List." 2018. https://fortress.wa.gov/ecy/approvedwqa/ApprovedSearch.aspx.

EPA. 1986. "Ambient Water Quality Criteria for Bacteria." *EPA440/5-84-002*.

———. 1988. "Sediment Quality Values Refinement, 1988 Update and Evaluation of Puget Sound AETs. Volume I."

FDA. 2015. "National Shellfish Sanitation Program (NSSP) Guide for the Control of Molluscan Shellfish." *Interstate Shellfish Sanitation Conference 2015 Revision*. https://www.fda.gov/Food/GuidanceRegulation/FederalStateFoodPrograms/ucm2006754.htm.

Feist, Blake E., Eric R. Buhle, David H. Baldwin, Julann A. Spromberg, Steven E. Damm, Jay W. Davis, and Nathaniel L. Scholz. 2017. "Roads to Ruin: Conservation Threats to a Sentinel Species across an Urban Gradient." *Ecological Applications* 27 (8): 2382–96. https://doi.org/10.1002/eap.1615.

Hausmann, Sonja, Donald F. Charles, Jeroen Gerritsen, and Thomas J. Belton. 2016. "A Diatom-Based Biological Condition Gradient (BCG) Approach for Assessing Impairment and Developing Nutrient Criteria for Streams."

Science of the Total Environment 562 (November 2018): 914–27. https://doi.org/10.1016/j.scitotenv.2016.03.173.

Herrera Environmental Consultants. 2016. "Phosphorus Management Plan; Green Lake Alum Treatment 2016." *Prepared for Seattle Parks and Recreation*.

King County. 2014. "Recalibration of the Puget Lowland Benthic Index of Biotic Integrity (B-IBI)," no. November.

———. 2016. "Quick Facts on Lake Washington's Status." Lakes. 2016.

———. 2017a. "The 2015 Combined Sewer Overflow Water Quality Synthesis. Final Report on the Duwamish Estuary, Elliott Bay, and Lake Union/Ship Canal Water Quality Assessment and Monitoring Study."

———. 2017b. *Water Quality Assessment and Monitoring Study: Analysis of Existing Data on Elliott Bay*.

———. 2017c. "Water Quality Assessment and Monitoring Study: Analysis of Existing Data on Lake Union/Ship Canal."

———. 2017d. "Water Quality Assessment and Monitoring Study: Analysis of Existing Data on the Duwamish Estuary."

———. 2017e. "Water Quality Assessment and Monitoring Study: Estimated Present- Duwamish Estuary/Elliott Bay and Day Contaminant Loadings to Lake Union/Ship Canal."

———. 2018a. "Major Lakes Monitoring." 2018. https://green2.kingcounty.gov/lakes/.

———. 2018b. "Major Lakes Monitoring." Lakes. 2018.

———. 2018c. "Puget Sound Marine Monitoring." 2018. https://green2.kingcounty.gov/marine/Monitoring.

———. 2018d. "Puget Sound Stream Benthos Monitoring and Analysis." 2018. https://www.pugetsoundstreambenthos.org/Default.aspx.

———. 2018e. "Sediment Monitoring for Streams and Rivers." 2018. https://green2.kingcounty.gov/streamsdata/Sediment.aspx.

———. 2018f. "Small Lakes Data and Information - King County." 2018. https://green2.kingcounty.gov/SmallLakes/.

———. 2018g. "Stormwater Action Monitoring Status and Trends Study of Puget Lowland Ecoregion Streams: Evaluations of the First Year (2015) of Monitoring Data." *Prepared for Washington Department of Ecology Stormwater Action Monitoring Program*.

———. 2018h. "Streams Monitoring Home - King County." 2018. https://green2.kingcounty.gov/streamsdata/.

———. 2018i. "Swimming Beach Bacteria and Algal Toxin Levels, and Water Temperature." 2018. http://green2.kingcounty.gov/swimbeach/.

Moshenberg, Kari L. 2004. "A Sediment Triad Analysis of Lakes Sammamish , Washington ,."

Scholz, Nathaniel L., Mark S. Myers, Sarah G. McCarthy, Jana S. Labenia, Jenifer K. McIntyre, Gina M. Ylitalo, Linda D. Rhodes, et al. 2011. "Recurrent Die-Offs of Adult Coho Salmon Returning to Spawn in Puget Sound Lowland Urban Streams." Edited by Howard Browman. *PLoS ONE* 6 (12): e28013. https://doi.org/10.1371/journal.pone.0028013.

Seattle Public Utilities. 2004. "2004 Comprehensive Drainage Plan" II.

———. 2015. "Integrated Plan." Vol. 3.

SPU. 2007a. "Volume 1: Seattle Watercourses." In *City of Seattle State of the Waters 2007*.

———. 2007b. "Volume I: Seattle Watercourses." In *City of Seattle State of the Waters 2007*.

———. 2007c. "Volume II: Seattle Small Lakes." *City of Seattle State of the Waters 2007*.

———. 2010. "Receiving Water Conditions Report – Duwamish River."

———. 2013a. "Integrated Plan." Vol. 3.

———. 2013b. "Investigation of Bacteria Sources in the Thornton Creek Watershed." *Prepared for Washington Department of Ecology Water Quality Program*.

———. 2019. "Drainage Systems Analysis Regulatory Summary."

US EPA. 2014. "Record of Decision Lower Duwamish Waterway Superfund Site," no. November.

Voss, Frank D, and Sandra S Embrey. 2000. "Pesticides Detected in Urban Streams During Rainstorms in King and Snohomish Counties , Washington , 1998." Tacoma, WA.

