Seattle Public Utilities

Protecting Seattle's Waterways

Volume 3

Integrated Plan Appendices

Final | May 29, 2015

Appendix A: Consent Decree Requirements for the Integrated Plan

Seattle Public Utilities

Protecting Seattle's Waterways

Volume 3 – Integrated Plan

Appendix A: CONSENT DECREE REQUIREMENTS FOR THE INTEGRATED PLAN

Final

May 29, 2015

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List of Abbreviations

Term	Definition
BOD	biochemical oxygen demand
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
City	City of Seattle
CSO	combined sewer overflow
CWA	Clean Water Act
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
LTCP	Long-Term Control Plan
MTCA	Model Toxics Control Act
NPDES	National Pollutant Discharge Elimination System
PCB	polychlorinated biphenyl
TSS	total suspended solids
WWPCA	Washington Water Pollution Control Act

Consent Decree Requirements for the Integrated Plan

The Integrated Plan addresses a number of criteria or requirements described in the negotiated Consent Decree, including:

- Stormwater quality project(s) that result in significant benefits to water quality beyond those that would be achieved by implementation of the Long-Term Control Plan (LTCP) alone.
- Stormwater quality project(s) that will be in addition to all combined sewer overflow (CSO) control measures required in the LTCP, but that may affect the schedule of CSO control measures and CSO project completion by the compliance date of 2025.
- A schedule for implementation of the Integrated Plan projects and the deferred CSO control measures that would be completed after 2025. (All CSO control projects in the approved LTCP will be completed, but some would be deferred beyond 2025 under an approved Integrated Plan.)

The Consent Decree cites specific elements that must be included within the Integrated Plan, as summarized below:

- V.B.20.a: Describe in detail each proposed project, including at a minimum, the following information:
  - V.B.20.a.i: the design criteria and cost estimates for each proposed project contained within the Integrated Plan
  - V.B.20.a.ii: a cost-benefit analysis for implementation of the Integrated Plan
  - V.B.20.a.iii: a pollutant load reduction analysis, including projected load reductions for conventional pollutant parameters (e.g., biochemical oxygen demand [BOD], fecal coliform bacteria, total suspended solids [TSS], oil and grease, and pH), metals, nitrogen ammonia, phosphorus, and pathogens, as well as projected dissolved oxygen (DO) concentrations associated with each proposed project under the Integrated Plan
  - V.B.20.a.iv: a description of the public participation process that the City of Seattle (City) will use in its development and implementation of the proposed project(s) under the Integrated Plan
  - V.B.20.a.v: a description of the projected pollutant reductions to water bodies impaired for pathogens, metals, nitrogen ammonia, and DO through implementation of each proposed project under the Integrated Plan
  - V.B.20.a.vi: a description of projected pollutant reductions, including toxic organic compounds (i.e., select indicators for polychlorinated biphenyls [PCBs], polybrominated diphenyl ethers [PBDEs], semi-volatile organic compounds, and pesticides) as appropriate, to water bodies with specialized circumstances, such as beach closure advisories, protected spawning grounds, and contaminated sediment sites listed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Model Toxics Control Act (MTCA), through implementation of each proposed project under the Integrated Plan
  - V.B.20.a.vii: a description of projected reductions in pollutant exposure for humans, ecological receptors, and/or threatened or endangered species through implementation of the proposed project(s) under the Integrated Plan
- V.B.20.b: Demonstrate that the Integrated Plan will achieve compliance with the federal Clean Water Act (CWA) and the Washington Water Pollution Control Act (WWPCA), as well as their implementing state and federal requirements for CSO discharges

- V.B.20.c: Propose a schedule for implementation of the Integrated Plan and all remaining CSO control measures that is as expeditious as possible that may include an extension to the final construction completion milestone
- V.B.20.d: Propose a plan and schedule for performing any post-construction monitoring required for the proposed project(s)
- V.B.20.e. Include all documents, models, studies, and information supporting implementation of the Integrated Plan

Table 1 shows where the Consent Decree requirements are addressed in this Integrated Plan.

Table 1. Regulatory Compliance Crosswalk

Consent decree item	Chapter	Comments
V.B.20	1.1 1.5	• Chapter 1.1 provides an overview of integrated planning. • Chapter 1.5 describes the integrated planning in the Consent Decree.
V.B.20.e	1.4	• Describes the supporting documentation for the development of the Integrated Plan.
V.B.20.a.iii, v, vi, vii	2.0	• Describes the water bodies in the planning area.
None	3.1 3.2 3.3	• Chapter 3.1 provides a description of the existing combined sewer system. • Chapter 3.2 provides a description of the existing separated system. • Chapter 3.3 provides a description of the existing partialy separated system.
V.B.20.a.iv	4.0	• Describes the public participation process incorporated into the integrated planning process.
V.B.20.a	5.1 5.2 5.3	• Chapters 5.1 and 5.2 describe the planning approach and methodology used for identifying the candidate LTCP projects proposed for deferral. • Chapter 5.3 describes the planning approach and methodology used for identifying the candidate stormwater projects.
V.B.20.a, V.B.20.a.iii, V.B.20.a.v, V.B.20.a.vi, V.B.20.a.vii	6.5 6.6 6.7	• Chapter 6.5 describes the methodology and data used to estimate the pollutant load reductions of the candidate LTCP projects proposed for deferral. • Chapter 6.6 describes the methodology and data used to estimate the pollutant load reductions of the candidate stormwater projects. • Chapter 6.7 describes the methodology used for evaluating the exposure assessments on the candidate LTCP and stormwater projects.

Table 1. Regulatory Compliance Crosswalk		
Consent decree item	**Chapter**	**Comments**
V.B.20.a.iii, v, vi, vii	7.2 7.3 7.4	• Chapter 7.2 describes the project evaluation results for the pollutant load reduction estimations on the candidate LTCP projects proposed for deferral. • Chapter 7.3 describes the project evaluation results for the pollutant load reduction estimations on the candidate stormwater projects. • Chapter 7.4 describes the exposure assessment results for the candidate LTCP and stormwater projects.
V.B.20.a.ii	8.4	• Describes the estimated costs and cost-benefit analysis for the selected stormwater project option.
V.B.20.a.iii, v, vi, vii V.B.20.b	8.4	• Discusses the significant benefits of the Integrated Plan projects and describes the compliance assurance and documents that the Integrated Plan will achieve compliance with the CWA, WWPCA, municipal sewer system and state and federal requirements for CSO discharges, and EPA CSO Control Policy.
V.B.20.c	9.0	• Describes the implementation schedule for the Integrated Plan stormwater projects and the candidate LTCP projects that will be deferred.
V.B.20.d	10.0	• Describes the post-construction monitoring that will be conducted for the Integrated Plan stormwater projects.

Appendix B: Surface Water Resources of the Integrated Plan

This appendix contains a description of the surface water resources of the Integrated Plan area, which was originally provided as Appendix A to the following document: *Integrated Plan: Briefing Memorandum for April 29, 2013, Expert Panel Meeting. Briefing Memorandum on Stormwater and CSO Project Evaluation and Exposure Assessment Methods. April 22, 2013. Revised May 23*.

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Appendix B: SURFACE WATER RESOURCES OF THE INTEGRATED PLAN

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List of Abbreviations

Term	Definition
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSO	combined sewer overflow
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ft/s	foot/feet per second
MTCA	Model Toxics Control Act
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl

Summary

This document describes the major water bodies in the Integrated Plan area, and was originally provided as Appendix A to the Receiving Water Body and Drainage Basin Ranking Memorandum (SPU, 2013e). The receiving water bodies located around the city that are discussed within this appendix are shown in Figure 1.

Table 1 lists the State of Washington use designations and Table 2 lists the State of Washington 303(d) Impairments for the water bodies discussed in this appendix.

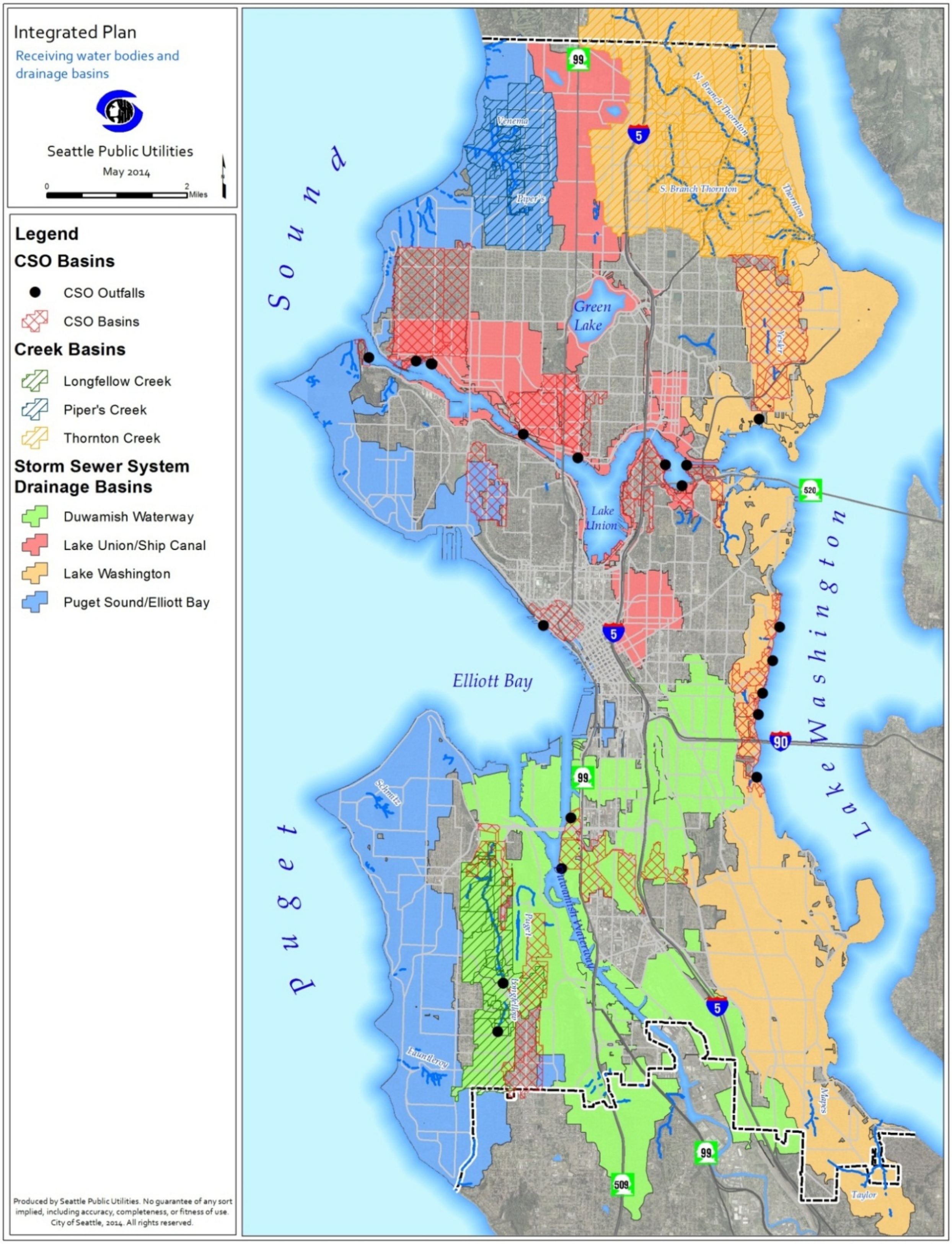

Figure 1. Receiving water bodies and drainage basins

Table 1. State of Washington Use Designations for Receiving Water Bodies in and around Seattle

Uses	**Aquatic Life: Freshwater**						**Aquatic Life: Marine**				**Recreational: Freshwater**			**Recreational: Marine**			**Water Supply**				**Miscellaneous**				
Surface water criteria relevant to use designation[1]	**Numeric for temperature, turbidity, dissolved oxygen, total dissolved gases, pH, and toxic substances; also narrative**						**Numeric for temperature, turbidity, dissolved oxygen, pH, and toxic substances; also narrative**				**Numeric for fecal bacteria; also narrative**						**Narrative only**				**Narrative only**				
Use designation	**Char Spawning/ Rearing**	**Core Summer Habitat**	**Spawning/Rearing**	**Rearing/Migration Only**	**Redband Trout**	**Warm Water Species**	**Extraordinary**	**Excellent**	**Good**	**Fair**	**Extra. Primary Contact**	**Primary Contact**	**Secondary Contact**	**Shellfish Harvesting**	**Primary Contact**	**Secondary Contact**	**Domestic Water**	**Industrial Water**	**Agricultural Water**	**Stock Water**	**Wildlife Habitat**	**Harvesting**	**Commerce/Navigation**	**Boating**	**Aesthetics**
Puget Sound[a]							✓							✓	✓						✓	✓	✓	✓	✓
Elliott Bay[b]								✓						✓	✓						✓	✓	✓	✓	✓
Lake Washington		✓									✓						✓	✓	✓	✓	✓	✓	✓	✓	✓
Ship Canal/Lake Union[c]		✓									✓						✓	✓	✓	✓	✓	✓	✓	✓	✓
Duwamish River[d]				✓									✓					✓	✓	✓	✓	✓	✓	✓	✓
Longfellow Creek			✓									✓					✓	✓	✓	✓	✓	✓	✓	✓	✓
Thornton Creek		✓									✓						✓	✓	✓	✓	✓	✓	✓	✓	✓
Piper's Creek			✓								✓						✓	✓	✓	✓	✓	✓	✓	✓	✓

1. Surface water criteria:

173 201A 200: freshwater numeric for aquatic life uses (temperature, turbidity, dissolved oxygen, total dissolved gas, and pH) and for recreation (fecal bacteria)
173 201A 210: marine numeric for aquatic life uses temperature, turbidity, dissolved oxygen, and pH) and for recreation/shellfish harvest (fecal bacteria)
173 201A 220: lake nutrient criteria (miscellaneous uses: aesthetics)
173 201A 240: toxic substances (aquatic life uses for freshwater and marine acute and chronic criteria)
173 201A 250: radioactive substances (relevant to all uses)
173 201A 260: natural conditions and other water quality criteria and applications (narrative criteria relevant to all designated uses)

Excerpts from WAC 173-201A Surface Water Standards for the State of Washington, Table 602:

a. Puget Sound through Admiralty Inlet and South Puget Sound, south and west to longitude 122°52'30"W (Brisco Point) and longitude 122°51'W (northern tip of Hartstene Island).

b. Elliott Bay east of a line between Pier 91 and Duwamish Head.

c. Lake Washington Ship Canal from Government Locks (river mile 1.0) to Lake Washington (river mile 8.6).

d. Duwamish River from mouth south of a line bearing 254° true from the NW corner of berth 3, terminal 37 to the Black River (river mile 11.0) (Duwamish River continues as the Green River above the Black River).

Table 2. Washington Department of Ecology Water Quality Assessment (303(d) Listings)
Source: http://www.ecy.wa.gov/programs/wq/links/wq_assessments.html

Water body	Impairment: 303(d) Category 5 Listing
Duwamish Waterway	Fecal Coliform (water column)
	Dissolved Oxygen (water column)
	PCB (tissue)
	Dieldrin (tissue)
	HPAH (tissue)
	Numerous Sediment Listings
Lake Washington	Total Phosphorus (water column)
	Fecal Coliform (water column)
	2,3,7,8-TCDD (tissue)
	PCB (tissue)
	4,4'DDD (tissue)
	4,4'DDE (tissue)
	Total Chlordane (tissue)
Puget Sound/Elliot Bay	Fecal Coliform (water column)
	PCB (tissue)
	2,3,7,8-TCDD (tissue)
	Total Dioxins (tissue)
	Total Furans (tissue)
	Benz(a)anthrecene (tissue)
	Benzo(a)pyrene (tissue)
	Benzo(b)fluoranthene (tissue)
	Benzo(k)fluoranthene (tissue)
	Chrysene (tissue)
	Indeno(1,2,3-cd)pyrene (tissue)
	Dibenzo(a,h)anthracene (tissue)
Ship Canal/Lake Union	Total Phosphorus (water column)
	Lead (water column)
	Aldrin (water column)
	Fecal Coliform (water column)
Thornton Creek	Dissolved Oxygen (water column)
	Temperature (water column)
	Fecal Coliform (water column)
Longfellow Creek	Fecal Coliform (water column)
	Dissolved Oxygen (water column)
Piper's Creek	No 303(d) Category 5 Listings. Listed 4a for Fecal Coliform

Chapter 1

Lower Duwamish Waterway

The Duwamish River originates at the confluence of the Green and Black rivers near Tukwila and flows northwest for approximately 12 miles, splitting at the southern end of Harbor Island to form the East and West waterways, prior to discharging into Elliott Bay. The downstream portion of the Duwamish Waterway, located in Seattle, serves as a major shipping route for bulk and containerized cargo, and the shoreline along the majority of the lower Duwamish River (i.e., the reach downstream of the Upper Turning Basin, about 5.5 miles in length) has been developed for industrial and commercial operations. A portion of the lower Duwamish River is maintained as a federal navigation channel by the U.S. Army Corps of Engineers (Corps).

The Green River, which is the main freshwater source for the lower Duwamish Waterway, originates in the Cascade Mountains near Stampede Pass and is impounded by the Howard Hanson Dam and the Tacoma Headworks Dam. Between 2000 and 2006, the annual average flow rate measured at the Auburn gauging station was 1,190 cubic feet per second (cfs), and ranged from 851 to 1,549 cfs. Approximately 80 percent of the water in the Duwamish River eventually flows through the West Waterway because of a sill at the south end of the East Waterway. Flow rates are greatest during the winter months because of seasonal precipitation and lowest throughout the late summer dry season. Water circulation within the lower Duwamish River is driven by tidal actions and river flow; the relative influence of each is highly dependent on seasonal river discharge volumes.

Consent Decree Information

Table 1 lists the State of Washington use designations and Table 2 lists the State of Washington 303(d) Impairments for the Duwamish River.

The Duwamish River is listed as secondary contact recreation; there are no monitored swimming beaches on the Duwamish River and therefore there is no information on beach closures.

The Lower Duwamish Waterway is listed as a Superfund Site under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (EPA, 2013) and as a Model Toxics Control Act (MTCA) site (Ecology, 2013b). The CERCLA and MTCA listings are for sediments in the river that contain a wide range of contaminants associated with industrial activity. The contaminants include polychlorinated biphenyls (PCBs), carcinogenic polycyclic aromatic hydrocarbons (cPAHs), arsenic, and chlorinated dioxins and furans.

The Duwamish River is listed as Critical habitat for the following Proposed, Threatened, and Endangered species (City of Seattle, 2012):

- Chinook Salmon (*Oncorhynchus tshawytscha*) are listed as a Threatened species.
- Coastal-Puget Sound Bull Trout (*Salvelinus confluentus)* are listed as a Threatened species.
- Puget Sound Steelhead (*Oncorhynchus mykiss)* are listed as a Threatened species; however, no Critical habitats are designated at this time.

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Chapter 2

Lake Washington

Lake Washington is the second-largest natural lake in the state, with a surface area of 21,500 acres and a watershed of 472 square miles. Overall, almost two-thirds of the land use in the Lake Washington watershed has been converted to residential, commercial, or industrial uses (King County, 2009). Historically, Lake Washington drained to the south through the Black River to the Duwamish River and Puget Sound. In 1912, the Cedar River was diverted into Lake Washington from its original discharge into the Duwamish River. In 1916, construction of the Lake Washington Ship Canal system diverted Lake Washington's outlet from the Black River to Shilshole Bay (Chrzastowski, 1983).

Lake Washington's two major influent streams are the Cedar River at the southern end, and Lake Sammamish via the Sammamish River from the north. In addition, numerous small streams enter Lake Washington.

The Lake Washington basin is a deep, narrow, glacial trough with steeply sloping sides. The Corps maintains daily lake elevations to within 0.01 foot. The summer high-water level is 22 feet mean sea level; the lake is lowered approximately 2 feet during the winter to minimize shoreline erosion and property damage and to allow dock and other facility maintenance (Chrzastowski, 1983; Corps, 2012a, 2012b).

The mean depth of the lake is 108 feet with a maximum depth of 214 feet (King County, 2009). The average water-residence time in Lake Washington is currently about 2.3 years, which is about half of its historical flushing rate of 5 years (Chrzastowski, 1983). This change in replacement rate was caused by construction of the Lake Washington Ship Canal system and diversion of the Cedar River into the lake.

Consent Decree Information

Table 1 lists the State of Washington use designations and Table 2 lists the State of Washington 303(d) Impairments for Lake Washington.

King County (King County, 2013) monitors swimming beaches along the shore of Lake Washington once per week from May through September to determine the fecal coliform level and to inform the public on the risks to swimmers. There are seven monitored beaches in the city of Seattle on Lake Washington and over the period of 1996–2012 there have been 39 beach closures.

At this time there are no CERCLA or MTCA listings for Lake Washington in the waters adjacent to Seattle (EPA, 2013 and Ecology, 2013b).

Lake Washington is listed as Critical habitat for the following Proposed, Threatened, and Endangered species (City of Seattle, 2012):

- Chinook Salmon (*Oncorhynchus tshawytscha*) are listed as a Threatened species.
- Coastal-Puget Sound Bull Trout (*Salvelinus confluentus*) are listed as a Threatened species.
- Puget Sound Steelhead (*Oncorhynchus mykiss*) are listed as a Threatened species; however, no Critical habitats are designated at this time.

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Chapter 3

Puget Sound

Puget Sound is a fjord-like estuary that consists of a series of underwater valleys and ridges (called basins) and submerged hills (called sills). Sills impede the flow of water in and out of the Sound and also induce vertical mixing as water moves over the sill. Puget Sound consists of four major interconnected basins: the Main (Admiralty Inlet and the Central Basin), Whidbey, Southern, and Hood Canal Basins (King County, 2009). All of Seattle's marine combined sewer overflows (CSOs) and stormwater outfalls discharge to the Central Basin. The Central Basin has near-oceanic salinity throughout the year and is supplemented with cold, nutrient-rich, low-oxygenated deep oceanic water upwelled off the Washington coast during the late summer months. The Central Basin contains water depths up to 932 feet. Freshwater flows influence water circulation in the Central Basin as the amount of freshwater input varies seasonally and affects water temperature, salinity, and density, which then determines stratification of the water column. Water column stratification can affect biological populations by trapping nutrients and/or affecting vertical migration through the water column. Freshwater input into rivers is mainly through rainfall; however, snowmelt also contributes a large source in later spring and early summer.

The two main freshwater inputs to the Central Basin are the Green/Duwamish River, which enters Elliott Bay, and the Cedar River (Lake Washington drainage basin), which flows into the Sound primarily through the Lake Washington Ship Canal. Because flows in the Lake Washington drainage basin and the Green River are regulated, snowmelt does not increase the flows in these river systems to the extent that it does in unregulated systems and has little effect on salinity and stratification near the river mouths.

Water circulation in the Central Basin is dominated by tidal currents and generally consists of a two-layered flow, with incoming, saltier oceanic water flowing along the bottom and a fresher, less dense water layer flowing out at the surface. Salty, cold, dense waters enter Puget Sound at depth through Admiralty Inlet. A portion flows south in the Central Basin while the other portion flows northeast through Possession Sound to the Whidbey Basin. Water tends to flow faster on the eastern side of the Central Basin near Alki Point and Point Wells and along the western side near Point Monroe and north of Kingston, where major topographic features affect the currents (Ebbesmeyer and Cannon, 2001). The residence time of water in the Central Basin is about 48 days, depending upon the time of year (King County, 2009). Amplitudes of tidal currents in the Central Basin are about 1.6 feet per second (ft/s). Estuarine circulation is important for transporting water masses and is typically up to about 0.3 ft/s, but can be higher during storms and bottom-water saltwater intrusion from Admiralty Inlet (Ebbesmeyer et al., 2002).

Consent Decree Information

Table 1 lists the State of Washington use designations and Table 2 lists the State of Washington 303(d) Impairments for Puget Sound.

There around 21 official beach/water access locations within Seattle for Puget Sound. Of these, the State of Washington monitors four within the city of Seattle from Memorial Day to Labor Day each year. There were 13 beach closures for the period of 2004–10 (Ecology, 2013a).

At this time there are no CERCLA or MTCA listings for Puget Sound in the waters adjacent to Seattle (EPA, 2013 and Ecology, 2013b).