Washington State Department of Health. 2018a. "Fish Consumption Advisories in Washington State." 2018.

———. 2018b. "Recreational Shellfish: Marine Biotoxins." 2018. https://www.doh.wa.gov/CommunityandEnvironment/Shellfish/RecreationalShellfish/Illnesses/Biotoxins.

Washington State Departments of Ecology and Agriculture. 2013a. "Surface Water Monitoring Program for Pesticides in Salmonid-Bearing Streams." *July 2013 Ecology Publication No. 13-03-028 Agriculture Publication No. AGR PUB 102-388 (N/7/13)*. Vol. 392.

———. 2013b. "Surface Water Monitoring Program for Pesticides in Salmonid-Bearing Streams 2009-2011." *Department of Ecology Publication No. 13-03-002 Department of Agriculture Publication No. AGR PUB 102-377*.

Water Quality Standards for Surface Waters of the State of Washington. 2016. http://water.epa.gov/scitech/swguidance/standards/.

WDFW. 2005a. "Region 4 Catchable Trout Allottment Plan Summary, 2005." 2005. http://www.wdfw.wa.gov/fish/plants/regions/reg4/index.htm.

———. 2005b. "Warmwater Fishes of Washington. Report #FM-93-9." Olympia, WA.

Windward Consulting. 2010. "Lower Duwamish Waterway Remedial Investigation." *For Submittal to: The US Environmental Protection Agency Region 10 and The Washington State Department of Ecology*.

Appendix B: Structural Stormwater Control Priorities Technical Memorandum



DRAINAGE SYSTEMS ANALYSIS

WATER QUALITY & FLOW CONTROL (Aquatic Life)

Structural Stormwater Control Priorities

February 14, 2019

PHOTO CREDITS from top left:

Salmon in Longfellow Creek, Seattle. Holli Margell, 2009. http://nativelightphoto.com/

Thornton Creek Confluence Restoration, Seattle. Natural Systems Design, 2014. http://naturaldes.com

Flooding in South Park, Seattle. Sheila Harrsion, Seattle Public Utilities, 2009.

Lake Union, Seattle. Seattle Public Utilities Photo Archive, date unknown.

Water Quality & Flow Control
(Aquatic Life)

Technical Memorandum

Date:	February 14, 2019
Deliverable title:	Structural Stormwater Control Priorities Technical Memorandum
Task No.:	3.5
To:	Ingrid Wertz, SPU Water Quality Task Lead
From:	Christian Nilsen, PE Geosyntec Consultants
Copy to:	Mike Milne, Brown and Caldwell

Prepared by: Christian Nilsen, Senior Engineer
Geosyntec Consultants

Reviewed by: ______________________ 4/18/19
Leslie Webster, Planning Program Manager, SPU

Table of Contents

Figures

Tables

Appendices

Abbreviations

BC	Brown and Caldwell
B-IBI	benthic indicator of biological integrity
City	City of Seattle
GIS	geographic information system
IP	Integrated Plan
ISP	Integrated System Plan
kg/acre/year	kilogram per acre per year
MS4	municipal separate storm sewer system
SMC	Seattle Municipal Code
SPU	Seattle Public Utilities
TM	technical memorandum
TMDL	total maximum daily load
TSS	total suspended solids

1. Introduction

This technical memorandum (TM) summarizes the methods and results for ranking receiving waters and stormwater basins for structural stormwater retrofits that was done for Seattle Public Utilities' (SPU) Integrated Plan (IP). The methods and results are described in detail in the 2012 *Integrated Plan – Stormwater Priority Basins Technical Memorandum* (SPU 2012). The 2012 TM was the first step in identifying candidate structural stormwater projects for potential inclusion in the IP.

The 2012 TM along with other IP documents were reviewed by an independent expert panel that the City of Seattle (City) convened to guide the development of the Integrated Plan. The expert panel confirmed that SPU's integrated planning methods and results were reasonable and scientifically defensible. The IP stormwater project identification process, including a brief summary of the methods for ranking receiving water and stormwater basins based on the 2012 TM, is found in *Appendix C Stormwater Project Identification Process* (SPU 2015). The expert panel's findings are summarized in *Appendix D Expert Panel for the Integrated Plan* (SPU 2015).

SPU plans to use the IP basin rankings to inform the prioritization of areas for structural stormwater retrofits to address water quality and flow control needs.

2. Stormwater Basin Priority Framework

To determine stormwater basin retrofit priorities for the IP, SPU used a simplified risk assessment framework that considered the priority of receiving waters for stormwater retrofitting (Receiving Water Priority) along with the threat of stormwater pollution to affect receiving water quality (Stormwater Basin Pollution Potential). SPU used slightly different criteria to evaluate *waterbodies* and *watercourses*. In the IP, watercourses were defined as creeks. The seven creeks that were evaluated are listed below.

- Fauntleroy Creek
- Longfellow Creek
- Mapes Creek
- Piper's Creek
- Schmitz Creek
- Taylor Creek
- Thornton Creek

Waterbodies were defined as non-creek receiving waters, and the ones that were evaluated are listed below.

- Bitter Lake
- Green Lake
- Haller Lake

- Lake Washington
- Lake Union
- Central Puget Sound/ Elliot Bay
- North Central Puget Sound
- South Central Puget Sound
- Duwamish Waterway
- Ship Canal/ Salmon Bay

Figure 2-1 provides an overview of SPU's prioritization framework for waterbodies. Figure 2-2 provides an overview of the framework as applied to watercourses.

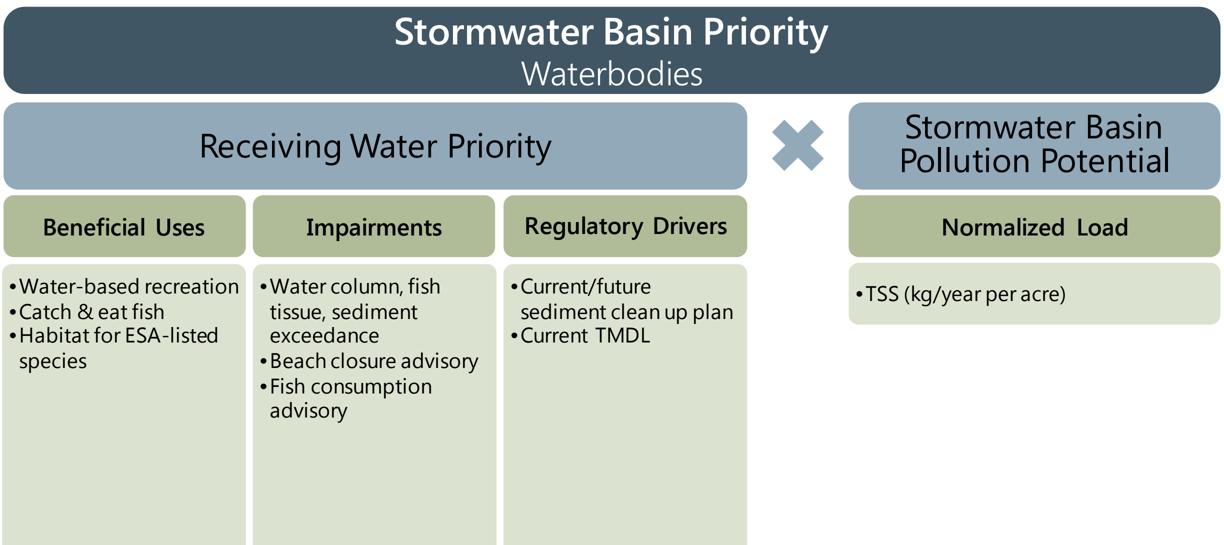


Figure 2-1. Stormwater basin prioritization framework for waterbodies

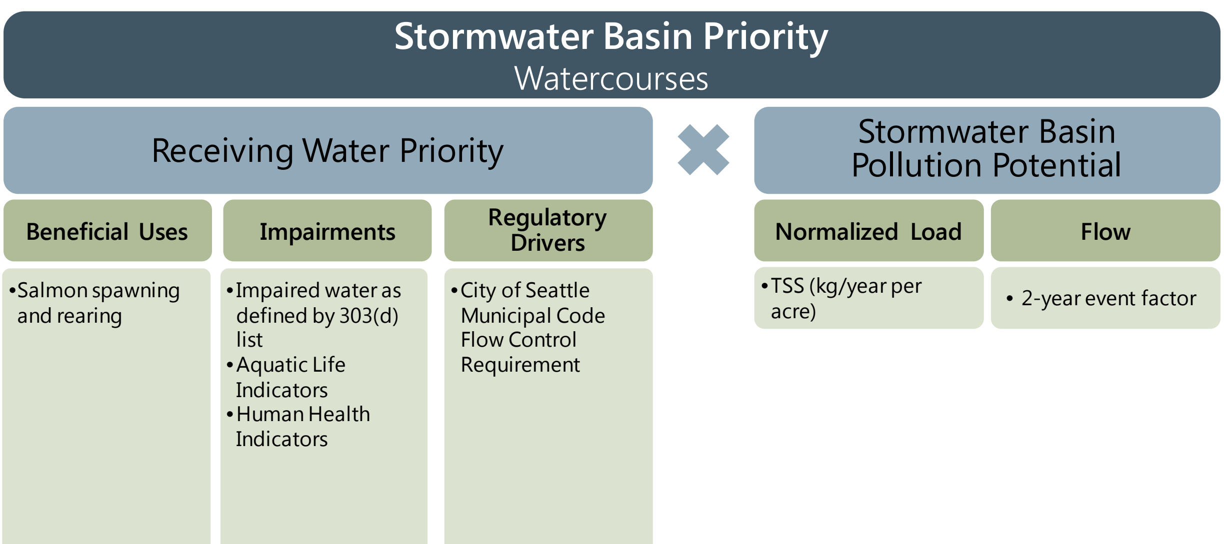


Figure 2-2. Stormwater basin prioritization framework for watercourses

2.1 Receiving Water Priority

SPU prioritized receiving waters based on three factors: beneficial uses, impairments, and regulatory drivers. These factors were combined and weighted equally into an overall receiving water priority score. While the methodology used to evaluate priority for waterbodies and watercourses was similar, different criteria were used to reflect the unique factors and drivers particular to each receiving water type.