Puget Sound is listed as Critical habitat for the following Proposed, Threatened, and Endangered species occurring within Puget Sound adjacent to Seattle (City of Seattle, 2012):

- Chinook Salmon (*Oncorhynchus tshawytscha*) are listed as a Threatened species, with the inshore and offshore habitat (to depths of 98 feet) listed as Critical habitat.
- Coastal-Puget Sound Bull Trout (*Salvelinus confluentus*) are listed as a Threatened species, with the inshore and offshore habitat (to depths of 33 feet) listed as Critical habitat.
- Killer Whale (*Orcinus orca*) are listed as Endangered, with all waters greater than 20 feet deep listed as Critical habitat.
- Puget Sound Steelhead (*Oncorhynchus mykiss*) are listed as a Threatened species; however, no Critical habitats are designated at this time.

Chapter 4

Elliott Bay

Elliott Bay, part of Puget Sound, is a partially enclosed embayment that is surrounded on the north, east, and south sides by urbanized areas. The eastern shoreline borders downtown Seattle and has been heavily modified from historical conditions. Most of the shoreline is armored, generally with rock, riprap, and/or bulkheads. Much of the southern and eastern waterfront land area was created by filling in what was once intertidal habitat by constructing bulkheads. As a result, the shoreline is much steeper than a natural shoreline. Harbor Island, located in the southern portion of the bay, is a man-made island completed in 1909.

Other than a few intertidal areas, depths in Elliott Bay range from about 33 feet to slightly over 490 feet near the western portion of the bay. The eastern and western (from Duwamish Head south of Seacrest Park) shorelines have steep slopes, and the middle of the bay has deep, flat areas.

Consent Decree Information

Table 1 lists the State of Washington use designations and Table 2 lists the State of Washington 303(d) Impairments for Elliott Bay.

Information on Beach closures for Elliott Bay is included in the Puget Sound section above.

At this time there are no CERCLA or MTCA listings for Elliott Bay in the waters adjacent to Seattle (EPA, 2013 and Ecology, 2013b).

Elliott Bay, like Puget Sound, is listed as Critical habitat for the following Proposed, Threatened, and Endangered species occurring within Puget Sound adjacent to Seattle (City of Seattle, 2012):

- Chinook Salmon (*Oncorhynchus tshawytscha*) are listed as a Threatened species, with the inshore and offshore habitat (to depths of 98 feet) listed as Critical habitat.
- Coastal-Puget Sound Bull Trout (*Salvelinus confluentus*) are listed as a Threatened species, with the inshore and offshore habitat (to depths of 33 feet) listed as Critical habitat.
- Killer Whale (*Orcinus orca*) are listed as Endangered, with all waters greater than 20 feet deep listed as Critical habitat.
- Puget Sound Steelhead (*Oncorhynchus mykiss*) are listed as a Threatened species; however, no Critical habitats are designated at this time.

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Chapter 5

Ship Canal/Lake Union

The Lake Washington Ship Canal system is an 8.6-mile-long (13.8-kilometer-long) man-made navigable waterway connecting Shilshole Bay in Puget Sound to Union Bay in Lake Washington in Seattle. This system includes the following interconnected waterways:

- Hiram M. Chittenden Locks (Ballard Locks)
- Salmon Bay
- Salmon Bay Waterway
- Fremont Cut
- Lake Union
- Portage Bay
- Montlake Cut

Lake Union is a freshwater lake with a maximum depth of 50 feet. The lake receives most of its inflow from Lake Washington via the Montlake Cut and Portage Bay. Lake Union discharges to the Puget Sound Central Basin via the Hiram Chittenden Locks. At certain times of the year the lake has a significant amount of salt water near the bottom because of saltwater intrusion entering from the Ballard Locks.

Water circulation patterns in Lake Union are complex and affected by several factors, such as saltwater intrusion, freshwater flows from Lake Washington, wind, and temperature and density stratification. Lake Union exhibits a general pattern of winter flushing and summer stratification. The water in Lake Union is completely replaced about once per week during high freshwater flows in the winter (King County, 2012b), but there is a significant amount of short circuiting of flow, where the inflowing water does not completely flush southern portions of the lake. During the dry summer months, water movement from Lake Washington into Lake Union decreases by over 90 percent compared to peak winter flows (Herrera, 1993).

As the flow from Lake Washington decreases, the water temperature in Lake Union rises and saltwater moves into the lake from the Ballard Locks. This results in a stratified water column with colder, saltier water on the bottom and warmer fresh water at the surface. The saltwater intrusion begins around May and continues through the summer until around November, when rainfall increases freshwater flow into the lake and flushes out salt water.

Consent Decree Information

Table 1 lists the State of Washington use designations and Table 2 lists the State of Washington 303(d) Impairments for Lake Union.

There are no monitored swimming beaches on Lake Union and therefore there is no information on beach closures.

Gas Works Park is located on the north shore of Lake Union and is listed by the Washington Department of Ecology as a MTCA site (Ecology, 2013b). Gas Works is now a City of Seattle park but prior to this use it was the location of a plant that converted coal and oil into manufactured gas. The sediments off the shore of Gas Works Park contain polycyclic aromatic hydrocarbons (PAHs), which are currently undergoing study to determine the best cleanup remedy.

The Lake Washington Ship Canal/Lake Union is listed as Critical habitat for the following Proposed, Threatened, and Endangered species (City of Seattle, 2012):

- Chinook Salmon (*Oncorhynchus tshawytscha*) are listed as a Threatened species.
- Coastal-Puget Sound Bull Trout (*Salvelinus confluentus*) are listed as a Threatened species.
- Puget Sound Steelhead (*Oncorhynchus mykiss*) are listed as a Threatened species; however, no Critical habitats are designated at this time.

Chapter 6

Thornton Creek

The Thornton Creek watershed is the largest drainage basin within Seattle, draining 7,120 acres or 11.1 square miles. The watercourse headwaters are located in northeast Seattle and the city of Shoreline, flowing generally south and east before discharging to Lake Washington. The drainage system is the longest within the city of Seattle, with nearly 20 miles of watercourse channel length contained in two main branches, the main stem, and 20 tributaries (City of Seattle, 2007).

The north branch of Thornton Creek originates at the Ronald bog in the city of Shoreline and flows 5 miles southeast through Seattle's Jackson Park golf course and the Lake City Way commercial area. This branch drains 7 square miles, or 60 percent of the watershed. The south branch, also known as Maple Leaf Creek, drains a watershed of 3.8 square miles, or 33 percent of the watershed. The south branch originally began in wetlands in the Northgate–North Seattle Community College–Interstate-5 area, but the headwaters were extensively filled during development of the area. Consequently, the south branch now begins at a reach that has been recently uncovered and restored in the Northgate shopping center, and flows 2.3 miles before joining the north branch.

The north and south branches converge just upstream of Meadowbrook pond near 35th Avenue NE and NE 107th Street. The main stem of Thornton Creek drains a small portion (7 percent) of the watershed and flows southeast approximately 1.4 miles before emptying into Lake Washington at Matthews Beach. The Thornton Creek watershed is the most extensively developed of Seattle's five major watercourse basins. Most of the development is residential with some areas preserved as park land or open space.

Thornton Creek flows throughout the year, with mean annual flows of 13 and 12 cfs at the mouth for water years 2004 and 2005, respectively (City of Seattle, 2007). The peak flows recorded for water years 2004 and 2005 were 539 cfs and 129 cfs, respectively (based on 15-minute data), and the 7-day low flows were 3.9 and 3.6 cfs, respectively. A high-flow bypass at Meadowbrook Pond can divert up to 350 cfs directly to Lake Washington and dampen storm flow peaks at the mouth of Thornton Creek. Thornton Creek has no City of Seattle CSOs discharging into the creek but does have numerous stormwater outfalls.

Consent Decree Information

Table 1 lists the State of Washington use designations and Table 2 lists the State of Washington 303(d) Impairments for Thornton Creek.

There are no monitored swimming beaches on Thornton Creek and therefore there is no information on beach closures.

At this time there are no CERCLA or MTCA listings for Thornton Creek in Seattle (EPA, 2013 and Ecology, 2013b).

Thornton Creek does not contain any Critical habitat for Threatened or Endangered species.

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Chapter 7

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). 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 mile of tributaries.

Longfellow Creek is relatively flat compared to other major watercourses in Seattle. The watercourse flows through the broad Delridge Valley, which prior to urbanization would have allowed wide meandering of the stream and extensive valley bottom wetlands (City of Seattle, 2005). Longfellow Creek flows from south to north, dropping 250 feet in elevation from its headwaters near the southern city limits to its mouth at the Duwamish River near Harbor Island. The watercourse discharges to the Duwamish River through a 3,250-foot-long culvert.

The Longfellow watershed is heavily developed with residential, industrial, and commercial uses. Urbanization increases the amount of impervious surface area in the watershed, which drains stormwater to watercourses more quickly and causes higher-than-normal peaks in flow. These peaks rise and fall rapidly and produce a characteristic flashiness in the watercourse's hydrograph. The areas that have the highest potential to contribute large storm flows quickly are located in the upper portion of the basin (City of Seattle, 2007). Although the upper portion of the basin has the lowest gradient, it is characterized by high levels of impervious surfaces and some areas with low permeability. Based on limited flow data collected from November 2004 through December 2005, the peak flow on Longfellow Creek was 45 cfs with a 7-day low-flow rate of 0.4 cfs (City of Seattle, 2007). Longfellow creek has numerous stormwater outfalls and two City of Seattle CSO outfalls discharging into the creek.

Consent Decree Information

Table 1 lists the State of Washington use designations and Table 2 lists the State of Washington 303(d) Impairments for Longfellow Creek.

There are no monitored swimming beaches on Longfellow Creek and therefore there is no information on beach closures.

At this time there are no CERCLA or MTCA listings for Longfellow Creek in Seattle (EPA, 2013 and Ecology, 2013b).

Longfellow Creek does not contain any Critical habitat for Threatened or Endangered species.

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Chapter 8

Piper's Creek

The Piper's Creek watershed covers 1,604 acres, or 2.5 square miles, in northwest Seattle. Piper's Creek is the third-largest watershed in the city, and is just under one-quarter the size of the largest watershed, Thornton Creek. The main stem channel is roughly 2 miles in length, with an additional 3 miles in tributaries, including one major tributary (Venema/Mohlendorph) and 13 minor tributaries.

The watershed has three distinct zones: a gently rolling upland plateau, an area of steep-walled ravines, and a low gradient valley. The headwaters of Piper's Creek originate on the upland plateau, and the watercourse enters Carkeek Park as it drops down from the plateau through a steep ravine. Once on the low-gradient valley, the watercourse discharges to Puget Sound. Piper's Creek is perennial with average flows of 3 to 9 cfs.

Historically, the Piper's Creek watershed was a heavily forested drainage but urbanization has developed nearly 90 percent of the watershed into residential (59 percent), transportation, and commercial areas (31 percent), with the remainder in parks (10 percent).

Consent Decree Information

Table 1 lists the State of Washington use designations for Piper's Creek. There are no 303(b) Category 5 listings for Piper's Creek.

There are no monitored swimming beaches on Longfellow Creek and therefore there is no information on beach closures.

At this time there are no CERCLA or MTCA listings for Piper's Creek in Seattle (EPA, 2013 and Ecology 2013b).

Piper's Creek does not contain any Critical habitat for Threatened or Endangered species.

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Chapter 9

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Appendix C: Stormwater Project Identification Process

Seattle Public Utilities

Protecting Seattle's Waterways

Volume 3 – Integrated Plan

Appendix C: STORMWATER PROJECT IDENTIFICATION PROCESS

Final

May 29, 2015

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List of Abbreviations

Term	Definition
303(d)	list of impaired water bodies
AARV	average annual runoff volumes
AUI	area unsuitable for infiltration
BMP	best management practice
CERCLA	Comprehensive Environmental Response, compensation, and Liability Act
CIP	capital improvement project
City	City of Seattle
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSO	combined sewer overflow
Ecology	Washington State Department of Ecology
GIS	geographic information system
LDW	Lower Duwamish Waterway
LUST	leaking underground storage tank
MODA	Multiple Objective Decision Analysis
MTCA	Model Toxics Control Act
NDS	Natural Drainage Systems
PACT	Planning, Analysis, and Coordination Tool
PCB	polychlorinated biphenyls
PLT	Pollutant Load Estimator Tool
POC	pollutant of concern
ROW	right-of-way
SDOT	Seattle Department of Transportation
T&E	threatened and endangered
TMDL	total maximum daily load
TSS	total suspended solids
UIC	underground injection control
WSDOT	Washington State Department of Transportation
WWHM3	Western Washington Hydrology Model, version 3

Summary

This document provides an overview of the process, methods, and criteria that the City of Seattle (City) used to identify stormwater best management practices (BMPs) projects for evaluation as part of the planning effort known as the Integrated Plan. The process outlined in this document served as a first screen to help the City team identify stormwater BMP projects that could meet the objectives of the Integrated Plan. Additional screening by way of the pollutant load estimates, significant benefits analysis and Multiple Objective Decision Analysis (MODA) were used to further refine the list of candidate stormwater projects for inclusion in the Integrated Plan.

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CHAPTER 1

Stormwater Project Identification Process

This section provides a high-level overview of the stormwater treatment project identification process that was used to identify stormwater projects for consideration in the Integrated Plan. The process was a broad approach for identifying potential projects that would have significant merit for further analysis and potential inclusion in the Integrated Plan. Additional evaluations in the future development of each project in the Integrated Plan may be affected by the following factors:

- Further detailed investigation of individual basins or projects may indicate new alternatives that need to be investigated.
- Currently unknown collaborative projects with other departments or agencies may be identified.
- Community involvement and the environmental review process may influence projects.
- Determination of implementation needs would be an iterative process gained as information is further developed and other non-cost factors are integrated into the recommended alternatives.

1.1 Methodology for Identifying Projects

The Integrated Planning team employed the following steps to develop a list of stormwater treatment projects:

- develop pollutant and average annual runoff volume (AARV) estimates for each storm sewer system basin
- rank receiving water bodies and identify primary pollutant(s) of concern (POCs) for each water body
- rank storm sewer system drainage basins using the pollutant estimates and rank of receiving water body
- create a geographic information system (GIS) basin atlas for high-ranking storm sewer system basins in Seattle
- use the GIS basin atlas information and knowledge of stormwater treatment technologies to identify potential locations for stormwater treatment considering the general and project-specific screening criteria
- develop planning-level stormwater project descriptions and cost estimates for each of the stormwater projects to be considered in the Integrated Plan
- evaluate the stormwater projects against criteria to further refine the list of projects for consideration in the Integrated Plan

1.1.1 Develop Pollutant Load and Flow Estimates for Each Storm Sewer System Basin

The team used information on land use within each storm sewer system basin to develop total suspended solids (TSS) and AARV estimates for each basin area greater than 100 acres in size. The TSS load for each of the basins was estimated using the GIS Pollutant Load Estimator Tool (PLT) developed by the City. The PLT estimates AARV and TSS loads based on the 25th, 50th (median), and 75th percentile concentrations for each storm sewer system basin. Runoff calculations and TSS input were divided into categories based on land use/zoning and surface cover conditions.

AARV was estimated using the Simple Method (Stormwater Center, 2006). The median TSS concentration was used to estimate average annual TSS loads for each basin. The TSS values used in the PLT were based upon data obtained from the report, Sources of Pollutants in Urban Areas (Pitt et al., 2005a). Additional information on the PLT can be found in the City's Standard Operating Procedures Water Quality Evaluation (WQE) 1100 and WQE 1200.

For each stormwater project, the Western Washington Hydrology Model, version 3 (WWHM3) was used to model each storm sewer system basin and to estimate the flow volume, online flow, and offline flow for the storm sewer system basin or the area of the storm sewer system basin that the stormwater project would serve. These flow data were used to size the stormwater facilities that served as the basis for the cost estimates for each project.

The team used the AARV data from WWHM3 and estimates of TSS concentrations (based on land use of the basin upstream of the project) to estimate the TSS load removed per year in kilograms for each of the stormwater projects.

1.1.2 Receiving Water Body Ranking

In Seattle, stormwater storm sewer system outfalls deliver runoff to the Lower Duwamish Waterway (LDW), Lake Washington, Puget Sound, Elliott Bay, Lake Washington Ship Canal/Lake Union, and a number of smaller urban creeks and lakes.

The City ranked these water bodies in order to help focus its efforts to identify potential stormwater projects and programs for the Integrated Plan that would meet the Consent Decree requirements. A complete discussion on this receiving water body ranking process is provided in the City's draft memo: Receiving Water Body and Drainage Basin Ranking Memo (SPU, 2013). The ranking of receiving water bodies incorporated the following Consent Decree elements:

- receiving water body impairments determined by consulting the Washington Department of Ecology (Ecology) list of impaired water bodies 303(d) lists
- presence of threatened or endangered (T&E) species and habitats
- receiving water bodies with swimming beaches where closures have occurred
- receiving water bodies that have Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Model Toxics Control Act (MTCA) designations

In addition to the Consent Decree elements, the City added consideration of fish consumption advisories in the receiving water body.

Each receiving water body was ranked against the criteria above and given a score of High, Moderate, or Low, as summarized below:

- High (●) rating: High ratings were given to receiving water bodies that contained multiple 303(d) listings in the water column, sediment, and/or fish tissue indicating that they were impaired, were listed as providing a primary migration corridor and critical rearing habitat for ESA-listed (T&E) species, were listed as having swim beach closures, had CERCLA and/or MTCA listings, and had any fish consumption advisories.
- Moderate (●) rating: Moderate ratings were given to receiving water bodies that contained multiple 303(d) listings in the water column, sediment, and/or fish tissue indicating that they may be at risk for impairment, were listed as providing a migration corridor and critical habitat for ESA-listed (T&E) species for some life stages, were listed as having swim beach closures, had CERCLA and/or MTCA listings, or had any fish consumption advisories.

- Low (🟡) rating: Low ratings were given to receiving water bodies that had a combination of bacteria 303(d) listings and other historical use or suspected contamination problems indicating that the water column, sediment, and/or fish tissue may be at risk for impairment, were listed as not providing critical habitat for ESA-listed (T&E) species, had no listing of beach closures but contained an active swimming beach, had no CERCLA or MTCA listings, or had any fish consumption advisories.
- Not applicable (⚪): NA ratings were given to receiving water bodies that had no information or no 303(d) listings, no T&E species use, no designated swimming beaches, no CERCLA or MTCA listings, and no fish consumption advisories.

The scores were then added together to provide an overall rank for each receiving water body. Table 1-1 provides a summary of the ranking criteria results for each of the evaluated receiving water bodies discussed within the Integrated Plan.

Table 1-1. Ranking Criteria for Receiving Water Bodies

Water body	303(d)	T&E species	Swim beach closures	CERCLA/ MTCA sites	Fish consumption	Overall rank[a]
Duwamish Waterway	⚫	⚫	⚪	⚫	⚫	1
Lake Washington	⚫	⚫	⚫	⚪	⚫	2
Puget Sound/Elliott Bay	🔴	🔴	🟡	⚪	⚫	3
Ship Canal/Lake Union	🔴	⚫	⚪	🔴	⚪	4
Thornton Creek	🔴	⚫	⚪	⚪	⚪	5
Longfellow Creek	🔴	⚪	⚪	⚪	⚪	6
Piper's Creek	🔴	⚪	⚪	⚪	⚪	7

Notes:

⚫ *High rank* 🔴 *Moderate rank* 🟡 *Low rank* ⚪ *Not applicable*

a. This process is a high-level planning tool to assist the planning and development of stormwater projects for evaluation as part of the Integrated Plan. Note that for programs and projects outside the Integrated Plan, the City may use different ranking systems and rank receiving waters and basins in different ways based on the objective of the program.

1.1.3 Storm Sewer System Basin Ranking

The next step in the storm sewer system basin ranking process was to combine the pollution potential (TSS load) of each storm sewer system basin with the receiving water body ranking in order to develop a list, in order of preference, of storm sewer system basins draining to large water bodies and storm sewer system basins draining to creek watersheds (Figure 1-1). A basin atlas was subsequently developed for the highest-ranked basins.

1.1.4 Basin Atlas Development

GIS data were used to create a Basin Atlas for each of the basins identified by the City's Integrated Planning team as a high-priority basin. These GIS data were displayed in a series of maps to provide basin characteristics to the team charged with identification of potential stormwater projects. Each Basin Atlas included the following information:

- aerial overview
- surface type; i.e., impervious or pervious and the percentage of the basin that discharges to combined sewer overflow (CSO) vs. the stormwater system

- land use and zoning
- existing/proposed water quality treatment
- underground facility opportunities/constraints
- partnership opportunities
- location opportunities for retrofit
- green stormwater infrastructure suitability
- source control and monitoring
- topography

1.1.5 Pollutants of Concern for Receiving Water Bodies

The City established the POCs for each receiving water body for the Integrated Plan based on consideration of the Consent Decree, total maximum daily load (TMDL) listings or impairments, available water quality data, and professional judgment. Pollutants considered included TSS, phosphorus and nitrogen, dissolved metals, hydrocarbons, fecal coliform, temperature, and flow rate and volume for streams. TSS was often selected as the target POC for a receiving water body as it represents pollutants that tend to adsorb and those that are in particulate form that include many of the organics and total metals. The pollutants were rated on a High-Moderate-Low scale with each rating summarized as follows:

- High (●) rating: High ratings were given to the pollutant considered the target POC for a stormwater treatment project for a particular stormwater drainage basin. The target POC for a project was determined based on TMDL listings or impairments, available water quality data, and/or professional judgment. While the target POC was the focus for identifying a stormwater project, much of the time, addressing the target POC also reduces many of the moderate- and low- rated pollutants.
- Moderate (●) rating: Moderate ratings were given to a pollutant for which treatment is recommended (in addition to the target POC for the project). These pollutants are present in the stormwater from the basin and may be impacting the receiving water body; however, they are not the most critical pollutant to address.
- Low (●) rating: Low ratings were given to a pollutant for which treatment should be considered (in addition to the target POC for project), but it was not necessary for the pollutant removal to be planned for, or used, in the selection or sizing of a treatment project.
- Not applicable (●): NA was given to a pollutant that had no known measurable impact on the receiving water body.

Table 1-2 provides a summary of the ranking criteria results from the POC evaluation conducted for each of the evaluated receiving water bodies discussed within the Integrated Plan.

Table 1-2. Pollutants of Concern for Receiving Water Bodies[a]

Category	Water body	Flow rate	Volume	TSS	Phosphorus and nitrogen	Metals (total)	Metals (dissolved)	Hydrocarbons	Fecals	Temperature
Central Puget Sound	Central/Elliott Bay	Not applicable	Not applicable	High rank	Not applicable	Low rank	Low rank	Low rank	Moderate rank	Not applicable
	North Central	Not applicable	Not applicable	High rank	Not applicable	Low rank	Low rank	Low rank	Moderate rank	Not applicable
	South Central	Not applicable	Not applicable	High rank	Not applicable	Low rank	Low rank	Low rank	Moderate rank	Not applicable
Major Waterway	Duwamish Waterway	Not applicable	Not applicable	High rank	Moderate rank	Moderate rank	Moderate rank	Low rank	Moderate rank	Not applicable
	Ship Canal/Salmon Bay	Not applicable	Not applicable	High rank	Moderate rank	Moderate rank	Low rank	Low rank	Moderate rank	Not applicable
Major Lakes	Lake Washington	Not applicable	Not applicable	High rank	Moderate rank	Low rank	Low rank	Low rank	Moderate rank	Not applicable
	Lake Union	Not applicable	Not applicable	High rank	Low rank	Low rank	Low rank	Low rank	Low rank	Not applicable
Creeks	Thornton Creek	High rank	High rank	Low rank	Low rank	Moderate rank	Moderate rank	Low rank	Moderate rank	Moderate rank
	Longfellow Creek	High rank	High rank	Moderate rank	Low rank	Moderate rank	Moderate rank	Low rank	Moderate rank	Low rank
	Piper's Creek	High rank	High rank	Low rank	Low rank	Moderate rank	Moderate rank	Low rank	Moderate rank	Low rank

Notes:

● High rank ● Moderate rank ● Low rank ● Not applicable

a. *This process is a high-level planning tool to assist the planning and development of stormwater projects for evaluation as part of the Integrated Plan. Note that for programs and projects outside the Integrated Plan, the City may use different ranking systems and rank receiving waters and basins in different ways based on the objective of the program.*

1.1.6 Stormwater Project Identification

Using these GIS data, the City's Integrated Planning team conducted a high-level evaluation of the high-priority basins in order to identify potential locations to install stormwater projects. Once the location(s) were identified, the team used its knowledge of stormwater treatment and receiving water body POCs to identify a stormwater project(s) for the basin.

Each stormwater project was evaluated against the criteria discussed in Chapter 2 of this document in order to determine if the project should receive additional analysis and consideration as part of the Integrated Plan.