2.1.1 Waterbody Priority

SPU used the following equally-weighted criteria to prioritize waterbodies:

- **Beneficial Uses:** Higher priority was assigned to waterbodies with more beneficial uses as evaluated by the following equally weighted criteria:
  - extent of water-based recreation
  - extent of subsistence fishing or sport fishing and access to fishing piers
  - extent of critical habitat for Endangered Species Act listed species
- **Impairments:** Higher priority was assigned to waterbodies that are impaired as evaluated by the following criteria:
  - Water column exceedances of regulatory criteria or guidance. Known impairments were weighted three times more than potential impairments, and the following weighting factors were used for pollutant impairments: toxics (0.8), nutrients (0.6), conventionals (0.4), and bacteria (0.2).
  - Fish tissue exceedances of regulatory criteria or guidance
  - Sediment exceedances of regulatory criteria or guidance
  - Beach closure advisories
  - Fish consumption advisories

  All criteria were weighted equally with the exception of beach closures which were weighted at 25 percent of other criteria because current stormwater treatment technologies may not be an appropriate pathogen control measure.
- **Regulatory drivers**: Higher priority was assigned to waterbodies that are under federal or state cleanup plans as evaluated by the following equally weighted criteria:
  - Ongoing large sediment cleanup under the federal Comprehensive Environmental Response, Compensation, and Liability Act or the state Model Toxics Control Act
  - Current total maximum daily load (TMDL) – Bacteria TMDLs were given a lower score.

Table 2-1 shows the results of the waterbody prioritization. The three factors of beneficial uses, impairments, and regulatory drivers were combined and weighted equally into an overall priority. The highest-ranking waterbodies were the Duwamish Waterway, Lake Washington, Central Puget Sound/Elliot Bay, and Lake Union.

Table 2-1. Waterbody Priority Ranked From Highest to Lowest

Rank	Waterbody	Beneficial Uses	Impairments	Regulatory Drivers	Waterbody Priority
1	Duwamish Waterway	High score	High score	High score	High score
2	Lake Washington	High score	High score	Not applicable	Moderate score
3	Central Puget Sound/Elliot Bay	Moderate score	High score	Low score	Moderate score
4	Lake Union	High score	Low score	Low score	Moderate score
5	Green Lake	Moderate score	Moderate score	Not applicable	Low score
6	Ship Canal/Salmon Bay	Moderate score	Moderate score	Not applicable	Low score
7	North Central Puget Sound	Moderate score	Low score	Not applicable	Low score
8	South Central Puget Sound	Moderate score	Low score	Not applicable	Low score
9	Bitter Lake	Low score	Low score	Not applicable	Low score
10	Haller Lake	Low score	Low score	Not applicable	Low score

Key: ● High score ● Moderate score ● Low score ● Not applicable

2.1.2 Watercourse Priority

SPU used the following equally-weighted criteria to prioritize watercourses:

- **Beneficial Uses:** Higher priority was assigned to watercourses that have salmon and are impaired as evaluated by the following equally weighted criteria:
  - number of salmon species present
  - magnitude of pre-spawn mortality (greater percent mortality was a higher priority)
  - benthic index of biological integrity (B-IBI) score (lower score was a higher priority)
- **Impairments:** Higher priority was assigned to watercourses that are impaired as evaluated by the following equally weighted criteria:
  - listed as an impaired water under section 303(d) of the Clean Water Act
  - pollutants that affect aquatic life (temperature, dissolved oxygen, turbidity/total suspended solids [TSS], ammonia, metals, and organics)
  - pollutants that affect human health (fecal coliform and metals).
- **Regulatory drivers**: Priority was assigned to watercourses based on the applicable flow control standard in the Seattle Stormwater Code (Seattle Municipal Code [SMC] 22.800-22.808 2016). Watercourses with a pre-developed pasture flow control standard were assigned a moderate score. Watercourses with a pre-developed forested standard were assigned a low-score. High scores were not used for regulatory drivers.

Table 2-2 shows the results of the watercourse prioritization. Similar to the waterbody rankings, the three factors of beneficial uses, impairments, and regulatory drivers were combined and weighted equally into an overall priority. The highest-ranking watercourses were Thornton Creek, Longfellow Creek, Piper's Creek, and Fauntleroy Creek.

Table 2-2. Watercourse Priority Ranked From Highest to Lowest

Rank	Watercourse	Beneficial Uses	Impairments	Regulatory Drivers	Watercourse Priority
1	Thornton Creek	High	High	Moderate	High
2	Longfellow Creek	High	High	Moderate	High
3	Piper's Creek	Moderate	High	Moderate	Moderate
4	Fauntleroy Creek	Moderate	High	Moderate	Moderate
5	Taylor Creek	Low	Low	Low	Low
6	Mapes Creek	Low	Not applicable	Moderate	Low
7	Schmitz Creek	Low	Not applicable	Low	Low

Key: ● High score ● Moderate score ● Low score ● Not applicable

2.2 Stormwater Basin Pollution Potential

Next, SPU evaluated individual municipal separate storm sewer system (MS4) basins based on their potential to pollute downstream receiving waters. Basins with a drainage area greater than 100 acres were included in the analysis. A total of 57 individual basins were analyzed, representing about 36,000 acres of drainage area, or about 90 percent of the City's drainage area.

2.2.1 Stormwater Basins Draining to Waterbodies: Pollution Potential

SPU evaluated pollution potential for the basins draining to waterbodies based on their estimated TSS loads. TSS was used as an indicator since many pollutants of concern (e.g., metals and organics) are correlated with TSS, and stormwater treatment systems often target TSS removal. SPU used a geographic information system (GIS) model to estimate the average annual TSS load contributed from each basin based on its existing land uses (commercial, industrial, and residential uses) and land cover (roof, street, driveway, open space, etc.). The normalized annual TSS load (kilogram per acre per year [kg/acre/year) was used as the basis for assigning estimated pollutant loads. Basins contributing more than 117 kg/acre/year TSS were assigned a high score, basins contributing between 57 and 116 kg/acre/year TSS were assigned a moderate score, and basins contributing less than 57 kg/acre/year TSS were assigned a low score (Appendix A).

2.2.2 Stormwater Basins Draining to Watercourses: Pollution Potential

SPU evaluated pollution potential of basins draining to watercourses based on two factors: 1) TSS normalized load and 2) the "2-year storm event factor".

TSS load to watercourses was estimated using the same methods employed for estimating loads to waterbodies. For watercourses, basins contributing more than 89 kg/acre/year TSS were assigned a high score, basins contributing between 39 and 88 kg/acre/year TSS were assigned a moderate score, and basins contributing less than 39 kg/acre/year TSS were assigned a low score.

The "2-year storm event factor" from *City of Seattle* State of the Waters 2007 (Herrera Environmental Consultants and SPU 2007) was used to represent contributions of excess flow from stormwater basins. The "2-year storm event factor" is the increase in the 2-year storm event peak flow between the forested and current condition (e.g., a factor of 2 means that the stream flow during the 2-year storm event has doubled under current conditions compared to forested conditions). Basins with a factor greater than five were assigned a high score, basins with a factor between four and 4.9 were assigned a moderate score, and basins with a factor less than four were assigned a low score.

The TSS normalized load score and the 2-year storm event factor score were combined and equally weighted to arrive at the Stormwater Basin Pollution Potential score for each watercourse (Appendix B).

3. Stormwater Basin Priorities

For each stormwater basin, the waterbody or watercourse priority and the stormwater basin pollution potential score were combined, and equally weighted, to arrive at the overall stormwater basin priority. Scores and priorities for stormwater basins draining to waterbodies are shown in Figure 4-1 and provided in Appendix A. Scores and priorities for stormwater basins draining to watercourses are shown in Figure 4-2 and provided in Appendix B.

4. Discussion

The IP team identified the following limitations in applying the Stormwater Basin Priority Framework:

- **Basin Size:** Only basins larger than 100 acres were included in the analysis. This approach was deemed appropriate for a planning level analysis with limited resources and a tight schedule.
- **Receiving Waterbody Segmentation:** Receiving waters with multiple regulatory-defined segments (e.g., Lake Washington, Duwamish Waterway, or Thornton Creek) were each considered a single receiving waterbody.
- **TSS:** TSS was the only pollutant used to estimate each basin's pollution potential because it is a common surrogate for other stormwater pollutants and a targeted pollutant of most stormwater treatment technologies. Other pollutants may need to be considered in the development of specific stormwater treatment projects.

As information from the IP is used the following information should be considered:

- Some stormwater basin delineations have changed since the IP analysis was conducted. This TM presents the basins as delineated for the IP analysis.
- The scoring and ranking for the IP was based on data and information available in 2012. Using updated information may alter the results of the analysis. However, SPU subject matter experts believe that there is relatively little new information since 2012 and that any more recent data would not significantly alter the priorities from the IP.

For more detailed information on the methods and results for ranking receiving waters and stormwater basins for structural stormwater retrofits refer to the 2012 *Integrated Plan – Stormwater Priority Basins Technical Memorandum* (City of Seattle 2012). For the purposes of this TM, some of the terminology used in the 2012 was simplified. A crosswalk of the terminology used in the TM and the 2012 TM is provided in Table 4-1.

Table 4-1. Terminology Cross Walk

2012 Integrated Plan TM	This TM
Basin Level Risk	Stormwater Basin Priority
Maintain Restored Uses (Regulatory Driver)	Regulatory Drivers
Pollution Potential Index	Stormwater Basin Pollution Potential
Protect Existing Uses	Beneficial Uses
Restored Impaired Uses	Impairments
Use Index	Receiving Water Priority