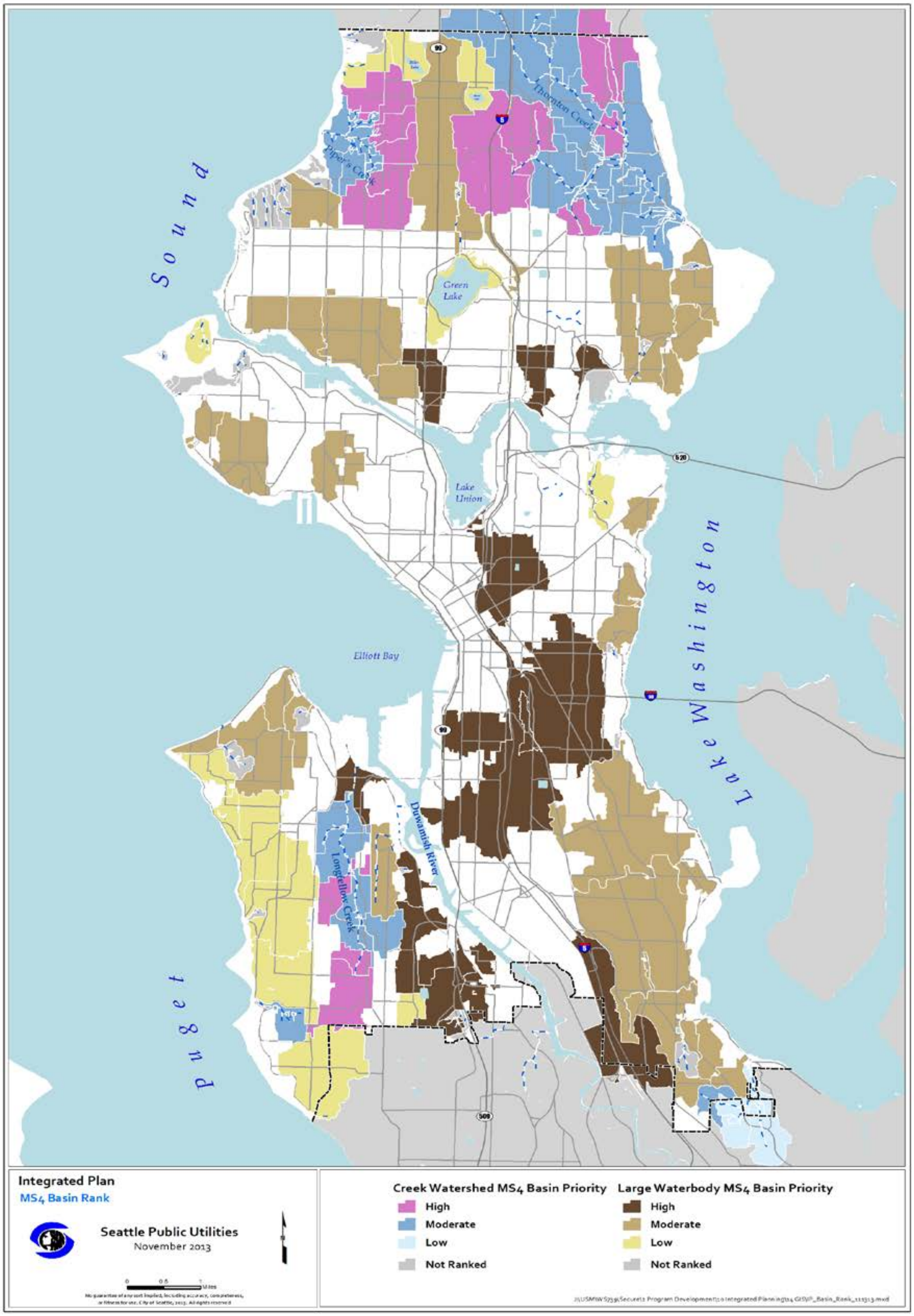

Figure 1-1. Priority ranking of storm sewer system basins in Seattle

CHAPTER 2

Initial Project Screening

The proposed stormwater projects developed using the methods described in Chapter 1 were screened against the following criteria in order to develop a list of stormwater projects that could be designed at the conceptual level along with commensurate cost estimates. Criteria were both general priority assignments (Section 2.1) and area and project-specific (Section 2.2).

2.1 Priority Assignments

Designations of High, Moderate, and Low priority were given to each evaluated stormwater project, as described below.

2.1.1 High-Priority Assignments

A High priority was assigned to the following elements, traits, or details that were deemed desirable:

- must be connected to and discharge into the City of Seattle storm sewer system
- construction in the City's right-of-way (ROW)
- construction on City-owned property
- gravity operated
- multiple benefits
- meeting code requirements/code equivalent
- sited on a vacant and available parcel or City's ROW
- treats runoff from a subbasin with high pollutant loading potential (e.g., industrial use, known pollutant sources, source control efforts likely to be unsuccessful)
- opportunity to leverage water quality project with other ongoing projects to reduce cost
- can be constructed by 2025

2.1.2 Moderate-Priority Assignments

A Moderate priority was assigned to elements, traits, or details that were deemed acceptable:

- sited on Seattle City Light owned property
- sited on property with a willing seller
- pumped operations
- sited on school property
- sited in a parking lot
- sited on City of Seattle Fleets and Administrative Services Department owned property

2.1.3 Low-Priority Assignments

A Low priority was assigned to those elements, traits, or details that were not desirable:

- sited in City of Seattle Parks and Recreation Department property
- sited on Washington Department of Transportation (WSDOT)-owned property
- sited on Port of Seattle property
- sited on church property
- requires adversarial condemnation
- sited in a landfill
- sited with high groundwater
- sited where there is significant flooding
- requires significant mitigation
- impacted by sea level rise
- sited on federal property

2.2 Stormwater Project Criteria

In addition to priority assignments, area- and project-specific criteria were evaluated.

2.2.1 Citywide Criteria

Probably the most common and significant difficulty in developing a stormwater project was the need for the treatment facility to be to constructed by 2025. The City does not currently have many projects in the pipeline that could be designed/constructed in such a short time frame. Large regional stormwater treatment facilities typically require land acquisition (often condemnation) that often needs substantial environmental cleanup before work can begin and involves coordination among multiple local agencies, which results in significantly more time to plan, develop, design, and construct. For this reason, large end-of-pipe treatment facilities were generally not considered for this Integrated Plan.

The City determined that standalone pretreatment projects would not be considered due to the following:

- Pretreatment technologies target larger-sized solids and a limited number of pollutants.
- Pretreatment is intended to ensure and extend performance of downstream treatment facilities. No downstream stormwater treatment facilities are associated with the pretreatment projects evaluated for inclusion in the Integrated Plan.

The City determined that in those storm sewer system basins that had existing regional stormwater treatment, a lower priority would be given to the basin so that efforts could be focused on other high-ranking storm sewer system basins that currently have no regional stormwater treatment at all.

2.2.2 Lower Duwamish Waterway Project Criteria

The LDW has been the subject of extensive source control efforts over the past 10 years due to its status as a Superfund site and ongoing efforts to clean up sediments containing elevated levels of arsenic, polychlorinated biphenyls (PCBs), carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and dioxins/furans. The City has inspected businesses and collected numerous sediment samples from the collection/conveyance system in order to identify and control pollutant sources in the LDW basin. As a result, the City likely knows more about potential sources and its ability to control them in this basin than in any other drainage basin in the city. Because of its Superfund status, this area is also subject to significantly more scrutiny from regulatory agencies, which is leading to more extensive requirements for City programs (e.g., source controls, expanded line cleaning to remove accumulations of contaminated sediment, stronger operations/maintenance efforts), as well as structural retrofits to reduce the potential for sediment in the waterway to recontaminate subsequent to a cleanup.

Stormwater treatment projects in the LDW were selected to capture and treat runoff from the most significant source areas. To better address the water quality concerns described above, the City looked for potential opportunities to implement higher levels of treatment. Examples of targeted projects included:

- subbasins where fugitive dust emissions/atmospheric deposition from local industries and vehicle emissions are affecting stormwater quality and where existing regulations are insufficient to address these issues
- large multi-use basins that contribute a large proportion of the overall stormwater load and where given the drainage infrastructure, it would be difficult to isolate specific industrial/high pollution generating subbasins for treatment (e.g., subbasins within the 2,600-acre Diagonal Avenue S drainage basin) and where there is an opportunity to team with King County on a joint-use facility
- major arterials in industrial/commercial areas
- sites where Ecology has already requested drainage/roadway improvements to reduce stormwater pollution

A number of sites/projects were considered, but were not found to be feasible given one or more of the following constraints:

- The City determined that while it represented a great opportunity for both the City and King County, inclusion of an opportunity to partner with King County on a wet weather treatment plant was not appropriate for consideration in the Integrated Plan for the following reasons:
  - The project was not a City project.
  - The timeline of the construction was beyond the timeline for the Integrated Plan.
  - The cost of the project (~$380 million) was greater than the dollars available from the potential deferred CSO projects.
- Projects on major arterials/transportation corridors, where the remaining ROW has already been developed for pedestrian paths and other non-motorized use, would leave no space to construct surface treatment systems (e.g., biofiltration and/or bioretention systems) and high-volume traffic would create significant barriers to construct and operate large underground facilities.
- Other areas with a lack of space to construct a stormwater treatment facility would necessitate a lengthy, expensive, and/or politically unpopular condemnation process and/or would lack a suitable site to even consider condemnation.
- A site is suitable to construct a stormwater facility, but the property is located within the WSDOT ROW. WSDOT is unwilling to allow any activity in its ROW that could preclude future transportation use.

2.2.3 Street Sweeping Program Criteria

Unlike construction of major structural treatment facilities, street sweeping is not constrained by site feasibility, is scalable, and can be readily implemented. Specific criteria that were considered for this program include:

- sweeping curbed roadways that drain directly to Seattle's receiving waters
- using high-efficiency sweepers
- having a frequency of every 1 to 2 weeks

- requiring a specified speed for the sweepers to ensure effectiveness
- consideration of parking; currently no parking enforcement on swept streets

2.2.4 Creek Watersheds Project Criteria

Stormwater treatment projects to be considered within creek watersheds were selected based upon the criteria of providing water quantity benefit in addition to achieving the water quality objectives consistent with the other basins evaluated for the Integrated Plan. Stormwater projects included alternatives relying on flow routing, as well as practices addressing flow directly at the source of the runoff.

Solutions that include routing (or capturing existing routed) flows from multiple blocks to a stormwater project location tend to maximize the cost-effectiveness of the solution. Locations with minimal alterations of the upstream and downstream conveyance system were preferred. The following practices were considered for each basin evaluated where feasible:

2.2.4.1 Projects with Flow Routing

Criteria associated with project flow routing are presented below.

2.2.4.1.1 Roadside Bioretention with Flow Routing (Green Infrastructure Project)

Roadside bioretention with flow routing consists of constructing bioretention facilities within the planter area of the ROW to capture and infiltrate runoff in a shallow landscaped depression (a.k.a. natural drainage systems or NDS). Where infiltration hazards did not exist and infiltration potential was considered to be high, these practices would be designed to capture the water quality event for infiltration into native soils. Where site condition constraints existed, underdrains were assumed, either directing flow to an underground injection control (UIC) or an orifice control outlet. Where space or slopes considerations were more challenging, vertical walls and/or use of weirs was assumed.

2.2.4.1.2 Biofilter Wetland Channel with Bioretention Elements (Green Infrastructure Project)

Biofilter wetland channels consist of a sloped vegetated channel that filters runoff as it flows through the vegetation to an outlet. An example of this type of design includes the Swale on Yale project. These practices are enhanced to provide additional flow retention through storage, infiltration, and evapotranspiration by adding underlying bioretention soils. Biofilter wetland channels typically include an upstream flow splitter to bypass high flows around the channel to avoid resuspension of captured pollutants and typically have a smaller footprint than bioretention facilities and therefore provide reduced flow retention. A pretreatment BMP such as a swirl concentrator may also be included upstream of the biofilter wetland channel.

2.2.4.1.3 Extended Detention Basins

Extended detention basins are a more traditional method of stormwater management intended to provide flow control through temporary storage, and to provide some water quality benefit through settling and biological processes. This type of stormwater project is expected to provide minimal volume reduction, as there is little opportunity for infiltration or evapotranspiration.

2.2.4.2 Projects Evaluated without Flow Routing (NDS Partnering)

Social and technical considerations can limit the opportunity for solutions with flow routing. Additionally, addressing polluted runoff at the source allows addressing other utility or agency goals (e.g., local conveyance and sidewalks). Projects such as the NDS Partnering (Piper's, Longfellow, and Thornton Creeks) were planned to maximize overlap with other agency or community goals. Project blocks would be prioritized through a community engagement process.

This type of stormwater project focused on the most cost-effective of the NDS practices for ROW application, bioretention. Each stormwater project block was planned to be designed to provide stormwater conveyance improvements within the block with bioretention cells installed at the lower portion of the block to manage the runoff flow reaching that block. For the analysis of this stormwater project, runoff was assumed to be the project block only; future refinements of this project were anticipated to reflect the increased loading when the upstream drainage area is routed to the project street (for example, a block that currently has a ditch and culvert system).

2.2.4.3 Basin-Scale Feasibility Screening

Stormwater projects identified for consideration in creek watersheds were screened within each individual priority basin by developing map atlases, identifying opportunities and constraints, and conducting a screening workshop.

If a stormwater project was able to be sited only within a low-priority site, as defined above, those projects were not put forward as prioritized projects. This was the case for all the considered extended detention pond options.

NDS-related projects were all identified within high-priority sites, specifically in the City's ROW. Opportunities for NDS-related projects were prioritized based upon their generally accepted technical feasibility. Sites where infiltration is restricted due to generally accepted geotechnical information of the site were excluded. Primary NDS-related project suitability was determined by excluding sites with the characteristics outlined below.

2.2.4.3.1 Areas Unsuitable for Infiltration (AUI)

This includes the following and designates any land parcel as an AUI if at least 5 percent of its area is unsuitable for infiltration, which is determined by evaluating the following components:

- steep slopes (greater than 40 percent) with less than 100 feet of an uphill buffer from the stormwater project site
- potential for landslides within 500 feet down gradient of the project site (landslides are based on known landslide events from City records, including those in the ROWs and private property)
- confirmed and suspected contaminated sites, including:
  - leaking underground storage tank (LUST) sites
  - other known or suspected sites/plumes
- landfills located within 100 feet of the project site
- bedrock near the land surface
- groundwater near the land surface

2.2.4.3.2 ROW Considerations

The minimum available "planting strip" width must be at least 10 feet (for both sides of the street added together). This was determined by calculating "available ROW width," which was calculated by subtracting the required roadway width and the curb width from the total required ROW width. The formula is as follows:

*Available ROW = Required ROW – (Required Roadway Width + (# of curbs * 6.5 feet))*

- Required ROW is specified in the Seattle Department of Transportation (SDOT) ROW Improvements Manual. Arterial widths or the minimum street ROW are derived from Figure 3.1.1b (SDOT, on-line ROW Improvements Manual).
- Curb counts is the number of curbs for the street segment with possible values of 0, 1, or 2, and No Data receiving zero curbs. Each curb receives 6 feet for sidewalk and 0.5 foot for curbs.

2.2.4.3.3 Street Slope Considerations

Street slope is the percentage slope of the roadway segment with the optimum range for horizontal treatment systems, being 0 to 4 percent. Sites with 0 to 7 percent slopes were also considered potentially feasible.

2.2.4.3.4 Areas Mitigated by NDS

Areas already partially or fully managed by previous retrofit capital improvement projects (CIPs) were excluded from the evaluation for installing new potential stormwater projects. Although there are potential project opportunities and an ability to further improve water quality and/or water quantity objectives, a focus was placed on areas with limited or no improvements.

For NDS-related projects with flow routing, the Integrated Planning project team also reviewed the City's Planning, Analysis, Coordination Tool (PACT) database, and using GIS and Google Earth, evaluated available widths, sidewalks, informal drainage systems, areas of high pollutant loads (e.g., arterials), and City priority areas in order to identify opportunities to locate water quality improvement projects to provide additional benefits with minimal infrastructure improvement costs. General considerations for stormwater project refinement included:

- facilities that were not located on arterials, but that however would ideally receive runoff routed from a nearby arterial to maximize pollutant reductions
- streets with informal drainage systems (i.e., no curb) were preferred.

Specific considerations were given for bioretention facilities where an underdrain was included where the infiltration potential was considered low or medium, as follows:

- Potential for UIC wells was determined from the map atlases, based on elevation in the basin relative to nearby surface water or known shallow groundwater.
- Sufficient space was provided in the ROW to accommodate the required sizing factor for water quality.

Specific considerations were given for biofilter wetland channels (with bioretention elements) facilities and included that a project would be considered infeasible where sufficient uninterrupted longitudinal flow (i.e., presence of driveways) was unavailable.

CHAPTER 3

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Appendix D: Expert Panel for the Integrated Plan

This appendix contains the information on the Expert Panel and the meeting minutes notes.

Seattle Public Utilities

Protecting Seattle's Waterways

Volume 3 – Integrated Plan

Appendix D: EXPERT PANEL FOR THE INTEGRATED PLAN

Final

May 29, 2015

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List of Abbreviations

Term	Definition
BMP	best management practice
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
City	City of Seattle
CSO	combined sewer overflow
District	Northeast Ohio Regional Sewer District
EA	environmental assessment
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
IRIS	Integrated Risk Information System
NACWA	National Association of Clean Water Agencies
NPDES	National Pollution Discharge Elimination System
USGS	U.S. Geological Survey

Background

The City of Seattle (City) worked with a five-member Expert Panel during the development of the Integrated Plan. The role of the Expert Panel was to provide input on the data, methods, and assumptions used to develop the Integrated Plan. The Expert Panel acted as a technical sounding board for the City, reviewing and commenting on technical questions and issues relevant to the methodology developed and implemented. The Expert Panel was not involved in the selection of the stormwater projects included in the Integrated Plan. The process included participating in three face-to-face meetings and three group conference calls, as well as reviewing technical materials provided by the City before and after meetings during March through October 2013. The Expert Panel summarized its notes in a letter to Ray Hoffman (see Attachment D-1 to this appendix). The observations made at each Expert Panel meeting and call were documented (see Attachment D-2 to this appendix).

Expert Panel Members

The Integrated Plan Expert Panel consists of five members appointed by Seattle Public Utilities Director Ray Hoffman. Panelists represent a diverse set of perspectives with technical expertise in the following areas:

- receiving water quality: Bob Gearheart, Ph.D., PE
- effects of urbanization on stream water quality and morphology: Derek Booth, Ph.D., PE, PG
- managing large wet weather programs: Kyle Dreyfuss-Wells
- effectiveness of best management practices (BMPs): Bob Pitt, Ph.D.
- human exposure: Jean Zodrow, Ph.D.

Bob Gearheart, Ph.D., PE, Panel Chair

Bob Gearheart is a Professor Emeritus at Humboldt State University in Arcata, California. Dr. Gearheart teaches courses in environmental impact assessment, hazardous waste management, and water quality management. Dr. Gearheart is an international expert on water quality, wetlands, and wastewater treatment. Dr. Gearheart is involved with the development of Arcata's Integrated Wetland and Wastewater Treatment Facility and the Arcata Marsh. The Arcata Marsh serves as a sewage treatment plant, recreation area, wildlife sanctuary, and aquaculture project. He is also involved with a number of public- and private-sector agencies providing support for water supply facilities in developing countries, such as Indonesia, Kenya, Ghana, and Sierra Leone.

Dr. Gearheart's area of expertise is water quality and wastewater treatment. He was included in the Expert Panel to provide input on fate and transport assumptions and water quality of local receiving waters.

Derek Booth, Ph.D., PE, PG

Derek Booth is an Adjunct Professor at the Bren School of Environmental Science and Management, University of California Santa Barbara, in Santa Barbara, California. Dr. Booth is also President of Stillwater Sciences, a 60-person environmental consulting firm in California, Oregon, and Washington. He has studied geomorphology, hydrology, and watershed management for the past 30 years. His publications include more than 40 peer-reviewed articles, 26 U.S. Geological Survey (USGS)-published geologic maps, more than a dozen book chapters, and the National Research Council's 2009 report, *Urban Stormwater Management in the United States,* which he coauthored.

His area of expertise is the impact of urbanization on streams. He was included on the Expert Panel to provide input on the effects of urbanization on stream water quality and morphology.

Kyle Dreyfuss-Wells

Kyle Dreyfuss-Wells is the Manager of Watershed Programs for Northeast Ohio Regional Sewer District (District) in Cleveland, Ohio. Ms. Dreyfuss-Wells leads the District's watershed management efforts across District programs, including implementation of the Regional Stormwater Management Program to provide innovative options to address the flooding, erosion, water quality, and infrastructure needs of the region; the application of stormwater control measures to combined sewer overflow (CSO) control through the District's green infrastructure program; and implementation of stormwater management and stream restoration projects across the District's 62 Member Communities. She is chair of the National Association of Clean Water Agencies' (NACWA) Stormwater Management Committee and Vice Chair of the Urban Water Sustainability Council of the U.S. Water Alliance.

Ms. Dreyfuss-Wells area of expertise is managing large wet weather programs. She was included on the Expert Panel to provide input on municipal wet weather management programs.

Bob Pitt, Ph.D.

Bob Pitt is the Cudworth Professor of Urban Water Systems in the Department of Civil, Construction and Environmental Engineering at the University of Alabama in Tuscaloosa, Alabama. Dr. Pitt has conducted research for the U.S. Environmental Protection Agency (EPA), Environment Canada, Ontario Ministry of the Environment, states, and local governments concerning the beneficial uses, effects, sources, and control of wet weather flows for more than 35 years. He has also been involved in a number of projects that have used this research information to develop management plans, stormwater ordinances, and design manuals. Dr. Pitt has also conducted research for the EPA to develop and test procedures to recognize and reduce inappropriate discharges of wastewaters to separate storm drainages. These procedures are being used by municipalities involved in the Clean Water Act's stormwater permit program as a field screening technique to identify and quantify discharge sources. Dr. Pitt has evaluated the effects of municipal, industrial, and nonpoint water pollution discharges on receiving water quality and beneficial uses, including model development.

Dr. Pitt's area of expertise is stormwater quality and stormwater BMPs. He was included on the Expert Panel to provide input on issues related to the effectiveness of BMPs in removing pollutants.

Jean Zodrow, Ph.D.

Jean Zodrow is a Project Toxicologist at ARCADIS U.S., Inc., in Lakewood, Colorado. Dr. Zodrow has more than 7 years of experience as a toxicologist/ecological risk assessment expert for EPA, where she prepared biological evaluations for National Pollution Discharge Elimination System (NPDES) permit reviews, managed Integrated Risk Information System (IRIS) toxicological reviews, and performed Endangered Species Act (ESA) Section 7 consultations both for oil and gas exploration and mining activities and for wastewater treatment plant discharges. Dr. Zodrow has also contributed to environmental assessments (EAs) and environmental impact statements (EISs) where impacts to water quality were critical concerns and provided oversight of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) ecological risk assessments.

Dr. Zodrow's area of expertise is exposure analysis. She was included on the Expert Panel to prove input on the exposure assessment.

Expert Panel Recommendations

During the project calls and meetings, the Expert Panel provided input on the City's data, methods, and assumptions. The observations made at each Expert Panel meeting and call were documented in meeting summary notes (see Attachment D-2 to this appendix). The Expert Panel summarized these notes in a letter to Ray Hoffman (see Attachment D-1 to this appendix). One of the recommendations regarding utility curves was not applicable to the Integrated Plan. This is explained in Attachment D-3 to this appendix.

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Attachment D-1: Expert Panel Comments and Recommendations Letter

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November 12, 2013

Ray Hoffman, Director
Seattle Public Utilities
700 Fifth Avenue, Suite 4900
PO Box 34018
Seattle, WA 98124

Subject: Expert Panel Comments and Recommendations on the Integrated Plan

Dear Mr. Hoffman:

Thank you for providing us the opportunity to participate in the Expert Panel for Seattle Public Utilities' (SPU) Integrated Plan. We appreciate the opportunity to provide technical input on the methodology that SPU is planning to use for its Integrated Plan. This plan will be submitted to the U.S. Environmental Protection Agency and the Washington State Department of Ecology as part of SPU's Long Term Control Plan (LTCP) for controlling combined sewer overflows (CSOs). The Integrated Plan is an important effort for the City of Seattle (City). It allows the City to evaluate the relative water quality benefits of a variety of alternative stormwater and CSO control projects. Based on this evaluation, the City is planning to request from its regulators the ability to invest in projects that will likely produce significantly better water quality outcomes for the community while meeting or exceeding the overall intent of regulatory requirements.

Role of the Expert Panel and the Integrated Plan Option in the City's Consent Decree

Our role as the Expert Panel was to provide input on the data, methods, and assumptions that SPU is using to develop the Integrated Plan. We acted as a technical sounding board for SPU, reviewing and commenting on technical questions and issues relevant to the methodology. We did not, however, review or comment on SPU's potential decisions about final project selection. Our process included participating in three face-to-face meetings and three group conference calls, as well as reviewing technical materials provided by SPU before and after meetings. The observations that we made at each of the Expert Panel meetings and calls were documented in summaries of those meetings (attached).

As outlined in the City's consent decree, which was lodged on July 3, 2013, the City may propose alternative water quality improvement projects (stormwater projects) in the Integrated Plan that will result in significant benefits to water quality beyond those that would be achieved by implementing the approved CSO control measures only. The City would proceed with these stormwater projects and defer selected CSO control measures that it determined would result in significantly less benefit to water quality than would the stormwater projects. The CSO control measures selected for deferral are referred to as "low-benefit CSO control measures." If the Integrated Plan is approved, the City would defer implementation of these low-benefit CSO control measures until after 2025 and then implement both the stormwater projects proposed in the Integrated Plan and the higher benefit CSO control measures in the LTCP by 2025. Regardless of the stormwater and CSO control projects the City implements, the City must meet Clean Water Act and Washington Water Pollution Control Act requirements.

We understand that the City has a long history of CSO and stormwater control research and implementation, and that SPU has controlled most of the CSO volumes under its jurisdiction. Seattle has reduced its annual CSO discharge volumes by more than 99 percent, from an estimated 20 to 30 billion gallons in the 1960s to 154 million gallons in 2012. SPU also has a stormwater management program that manages 6,400 million gallons per year of runoff volume. This history of CSO and stormwater control research and implementation in the City provides context for understanding the range of alternatives that SPU is considering for the Integrated Plan.

Work Completed on the Integrated Plan and Discussed with the Expert Panel

Our understanding is that SPU and the Integrated Plan consultant teams have completed the following work to date on the Integrated Plan:

- Identified low-priority CSO control projects that address low-volume, low-frequency CSOs (i.e., nearly controlled) to consider for deferral in the Integrated Plan.
- Identified potential stormwater pollution control projects to consider for inclusion in the Integrated Plan through a process that examined receiving water body rankings, pollutant and flow estimates, and the cost-effectiveness of different treatment alternatives within each basin.
- Selected representative constituents of concern (RCOCs) for the pollutants identified in the consent decree.
- Estimated the pollutant load reductions that would be attained from the CSO projects to be deferred using calibrated hydrologic and hydraulic models of the combined sewer system.
- Estimated the pollutant load reductions that would be attained from the stormwater projects (other than street sweeping) based on information about volume, land use, and best management practice effectiveness.
- Developed estimates of pollutant load reductions from street sweeping projects based on information about pickup rates and sample concentration data from past sweeping efforts, anticipated curb-miles swept, and local studies about washoff pollutant loads and concentrations.
- Conducted a relative assessment of the effects of the stormwater and CSO projects on exposure to ecological receptors and exposure to human health receptors (considering acute exposure to bacteria separately from chronic exposure to toxic pollutants).
- Identified criteria—including criteria for positive environmental outcomes, social good for the community, external drivers, technical feasibility, and life-cycle cost—to use to evaluate projects through multi-objective decision analysis (MODA) to select the final set of stormwater and CSO projects in the Integrated Plan.

Observations and Recommendations

Based on the information provided to us, our major observations about the Integrated Plan methodology, data, and assumptions include the following:

- The results of SPU's analysis show that the stormwater projects SPU is considering for the Integrated Plan, in part or in whole, provide significant net benefits to receiving water quality compared to the CSO projects SPU may propose to defer.
    - The considerable difference in discharge volume reductions of the stormwater projects compared to the CSO projects drives much of these benefits.
    - We believe SPU can create a set or sets of stormwater projects that yield significantly better water quality outcomes than the set of CSO projects to be deferred, even though any individual CSO project to be deferred may provide modestly greater benefit for one or a few of the water quality parameters relative to one or a few of the individual stormwater projects.
- SPU has based its methodology for the exposure assessment on standard procedures for ecological risk assessment, and enhanced those procedures based on project-specific data and assumptions relevant to the task of creating relative exposure assessments. We explored this methodology in some detail in our meetings, and believe it is reasonable but operationally complicated. The complexity derives from the number of assumptions and subjective scaling factors that are necessary to incorporate the available data and conduct a relative assessment of the effects of the proposed projects on exposures to ecological and human receptors.
- We reviewed SPU's methodology for estimating the pollutant load reductions from street sweeping projects specifically, and believe that SPU's approach to the methodology, use of data, and assumptions is reasonable. We also believe that it is important for SPU to characterize the uncertainty in its estimates for street sweeping projects.
- In SPU's analysis of the differential benefits from projects, we believe it is important to consider not only the magnitude of pollutant load reduction benefit or exposure reduction benefit from projects, but also the importance of those changes. For example, depending on how ranges are normalized in the analysis, changes that occur at or near ecological and/or human health thresholds could appear to be equivalent to similar magnitude changes that occur far from those regulatory thresholds, even though the relative "importance" of those changes differs.
- We appreciate that SPU has highlighted areas of uncertainty and data gaps in its analysis thus far. We believe it will be important to appropriately document these data gaps, areas of uncertainty, and confidence intervals in the Integrated Plan and supporting materials.
- Overall, we feel that SPU and the consultant team used an innovative, scientifically sound, and understandable approach to evaluating stormwater and CSO projects in the Integrated Plan according to the consent decree requirements, and that this approach has thus far produced results that are defensible and reasonable.

- We also believe that future integrated planning processes in other jurisdictions need not be as extensive, exhaustive, or complicated as this to make these types of decisions. However, because SPU is leading nationally on integrated planning, we agree that such a robust approach was worthwhile here.

Our recommendations to SPU for the Integrated Plan include the following:

- While it is important to articulate the uncertainty inherent in an analysis such as SPU has done, the focus on uncertainty should not obscure the overall message that the stormwater projects to be proposed in the Integrated Plan are expected to produce significantly greater reductions in pollutant loads and exposures to human and ecological receptors than the CSO projects to be deferred.
- In the final selection of stormwater projects for the Integrated Plan, we understand that SPU is considering the tradeoffs between potentially competing objectives through a systematic multi-objective decision analysis (MODA) process. We believe that this analysis would be stronger if it incorporated the concept of utility curves, which would allow normalization of the units and which would consider non-linear cause-and-effect relationships in the MODA criteria. If SPU does not choose to use utility curves in this analysis, it should document its rationale for this decision.
- Post-construction monitoring of the performance of the CSO and stormwater projects in the Integrated Plan will be important to demonstrate the projects meet consent decree requirements. SPU should also use post-construction compliance monitoring to address uncertainties and data gaps in its analysis and add to the stock of knowledge associated with the stormwater best management practices, including street sweeping. Performance monitoring of areas likely to be affected by the planned CSO and stormwater projects should begin as soon as feasible to provide a useful "before implementation" baseline for subsequently evaluating project effectiveness.

Upon reflection about the transferability of this approach to other jurisdictions that are considering the development of an Integrated Plan, we offer the following observations:

- The analysis that SPU and its consultant team conducted was applied to a specific set of high-value stormwater projects compared to a specific set of low-priority (low-frequency/low-volume) CSO projects. This set of projects was specific to Seattle, but a different suite of CSO and stormwater projects, both in Seattle and in other communities, would not necessarily demonstrate similar anticipated water quality benefits. As a result, communities across the country can learn a great deal from the structure of SPU's analysis but must realize that the implementation in each community will be specific to their unique history, land use, governance, and other factors.
- While it is important to carefully examine and document the comparative water quality benefits of CSO and stormwater projects through Integrated Planning processes, we do not believe that other communities will necessarily need to conduct the same level of analysis or data utilization to demonstrate differences in anticipated water quality benefits. In particular, the data analysis should not need to be as complicated, exhaustive, or costly to make these types of decisions about the comparative water quality benefits of projects. It may also be appropriate for other communities to

evaluate significant benefits differently, such as by considering co-benefits from stormwater projects and/or the cost-effectiveness of projects.

- The MODA criteria will always be jurisdiction-specific and should not be "exported" elsewhere without careful consideration of their local applicability and need. Excess attention to these ancillary considerations may risk losing sight of the primary purpose of an Integrated Plan, namely to achieve greater improvements in water quality more rapidly and at reduced cost.

We look forward to hearing how SPU uses the methodology we have reviewed to select projects for the Integrated Plan and to document how the projects meet the consent decree requirements. Please keep us informed as SPU selects stormwater and CSO projects for the Integrated Plan and as the LTCP and Integrated Plan go through review by the regulatory agencies.

We appreciate the opportunity to assist SPU in its development of the technical methodology for its Integrated Plan.

Sincerely,

Robert Gearheart, Ph.D., P.E., Chair
Professor Emeritus, Humboldt State University, Arcata, CA

Derek Booth, Ph.D., P.E., P.G.
Adjunct Professor, Bren School of Environmental Science and Management, University of California Santa Barbara, Santa Barbara, CA

Kyle Dreyfuss-Wells
Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH

Robert Pitt, Ph.D., P.E., BCEE, D.WRE
Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL

Jeanmarie Zodrow, Ph.D.
Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO

CC: Nancy Ahern, Deputy Director, Utility Systems Management, SPU
Andrew Lee, CSO Program Manager, SPU
Kevin Buckley, Integrated Plan Project Manager, SPU

Enclosures

Attachment D-2: Expert Panel Meeting Summaries

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Seattle Public Utilities Integrated Plan Expert Panel
Meeting (Call) #1, March 14, 2013
Call Summary

Call Objectives

- Review and clarify the purpose and responsibilities of Expert Panel members
- Answer questions about SPU's Stormwater and CSO Programs and the Integrated Plan option in SPU's Consent Decree
- Discuss the scope of the Expert Panel's discussions, including questions the Expert Panel will be asked to consider
- Review upcoming meeting plans and identify next steps

Summary

Opening Remarks

- Kevin Buckley of Seattle Public Utilities (SPU) welcomed members of the Expert Panel. He described the importance of the Integrated Plan as an opportunity for Seattle, and noted that the methodology also could be used to evaluate stormwater projects in the future.
- Bob Gearheart, the Expert Panel chair, also welcomed the group and thanked members for their participation.

Schedule for the Expert Panel and Integrated Plan

- The Integrated Plan is being developed along with the combined sewer overflow (CSO) Long Term Control Plan (LTCP), a draft of which is due to EPA and the Washington State Department of Ecology in May 2014 (final in May 2015).
- The Integrated Plan has a similar process to the LTCP and the same final deadlines but the work on the Integrated Plan started much later.
- During the development of the LTCP and Integrated Plan SPU is doing quarterly updates with EPA and the Washington Department of Ecology as well as public outreach and engagement activities.
- The Expert Panel will be meeting at least three more times this summer and fall, as follows.
    - **Expert Panel Meeting #2 (April 29, in Seattle):** This meeting will include a review and discussion of the pollutant estimating methodology and a discussion of how SPU is planning to use the existing data in its analysis.
    - **Expert Panel Meeting #3 (June, in Seattle):** This meeting will feature a discussion of the technical evaluation criteria SPU plans to use in the Multi-Objective Decision Analysis (MODA).
    - **Expert Panel Meeting #4 (September, potentially via web-enabled teleconference):** This meeting will review and discuss how SPU has evaluated selected CSO and stormwater projects using the technical evaluation criteria.

Expert Panel Charter Discussion

- Facilitator Bill Ross reviewed the main components of the Draft Charter for the Expert Panel with the group, including the focus on providing input on the technical methodology and data for estimating the environmental benefits from CSO and stormwater projects. SPU will be using the technical methodology, along with other factors (such as cost benefit), to make decisions about stormwater projects to include in the Integrated Plan and which CSO projects to defer.
- He noted that the objective for this group is not consensus, since the Expert Panel won't be making decisions; however, to the extent that panel members differ in their views, these will be recorded.
- Expert Panel meetings will be open to members of the public.
- The Expert Panel members did not have any questions or concerns about the charter.

Questions about SPU's Stormwater and CSO Programs, and the Integrated Plan

- Trish Rhay of Seattle Public Utilities thanked the Expert Panel members for their participation and the opportunity to help Seattle potentially develop the first Integrated Plan in the nation.
- She said that she hoped the Integrated Plan would help SPU work in all areas of its system—the combined sewer system, the fully separated system, and the partially separated system, each of which represents a third of the geographic area of the city.
- The Expert Panel asked questions of SPU about the background video presented by Trish Rhay and SPU's consent decree. The responses were as follows.
  - **LTCP and Integrated Plan Approach:** In the LTCP, SPU must control overflows to one overflow event per outfall per year by 2025. With the Integrated Plan, the compliance deadline for getting some CSO outfalls to meet that one overflow per year state standard can be later, and it allows SPU to invest in stormwater projects that will provide greater water quality benefits before 2025. It does not change the level of control (quality or frequency) for CSOs, only the compliance schedule.
  - **Deferred CSO Projects:** SPU will still implement the highest priority CSO projects, including the "big three" on Lake Washington. There are 5-10 projects that are being considered for deferral in the Integrated Plan.
  - **Relation of Stormwater and CSO Projects in Integrated Plan:** The consent decree does not specify the relationship of the deferred CSO projects and the stormwater projects in the Integrated Plan (e.g., proximity, receiving water body).
  - **Expert Panel Not in Consent Decree:** The Expert Panel is not mentioned in the consent decree. It was SPU's idea to have an Expert Panel to provide a check on the methodology for showing the difference in environmental benefit between projects.
  - **Stormwater Project Parameters:** The stormwater projects will not have to meet specific parameters. SPU is focusing on projects that will show the significant relative difference in pollutant loading reductions between the deferred CSO projects and the stormwater projects, as well as other requirements in the consent decree.

Scope of the Expert Panel's Discussion – Review of Questions for the Panel

- The Expert Panel reviewed and discussed the document, "Questions for the Expert Panel," and the section of SPU's consent decree that focuses on the Integrated Plan, pages 15-19. Highlights of this discussion include:

- The key pollutants and parameters for which the Expert Panel will be advising SPU on how to evaluate CSO and stormwater projects on are listed on page 16 of the consent decree.
- For some of these pollutants (e.g., toxic organic compounds), the data are not available, so it will be necessary to identify appropriate surrogates.
- Several of the Expert Panel members indicated an interest in a presentation on MODA. Some indicated experience using MODA, but not commercial software for it.
- The regulatory agencies will be briefed about the MODA analysis and the Expert Panel's work as part of the quarterly meetings. They also will be invited to the Expert Panel meetings and likely will follow the Expert Panel's discussions closely.
- Expert Panel members noted that the transparency of the Expert Panel process to the regulatory agencies and the public will be very important.

Next Steps

- The **next Expert Panel meeting** will be on **Monday, April 29, 2013,** in Seattle.
  - The materials for the April meeting will include a summary of the available data and how it will be used in the evaluation methodology.
  - Materials for meetings will be provided to Expert Panel members at least a week in advance to allow for review.
  - If panel members have questions about materials they'd like to have addressed, please let the facilitation team (Bill Ross or Jennifer Tice of Ross Strategic) know, so we can ensure that the appropriate technical staff are present at the meeting.
- The June and September Expert Panel meetings will be scheduled soon.
- A briefing on MODA will be scheduled for sometime before the June meeting.

Participants

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Humboldt State University (Professor Emeritus)
Derek Booth	University of California Santa Barbara
Kyle Dreyfuss-Wells	Northeast Ohio Regional Sewer District
Bob Pitt	University of Alabama
Jean Zodrow	ARCADIS U.S., Inc.
Other Participants	
Kevin Buckley	Integrated Plan Project Manager, Seattle Public Utilities
Trish Rhay	Drainage and Wastewater Division Director, Seattle Public Utilities
Mike Milne	Brown and Caldwell
Eric Strecker	Geosyntec Consultants
Bill Ross	Ross Strategic
Jennifer Tice	Ross Strategic

Seattle Public Utilities Integrated Plan Expert Panel
Meeting #2, April 29, 2013
Meeting Summary

Participants

The second meeting of Seattle Public Utilities (SPU) Integrated Plan Expert Panel was attended by the five Expert Panel members, SPU managers and staff, consultants, and observers. The audience consisted largely of SPU staff and technical consultants. A full list of attendees is at the end of the summary.

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
Derek Booth	Adjunct Professor, Bren School of Environmental Science and Management, University of California Santa Barbara, Santa Barbara, CA
Kyle Dreyfuss-Wells	Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH
Bob Pitt	Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL
Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Kevin Buckley	Integrated Plan Project Manager, SPU
Ray Hoffman	Director, SPU
Trish Rhay	Drainage and Wastewater Division Director, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic

Meeting Objectives

The objectives for the Expert Panel meeting included:

- Review and gather Expert Panel feedback on SPU's proposed methodology for evaluating the potential water quality impacts of stormwater and combined sewer overflow (CSO) projects, including whether it seems appropriate given the consent decree requirements and available data.
- Collect Expert Panel feedback on proposed approaches to using data in the methodology, including proposed metrics and representative constituents of concern for evaluation.
- Identify additional available data or data sources that could help SPU and the technical team to refine and improve the proposed methodology and analysis of stormwater and CSO projects.
- Review upcoming meeting plans and identify next steps.

A summary of the meeting discussions, organized by the agenda topic, is below. Key themes from the meeting are not attributed to individuals, but comments pertaining to individual sessions are attributed.

Summary

Opening Remarks

- SPU Director Ray Hoffman welcomed the Expert Panel and thanked members for their participation. He described the challenges Seattle is facing, including stormwater runoff, CSOs, climate change, urban streams, and a landscape that is 65 percent impermeable surfaces.
- He noted that SPU had just signed its consent decree, and has an opportunity to do an Integrated Plan, which could potentially be a model for other jurisdictions. He said the Expert Panel would be important in helping SPU with the Integrated Plan.

Key Themes from the Expert Panel's Comments

Throughout the meeting, Expert Panel members commented on SPU's proposed methodology for evaluating stormwater and CSO projects, including the use of available data and the multi-objective decision analysis (MODA) process. The following were key themes from these comments and notes about SPU's responses (individual comments and responses are also included later in the summary):

- SPU should provide information on the process and criteria it used to identify projects for consideration for the Integrated Plan, including any "fatal flaw" screening criteria and the locations of projects, as this is an important part of the project evaluation.
  - <u>SPU Response:</u> The Integrated Plan team is preparing a memorandum on the selection criteria that were used to help the team identify projects for consideration as part of the Integrated Plan. In general, the criteria were developed to help the team identify a list of potential projects that would meet the objectives established by the Integrated Plan, focus on receiving water bodies with water quality impairments, fit into the existing built-out environment, and provide reasonable assurance that the list of potential projects can be constructed by 2025.
- It is not clear how SPU plans to consider and evaluate benefits from projects other than pollutant load reductions and other criteria listed in the consent decree. Expert Panel members recommended that co-benefits from projects, including habitat improvements, be considered. Furthermore, some Expert Panel members expressed concern that the proposed methodology for the CSO and stormwater project evaluations could become a matter of "dueling spreadsheets" and might ignore other important factors that do not lend themselves well to quantitative comparisons.
  - <u>SPU Response:</u> Benefits in addition those identified in the Consent Decree will be considered as part of the MODA that SPU will use to help inform the decision process for selection of stormwater projects to propose and the identification of CSO projects to defer in the Integrated Plan. SPU will be discussing these benefits and the technical criteria for the MODA evaluation of stormwater and CSO projects with the panel members at the June 25th meeting.
- Verification monitoring, including pre-project monitoring and monitoring of receiving water quality, is important to show whether projects achieve their goals and to reduce uncertainties.
  - <u>SPU Response:</u> SPU will consider this input as it plans the monitoring that will be proposed as part of the Integrated Plan. Monitoring for the Integrated Plan will include a post-project monitoring plan.

- It is important that the proposed metrics match the projects (both CSO and stormwater) that are being considered, and that the proposed analytic methods match the data being evaluated (e.g., the nomographs relate to the devices).
  - SPU Response: SPU agrees that the proposed metrics for evaluating CSO and stormwater projects should be appropriate for both types of projects. The purpose of the nomograph approach is to bracket the (hydrologic and hydraulic) performance of best management practices (BMPs). The nomographs are one way to represent the uncertainty in performance expected in modeling. The performance range for the nomographs will be geared to the BMPs being considered.
  - Care must be given to how these performance ranges are used in generating output that will then be compared with the metrics. The list of proposed metrics will be refined in the coming weeks as the technical team better understands the data going into the model and the stormwater projects being considered versus the CSO projects. For example, a stormwater project is usually designed to capture higher frequency, low-intensity storm events while a CSO project is designed to capture low frequency, but higher intensity storm events, so simply comparing reduced frequency of occurrence between the two types of projects is not a fair comparison. Other metrics may be considered, such as volume reduction or phosphorus reduction, as more appropriate comparisons between projects. SPU and the technical team will update the Expert Panel as this list of metrics is refined.

Overview of Approach to CSO and Stormwater Project Evaluation

- Mike Milne of Brown and Caldwell and Kevin Buckley of SPU gave a presentation that provided an overview of SPU's approach to the evaluation of CSO and stormwater projects in the Integrated Plan. This included:
  - The consent decree requirements for analyzing pollutant load reductions and describing reductions in exposure
  - The process SPU used to prioritize receiving water bodies for the purpose of selecting locations for stormwater projects
  - The overall evaluation process, from the ranking of water bodies and selection of candidate stormwater and CSO projects to the analysis of those projects and alternative combinations using the multi-objective decision analysis (MODA) process
  - An overview of the work completed to date to compile data and develop evaluation methods
- SPU manages a stormwater system that has 6,400 million gallons of stormwater runoff annually, and a combined sewer system that discharged 154 million gallons of CSOs in 2012.

Expert Panel Comments and Responses

Scope/Criteria for the Project Evaluation:

- Derek Booth and Bob Pitt asked whether the project evaluation was only focused on pollutant loads. Derek Booth expressed concern that the analysis would only cover chemical loads rather than other benefits such as habitat improvements from stormwater projects. Kyle Dreyfuss-Wells added that many of those other benefits are not part of the consent decree.

    - Mike Milne and Rob Annear of the technical team responded that pollutant loads are important, but SPU would also look at exposure, frequency, duration, flow, volume, and other issues.
- Kyle Dreyfuss-Wells noted that co-benefits from stormwater projects need to be considered as part of the analysis.
- Bob Gearheart asked about the relationship of the pollutant load evaluation and Total Maximum Daily Loads (TMDLs).
    - Technical team members noted that the pollutant load evaluation of projects for the Integrated Plan is separate from looking at the assimilative capacity of water bodies; however, the Integrated Plan analysis (and associated information from the Integrated Plan) could help with TMDL efforts in the future.

<u>Comments on the Basin Ranking and Criteria:</u>

- Bob Pitt asked whether the technical team had considered locations where there had been a lot of work done already.
    - SPU acknowledged that although most of the "low-hanging fruit" for CSO control had already been addressed, SPU did not consider prior project work in the ranking of basins and initial selection of projects.
- Jean Zodrow asked why certain salmon-bearing streams were rated as not applicable in the basin ranking results.
    - SPU clarified that the ranking focused on federally listed threatened and endangered species, which wouldn't capture the problems with pre-spawn mortality of coho salmon since coho salmon aren't a listed species in Seattle.
- Derek Booth noted that the fishable/swimmable criterion for the basin ranking is dependent on the other criteria, rather than a fully separate criterion.

<u>Comments on Stormwater Projects Being Considered and the Comparison to CSO Projects:</u>

- Kyle Dreyfuss-Wells expressed concern about how CSO and stormwater projects were being compared, and noted that it is important that stormwater projects are not asked to solve all issues associated with a watershed.
- Bob Pitt commented on the Consent Decree standard for showing that the stormwater projects are "significantly better" than the CSO projects that will be deferred.[1] He said most communities only need to show that the projects are equivalent or better. Moreover, SPU will also need to consider uncertainty.
- Kyle Dreyfuss-Wells asked about the relationship of the types of stormwater projects SPU is considering and green stormwater infrastructure.
    - SPU noted that green infrastructure (natural drainage solutions) is part of the city's code.
    - Eric Strecker of Geosyntec and Beth Schmoyer of SPU said that many of the solutions are not "green" in part because they occur in areas where there is contaminated sediment, and the Consent Decree has standards for meeting pollutant load removals such as PCBs.