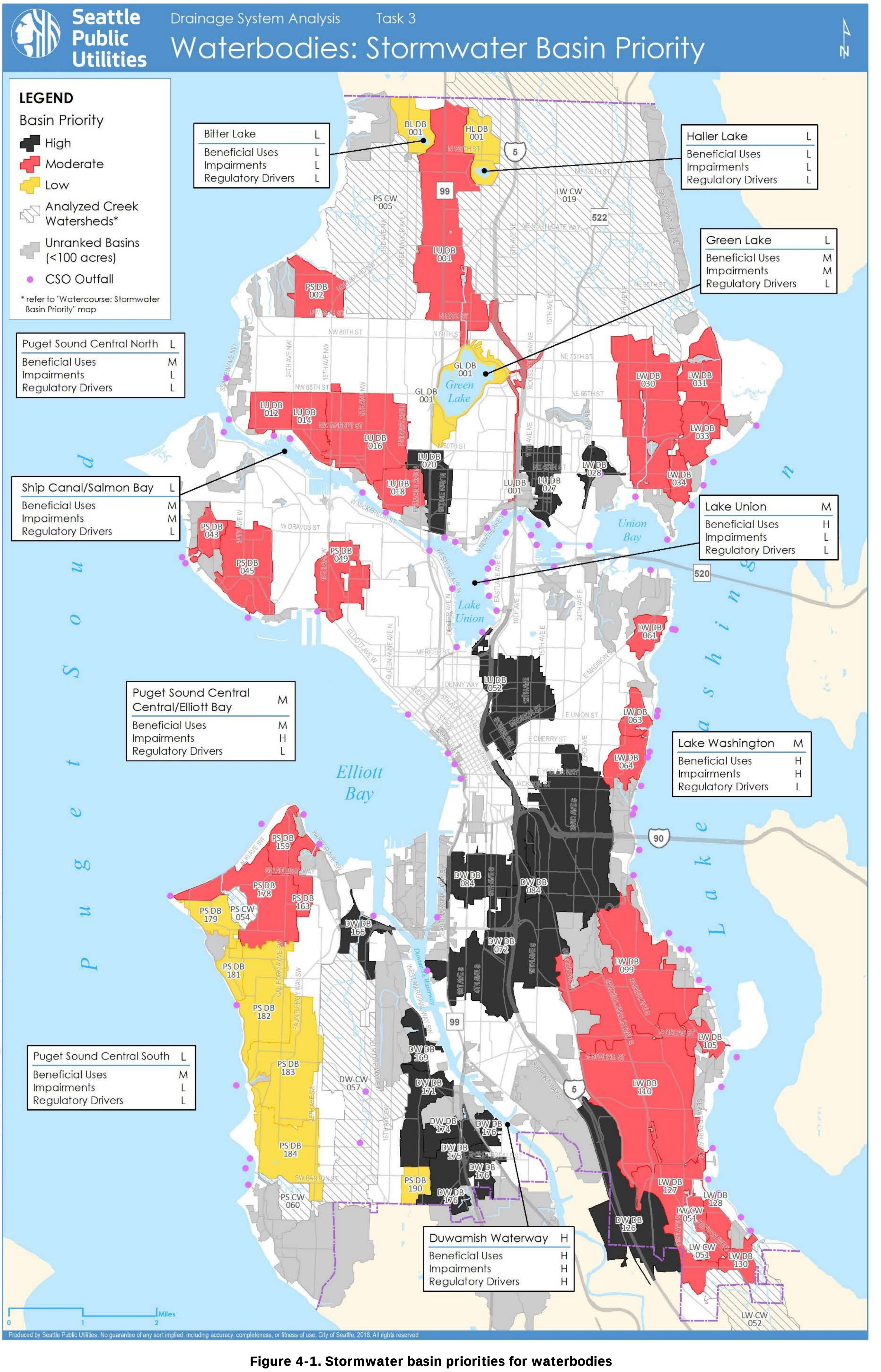


Figure 4-1. Stormwater basin priorities for waterbodies

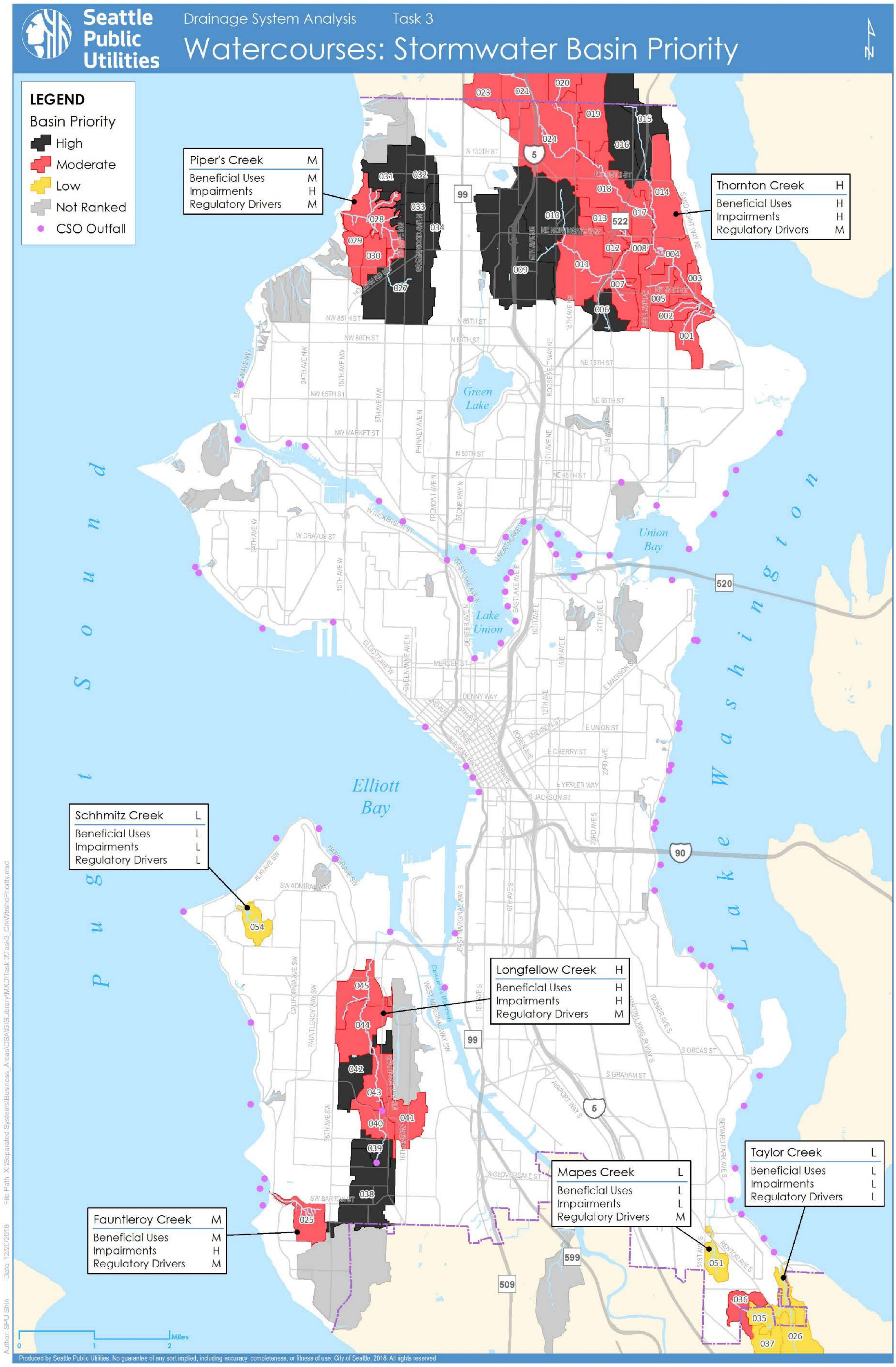


Figure 4-2. Stormwater basin priorities for watercourses

References

Seattle Public Utilities. 2012. “Draft Stormwater Priority Basins Technical Memorandum.”

Herrera Environmental Consultants, and SPU. 2007. “Volume 1: Seattle Watercourses.” In *City of Seattle State of the Waters 2007*.

Seattle Public Utilities. 2015. “Integrated Plan.” Vol. 3.

SMC 22.800-22.808. 2016. *Seattle Stormwater Code*.

Appendix A: Waterbodies: Stormwater Basin Prioritization Results

Table A-1. Waterbodies: Stormwater Basin Prioritization Results (ranked from highest to lowest)					
Rank	**Waterbody**	**Basin ID**	**Waterbody Priority**	**Stormwater Basin Pollution Potential**	**Stormwater Basin Priority**
1	Duwamish Waterway	DW_DB_126 (Norfolk)	High	High	High
2	Duwamish Waterway	DW_DB_072 (Diagonal)	High	High	High
3	Duwamish Waterway	DW_DB_084 (Lander)	High	High	High
4	Duwamish Waterway	DW_DB_166 (S Hinds)	High	High	High
5	Duwamish Waterway	DW_DB_176 (South Park1)	High	High	High
6	Duwamish Waterway	DW_DB_174 (1st Ave S)	High	Moderate	High
7	Duwamish Waterway	DW_DB_175 (1st Ave S)	High	Moderate	High
8	Lake Washington	LW_DB_028	Moderate	High	High
9	Duwamish Waterway	DW_DB_169 (SW Kenny)	High	Moderate	High