[1] The consent decree language pertaining to this comment is as follows: "the City may submit…a work plan ("Integrated Plan") that proposes water quality improvement project(s) ("Proposed Project") to be implemented by the City, provided that the Proposed Project(s) will result in significant benefits to water quality beyond those that would be achieved by implementation of the approved CSO Controls Measures only."

Terminology and Definitions:

- Bob Pitt recommended that SPU be specific about its terminology and definitions.
    - Based on this comment, SPU and the Integrated Plan team have begun preparing a glossary to address this need.

Discussion of Representative Constituents of Concern for Evaluation and Proposed Metrics for Technical Comparison of Stormwater and CSO Projects

- Eric Strecker of Geosyntec provided an overview of the proposed representative constituents of concern (RCOCs) for evaluation, the data compiled on the RCOCs, the extent of stormwater characterization data and the gaps in that data, and potential metrics to use in comparing stormwater and CSO projects.
    - The stormwater characterization data is from three sites in Seattle with different land uses.
    - He noted that the technical team was continuing to analyze the data it had received. In some cases, the technical team had not yet determined how much data is above detection levels.
    - The technical team is still evaluating appropriate constituents to measure for certain RCOCs, including oil and grease, pesticides, and PBDEs.
    - The candidate metrics for evaluation presented in this session did not include the metrics for the exposure assessment.
- In response to a question, SPU clarified the relationship of SPU's and King County's stormwater and wastewater systems, noting that both agencies have CSOs within the city of Seattle, SPU has responsibility for the majority of stormwater pollution control (for all but two stormwater basins where SPU and King County have MOAs), and SPU's wastewater collection system feeds into King County's regional wastewater treatment system.
- SPU reported that Ecology has recently changed the NPDES Municipal Stormwater permit requirement for monitoring from end-of-pipe monitoring to a regional, Puget Sound-wide monitoring of receiving waters, including marine nearshore and second order streams. Municipalities across Puget Sound (NPDES Phase I and Phase II) pay in to the regional monitoring. The sites were selected randomly across Puget Sound, and this has meant that there is only one site in Seattle.
- Members of the technical team noted that metrics for evaluation could consider peak events, and benefits such as how stormwater projects could reduce peak load and reduce floods.

Expert Panel Comments and Responses

Monitoring:

- After learning about SPU's monitoring of receiving waters, Bob Pitt commented that it would have been better if SPU had conducted monitoring that could show a connection between water quality in the pipes and in the receiving waters.
    - Jonathan Frodge of SPU noted that the best data showing increased body burden of pollutants associated with stormwater are from the National Mussel Watch Contaminant Monitoring program.
- Bob Pitt recommended that SPU start pre-project monitoring soon, and said that verification monitoring was critical.

Comments on RCOCs:

- Bob Pitt cautioned against using five-day biological oxygen demand (BOD) to evaluate stormwater projects, as the analytical method can give distorted results. This is particularly a problem for measuring dissolved oxygen in sediments. The ultimate BOD (or also looking at the chemical oxygen demand, COD) is more accurate than the five-day measure.
    - Based on this comment, Geosyntec will further investigate how to characterize BOD when ultimate BOD was not measured but five-day BOD was included in the sampling events. There are a few alternatives to address this issue.

Comments on Candidates for Comparison Metrics:

- Bob Gearheart and Kyle Dreyfuss-Wells asked about the sediment issues that were being considered. Legacy sediments will be mobilized in different runoff events.
    - Eric Strecker said that the evaluation is considering both minimizing recontamination of remediated legacy sediment sites and reducing new sediment loads. The idea is that retrofitting an area will reduce or prevent mobilization of certain sediments.
- Kyle Dreyfuss-Wells noted that it is important for there to be a connection between the projects and the metrics that will be used to evaluate them. It was not clear that some of the projects would have the types of benefits listed. Many of the CSO projects would not have the benefits.
- Derek Booth commented that the "frequency of untreated discharges" metric did not seem appropriate for stormwater projects, and therefore it was not useful for comparing CSO and stormwater projects. He said the benefits from projects come from attributes other than frequency of discharges, and that it would be disingenuous to consider green stormwater infrastructure as "treatment."
    - Eric Strecker said that the technical team would work on that metric. He mentioned that one attribute they were considering was volume reduction.

Discussion of Pollutant Estimation Methodology for Stormwater and CSO Projects

- Rob Annear of Geosyntec gave a presentation on the proposed methodology for estimating pollutant loads from stormwater projects. His presentation covered:
    - Understanding baseline conditions and developing a pollutant load model to estimate average annual runoff volumes, pollutant loads, and pollutant concentrations
    - The stormwater structural projects and programmatic measures SPU is considering in the Integrated Plan evaluation
    - The process proposed for estimating and evaluating the expected performance of stormwater projects, factoring in conceptual design parameters, variability, and uncertainty
- He noted that the technical team proposes using pre-processed nomographs for evaluating hydrology and hydraulics (H&H) performance, where possible, rather than facility-specific models.
- Justin Twenter of Brown and Caldwell presented on the technical team's proposed methodology for estimating pollutant loads from CSO projects. His presentation covered:
    - The CSO projects SPU is considering to defer as part of the Integrated Plan
    - Information on the CSO basins from modeling conducted for the long-term control plan (LTCP)
    - Four potential approaches for evaluating deferred CSO projects: source area evaluation, land-use evaluation, CSO characterization, and/or a hybrid approach

- The 10 potential CSO projects to defer would reduce out of compliance volume by 10 million gallons per year on average.
    - SPU is doing an environmental impact statement, which will describe the potential impacts of the projects. In general, they will involve local disturbance during construction. For example, SPU needs to find seven storage tanks to control four million gallons of overflow in a waterfront area of Seattle. Green infrastructure projects also can be disruptive (e.g., to parking).
    - The 10 CSO projects represent about 20 percent of the projects in the long-term control plan.
- Trish Rhay of SPU noted that without the Integrated Plan, all the CSO projects would have to be built by 2025, for a cost of $500-$550 million. With the Integrated Plan, SPU can propose to defer some of those CSO projects, proposing other completion dates, and then implement stormwater projects between now and 2025 that could provide greater water quality benefits. SPU is assuming that these stormwater projects would be done without increasing the cost through 2025.
- SPU staff and the technical team noted that because of the requirements of the consent decree for the Integrated Plan, SPU would need to evaluate the CSO projects being considered for deferral according to additional water quality parameters.
- There is not much public reaction to CSOs in Seattle, which mostly occur in the winter. SPU and King County have a website that shows where CSO outfalls are and when they are overflowing.
- Overflows are evaluated on a 20-year rolling average, so if there are 21 overflows at one site in 20 years the CSO is in violation of the one overflow per outfall per year standard. Seattle's NPDES permit is on a five-year window.

Expert Panel Comments and Responses

<u>Selection of Projects for Consideration:</u>

- Derek Booth commented on the projects that SPU had selected for consideration for the Integrated Plan, and asked for more information about the process SPU used to get to the initial list. He thought the Expert Panel could have provided input on that phase of the evaluation.
    - Kevin Buckley of SPU explained that SPU's process for identifying stormwater projects included prioritizing the basins and looking at the goals for the water bodies, evaluating technologies and green infrastructure options for meeting the goals, estimating the cost per weight of total suspended solids (TSS) removed for the potential solutions, and reviewing the options with management. He noted that SPU selected a list of stormwater projects for the Integrated Plan evaluation that went far beyond the number needed for the Integrated Plan, in order to ensure that there would be a healthy menu of options to evaluate, while not being an overly exhaustive list that would be too time consuming to optimize.
- Kyle Dreyfuss-Wells and Bob Pitt asked about whether the projects were limited to those that were under SPU's control or whether they could include projects with private landowners. In Kansas City, the efforts with private land were done simultaneously to those on public land.
    - Kevin Buckley and Tracy Tackett of SPU said that there were some constraints on the projects selected, since SPU needed to have assurance that the projects will be completed for the Consent Decree. One of the stormwater alternatives focuses on retrofitting neighborhood blocks for natural drainage; this focuses on the right-of-way, but it could be expanded to include the RainWise program, which affects private property.

- Bob Pitt asked about the street sweeping projects planned, and noted that the current street sweeping efforts could be evaluated for their effects on receiving water quality.
    - Shelly Basketfield of SPU described Seattle's street sweeping program, and that the projects being considered for the Integrated Plan would increase both the frequency of sweeping and the coverage. SPU is evaluating whether street sweeping is cost-effective in areas that do not have curbs.
    - Beth Schmoyer of SPU noted that SPU did a mass balance analysis for the street sweeping pilot in 2007-08, but acknowledged the utility does not have stormwater monitoring data.
- Kyle Dreyfuss-Wells asked why green stormwater infrastructure (GSI) / natural drainage solutions were considered part of the CSO projects, not the stormwater projects.
    - SPU staff said that the GSI projects are viewed differently depending on where they are in the system. Within the CSO area, GSI projects can reduce the volume of CSO overflows or the size of CSO storage facilities.
- Kyle Dreyfuss-Wells also asked whether the City's stormwater monitoring basins contain any stormwater treatment BMPs that could reduce pollutant concentrations in the samples.
    - Kevin Buckley of SPU replied that the monitored basins have minimal BMPs.
- Bob Pitt suggested that it would be important to know where the potential deferred CSO projects are, and how that relates to where benefits might be gained through stormwater projects. Derek Booth expressed doubt about whether regulators would see a pound of pollutant reduced in Pipers Creek as equivalent to a pound of pollutant reduced in Lake Washington, even though the Consent Decree is not explicit on this issue.
- Bob Pitt, Bob Gearheart, and Derek Booth commented on the high proportions of groundwater shown in the delineation of flow source areas for CSO basins.
    - Ed Mirabella of SPU noted that the "groundwater" included inflow and infiltration (I&I), and the numbers were from CSO events.
    - Bob Pitt said that the numbers imply that SPU needs to do more than just address surface water, including I&I reduction efforts. He also asked whether there was any way to validate the constituents in the groundwater.
    - Derek Booth recommended comparing the modeled groundwater flows for the CSO basins to the groundwater table.

<u>Comments on Proposed Process for Evaluating Projects:</u>

- Bob Pitt noted that a potential problem with nomographs is that they assume a certain device. It is therefore important to include a step to verify that the device fits within the range of data.
    - SPU and the technical team agree with the comment. Nomographs can be very general or made more site- and device-specific. The team will make sure that either the nomographs are specific to the performance range for a site or will be verified afterwards if a more general nomograph has been used.
- Bob Pitt said that SPU has an opportunity to reduce uncertainty by incorporating water quality monitoring into projects so that SPU can evaluate whether the projects achieve their expected benefits. He also observed that SPU doesn't have baseline data for the projects.

  - Kevin Buckley said that SPU would be doing post-construction monitoring of the stormwater projects, as it does with CSO projects. However, he acknowledged that this monitoring is tied to the projects, not to the receiving water bodies.
  - Bob Pitt suggested considering small-scale intensive demonstration projects that are monitored intensively, such as a drainage area of a watershed that is intensively retrofitted as compared to an area that is not retrofitted. Once you have confidence in the drainage area, then you may understand more about the receiving water body.
- Bob Gearheart asked whether it might be possible to focus projects in one watershed so that success could be more easily demonstrated, rather than dispersing the projects.
- Reacting to the example metric for the project evaluation, Derek Booth expressed concern that the comparison of projects could overlook ancillary benefits from projects by focusing on metrics that can be easily compared in spreadsheets. Jean Zodrow added that it would be important to tie all the benefits together and not just focus on pollutant loads.
  - Rob Annear mentioned that SPU and the technical team welcome suggestions for other ways to compare projects, such as effects on habitat.
- Bob Pitt noted that cost (capital cost, land cost, opportunity cost) is another factor that will need to be built into the decision analysis.
- Kyle Dreyfuss-Wells observed that “gray” infrastructure projects could have much greater impacts during construction compared to “green” infrastructure projects. Bob Pitt added that green infrastructure projects are also disruptive, but the disruption is often smaller and for a shorter time.
  - Ed Mirabella of SPU and Jennifer Price of CH2M HILL noted that community reactions to disruption from green and gray CSO/stormwater projects has varied in Seattle, and some neighborhoods have had more issues with green infrastructure projects than CSO storage tanks.

Receiving Water Exposure Assessment Methodology Discussion

- Rick Pleus of Intertox gave a presentation on the proposed exposure assessment for the Integrated Plan, which would look qualitatively at the hazard (toxicity) and the exposure for both human and ecological receptors.
  - This methodology can be used to compare projects, as well as to compare “before” and “after” conditions associated with projects, for the RCOCs discussed earlier.
  - While the initial approach to the Exposure Assessment methodology has been developed, SPU and the technical team will refine the methodology for the Exposure Assessment after SPU reviews the quality and quantity of the data relevant to the assessment. The key parameter at this point is the concentration of a relevant RCOC.

Expert Panel Comments and Responses

Comments on RCOCs and Data Gaps:

- Jean Zodrow observed that it seemed as though SPU did not have good data for some constituents, such as pesticides, and asked what the technical team would do in the absence of anything other than TSS to measure those constituents. Semi-volatile organic compounds (SVOCs) are another area where there may not be much data.

- Rick Pleus of Intertox clarified that the issue with pesticides was not that SPU did not have data for pesticides, but that the technical team had not identified which pesticide it would evaluate and what data are available to consider. The technical team is currently evaluating the data available. For example, it appears that two weaknesses in data quality and quantity may be PBDEs and oil/grease. He also asked whether choosing certain surrogates, such as copper for metals, would cause the team to miss anything important.
- Jean Zodrow suggested that PCBs could be a surrogate for PBDE, as those constituents may have similar behavior. For SVOCs, TSS could potentially be used. It is important to pick the right constituents to measure, since they get carried through. Rick Pleus said he understands the possible use of surrogates in the Exposure Assessment but would need to consider the data sets and constituents better to provide an opinion whether either of these is reliable.

- Bob Pitt noted that some constituents, such as copper, could be present in many types of form (complex, ionic, coil, associated with sediment, etc.). The different forms of the constituent will behave differently, and that could affect toxicity and exposures.
    - Bob Pitt asked whether SPU would use water chemistry modeling to evaluate the behavior of different speciation of constituents. Rob Annear of Geosyntec said that the technical team would be relying on receiving water and stormwater sampling data.

<u>Comments on Variations in Exposure:</u>

- In regards to Rick Pleus' question of the Expert Panel on whether acute exposures should be considered, Bob Pitt noted that acute (short exposure) issues are rare for receiving waters; chronic issues, especially associated with sediment, are much more common. Chronic exposure to fecal coliform can lead to regrowth in streams, for example.
- Jean Zodrow said that there are acute issues associated with the first stormwater event. For example, there is the potential for fish to be exposed to dissolved copper, which is what the National Marine Fisheries Service focuses on.
    - Bob Pitt observed that it would be important not to oversimplify the answer, given the complexity of the exposures.
    - Mike Milne of Brown and Caldwell added that the key is not to introduce any bias when comparing projects.
- Kyle Dreyfuss-Wells observed that it would be useful to know what happens to the first flush of stormwater for evaluating effects on exposures. She added that it is important to consider how projects affect exposure in the context of how the overall system is operating.
    - Eric Strecker noted that sediments are often more suspended in CSO areas.
    - Bob Pitt said that volume reduction and maximizing the flows that go to the treatment plant are important strategies.
- Bob Gearheart asked how the technical team would evaluate temporal effects.
    - Rick Pleus of Intertox said that the technical team would review on a case-by-case basis whether it would be useful to get more detail for a given parameter for the Exposure Assessment (e.g., season, duration, etc.).

Bringing It All Together: Reflections on the Proposed Methods and Data Sources

- At this point in the meeting, the Expert Panel was asked for overall impressions and reflections on the proposed methodology and the data that SPU plans to use for the evaluation. Reflections included the following:
  - Bob Gearheart said that the momentum of the project seems to be on the right track.
  - Jean Zodrow said she believed that things were on the right track, except for minor details.
  - Derek Booth commented on the difference between the complexity of understanding the behavior of constituents and their effects on exposure on the one hand and the simplicity of the exposure assessment tools being proposed to evaluate them on the other hand. He did not have suggestions for the exposure assessment methodology, but expressed doubts that it would be adequate.
    - Eric Strecker noted that SPU only needs to compare projects, as opposed to show what the exposure is.
  - Bob Pitt commented that he was astonished by the rapid time frame in which this is being done, and the limited time for evaluation. He noted that it is critical that SPU will be able to verify its efforts, and suggested reserving a fraction of the money for projects for verification.
    - Mike Milne of Brown and Caldwell said that there may be ways to address uncertainties based on how projects are combined into alternatives and selected.
  - Kyle Dreyfuss-Wells said that overall this is a good idea, and that the "perfect can be the enemy of the good." She expressed concern that stormwater projects are not getting adequate consideration as compared to CSO projects.
    - Bob Pitt added that we should not need a different standard for comparison.

Overview of the Multi-Objective Decision Analysis (MODA) Process

- Emiko Takahashi of SPU presented on SPU's use of MODA, covering:
  - When and why SPU uses MODA
  - A car example showing different elements of MODA process—the criteria, measurement scale, and weighting of social and environmental criteria, and then comparing those benefits or values to the costs of the options
  - An example of MODA applied to stormwater projects from Bob Pitt's paper, with the key difference in SPU's analysis that costs were analyzed separately from other criteria
  - Categories of draft MODA criteria SPU is considering for the Integrated Plan
- She noted that MODA will be used to evaluate CSO and stormwater projects individually, and then to compare CSO and stormwater projects. The MODA doesn't make the decisions, but helps inform the decisions.
- In June, SPU will present draft technical criteria for the MODA evaluation for the Expert Panel to review and comment on.

Expert Panel Comments and Responses

- Derek Booth asked how SPU would use MODA to choose projects when there is a hard decision—that is, there are no obvious choices (high value/low cost) that emerge.

  - Emiko Takahashi said that one way to help with those situations is to reconsider the weights for the criteria.
  - Bob Pitt said that external constraints, such as budget, also influence the decision.
- Bob Gearheart said that the transparency of the weighting is critical. He also asked how the weighting would be done.
  - Emiko Takahashi replied that SPU would have a diverse staff group do the weighting, and then would conduct sensitivity analyses of the results.
- Bob Pitt suggested incorporating dollars per pound into the analysis, rather than evaluating cost separately.
- Derek Booth said that an important weighting is the "fatal flaw weighting"—how SPU decided which projects would be considered for the Integrated Plan. The Expert Panel needs to know what criteria were used to determine whether projects were fatal flaws. People have different opinions of what makes something a fatal flaw.
  - Emiko Takahashi said that one fatal flaw criterion was whether SPU could fund the project.
- Derek Booth and Kyle Dreyfuss-Wells discussed the potential criterion for leveraged funding. Derek Booth noted that leveraged funding could be double counted since cost is considered elsewhere in the MODA; instead of including it as a social/environmental value, the cost with leveraged funding could be plotted as another point on the cost chart. Kyle Dreyfuss-Wells said that this criterion should not be overlooked, but agreed it could be handled that way.
- Several Expert Panel members commented that may have advice relevant to the non-environmental criteria for the MODA and could offer comments, even though they may not be "experts" on those topics.

Observer Comments

- Rachel McCrea of the Washington State Department of Ecology said that some of the comments expressed at the meeting resonated with her, but she had no further comments at this time.
- Jennifer Price of CH2M HILL noted that she was attending the meeting as an observer for the City of Spokane, which is evaluating similar issues, but not within the context of a consent decree. She is interested in identifying a methodology that could be replicated that is not too cost prohibitive or complicated.

Wrap Up and Next Steps

- Trish Rhay of SPU thanked Expert Panel members for their participation, and said that SPU's challenge is to have solid enough data to tell a reasonable story and have enough time to get the analysis done.
- Bob Gearheart acknowledged his appreciation for the staff work supporting the Integrated Plan thus far, and noted that engineers need to make decisions with less data than this all of the time.
- Bill Ross of Ross Strategic added that SPU will need to make a reasoned judgment comparing stormwater and CSO projects based on available data, without understanding everything that may be occurring in the landscape and water bodies.
- Next steps identified at the meeting included:

- The **next Expert Panel meeting** will be on **Tuesday, June 25, 2013,** in Seattle. It will focus on the technical criteria for the MODA evaluation.
- Kevin Buckley of SPU said that he will brief SPU management on this meeting, and will meet with the technical team to discuss how to respond to the Expert Panel's suggestions. Information on the technical team's proposed responses will be distributed to the panel.

Participants and Observers

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
Derek Booth	Adjunct Professor, Bren School of Environmental Science and Management, University of California Santa Barbara, Santa Barbara, CA
Kyle Dreyfuss-Wells	Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH
Bob Pitt	Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL
Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Kevin Buckley	Integrated Plan Project Manager, SPU
Ray Hoffman	Director, SPU
Trish Rhay	Drainage and Wastewater Division Director, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic
Audience Members	
Nancy Ahern	SPU
Maythia Airhart	SPU
Martin Baker	SPU
Shelly Basketfield	SPU
Andy Chittick	SPU
Rex Davis	SPU
Pam Emerson	SPU
Jonathan Frodge	SPU
Ed Mirabella	SPU
Charles Oppelt	SPU
Beth Schmoyer	SPU
Tracy Tackett	SPU
Emiko Takahashi	SPU
Ingrid Wertz	SPU
Justin Twenter	Brown and Caldwell
Jennifer Price	CH2M HILL
Molly Adolfson	ESA
Rob Annear	Geosyntec Consultants
Eric Strecker	Geosyntec Consultants

Name	Organization
Rick Pleus	Intertox
Jennifer Tice	Ross Strategic
Rachel McCrea	Washington State Department of Ecology

Seattle Public Utilities Integrated Plan Expert Panel
Meeting #3, June 25, 2013
Meeting Summary

Participants

The third meeting of Seattle Public Utilities (SPU) Integrated Plan Expert Panel was attended by the five Expert Panel members, SPU managers and staff, consultants, and observers. The audience consisted largely of SPU staff and technical consultants. A full list of attendees is at the end of the summary.

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Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
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Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Kevin Buckley	Integrated Plan Project Manager, SPU
Andrew Lee	Combined Sewer Overflow Program Manager, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic

Meeting Objectives

The objectives for the Expert Panel meeting included:

- Review the overall flow of the decision-making framework for the Integrated Plan, including the purpose and role of multi-objective decision analysis (MODA) in that context.
- Review and collect Expert Panel member feedback on changes to the methodology for evaluating combined sewer overflow (CSO) and stormwater projects, including the pollutant load estimation methodology and the exposure assessment methodology.
- Present and obtain Expert Panel feedback on the proposed evaluation criteria and scales for the MODA.
- Review example projects, which have been previously implemented by SPU and which have been evaluated using the proposed MODA criteria, and discuss the process for ranking projects and evaluating benefits and costs.
- Review upcoming meeting plans and identify next steps.

A summary of the meeting discussions, organized by the agenda topic, is below. Key themes from the meeting are not attributed to individuals, but comments pertaining to individual sessions are attributed.

Summary

Opening Remarks

- Bill Ross of Ross Strategic welcomed participants to the meeting, reviewed the agenda, and noted that SPU's decision-making for the Integrated Plan will proceed soon after the Expert Panel's final meeting in September. He said that the Expert Panel's contributions to SPU's decision-making are recorded in the summaries of the Expert Panel meetings.

Key Themes from the Expert Panel's Comments

Throughout the meeting, Expert Panel members commented on SPU's proposed methodology for assessing exposure and evaluating pollutant loads from stormwater and CSO projects, and how SPU plans to use multi-objective decision analysis (MODA) to support its decision-making. The following were key themes from these comments and notes about SPU's responses (individual comments and responses are also included later in the summary):

- By focusing on concentrations, the proposed exposure assessment methodology ignores important considerations. SPU should add mass loadings to its formula for exposure index values (EIVs), so that mass, volume, frequency, timing, and concentration are considered in some way when evaluating exposure reductions from stormwater and CSO projects.
    - <u>SPU Response:</u> The Integrated Plan team has considered adding these factors to the EIV calculations, but has not finalized the algorithms to account for mass, volume, and timing of discharge. These algorithms will be developed during the next phase of the project. The intention is to have this work completed by the August conference call with the Panel.
- It is important for SPU to consider not only the relative change in exposure or loads, but also the value or utility of that change. Changes that occur near regulatory thresholds or levels associated with human health or ecological effects should be valued differently than changes that do not occur near these levels. Incorporating utility curves is one way that SPU could address this concern.
    - <u>SPU Response:</u> Following the June 25th Panel meeting, the Integrated Plan team considered the recommendation to use utility curves for evaluation of changes in the loads and concentrations associated with stormwater and CSO projects. The team acknowledged that utility curves could be a useful tool to help determine which stormwater projects provide significant benefit over CSO projects but decided that utility curves would not be used as part of the pollutant reduction methodology or MODA. This decision was based upon the reality that the consent decree does not require Seattle to meet a standard or target, only show a significant benefit of stormwater projects over CSO projects and that total maximum daily loads (TMDLs) have not been established for most of the consent decree constituents in our receiving water bodies; therefore, SPU does not have waste load or load allocations that could serve as benchmarks for the Integrated Plan project load reductions. Furthermore, the information required to make such an assessment cannot be generated given the available time and data for this project.

Because of these factors the team did not want to create a benchmark or target for use with the utility curves as suggested by the Panel.

- SPU should focus its analytic attention for the Integrated Plan first and foremost on meeting the consent decree requirements of showing that the proposed stormwater projects provide significantly better water quality benefits than the CSO projects proposed to be deferred. MODA is a useful second step for adding transparency to SPU's decision-making process; however, it does not warrant as much attention from the Expert Panel.
  - SPU Response: SPU and the Integrated Plan team remain committed to demonstrating the requirements of the consent decree with the Integrated Plan. Based on the Expert Panel's comments, SPU has revised plans for the final meeting of the Expert Panel in September and added a conference call in August to reflect this focus and the interests of the Panel. SPU also will be simplifying its process by conducting MODA only on options (combinations of proposed stormwater projects and CSO projects to be deferred) and not first conducting MODA on individual stormwater and CSO projects. For all of the options, SPU will demonstrate the consent decree requirements that the proposed stormwater projects provide greater water quality benefits than the CSO projects proposed for deferral.
- Since monetization cannot be done uniformly and consistently across the MODA criteria, the Expert Panel thought that this would not be a particularly useful investment of SPU time and resources.
  - SPU Response: After considering the Expert Panel's advice, SPU has decided not to monetize the MODA criteria for evaluating Integrated Plan projects. The Integrated Plan team will, however, quantify the benefits or impacts from projects where possible (e.g., CO_2 reductions).
- Expert Panel members commented on the difficulty of providing input on SPU's methodology in the abstract, particularly for the exposure assessment, and said that it would be helpful to see more of the analyses conducted by the SPU and the Integrated Plan team. For example, some of the potential issues the Panel raised included addressing data with significant amounts of non-detect values, using linear scales to represent non-linear data, considering results that are very similar (e.g., after normalization), and combining exposure scores from different pollutants or receptors.
  - SPU Response: There will be an Expert Panel conference call scheduled in August during which the Integrated Plan team will review its analyses for the exposure assessment and the assessment of water quality impacts of projects. This will allow the team to follow up on the potential issues the Panel identified.
- Expert Panel members had differing views regarding the complexity of SPU's analysis. On the one hand, Panel members noted the importance of avoiding over-simplification of analytic results, such as by summing all exposure index values or by reducing MODA results to a single score by normalizing, scaling, and averaging. They noted it is important for staff and decision-makers to understand the factors contributing to aggregate scores (effects of projects on individual pollutant loads, sensitivity analysis of how different MODA criteria affect the value scores, etc.). On the other hand, Panel members noted that it would also be important for SPU to avoid overcomplicating the analysis to demonstrate the consent decree requirements, particularly since this Integrated Plan could inform similar plans that other utilities develop across the country.

- <u>SPU Response:</u> Based on concerns about complexity and the importance of demonstrating the consent decree requirements, SPU is creating a more distinct divide between the first phase of its analysis, which focuses on demonstrating that proposed stormwater projects have significantly greater water quality benefits than the CSO projects to be deferred, and later stages of its decision-making, which include MODA and consideration of other decision factors. SPU will only evaluate options in MODA that meet the consent decree water quality requirements. SPU will also keep in mind the importance of providing relevant information to decision-makers based on SPU and team's analysis of exposures, pollutant loads, and other criteria.

Review of Integrated Plan Decision-Making Framework

- Emiko Takahashi and Kevin Buckley of SPU described the overall decision-making framework for the Integrated Plan, which includes four parts:
  - Evaluation of projects based on consent decree requirements (pollutant loads and exposure assessment) and other evaluation criteria relevant to SPU's decision-making
  - MODA on *individual* stormwater and CSO projects (Note: Following the meeting, SPU decided to skip this step in its process.)
  - MODA on Integrated Plan *options*—combinations of stormwater projects to be implemented and CSO projects to be deferred (all options must meet the consent decree requirement that proposed stormwater projects "will result in significant benefits to water quality beyond those that would be achieved by implementation of the approved CSO Controls Measures only")
  - Other decision factors (e.g., scheduling and financing)
- Emiko Takahashi added that MODA is used extensively at SPU to transparently consider potentially competing objectives in its decisions. SPU also intends to use MODA to satisfy the cost-benefit analysis requirements of the consent decree.
- Kevin Buckley said Integrated Plan options, all of which will have been analyzed as described above, will be presented to the public in the Environmental Impact Statement (EIS); one option will then be recommended to SPU management and included as the Integrated Plan option for the Long Term Control Plan (LTCP).

Expert Panel Comments and Responses

- Kyle Dreyfuss-Wells asked SPU to comment on SPU potentially using receiving waters with deferred CSO projects as a factor for selecting Integrated Plan options.
  - Kevin Buckley of SPU said the consent decree does not require SPU to consider the locations of the receiving water bodies for the stormwater projects and CSO projects to be deferred in the Integrated Plan, but SPU could consider this. In response to a question, he said the issue of deferring a CSO project in one location but getting the benefit in another location has not come up in public meetings, because the CSO projects SPU plans to defer are low priority.
  - Bob Gearheart asked whether this factor was implied by the performance standard for projects to meet water quality standards. Kevin Buckley responded that the consent decree requires comparing the pollutant load reductions and the relative water quality benefits of Integrated Plan projects. (This is a relative comparison of project impacts, rather than an evaluation of water quality standards attainment.)

- Bob Pitt recommended that SPU and the technical team avoid the terminology "deferred CSO," but rather specify "deferred CSO projects" to avoid confusion.

Exposure Assessment Methodology Discussion

- Rick Pleus of Intertox gave a presentation on the proposed exposure assessment methodology; his presentation covered the following topics:
  - The consent decree requirements for assessing reductions in pollutant exposure for human and ecological receptors
  - The use of relative, not absolute, estimates of exposure and hazard for the exposure assessment
  - The Integrated Plan team's progress to date in developing the exposure assessment methodology, including conducting site visits and identifying receptors
  - The equations fundamental to the exposure assessment, including Exposure Index Values (EIVs) and receptor factors
  - Steps in the exposure assessment to identify the components of the EIV equation (pre- and post-project concentrations, target concentrations, and receptor factors), calculate the EIVs, and sum and normalize the EIVs for human and ecological factors for each project
  - Remaining work to complete, including considering frequency, volume, and time in the algorithm
- In answer to questions from the Expert Panel, Rick Pleus clarified that the team visited sites that it thought would provide the best information about the different site types, rather than all of the project sites, and that the target values for water quality or human health are typically not mandates (e.g., they might be a reference dose for human health). He also noted that the EIVs for human and ecological receptors would not be combined, but would remain separate.

Expert Panel Comments and Responses

- Derek Booth and Bob Pitt commented on the fact that relying exclusively on comparisons of relative risk might not allow differentiation between cases where a very small risk is reduced and where a large risk is reduced.
  - Rick Pleus said that the Integrated Plan team will prioritize the biggest drivers of risk, based on 20 years of professional experience.
  - Based on this information that the team will consider other information, Bob Pitt said that he would have concerns if the team shared the same slides with the public since they are overly extreme about the use of relative risk and could cause the team to have to backtrack.
- Jean Zodrow asked the team about how sensitivity would be considered for threatened and endangered species, and whether it would consider species distribution.
  - Gretchen Bruce of Intertox said that they would be considering the age, life stage, and the threatened and endangered status of species, but it would not be worth the effort to consider species distribution for this analysis.
- Bob Pitt recommended that the Integrated Plan team adjust the formula for EIVs so that it considers volume and mass discharge, not simply concentration. He noted that target concentrations do not mean much for stormwater projects; the important factors are sediment and volume reduction. Groundwater contamination and the fate of groundwater is another consideration. He said that if

the TMDL requirement for the water body were based on exposure, the TMDL could be used as the target in the EIV. To avoid double counting (since concentration is based on mass over volume), Dr. Pitt recommended that the EIV be revised so that it examined the change in mass over the TMDL target value as well as the post-project concentration.

  - Rick Pleus noted that the TMDL is based on the entire reach or stream, and doesn't have the same nuances for assessing exposure. Bob Pitt responded that TMDL values could be assigned to locations. SPU staff also noted that TMDLs have not been established for most of the consent decree constituents in Seattle's receiving water bodies.
  - Jean Zodrow commented that this conversation omitted an important factor in the EIV equation—the receptor factor. If the receptor factor were 1 in a high-quality stream versus 0.5 in a degraded area, this would have a large effect on the final result. Rick Pleus agreed and pointed out the receptor factor in the newest version of the EIV algorithm.
- Derek Booth commented that the EIV formula captures the magnitude of the change, but not the value of the change. He said that may not be particularly useful. To illustrate his point, he provided an example of two projects that would produce the same results, even though one project would meet the target concentration (Case 1: 10-9 = 1; Case 2: 2-1 = 1 and meet target concentration).
  - Rick Pleus mentioned that, while he understood the point, it is important to remember that the consent decree emphasizes establishing the "benefit" of one project over another project, but that there is no requirement to meet some standard such as a water quality guideline. Furthermore, the data might not be sufficient to make an accurate prediction of the post-project concentration with any degree of certainty.
- Bob Pitt suggested that the Integrated Plan team consider the utility function in the exposure assessment. The utility function examines the overall utility or value of changes in a parameter. It would, for example, help SPU and the Integrated Plan team to assess how much more one concentration was worth than another (e.g., if the concentrations are well above the goal, changes do not matter as much). The paper Dr. Pitt circulated to SPU and the Panel previously describes the concept of utility function.
  - Gretchen Bruce of Intertox said that the team would be looking at the change in concentrations in the exposure assessment, but not the value of the change. Rick Pleus added that the team is not doing a full exposure assessment.
  - As noted in the summary of themes above, since the meeting, the Integrated Plan team reviewed the recommendation to use utility curves and concluded that the concept would be difficult to apply here since the consent decree does not require Seattle to meet a standard or target (it only requires that SPU show a significant benefit of stormwater projects over deferred CSO projects), and TMDLs have not been established for most of the consent decree constituents in receiving water bodies for Seattle's discharges. Thus benchmarks are not available to apply to the utility curves.
- Reflecting on the site photos, Expert Panel members commented on how public uses would be considered in the exposure assessment. Bob Pitt noted that it would be important to look not just at the site, but also in the vicinity of the site to identify swimming beaches, parks, and other nearby

public use areas. Kyle Dreyfuss-Wells said that the most important factor is whether the overflow is in a public beach or in a hidden or inaccessible area.

- Mike Milne of Brown and Caldwell and Rick Pleus of Intertox concurred with the comments about the importance of considering public uses and indicated that the team will incorporate information on locations of nearby beaches, parks, tribal fishing areas, and public access points. The EIV considers, for example, the distance to locations of public use from a given outfall. Several Expert Panel members commented that it would be useful to see numerical examples to better understand and comment on how the exposure assessment calculations would work.
  - The Integrated Plan team concurred and will generate data to input into the draft EIV algorithms. Given no unforeseen obstacles, these data will be available for the Expert Panel to review at a conference call in August.
- Bob Pitt and Derek Booth observed that treating the data linearly by normalizing the data could present some problems. For example, there may be a lot of low values in the results, and normalizing them could make them artificially high. Another outcome could be that the normalization will produce very similar results that are not very meaningful. Examining how the data are clustering could help as well as considering utility (as described earlier).
  - Integrated Plan team members acknowledged the Panel's potential concerns with normalization. Both the Integrated Plan team and Panel members noted that examining actual output data will allow appropriate assessments of how to normalize data..

Observer Comments and Responses

- Mark Henley of the Washington State Department of Ecology (Ecology) asked how the exposure assessment would consider impaired water bodies and those listed under section 303(d) of the Clean Water Act.
  - Mike Milne of Brown and Caldwell, Kevin Buckley of SPU, and Eric Strecker of Geosyntec identified several places in the Integrated Plan team's analysis where regulatory status has been or would be considered, as follows.
    - SPU considered impaired water bodies when it prioritized water bodies where candidate stormwater projects would be identified.
    - The numerical values in the EIVs (e.g., target concentration) relate to regulatory requirements.
    - When SPU forms "options" of stormwater projects to implement and CSO projects to defer, it will consider the offset in the receiving water body.
    - In SPU's MODA analysis, there is an opportunity to consider regulatory status (impaired water body, recontamination of Superfund site, etc.).
- Mark Henley commented that he did not want the Integrated Plan to undermine the overall value of achieving CSO control and that it should provide a fair and balanced evaluation of CSO project water quality benefits, particularly since SPU's Integrated Plan may serve as a national model for these plans. It should be clear that in the Integrated Plan SPU is looking at low-priority CSO projects that address CSOs that are almost under control, and that SPU does not plan to defer other CSO projects that have more benefits.

- Bill Ross of Ross Strategic said that the Integrated Plan would be examining the benefit of the deferred CSO projects if implemented (controlling the outfalls to one overflow per year) and the benefit of the stormwater projects if implemented.
  - Andrew Lee of SPU said that this issue was largely one of messaging for the Integrated Plan. SPU will state that it is looking at a certain set of projects for the Integrated Plan; the agency will not be claiming that all stormwater projects are better than all CSO projects.
- Mark Henley observed that the range of values in the receptor factor equation was 1 to 5 for the likelihood of exposure, but 1 to 15 for magnitude of exposure.
  - Gretchen Bruce of Intertox said that the basis of the 1-15 range is data compiled by EPA on relative exposure levels associated with different scenarios (e.g., skin surface area exposed to water during swimming or wading, incidental water ingestion rates during recreational activities, or fish and shellfish consumption). The team will provide documentation for the approach.

Updates to the Pollutant Load Estimation Methodology for Stormwater Projects

- Rob Annear of Geosyntec presented updates to the methodology for estimating pollutant load reductions from stormwater projects. His presentation included:
  - The current list of representative constituents of concern (RCOCs), including changes from the potential RCOCs identified at the April Expert Panel meeting
  - The status of the stormwater project analysis
  - Examples of the box plots of the pollutant load data the team is examining for commercial, residential, and industrial sites
  - Recommended project comparison metrics to meet the consent decree requirements (including water quality impacts and exposure assessment) and inform SPU's MODA
  - Proposed methodology for characterizing baseline conditions and estimating pollutant loadings from stormwater projects

Expert Panel Comments and Responses

<u>Comments on RCOCs and the Available Data:</u>

- Jean Zodrow asked why zinc was added as a constituent of concern.
  - Beth Schmoyer of SPU said that SPU added zinc because it is a specific benchmark for industrial stormwater permits that facilities often struggle with. SPU plans to look at both copper and zinc.
- For the proposal to assess PBDEs using total suspended solids (TSS), Jean Zodrow mentioned Sandy O'Neill's study of pollutant loads and cycling through biological organisms in Puget Sound, although Ms. Zodrow wasn't sure whether the study specifically considered PBDEs.
  - Members of the technical team said that they would examine that resource.
- Bob Pitt questioned the decision to use BOD/TSS as an RCOC for pH, if pH were specifically listed in the consent decree. He said that reduced concentrations result in subtle changes in pH. Rob Annear of Geosyntec said that the team can discuss the approach to pH at a future Expert Panel meeting.
- Panel members made several suggestions related to the presentation of the data, as follows.
  - Bob Pitt suggested adding the numbers of observations to the box plot charts.
  - He also suggested presenting the data with a truncated probability distribution, or plotting the data based on percent detected.

  - Some Panel members noted that the Y axis was different in the slides, but should be consistent in future presentations.
  - Eric Strecker of Geosyntec said the team would be increasing the font size for the charts.
- Several Panel members commented on the differences between the data for different site types, and noted that land use categories such as industrial can vary significantly. There are highly site specific reasons why the data may differ, such as roof runoff and urban wildlife in forested areas. In addition, Bob Pitt noted that seasonality is important, due to inputs to the land.
- Bob Pitt and Derek Booth commented that for some pollutants, there may be a significant amount of data that are below or very close to detection levels (practical quantification levels). Furthermore, they noted that scaling data containing a large amount of non-detected values could skew the overall results. (The suggestions above for indicating the number of observations in charts and presenting data with truncated probability distributions could help address issues with non-detects.) For the PCBs, in particular, Bob Pitt said that detection limits will be critical.

<u>Comments on the Stormwater Project Analysis:</u>

- Kyle Dreyfuss-Wells commented on the fact that only two metrics were proposed as inputs to MODA, when there were many other metrics proposed for comparing stormwater and CSO projects. Bob Pitt added that concentrations and loads could be considered separately in MODA.
  - Kevin Buckley of SPU indicated that SPU had not yet fully determined how water quality would be considered in MODA.
- Bob Pitt asked whether SPU would be conducting demonstration projects to supplement the performance data, or will it directly implement full-scale projects.
  - Andrew Lee of SPU said SPU would consider demonstration projects on a case-by-case basis.
- Bob Pitt added that there is more uncertainty on some projects than others, and recommended that SPU conduct mass-balance analysis to determine if anything looks odd. He noted that the performance of sweet sweeping, in particular, should be verified.
  - Eric Strecker of Geosyntec noted that the consent decree requires post-construction monitoring.
- In response to a question from Bob Gearheart, Rob Annear clarified that the team will apply the model to the catchments, but does not plan to include other subcatchments that feed into them.

Observer Comments and Responses

- Mark Henley of Ecology asked how the technical team would compare the reductions in fecal coliform loads from stormwater projects to those that come from eliminating CSOs. He indicated that the stormwater projects would have to reduce fecal coliform levels significantly to be comparable to the benefit from reducing CSOs.
  - Bob Pitt commented that there are highly site specific reasons why some sites have high fecal coliform levels. Jonathan Frodge of SPU said that some of the numbers may be correlated with homeless encampments in the vicinity of the sites.
- Beth Schmoyer of SPU expressed concern about the technical team's proposal to use bis(2-ethylhexyl)phthalate as the RCOC for semi-volatile organic compounds (SVOCs). She noted that bis(2-ethylhexyl)phthalate is everywhere (including lab contamination) and is not very toxic to humans. Other contaminants are more differentiated. Bob Pitt suggested that including the frequency of detection as a measure would help.

- o Beth Schmoyer and Rob Annear discussed the use of use bis(2-ethylhexyl)phthalate as the RCOC for SVOCs following the meeting and determined that given the available data, the use of use bis(2-ethylhexyl)phthalate as the RCOC for SVOCs would be acceptable.

Updates to the Pollutant Load Estimation Methodology for CSO Projects

- Justin Twenter of Brown and Caldwell provided an update on the Integrated Plan team's methodology for evaluating pollutant loads from the 10 candidate CSO projects that could be deferred.
  - o The team's proposed approach is to use simulated flow from models, and to pool city-wide sampling data and use average values for each of the residential and commercial sites.
  - o The team will also be using sampling data from a King County industrial site.

Expert Panel Comments and Responses

- Kyle Dreyfuss-Wells commented that in the consent decree it seems like fecal coliform is treated as equal to other pollutants, yet she believes that people would not tolerate having significant fecal coliform remaining in either CSO overflows or stormwater discharges. You do not want raw sewage in the water. Not all pollutants are created equal; a project could do a "rock star" job on some contaminants, but not as well on others.
  - o Jonathan Frodge of SPU said that the city's CSOs primarily occur in the winter, so fecal coliform levels are not necessarily the biggest concern from an actual exposure point of view.
  - o Bob Pitt commented that 10,000 CFU/100 mL is not unusual for stormwater discharges, and that it is difficult to get below 400 CFU/100 mL. He said that regrowth and initial die off of bacteria are complicating factors. Classical modeling only looks at the first phase.
  - o Mark Henley of Ecology said that the pollutants are treated equally in terms of having water quality standards that are appropriate for each pollutant and which must be met by any discharges.

Observer Comments and Responses

- Beth Schmoyer of SPU questioned whether the SPU sites were a mixture of industrial and non-industrial land uses, and proposed to discuss this outside of the meeting with the consultant team.
- In answer to a question from Mark Henley of Ecology regarding the fact that some years there might not be any CSO discharges, Justin Twenter said that the team would be looking at an average of 30 years when evaluating whether the CSO is controlled to an average of one overflow per year. Justin Twenter added that the team will examine seasonal loadings as well as the frequency of discharge.

Discussion of the Proposed MODA Criteria, Scales, and Process

- Dan Pitzler of CH2M HILL reviewed the criteria and scales that SPU and the Integrated Plan team have developed for the multi-objective decision analysis (MODA) that SPU will conduct for the Integrated Plan, although noted that the team is still working on water quality criteria, which could consider a variety of subfactors.
  - o The criteria reflect the City's goals and are intended to give insight into what SPU feels is important for its decision.
  - o All projects evaluated in MODA will meet the consent decree requirements for water quality.

    - Many of the scales are constructed to be on a 1-5 scale, with 5 being the best.
- In response to a question from the Expert Panel, Dan Pitzler clarified that carbon dioxide, which has a direct measure, will be normalized to a 0-1 scale and criteria will be measured on a qualitative 1-5 scale.
- Kevin Buckley of SPU reviewed five example stormwater and CSO projects that either have been or are about to be built. SPU and consultant staff scored these projects using the MODA criteria proposed for Integrated Plan.
- After reviewing the MODA criteria and scales with the Panel, Dan Pitzler described the steps in the MODA process, and showed the results of the analysis for the example projects. He described how SPU would plot the value scores for projects against the costs, conduct a sensitivity analysis of the weights, and then look at a graph of cumulative cost to cumulative value to identify the "knee of the curve." Finally, Mr. Pitzler said that a team is examining which of the MODA criteria can be monetized, and that SPU plans to conduct MODA both with and without monetized information.
- As part of this discussion, Emiko Takahashi of SPU and Dan Pitzler of CH2M HILL reviewed the steps in the overall Integrated Plan decision-making process, including the use of MODA on options or packages of stormwater and CSO projects, and other decision factors considered after MODA.
    - Ms. Takahashi noted that other factors SPU may consider in developing the options or later in its decision-making process include matching the locations of stormwater and deferred CSO projects, an emphasis on pedestrian/green grid, whether SPU has the money and ability to implement the projects, and for joint projects with King County, whether King County would be ready to implement the projects within the required schedule.

Expert Panel Comments and Responses

<u>Comments on the MODA Criteria and Scales:</u>

- Kyle Dreyfuss-Wells asked where in the MODA criteria would the tradeoff between capital and operations and maintenance (O&M) costs be considered. She noted that from an organizational standpoint, it is often easier to fund capital projects than projects that have high O&M costs.
    - Andrew Lee of SPU said that the City looks at total lifecycle costs, and does not differentiate between capital and O&M costs.
- Bob Pitt asked why energy use was not considered, and recommended that SPU document the methods it would be using to quantify impacts. Dan Pitzler of CH2M HILL said that the team thought that energy use would be captured by other factors, including CO_2 emissions.
- There was considerable discussion among Expert Panel members and observers about the environmental criteria for MODA, the importance of water quality, and the relationship of the consent decree requirements and MODA.
    - There was initially confusion about how the MODA water quality criteria differed from the consent decree requirements. The Integrated Plan team clarified that the water quality criteria in MODA represents incremental water quality benefit beyond consent decree requirements. To meet the requirements of the consent decree, SPU will be showing that the stormwater projects proposed to be implemented will have significantly better water quality benefits than the CSO projects that are proposed for deferral.

- Bob Pitt suggested that the MODA criteria for water quality consider concentration, volume, and mass loading, since the regulations deal with different issues, and MODA would allow each factor to be considered as specifically as desired. He also said that SPU shouldn't combine pollutants.
- Kyle Dreyfuss-Wells suggested that a simpler way to do the water quality analysis in MODA would be to filter out any projects that do not meet water quality requirements.
  - Bill Ross of Ross Strategic noted that stormwater projects do not have numerical standards that they need to meet, unlike CSO projects, which have the one overflow per year standard.
  - Beth Schmoyer of SPU said a concern with removing the water quality component from MODA is that there are different ways that projects could be "better" in terms of water quality, such as volume reductions, load reductions, and effects on regulatory requirements.