10	Duwamish Waterway	DW_DB_171 (Highland Park Wy)	High	Moderate	High
11	Lake Union	LU_DB_052 (Minor Avenue)	Moderate	High	High
12	Lake Union	LU_DB_027	Moderate	High	High
13	Lake Union	LU_DB_020	Moderate	High	High
14	Central Puget Sound/Elliot Bay	PS_DB_049 (Interbay)	Moderate	Moderate	Moderate
15	Lake Union	LU_DB_001 (Densmore)	Moderate	High	Moderate
16	Ship Canal/Salmon Bay	LU_DB_014	Low	High	Moderate
17	Lake Washington	LW_DB_110	Moderate	Moderate	Moderate
18	Lake Washington	LW_DB_130	Moderate	Moderate	Moderate
19	Lake Washington	LW_DB_128	Moderate	Moderate	Moderate
20	Duwamish Waterway	DW_CW_057 (Longfellow Creek)	High	Low	Moderate
21	Lake Washington	LW_DB_099	Moderate	Moderate	Moderate
22	Lake Washington	LW_DB_105	Moderate	Moderate	Moderate
23	Central Puget Sound/Elliot Bay	PS_DB_159	Moderate	Moderate	Moderate
24	Ship Canal/Salmon Bay	LU_DB_016	Low	High	Moderate
25	Lake Washington	LW_DB_063	Moderate	Moderate	Moderate
26	Lake Washington	LW_DB_127 (Henderson)	Moderate	Moderate	Moderate
26	Lake Washington	LW_DB_030	Moderate	Moderate	Moderate
28	Central Puget Sound/Elliot Bay	PS_DB_163	Moderate	Moderate	Moderate
29	Central Puget Sound/Elliot Bay	PS_DB_045	Moderate	Moderate	Moderate
30	Lake Washington	LW_DB_034	Moderate	Moderate	Moderate

Key: ● High ● Moderate ● Low

Table A-1. Waterbodies: Stormwater Basin Prioritization Results (ranked from highest to lowest)