<u>Comments on the Example Projects:</u>

- Bob Pitt commented that combinations of projects should be considered to meet water quality standards rather than individual control measures. For example, a smaller tank might be needed for CSO control in an area that also has green infrastructure.
  - Andrew Lee and Emiko Takahashi of SPU said that SPU looked at combinations of options to address the problems, even though they are not represented in the example projects. Bob Pitt said that does not detract from the method, but it should be documented that other projects were considered.
- Bob Pitt also recommended that the example projects be described by their control measure (e.g., wet pond) and then indicate that they were demonstrated with specific locations.
  - Rob Annear of Geosyntec and Dan Pitzler of CH2M HILL clarified that the projects are site specific and represent specific solutions to specific problems. The projects are being compared because SPU may have a certain amount of money and is deciding which projects to fund.

<u>Comments on the Monetization of MODA Criteria:</u>

- Derek Booth recommended that if SPU cannot uniformly and consistently monetize the MODA criteria, it should stop pursuing it. The criterion of whether to monetize—whether it is feasible—is arbitrary to the decision-making. He noted that once you have two ways to look at something, it is human nature to make them equivalent. The monetization does not consider water quality, among other criteria, and should not be considered side-by-side to the other method of evaluation, especially if the monetization is incomplete across all MODA factors.
  - Andrew Lee and Emiko Takahaski of SPU noted that they understood the skepticism about the monetization, and that SPU will keep in mind the Panel's comments that its methodology for the Integrated Plan could a set a national precedent.
  - Based on the advice of the Panel, SPU has decided not to monetize the MODA criteria, but will quantify the impacts of projects where possible to support its decision-making process.
- Bob Pitt commented that he could appreciate the value of monetization for explaining decisions to ratepayers, but he was less sure whether it would be of value to regulators. The important information is the quantification of the impacts (e.g., CO_2 emissions); monetization could be problematic when comparing monetary values of dissimilar items (e.g., CO_2 emissions and lost parking spaces).
  - Kyle Dreyfuss-Wells said that her utility (Northeast Ohio Regional Sewer District in Cleveland) did monetize the benefits of CSO controls, even though it was not required. She said this was

very useful in the utility's consent decree negotiations with regulators. For example, their tunnel project had a larger carbon impact as compared to green projects.
  - Mark Henley of Ecology said the consent decree does not require monetization. He advised being careful with how monetization is done, and that monetization is not accurate unless it is complete. For example, he said that all emissions would need to be considered for street sweeping projects.

<u>Comments on the Application of MODA and the Team's Overall Methodology:</u>

- Derek Booth expressed concern about the Integrated Plan team's methodologies (including MODA) that represent very complicated issues as a single number, commenting that they are "reductionist" approaches that obscure the impact of each individual factor in the decision-making. He recommended that more nuances of the MODA results be carried forward when SPU presents the information to decision-makers (e.g., the bar graph showing scores for the criteria, not simply the total MODA score), and noted that the sensitivity analysis would be very useful.
- Derek Booth indicated that the Integrated Plan team appeared to be spending a disproportionate level of effort in MODA, when the focus ("90-95% of the effort") should be on showing the water quality benefits of stormwater projects as compared to deferred CSO projects, although he acknowledged that this could be due to the structure of this meeting's agenda, which had reflected requests from the Panel. He added that SPU's analysis for the Integrated Plan is precedent setting, so SPU should be careful to not overly complicate things. He recommended that SPU concentrate on the analysis that shows which proposed stormwater projects "knock it out of the park" in terms of showing water quality benefits when compared to the CSO projects proposed for deferral. After that, SPU can consider other utility priorities through MODA to select which projects to implement.
- Bob Gearheart observed that MODA is important because it provides both transparency and a replicable methodology with respect to its decision-making process.

Observer Comments and Responses

- Mark Henley of Ecology said that environmental factors should be weighted highly in MODA given the focus of the consent decree and other regulations. He also observed that only select measures were proposed for evaluating environmental factors in MODA, and that others, such as carbon monoxide, were not included. Finally, he added that street sweeping would have more air emissions over the project lifetime than appears to be captured by the analysis demonstrated at this meeting.
  - Andrew Lee commented that one would have expected street sweeping to score lower in the MODA results for air quality given the emissions associated with the truck miles traveled.
  - Kyle Dreyfuss-Wells noted that there is an assumption that the projects to be proposed would meet water quality criteria; otherwise the regulators would not accept them.
- Mark Henley added that the Integrated Plan needs to show water quality benefit of stormwater projects as compared to deferred CSO projects, and that SPU will need to rationalize why CSO projects will be deferred. For example, if a CSO project is deferred and that CSO still has fecal coliform impacts, how will that key parameter be compensated?
  - Bill Ross of Ross Strategic noted that the consent decree does not specify that SPU compare pollutants on a one-by-one basis or compare impacts by receiving water body.

    - After the meeting, the Integrated Plan team provided the following additional clarification: While CSOs have a spike in fecal coliform when there is a release, some of the stormwater projects may reduce fecal coliform releases during more frequent smaller storm events, leading to reduced frequency and reduced coliform counts over a year.
- Mark Henley said that the Integrated Plan is a voluntary approach, and that the deferred CSO projects will be implemented at some point in the future.
    - Jonathan Frodge noted that there is no regulatory requirement that the stormwater projects be implemented. Mark Henley clarified that there could be requirements in MS4 permits.

Reflections on the SPU's Direction with the Consent Decree Analysis

- Near the end of the meeting, the Expert Panel was asked to reflect on the direction SPU was headed with its proposed analysis to meet the consent decree requirements. Reflections included:
    - Derek Booth said he thought the Integrated Plan team was well on its way towards evaluating the consent decree requirements of projects, as long as the team did not get "distracted" by less important analyses. Bob Pitt added that "distracted" was not the right word.
    - Bob Pitt noted the Panel had talked about providing additional detail and descriptions to explain various analyses. He would like the team to evaluate utility, not simply tradeoffs, in the exposure assessment. He also suggested considering non-linear results, and looking at contaminants individually rather than lumping them together.
    - Jean Zodrow commented that the EIVs needed more refinement, but that overall, it seemed as though the team was on a path to make the distinction that some projects are significantly better. She added that she was still struggling with having conversations in the abstract, and needed to see what the numbers do.
    - Bob Gearheart said he felt very comfortable with the direction of the team, even without having all the information. He noted that the meeting's conversation shifted from tactics to strategy. He believes MODA is useful for helping to evaluate non-technical considerations.
    - Kyle Dreyfuss-Wells noted that she felt the team was on the right track. She expressed concern, however, about the team overcomplicating the analysis ("building a complex house around a simple solution"), especially considering that this could set a national precedent.

Wrap Up and Next Steps

- Next steps identified at the meeting included:
    - There will be an **Expert Panel conference call** in August to follow up on this meeting's discussions related to the exposure assessment and the methodology to meet the consent decree requirements for the Integrated Plan.
    - The **final Expert Panel meeting** will be on **Monday, September 16, 2013,** in Seattle. There will also be a reception around this meeting to acknowledge the Panel's work.
        - This meeting will focus mostly on reviewing how SPU will show how proposed stormwater projects are significantly better than potentially deferred CSO projects, but may include some discussion of MODA.

Participants and Observers

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
Derek Booth	Adjunct Professor, Bren School of Environmental Science and Management, University of California Santa Barbara, Santa Barbara, CA
Kyle Dreyfuss-Wells	Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH
Bob Pitt	Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL
Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Kevin Buckley	Integrated Plan Project Manager, SPU
Andrew Lee	Combined Sewer Overflow Program Manager, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic
Audience Members	
Shanti Colwell	SPU
Rex Davis	SPU
Jonathan Frodge	SPU
Ed Mirabella	SPU
Pete Rude	SPU
Beth Schmoyer	SPU
Emiko Takahashi	SPU
Ingrid Wertz	SPU
Justin Twenter	Brown and Caldwell
Dan Pitzler	CH2M HILL
Rob Annear	Geosyntec Consultants
Eric Strecker	Geosyntec Consultants
Gretchen Bruce	Intertox
Rick Pleus	Intertox
Jennifer Tice	Ross Strategic
Mark Henley	Washington State Department of Ecology

Seattle Public Utilities Integrated Plan Expert Panel
Meeting #4 (Webinar), August 28, 2013
Call Summary

Participants

The fourth meeting of Seattle Public Utilities (SPU) Integrated Plan Expert Panel, a web-enabled call on August 28, 2013, was attended by four Expert Panel members, SPU managers and staff, consultants, and observers. A full list of attendees is at the end of the summary.

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
Kyle Dreyfuss-Wells	Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH
Bob Pitt	Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL
Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Kevin Buckley	Integrated Plan Project Manager, SPU
Andrew Lee	Combined Sewer Overflow Program Manager, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic

Meeting Objectives

The objectives for the Expert Panel meeting included:

- Present and obtain Expert Panel feedback on the results of pollutant load analysis for the proposed stormwater projects and combined sewer overflow (CSO) projects to be deferred in the Integrated Plan, including a comparison of loads for selected representative constituents of concern (RCOCs).
- Review the exposure assessment approach as modified since the June Expert Panel meeting, present results of the exposure assessment algorithms as applied to selected projects and RCOCs, and obtain Expert Panel feedback on the approach and the application of the methodology.
- Review upcoming meeting plans and identify next steps.

A summary of the meeting discussions, organized by the agenda topic, is below.

Summary

Discussion of Stormwater and CSO Project Load Analysis

Justin Twenter of Brown and Caldwell reviewed updates to the methodology for estimating loads for CSO projects, and then Rob Annear of Geosyntec reviewed updates to the methodology for estimating loads for stormwater projects and presented results from the preliminary pollutant load analysis for selected RCOCs for both CSO and stormwater projects. Their presentations included:

- The CSO characterization approach, based largely on simulated CSO flow from calibrated models and estimated RCOC concentrations from SPU and King County sampling results
- Estimates of the capture efficiency and volume reduction of the stormwater best management practices (BMPs) being considered for the Integrated Plan
- Methodology for evaluating water quality inputs for structural BMPs
- Updated methodology for evaluating water quality impacts of street sweeping
- Draft results for proposed stormwater projects and CSO projects being considered for deferrals for the following parameters:
  - Volume of water treated or reduced
  - Total suspended solids
  - Fecal coliform bacteria
  - Dissolved copper loads
  - Polychlorinated biphenyl (PCB) loads
  - Ammonia nitrogen loads

Expert Panel Comments and Responses

<u>Comments on the Methodology:</u>

- In response to a question, Eric Strecker of Geosyntec clarified that capture efficiency for stormwater projects referred to the percent treated (managing via infiltration or BMP) rather than the percent of flow held back.
- In response to a question about whether the Monte Carlo analysis was based on extreme values or event by event, Rob Annear noted that the Monte Carlo analysis uses randomly generated values from within the confidence intervals to derive the 50 percent range for the results.

<u>Comments on the Draft Results:</u>

- Bob Pitt and Bob Gearheart commented on the presentation of CSO project and stormwater project results in the same graphs, and that it was difficult to identify the reductions for the CSO projects since they were so small compared to the stormwater projects. Bob Pitt suggested that a log scale could show help to show the comparative results more clearly. Bob Gearheart suggested that results for CSO and stormwater projects could be displayed on different graphs.
- Kyle Dreyfuss-Wells noted that the difference in volume reductions is what is driving the difference in pollutant load reductions between CSO and stormwater projects. She said that needs to be clearly articulated. For example, Rob Annear of Geosyntec had noted that fecal coliform concentrations are higher with CSOs, but the load reductions are higher with the proposed stormwater projects rather than the CSO projects proposed for deferral since the volume being reduced is so much greater.

- In response to a question, SPU clarified that it does not need to show a positive benefit for the proposed stormwater projects compared to the CSO projects proposed for deferral on every one of the water quality pollutants for the stormwater projects to still have a significant overall water quality benefit.

Discussion of Exposure Assessment Analysis

- Rick Pleus of Intertox gave a presentation on the exposure assessment methodology and initial results from the exposure assessment analysis; his presentation covered the following topics:
  - Objectives of the exposure assessment for the Integrated Plan
  - Exposure index value (EIV) formula and calculations for human and ecological receptor factors
  - Results of EIV calculations, both summary results for the stormwater and CSO projects being considered and detailed calculations for two projects
  - The findings that the human EIVs are dominated by PCBs and fecal coliform, and that ecological EIVs are dominated by oil and grease, phosphorus and zinc (at freshwater stormwater locations), and nitrogen ammonia (at freshwater CSO locations)

Expert Panel Comments and Responses

- Several Panel members, including Jean Zodrow and Kyle Dreyfuss-Wells, commented on the "Initial Results" table in the presentation on slide 40 that displayed summary results for fifteen stormwater and CSO projects being considered for the Integrated Plan, noting in particular that the columns showing the "relative change in load" was not intuitive, especially since many of the projects with high load reductions had no change in volume.
  - Gretchen Bruce of Intertox explained that the relative change in load could be due to changes in volume, concentration, or both, and that the EIVs (in the final columns in the table) incorporate receptor factors, which are compound specific.
  - The Integrated Plan team agreed to examine ways to present the data in a more clear, and concise manner.
  - Kyle Dreyfuss-Wells added that it would be helpful to think about ways to graphically represent the exposure assessment results so that people could intuitively understand whether something was "good" or "bad" (for example, "percent reduction" makes sense).
- Jean Zodrow suggested that it would be helpful to see how the projects are broken out by RCOC. It could give a clearer picture of how the contaminants affect the EIVs, especially for ecological receptors. In particular, it could be helpful to differentiating those that have acute effects, such as fecal coliform, and those that have chronic effects.
- Bob Gearheart noted that although there are a number of factors that are subjective and/or judgment-based in the methodology, SPU and the Integrated Plan team will need to explain and market the methodology to others. Given that, it will be important to represent the methodology more clearly and to provide reference material to help establish credibility. Jean Zodrow added that the methodology was still somewhat a black box, and that it would be helpful to see actual data for where the values came from, as well as the supplementary information such as assumptions and rationales for decisions.

    - Gretchen Bruce said that the team used EPA criteria for the analysis, and derived assumptions based on established references.
    - Rick Pleus added that the team will be providing full data sets to SPU for documentation with the Integrated Plan with the goal of being transparent.
    - Bill Ross of Ross Strategic and Rick Pleus of Intertox said that the team would work to provide more documentation for the Panel of the steps of the exposure assessment analysis and additional data to track how the calculations are made.
- Some panel members commented that the bar charts in the exposure assessment slides were hard to read. For example, on slide 43 it was not clear what the different grays were in the chart, and panel members did not know that the pollutants were displayed in the bars in the same order as in the key on the charts until it was mentioned on the call.
- Bob Gearheart said he was surprised by the high oil and grease values. Gretchen Bruce responded that the team was using State of Washington values for oil and grease, but would be looking further into what was driving the results.

Wrap Up and Next Steps

- Kevin Buckley of SPU said that the next steps for the SPU and Integrated Plan team will be to examine whether the proposed stormwater projects provide significant water quality benefits relative to the CSO projects proposed for deferral, based on load reductions and exposures, and then look at other "soft" criteria through the multi-objective decision analysis (MODA) process in selecting projects for the Integrated Plan.
- Bob Gearheart said he would be interested in working with the other Expert Panel members to prepare a letter or small report that would summarize the goal of the Expert Panel process, the methods used by the Integrated Plan team, how the Panel felt about the methods, and any recommendations for SPU. It would be an opportunity to summarize the Panel's work that could be advanced with the process.
    - The Panel members present at the meeting—Bob Pitt, Kyle Dreyfuss-Wells, and Jean Zodrow—indicated support for the idea.
    - Bob Gearheart said he would develop an outline for the letter.
- The final Expert Panel meeting will be on **Monday, September 16, 2013,** in Seattle. There will also be a reception after this meeting to acknowledge the Panel's work.
    - This meeting will include updates on the exposure assessment and load results, a discussion of SPU's approach for evaluating how proposed stormwater projects are significantly better than CSO projects proposed for deferral in terms of the consent decree criteria, and final reflections and recommendations from the Expert Panel.

Participants and Observers

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
Kyle Dreyfuss-Wells	Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH
Bob Pitt	Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL
Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Kevin Buckley	Integrated Plan Project Manager, SPU
Andrew Lee	Combined Sewer Overflow Program Manager, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic
Audience Members	
Timothy Croll	SPU
Rex Davis	SPU
Jonathan Frodge	SPU
Beth Schmoyer	SPU
Tracy Tackett	SPU
Emiko Takahashi	SPU
Justin Twenter	Brown and Caldwell
Rob Annear	Geosyntec Consultants
Aaron Poresky	Geosyntec Consultants
Eric Strecker	Geosyntec Consultants
Gretchen Bruce	Intertox
Rick Pleus	Intertox
Jennifer Tice	Ross Strategic
Dino Marshalonis	U.S. Environmental Protection Agency
Alison Evans	Washington State Department of Ecology
Rachel McCrea	Washington State Department of Ecology

Seattle Public Utilities Integrated Plan Expert Panel
Meeting #5, September 16, 2013
Meeting Summary

Participants

The fifth meeting of Seattle Public Utilities (SPU) Integrated Plan Expert Panel was attended by the five Expert Panel members, SPU managers and staff, consultants, and observers. The audience consisted largely of SPU staff and technical consultants. A full list of attendees is at the end of the summary.

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
Derek Booth	Adjunct Professor, Bren School of Environmental Science and Management, University of California Santa Barbara, Santa Barbara, CA
Kyle Dreyfuss-Wells	Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH
Bob Pitt	Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL
Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Nancy Ahern	Deputy Director, Utility Systems Management, SPU
Kevin Buckley	Integrated Plan Project Manager, SPU
Andrew Lee	Combined Sewer Overflow Program Manager, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic

Meeting Objectives

The objectives for the Expert Panel meeting included:

- Review the consent decree requirements for the Integrated Plan and Seattle Public Utilities' approach to development of an Integrated Plan.
- Present results of the exposure assessment algorithms as applied to selected projects and selected representative constituents of concern (RCOCs), and obtain Expert Panel feedback on the approach and the application of the methodology.
- Present and obtain Expert Panel feedback on the pollutant load analysis for the proposed stormwater projects and potential combined sewer overflow (CSO) projects to be deferred in the Integrated Plan, including a comparison of loads for selected RCOCs.
- Discuss the team's approach to demonstration of "Significant Benefit" and hear Expert Panel members' overall reflections and recommendations on the Integrated Plan process.

A summary of the meeting discussions, organized by agenda topic, is below. Reflections from the Expert Panel and others on the Expert Panel process are included near the end of the summary.

Review of Consent Decree Requirements and Approach for Integrated Plan

- To begin the meeting, Kevin Buckley of SPU reviewed the requirements for the Integrated Plan in the City's consent decree, which was lodged on July 3, 2013. The Integrated Plan provides an opportunity for SPU to "propose water quality improvement project(s) that will result in significant benefits to water quality beyond those that would be achieved by implementing the approved CSO control measures only." The consent decree requirements include:
  - Pollutant load reduction analysis for conventional water quality parameters for each proposed project
  - Projected pollutant reductions to water bodies with impairments (impairments have focused on pathogens, metals, dissolved oxygen, and nitrogen ammonia)
  - Projected pollutant reductions, including toxic organic compounds, to water bodies with specialized circumstances such as beach closure advisories, protected spawning grounds, and contaminated sediment cleanup sites
  - Projected reductions in pollutant exposure for humans, ecological receptors, and/or threatened or endangered species
  - Cost-benefit analysis of projects
- In addition to the consent decree requirements, SPU is using multi-objective decision analysis (MODA) to add to the significant benefit evaluation and help select projects that meet "triple bottom line" criteria.
- SPU has also selected low frequency, low volume CSO projects to analyze for potential deferral.

There were no comments or questions during this session.

Discussion of Exposure Assessment Analysis

- Rick Pleus and Gretchen Bruce of Intertox gave a presentation that walked through the details of the exposure assessment methodology and presented initial results of the analysis for human and ecological receptors. Their presentation covered the following topics:
  - The team is now calculating three separate exposure index value (EIV) metrics:
    - Human: toxics (using chronic toxicity criteria)
    - Human: fecal coliform (using acute toxicity criteria)
    - Ecological: toxics and nutrients (using chronic criteria)
  - Steps involved in the EIV calculation, which is based on concentration, water quality criteria, change in load, and the receptor factor (a measure of exposure potential)
  - Steps needed to calculate human and ecological receptor factors
  - An example of exposure assessment calculations for the South Park Water Quality Facility
  - Draft results of human and ecological EIVs for toxics and fecal coliform for all potential stormwater projects and CSO projects under consideration for the Integrated Plan
- Intertox's presentation included the formulas for the exposure assessment, sources and assumptions for the analysis, and draft summary results for the three types of EIVs.

- In response to questions, Rick Pleus and Gretchen Bruce provided the following clarifications:
  - The water quality criteria provide a way of evaluating relative hazards of different pollutants, through the calculation of pre-project concentration divided by the water quality criteria. Their approach is not a formal risk assessment, but a relative analysis of exposure across common assumptions and data sets for the stormwater and CSO projects.
  - The water quality criteria used in the analysis are either federal government or state government criteria. If there are multiple criteria available (e.g., cancerous or noncancerous reference doses), the team used the criteria with the most conservative outcome.
  - The ingestion values for exposure are based on EPA guidelines, local studies, and at times professional judgment. The team focused on data that were the closest available to the outfall. For example, if data were obtained from a local risk assessment that reported that fish consumption rates were higher (or lower) than in the EPA assumptions, the team used the local values.
  - The human receptor factor calculations are based on an average "adult" and "child."
  - In answer to a question from Bob Gearheart about whether the exposure assessment considers race, Gretchen Bruce of Intertox said that the team used mean values in its analysis, but drew from local exposure assessments that considered the local population, which would include a diverse racial population.
  - In answer to a question from Jean Zodrow about whether the human receptor factor was based on an annual average, Gretchen Bruce responded that the team calculated EIVs separately for the "high" release (cool) and "low" release (warm) seasons, in order to account for differences in exposure potential during those seasons, and then calculated an annual average EIV by weighting the average for the number of months in each season. The final EIV results for the CSO and stormwater projects are based on annual conditions.

Expert Panel Comments and Responses

- Derek Booth commented that if the water quality criteria are based on certain thresholds, there may be a more significant effect on exposure or a "step function" that occurs around that threshold as compared to the effect of similar magnitude changes in concentration that are not near the criteria level. He noted that the EIV calculations do not differentiate between changes that occur near the criteria and those that occur at other concentration levels.
  - Gretchen Bruce of Intertox responded that the concentrations are end-of-pipe concentrations, not real exposure values (no one is really exposed to this concentration of RCOCs), and that the team is using the criteria to evaluate relative exposures.
- Jean Zodrow observed that the hardness of the water could change the pre-project concentration values. She suggested looking at the average hardness and seeing how that affects the ratio of pre-project concentration to water quality criteria. Rick Pleus of Intertox said the team could do that.
- Several Expert Panel members, including Kyle Dreyfuss-Wells, Derek Booth, and Bob Pitt, commented on the fact that the denominator in the EIV equation depended on values for all projects, not just the project being analyzed. Panel members noted that SPU should consider whether to change the denominator if it changes the set of projects that it actually puts forward in the Integrated Plan.

- Derek Booth said that an alternative would be to look at pre-project and post-project loads. Mike Milne of Brown and Caldwell said that the SPU team initially saw weird results, such as large projects not looking as good as expected, when the team did not consider changes in load relative to the reductions for all projects.
  - Dividing by the same value for all projects provides a way to show relative values, which Bob Pitt indicated was a good approach. Derek Booth added that although the approach may make sense, it may not be intuitive.
  - Panel members raised the issue of whether SPU would be updating the value for the change in load for all projects after SPU selected its projects for the Integrated Plan, or whether the denominator would be based on the original 14 projects that were considered. Gretchen Bruce of Intertox commented that since all of the values are divided by the same total load estimate, the EIV estimates would change in a proportional manner and this update would have no effect on the final results.
- Bob Pitt said that the distance of the receptor from the outfall does not have a linear effect on exposures, although that is how the receptor values are calculated. There will be a big impact of pollutant loads on receptors that are located really close to the outfalls, but differences in distance to the receptor will not matter as much for locations that are farther away. He suggested that SPU consider using a Gaussian distribution.
  - Eric Strecker of Geosyntec noted that sediment contamination studies show a non-linear distribution of contaminants.
  - The SPU Integrated Plan team will consider other ways of evaluating the distance component of the receptor factor equation whether these alternative approaches and how much impact they will have on the resulting EIV.
- Several Expert Panel members commented on how the EIV calculations depicted uncertainty, and that in several cases the information was presented as being more precise than it actually was, based on the significant figures in the analysis.
  - For example, Kyle Dreyfuss-Wells noted that the South Park project example had 0.3 hours per month of wading, but that number actually reflects survey results extrapolated to the water body being examined.
  - Eric Strecker of Geosyntec said that the team could pay more attention to the significant figures in the results.
  - Bob Pitt said that the most important thing would be to truncate the final result based on the significant figures.
  - A few panel members commented that it was surprising that one project accounted for 22 percent of the total reduction in zinc across all the projects, and they suggested that SPU double-check the numbers. Beth Schmoyer of SPU noted that this was a large project in an industrial basin, but said the team would take another look at the results.
- Bob Gearheart commented that the receptor factors for humans should indicate the number of people that the estimates apply to, not just the time for potential exposure over a given period. Gretchen Bruce of Intertox responded that this is incorporated implicitly into the overall “likelihood of exposure” estimate.