Rank	Waterbody	Basin ID	Waterbody Priority	Stormwater Basin Pollution Potential	Stormwater Basin Priority
31	Central Puget Sound/Elliot Bay	PS_DB_043	Moderate	Moderate	Moderate
32	Lake Washington	LW_DB_031	Moderate	Moderate	Moderate
33	Lake Washington	LW_DB_061	Moderate	Moderate	Moderate
34	Duwamish Waterway	DW_CW_058 (Puget Creek)	High	Low	Moderate
35	Lake Washington	LW_CW_019 (Thornton Creek)	Moderate	Moderate	Moderate
36	Lake Washington	LW_DB_064	Moderate	Moderate	Moderate
37	Lake Washington	LW_DB_033	Moderate	Moderate	Moderate
38	Ship Canal/Salmon Bay	LU_DB_012	Low	Moderate	Moderate
39	Ship Canal/Salmon Bay	LU_DB_018	Low	Moderate	Moderate
40	North Central Puget Sound	PS_DB_002	Low	Moderate	Moderate
41	South Central Puget Sound	PS_DB_178	Low	Moderate	Moderate
42	South Central Puget Sound	PS_DB_182	Low	Moderate	Low
43	South Central Puget Sound	PS_DB_179	Low	Moderate	Low
44	South Central Puget Sound	PS_DB_183	Low	Moderate	Low
45	South Central Puget Sound	PS_DB_184	Low	Moderate	Low
46	North Central Puget Sound	PS_CW_005 (Piper's Creek)	Low	Moderate	Low
47	South Central Puget Sound	PS_DB_190	Low	Moderate	Low
48	Lake Washington	LW_CW_052 (Taylor Creek)	Moderate	Low	Low
49	Lake Washington	LW_CW_045 (Washington Park Creek)	Moderate	Low	Low
50	North Central Puget Sound	PS_CW_004 (Broadview 4)	Low	Low	Low
51	Bitter Lake	BL_DB_001	Low	Moderate	Low
52	South Central Puget Sound	PS_DB_181	Low	Low	Low
53	South Central Puget Sound	PS_CW_060 (Fauntleroy Creek)	Low	Low	Low
54	Haller Lake	HL_DB_001	Low	Moderate	Low
55	South Central Puget Sound	PS_CW_061 (Seloa Beach Creek)	Low	Low	Low
56	Green Lake	GL_DB_001	Low	Low	Low
57	North Central Puget Sound	PS_CW_024 (Schuerman Creek)	Low	Low	Low

Key: ● High ● Moderate ● Low

Appendix B: Watercourses: Stormwater Basin Prioritization Results

Table B-1. Watercourses: Stormwater Basin Prioritization Results (ranked from highest to lowest)

Rank	Watercourse	Watercourse Basin	Watercourse Priority	Stormwater Basin Pollution Potential		Stormwater Basin Priority
				Load	Flow	
1	Longfellow Creek	LF_SW_038	High	High	High	High
2	Longfellow Creek	LF_SW_042	High	High	High	High
3	Piper's Creek	PI_SW_034	Moderate	High	High	High
4	Piper's Creek	PI_SW_032	Moderate	High	High	High
5	Piper's Creek	PI_SW_027	Moderate	High	High	High
6	Longfellow Creek	LF_SW_039	High	Moderate	High	High
7	Piper's Creek	PI_SW_031	Moderate	High	High	High
8	Piper's Creek	PI_SW_033	Moderate	High	High	High
9	Thornton Creek	TN_SW_015	High	High	Low	High
10	Thornton Creek	TN_SW_006	High	High	Low	High
11	Thornton Creek	TN_SW_016	High	High	Low	High
12	Thornton Creek	TN_SW_017	High	High	Low	High
13	Thornton Creek	TN_SW_009	High	High	Low	High
14	Thornton Creek	TN_SW_010	High	High	Low	High
15	Thornton Creek	TN_SW_012	High	High	High	Moderate
16	Piper's Creek	PI_SW_030	Moderate	High	High	Moderate
17	Thornton Creek	TN_SW_005	High	High	Low	Moderate
18	Thornton Creek	TN_SW_013	High	High	Low	Moderate
19	Longfellow Creek	LF_SW_041	High	Moderate	High	Moderate
20	Piper's Creek	PI_SW_029	Moderate	Moderate	High	Moderate
21	Thornton Creek	TN_SW_018	High	High	Low	Moderate
22	Thornton Creek	TN_SW_014	High	High	Low	Moderate
23	Thornton Creek	TN_SW_003	High	High	Low	Moderate
24	Thornton Creek	TN_SW_011	High	Moderate	Low	Moderate
25	Thornton Creek	TN_SW_021	High	Moderate	Low	Moderate
26	Longfellow Creek	LF_SW_040	High	Low	High	Moderate
27	Thornton Creek	TN_SW_002	High	Moderate	Low	Moderate
28	Thornton Creek	TN_SW_024	High	Moderate	Low	Moderate
29	Thornton Creek	TN_SW_004	High	Moderate	Low	Moderate
30	Thornton Creek	TN_SW_007	High	Moderate	Low	Moderate
31	Thornton Creek	TN_SW_008	High	Moderate	Low	Moderate
32	Thornton Creek	TN_SW_023	High	Moderate	Low	Moderate

Key: ● High ● Moderate ● Low

Table B-1. Watercourses: Stormwater Basin Prioritization Results (ranked from highest to lowest)

Rank	Watercourse	Watercourse Basin	Watercourse Priority	Stormwater Basin Pollution Potential		Stormwater Basin Priority
				Load	Flow	
33	Thornton Creek	TN_SW_022	High	Moderate	Low	Moderate
34	Thornton Creek	TN_SW_020	High	Moderate	Low	Moderate
35	Thornton Creek	TN_SW_001	High	Moderate	Low	Moderate
36	Thornton Creek	TN_SW_019	High	Moderate	Low	Moderate
37	Longfellow Creek	LF_SW_044	High	Low	High	Moderate
38	Longfellow Creek	LF_SW_045	High	Low	High	Moderate
39	Fauntleroy Creek	FA_SW_025	Moderate	Moderate	Moderate	Moderate
40	Piper's Creek	PI_SW_028	Moderate	Low	High	Moderate
41	Longfellow Creek	LF_SW_043	High	Low	High	Moderate
42	Taylor Creek	TA_SW_036	Low	Moderate	High	Moderate
43	Taylor Creek	TA_SW_026	Low	Low	High	Low
44	Taylor Creek	TA_SW_035	Low	Low	High	Low
45	Taylor Creek	TA_SW_037	Low	Low	High	Low

Key: ● High ● Moderate ● Low