- Derek Booth asked the team how much variability there was in the data for the relative change in load for the RCOCs, as that part of the EIV calculation relates to project effectiveness and will be a large driver in the end results. He also noted that the column that has the most variability in the equation will drive the results.
  - Rick Pleus agreed, and noted that the choice of RCOCs also drives the outcome. Derek Booth and Jean Zodrow commented that there was a history of why SPU selected the RCOCs, and that this was based in part upon data availability.
- Bob Pitt said he found it difficult to evaluate the differences between projects when the results were not normalized by volumes (the differences could be due to the size of the project and/or the effectiveness of the treatment controls).
  - He noted that for the table that showed projects with the volumes on slide 50 of the presentation, the projects seemed to generally be ranked according to the volume reduction.
  - One exception to the trend that the better ranked projects reduced the most volume were the Longfellow Creek projects, which may imply that SPU should evaluate whether more can be done to address the water quality problems in that area.
- Derek Booth asked why the figure 91 percent volume reduction was so common across the stormwater projects.
  - The SPU team responded that 91 percent is an estimate of the flow reduction from bioretention projects; it is not location specific. Members of the team added that this estimate would likely be revised to 80 percent.
- Expert Panel members also provided several comments on how the information was presented, as follows.
  - Kyle Dreyfuss-Wells said that it would be important to document the additional clarifications and explanatory statements provided during the meeting as part of the Integrated Plan.
  - Bob Pitt noted that the slides would be clearer if they used consistent units across slides for concentrations (micrograms/liter or milligrams/liter).
  - Derek Booth and Bob Pitt commented on how the team described the duration of exposure, and noted that since hours per day is what is in the calculation, the team could describe exposures as a range of least to most likely, without converting them to a 1-to-5 scale. Gretchen Bruce of Intertox agreed.
  - Bob Pitt suggested that the arrows on slide 43 indicating the amount of time for different activities (e.g., 0.3 hours/month of wading) could be represented as bars to show the ranges instead of precise point values. It was also noted that February was omitted from this slide in the seasons (it should be February-September, not March-September).
- Kyle Dreyfuss-Wells observed that the EIV calculations are very complex, with a lot of assumptions, and they can raise a number of questions. It is important to be comfortable about the analysis, but also, when communicating the results of the analysis, it is important for there to be a clear message. The data should “pop.” If the results are confusing or unclear, there is a risk that the Integrated Plan could be poorly understood when the actual results are quite clear. The “sale” of the Integrated Plan and the analysis behind it needs to be considered. She suggested a FAQ document could be helpful.
  - Bob Pitt added that it is important to have defensible analysis (for example, looking at distance to receptors as a non-linear function).

    - Jean Zodrow noted that people will have preconceived notions, such as copper is bad for salmon in the Northwest, so it will be important to frame the results in terms of people's reference point to get the message across. Transparency is important, so communicating what the exposure assessment analysis provides will be important.
    - Bob Gearheart suggested doing a sensitivity analysis to see what changes the results and what does not.

Observer Comments and Responses

- Rob Grandinetti of the U.S. Environmental Protection Agency (EPA) asked why SPU selected the specific RCOCs it did, such as copper and zinc.
    - Kevin Buckley of SPU said that SPU chose to use copper and zinc as RCOCs for the consent decree requirement to evaluate reductions in metals. Copper is a concern for species, and Eric Strecker added that it has been cited by NOAA Fisheries in biological opinions. Zinc has been present in industrial discharges in the city.
    - SPU's process and rationale for selecting RCOCs for the pollutants identified in the consent decree was more fully described in the background materials and presentations provided to the Expert Panel in April and June.
- Rachel McCrea of the Washington Department of Ecology asked how the Integrated Plan team derived the 3 hours per month estimate for fishing for the example exposure assessment calculations for the South Park project in the Duwamish River basin.
    - Gretchen Bruce said the estimate was based on a King County survey and was not specific to the Duwamish River.
    - Rachel McCrea said that there is specific information about the Duwamish River and immigrant use of it, but she is reserving judgment and not disputing the numbers.
- Rob Grandinetti of the U.S. EPA said that he was not clear how the EIV calculations allow for comparison across pollutants.
    - Andrew Lee of SPU and Rick Pleus of Intertox responded that the water quality criteria allow for the comparison of the relative hazard from different pollutants. Andrew Lee of SPU added that PCBs will make up a larger proportion of the EIV because they have high concentrations.
- Jonathan Frodge of SPU asked the Integrated Plan team why they only considered migratory species of fish (salmon) in the exposure assessment, and not non-migratory fish such as pile perch. He said state data show non-migratory species are a bigger issue for consumption than migratory species.
    - Rick Pleus of Intertox clarified that the human EIV calculations include migratory and non-migratory fish species (an average across all fish consumed).
    - It is the ecological EIV that uses salmon species as ecological receptors. SPU focused initially on threatened and endangered species as a means of meeting the consent decree requirements, and then decided to consider other species of salmon as other ecological receptors.
- Jonathan Frodge of SPU suggested that the Integrated Plan should emphasize that its goal is to select stormwater projects that will provide significant receiving water quality improvements compared to the deferred CSO projects, rather than to fully restore the receiving bodies.

Highlights of Stormwater and CSO Project Pollutant Load Analysis

- Justin Twenter of Brown and Caldwell and Rob Annear of Geosyntec provided updates on the pollutant load reduction analysis for CSO and stormwater projects being considered for the Integrated Plan, and reviewed the draft results for several key parameters.
  - Since the August Expert Panel webinar, the SPU Integrated Plan team simulated load reductions for CSO projects in the Long Term Control Plan (LTCP) that are not being considered for deferral to provide additional context for the analysis of projects for the Integrated Plan.
  - The presentation covered draft results of the pollutant load analysis for stormwater and CSO projects being considered for the Integrated Plan (and additional LTCP projects for some pollutants), focusing on volume treated/removed, total suspended solids, fecal coliform, dissolved copper, PCBs, and ammonia-Nitrogen. Results were shown in log and non-log scales.
  - The Integrated Plan team is working on several adjustments and updates to approach to evaluating stormwater project loads, including:
    - Revisiting the land use effluent mean concentrations for a few RCOCs
    - Refining the team's understanding of data collected for fecal coliform load reduction from street sweeping projects to ensure that estimates are sufficiently conservative regarding removal efficiency
    - Refining the approach for representing the performance of bioretention facilities

Expert Panel Comments and Responses

- Derek Booth commented on the fact that the street sweeping projects showed very high load reductions for many RCOCs, yet there were no error bars shown for those results, whereas other projects showed error bars indicating the uncertainty range.
  - Rob Annear of Geosyntec said that the load reduction estimates for street sweeping projects would be broken down by season (like other projects) and the team would be adding error bars.
  - He added that the street sweeping results are preliminary and most likely will come down. As noted above, the team is reevaluating the fecal coliform data collected for street sweeping projects, in particular, to make sure that load reduction estimates are sufficiently conservative.
  - Bob Pitt added that he would like to see the load reduction results for street sweeping projects, along with the supporting documentation, because the numbers were so high.
- Derek Booth also suggested that since there was not much variation in the results by season, perhaps SPU does not need to show both.
  - Rob Annear of Geosyntec said that the team did not know that there would not be significant seasonal variation until the data analysis was completed.
- Bob Gearheart asked whether there were any "pre-conditions" for projects, in particular whether street sweeping would eliminate load reduction benefits from other projects.
  - A member of the Integrated Plan team said that there would be some overlap across projects, but not much.
- Kyle Dreyfuss-Wells asked how the team was considering other flows that enter the system, such as sanitary sewer overflows and infiltration and inflow (I&I) from leaky pipes and other sources.
  - Rob Annear said that the team is using data collected by SPU that would reflect any I&I that occurred. There is some uncertainty in that SPU does not have groundwater sampling data.

- The Integrated Plan team asked for the Expert Panel's perspectives on different approaches for estimating pollutant load reductions from natural drainage systems, based on assumptions about whether water leaving biofiltration facilities enters the receiving waters, goes into an underdrain, or is "treated" as it goes through the ground (100 percent removal of pollutants). Tracy Tackett of SPU indicated that SPU plans to use a conservative estimate that half the biofiltration projects will have underdrains and half will discharge to the receiving waters. For the half with underdrains, data from past studies will be used to estimate the pollutant removal. For the half without underdrains, the assumption will be that there is 100 percent pollutant removal for the volume treated (80 percent).
    - Bob Gearheart indicated that it made sense to consider groundwater quality in considering the effects of projects on the receiving waters.
    - Bob Pitt said that the filters provide good removal, and that if underdrains are not included, the remaining water could go to the groundwater. The main problem with flows getting to the receiving waters after being filtered is when the underdrain is daylighted. This is primarily an issue for organic toxics, not metals. He added that local experience with biofiltration is critical.
    - Bob Pitt said that he thought SPU's proposed assumptions for where flows from biofiltration projects would end up seemed reasonable (literature values for removal efficiency of projects discharging to underdrains / 100 percent pollutant removal for projects discharging to groundwater).
    - In response to a question, SPU confirmed that it would also be changing the amount of volume treated by biofiltration projects from 91 to 80 percent, as mentioned earlier.

Observer Comments and Responses

- Mark Henley of the Washington Department of Ecology commented that his understanding was that the load reduction values were based on actual data for CSO projects, but based on published values for the stormwater projects.
    - Rob Annear of Geosyntec and Kevin Buckley of SPU responded that the stormwater project values are based on data collected locally, although the data are not specific to the project sites. The CSO project load reduction values are also modeled.
        - The Integrated Plan team examined the land uses relevant to the stormwater project sites, the range of pollutant loads coming from those land uses, and the estimated project performance based on the effectiveness of similar stormwater best management practices.
        - The load estimates from land use are based on the City's NPDES stormwater characterization data, which was collected for three sites. The team then compared those data to data from sites in Tacoma, Washington, and Western Oregon, as well as national data, using box plots and showing 95 percent confidence intervals.
    - Eric Strecker of Geosyntec added that for many projects there is less concentration data available for CSO projects than for stormwater projects.
- Rob Grandinetti of EPA asked how the street sweeping projects being considered for the Integrated Plan differ from what SPU is required to do under its MS4 municipal stormwater requirements.
    - Kevin Buckley of SPU responded that street sweeping is not required by the MS4 permit but that SPU is doing some street sweeping (every other week in certain areas of the city) as part of the structural controls in its stormwater management plan. The street sweeping projects and other

stormwater projects being considered for the Integrated Plan are in addition to the stormwater pollution controls in the City's MS4 permit.
  - Rachel McCrea, the City's MS4 permit manager at Ecology, confirmed that street sweeping is not a requirement in the MS4 permit.
  - SPU is considering two street sweeping projects for the Integrated Plan: Phase 1, which will expand the miles of sweeping; and Phase 2, which will extend sweeping into residential areas.
  - Rob Grandinetti also asked whether the street sweeping data were monitoring and/or modeling results. Kevin Buckley of SPU said that street sweeping performance data are collected monthly as a composite sample, and then examined for the wet and dry seasons.
- Mark Henley of Ecology said he was surprised that the LTCP CSO projects (for some of the larger CSOs in SPU's system, CSOs #147 and #152) included in the comparison with potential Integrated Plan projects did not show much difference in load reductions from the stormwater projects. He said he would expect that the results for fecal coliform reductions for those CSO projects should be even higher than shown since they are addressing large volume CSOs.
  - Eric Strecker said that the stormwater projects discharge more often than the CSO projects, and that CSOs are composed largely of stormwater, so those factors minimize the differences.
  - Andrew Lee of SPU commented that since the load reductions of CSO projects 147 and 152 are comparable to the proposed stormwater, SPU is not proposing to defer those CSO projects. In addition, those CSO projects would show a better "bang for the buck" with respect to fecal coliform load reductions.
  - Eric Strecker of Geosyntec said that the team could add a description to help explain the results.

Discussion of Approach to Demonstration of Significant Benefit

- Kevin Buckley of SPU and Mike Milne of Brown and Caldwell gave a brief presentation on how SPU is thinking about approaching the demonstration of significantly greater water quality benefits from the stormwater projects proposed in the Integrated Plan to those CSO projects proposed for deferral. Their presentation covered the following:
  - SPU will evaluate "packages" of stormwater and CSO projects according to the consent decree criteria, including:
    - Pollutant loads
    - Exposure
    - Water body characteristics (considering impaired water body status, frequency of overflows, volume treated, etc.)
  - As part of its analysis, SPU is considering how the pollutant load reductions for individual stormwater projects compare to the load reduction benefits of all the CSO projects SPU is considering for deferral.
  - To help show significant benefits, SPU is planning to present a bar graph of the total load reductions of all stormwater projects proposed in the Integrated Plan compared to the benefits from all CSO projects to be deferred. (The graphs in the presentation depicted results for all 14 stormwater projects under consideration, but similar graphs would be produced after SPU selects a subset of stormwater projects for the Integrated Plan. The bar graph results were shown with and without the street sweeping results, since those numbers were in flux.)

- In addition, SPU will examine the EIVs for stormwater projects as compared to the CSO projects; however, unlike the graphs for the pollutant loads, the EIV graphs uses the "most beneficial" CSO project as the baseline for comparison rather than using a baseline derived from summing the EIVs for all CSO projects being considered for deferral.
- Overall, most individual candidate stormwater projects show significant benefits above all potentially deferred CSO projects, according to loads, EIVs, and frequency. Multiple combinations of stormwater projects would provide even more significant benefits as compared to all the potentially deferred CSO projects.
- SPU will consider cost-effectiveness and other objectives (e.g., through the MODA process) to choose the final set of stormwater projects that will have load reductions and EIVs that far exceed the deferred CSO projects.

Expert Panel Comments and Responses

- Kyle Dreyfuss-Wells commented on the differential benefit shown between stormwater and CSO projects in the graphs. She asked whether any project that fell below the dotted black line representing the loads for all CSO projects (or the best CSO project, for EIVs) would be excluded from the Integrated Plan.
  - Mike Milne of Brown and Caldwell indicated that SPU would be choosing packages of projects that significantly exceed the load or exposure reduction benefit from the CSO projects, rather than excluding individual projects solely based on that comparison.
- Derek Booth indicated that there will be a lot of scrutiny on the results, and people could question them because they are so much in favor of stormwater projects—questioning why the projects had not already been done or questioning the validity of the results.
  - Mike Milne of Brown and Caldwell responded that SPU has a lot of "low-hanging fruit" with stormwater projects, while the City has already done most of the work to control CSOs; current CSO volumes are a fraction of what they were 20-30 years ago. The candidate CSO projects for potential deferral would address relatively small CSOs that are nearly under control. SPU has deliberately "stacked the deck" by identifying candidate stormwater projects that are expected to provide substantial water quality benefits compared to the small CSO projects that are candidate for deferral. That is one benefit of being able to do an Integrated Plan.
  - Nancy Ahern of SPU commented that regulatory drivers for CSO and stormwater control differ, and that one of the benefits of the Integrated Plan is that it lets the City prioritize implementation of stormwater projects that will have significant water quality benefits in the near term.
  - Derek Booth noted that comparing the stormwater projects to all the CSO projects is potentially doing the City a disservice in that the stormwater projects that do not show as good of benefits still outperform most of the CSO projects to be deferred. He thought it would be better to show why those stormwater projects were selected.
  - He also suggested that more precise project names, such as the amount of linear feet of natural drainage systems (NDS or green infrastructure), could be helpful rather than using general labels such as "NDS partnering." Bob Pitt added that many of the projects could probably be scaled.

- Bob Gearheart recommended that SPU consider the cost per pound of pollutant removal in comparing projects.
    - Kevin Buckley said that the combined costs for the deferred CSO projects is around $50-75 million, while the potential stormwater projects from which the City will choose is $150 million, so SPU will not propose all of them.
    - Kyle Dreyfuss-Wells said that it is not a fair comparison if SPU is comparing $150 million in stormwater projects to $75 million in CSO projects. The focus of the significant benefit analysis for the consent decree is on load reductions and other aspects of water quality. She added that it is important to note that the significant benefit analysis does not look at other co-benefits of stormwater projects for the community.

Observer Comments and Responses

- Mark Henley of Ecology noted that SPU intentionally chose CSO projects to defer that were low volume, and close to being controlled. Due to this, he is concerned about the potential for this plan to be taken out of context and used to undermine CSO control nationally.
    - Andrew Lee of SPU said that SPU would tell the story of how it selected CSOs that were nearly under control (had overflow frequencies close to the state standard of one event per outfall per year), and note that Seattle is different from other locations in that it manages smaller basins and has controlled most of the historical CSO volume already (e.g., reducing volumes from 20 billion million gallons initially to 200 million gallons now annually).
    - Kyle Dreyfuss-Wells agreed with that point, noting that Cleveland would never consider not addressing CSOs in its community that occur 40 to 80 times per year.
    - Rob Grandinetti added that there are significant flow disparities among cities; if five percent of New York City's discharges were controlled by green infrastructure, then that could represent more than the total volume in Seattle's municipal system.
    - One panel member suggested that an alternate graph could be to show the load reductions / volume treated for all CSO projects being deferred as well as for all the CSO projects in the LTCP.
- Rob Grandinetti of EPA asked how the SPU team derived the estimate of 150 stormwater discharges per year.
    - Kevin Buckley of SPU responded that 150 discharges per year was an educated guess, but that a better estimate would be calculated.
    - Beth Schmoyer of SPU suggested that the team could evaluate rain gage data to produce a better estimate.

Next Steps for the Integrated Plan Team and Summary Observations

- Kevin Buckley of SPU reviewed the next steps in SPU's overall process for the Integrated Plan, which include:
    - Reviewing/refining aspects of the Integrated Plan methodology and data as they pertain to street sweeping and natural drainage systems
    - Finalizing the pollutant load reduction estimates and the exposure assessment
    - Completing the significant benefit evaluation of potential projects for the Integrated Plan
    - Conducting a cost-benefit analysis of the potential Integrated Plan projects

    - Developing packages of stormwater and CSO projects and analyzing them in the MODA process
    - Submitting drafts of the Integrated Plan along with the Long Term Control Plan, Environmental Impact Statement, and a summary/overview to EPA and the Washington Department of Ecology by May 2014
- He noted that this meeting was the formal end of the Expert Panel process, but asked the Panel and observers if there were other areas where it would be useful for the Expert Panel to provide input on the methodology/approach.

Expert Panel Comments and Responses

- Bob Gearheart said he would like the Expert Panel to draft a letter to SPU with observations and recommendations from the Panel. He has worked with Jennifer Tice of Ross Strategic to prepare a draft outline of the letter, which was shared with the Expert Panel at the meeting.
- The group discussed the desired audience for the letter. Derek Booth suggested that it should be focused on SPU, but will be read by SPU management, the collective technical staff working on the Integrated Plan, the regulatory agencies, and others. Nancy Ahern of SPU added that the main audience should be SPU management, but that it will also be useful for the City Council, as it will help provide a lay perspective on the methodology.
    - Kyle Dreyfuss-Wells said that the City Council will focus on the summary and the list of panel members.
- Observations of the Expert Panel on SPU's Integrated Plan approach and ideas that the group discussed for the letter included the following:
    - Kyle Dreyfuss-Wells said that overall she feels very positive about SPU's Integrated Plan approach, but she has some concern about it being over complicated. It is important that SPU not lose the forest for the trees, since overall this is a "good news" story.
    - Jean Zodrow noted that SPU has used good science, with reasonable approaches and some innovations. The team has presented this information well. The exposure assessment was a "black box" earlier in the process, but the Expert Panel has looked at the science and finds it to be reasonable.
    - Bob Pitt said he found the Integrated Plan methodology to be an intriguing approach. There are some data gaps, and he expressed some concern that SPU had not covered how to explain remaining uncertainties that thoroughly. With large differentials in the results between stormwater and CSO projects, as long as the uncertainty bands are smaller than the overall differential, the results will hold.
    - Derek Booth echoed Bob Pitt's comments in saying that the overwhelming difference in the volumes treated between the stormwater and CSO projects forgives many of the uncertainties and questions about the data. He added that it is appropriate to do a good job on the individual elements of analysis, but that should not undermine the common-sense outcomes the project is heading towards. Overall, it should be clear that it makes sense to do the proposed stormwater projects in the Integrated Plan and defer the CSO projects.
    - Bob Gearheart observed that one of the things that he is taking away from this process is the way that the team has used site-specific information to make decisions about performance management.

- Comments that the group had about the relevance of this process to other communities included:
  - Bob Pitt noted that other communities are driven more by economics in their decision-making. They may need to show additional benefits from stormwater/green projects in order to show that they make sense from a cost-benefit standpoint.
  - Kyle Dreyfuss-Wells said that she thinks that overall the level of scrutiny on integrated planning is necessary at this point.
- Comments that the group had about the Expert Panel process included:
  - Jean Zodrow said that SPU was great at responding to comments.
  - Kyle Dreyfuss-Wells commented that she benefited from the process, and thought that utilities should share more about their efforts.
  - Bob Pitt said that the process was very condensed, but involved a good mix of participants.
  - Derek Booth observed that big and small issues raised by Expert Panel members seemed to receive equal weight/treatment. He suggested that the Expert Panel might have had an opportunity to form more refined/focused opinions and coalesce as a group if the panel members had had an opportunity to meet as a group on their own early on in the process
  - Kyle Dreyfuss-Wells added that if each panel member had been given 15 minutes to share his or her background at the first meeting/call, it might have allowed people to better tap each other's expertise.

Observer Comments and Responses

- Mark Henley of Ecology said that he would like the Expert Panel to provide more input on the street sweeping project alternatives and, in particular, on the assumptions about the effectiveness of street sweeping at reducing fecal coliform loads and how that compares to observed/sampled data.
  - SPU agreed and will be holding a call with the Expert Panel on the approach for the street sweeping alternatives in late October.
- Rob Grandinetti of EPA asked the group how the estimated pollutant load reductions would be evaluated and quantified after the projects are implemented, and whether SPU would be committing to those load reductions (e.g., 80 percent removal). Mark Henley of Ecology added that the consent decree specifies what the City must do if it does not meet its commitments.
  - Kevin Buckley of SPU said that this issue of tracking pollutant load reductions during implementation would be addressed as part of the City's post-construction compliance monitoring plan, which is a required part of the City's consent decree submittal.
  - Rob Annear noted that the estimates the team has developed have uncertainty bands associated with them, and that provides an indication about the confidence in individual results.
- Alison Evans of Ecology asked whether the Expert Panel had seen all the data they were interested in reviewing to feel comfortable with SPU's approach to the Integrated Plan. She added that Ecology would like to see a summary of the data that SPU used, the calculations performed, and the results.
  - Kevin Buckley of SPU and Rob Annear of Geosyntec said that the Integrated Plan team had presented a summary of the data used in the Integrated Plan analysis and where it came from, the methodology, the assumptions, and the results to the Expert Panel.
  - At the April Expert Panel meeting, the team presented the summary of the data sources and the assumptions.

- Bill Ross of Ross Strategic clarified that the Expert Panel had not done a quality control review on the data entry.
- Kyle Dreyfuss-Wells commented that what the Expert Panel asked for in terms of more details about the methodology and the numbers that SPU is using, particularly on the exposure assessment methodology, is what the SPU Integrated Plan team presented to the Panel at this meeting. She said that with the exception of additional information on the street sweeping project alternatives analysis, the Panel has been able to review the information it requested.
- Derek Booth noted that the Expert Panel was never asked to serve in an approval or judgment role; rather, SPU has asked the Expert Panel for opinions on topics related to its Integrated Plan methodology. SPU is not required to do anything with the Expert Panel's comments. He feels like the Panel has been of use to the utility in the Integrated Plan development process, and does not feel a need to explore into the data in more detail.
- Bob Pitt said that the April presentations did show that summary of the data and sources, and noted that for some of the results that looked "funny" (street sweeping/fecal coliform), it could be useful to look at those data further.

Wrap Up and Next Steps

- In wrapping up, Kevin Buckley of SPU said he and the Integrated Plan team have gotten the type of input they sought from an expert panel. The team meets after each Expert Panel meeting to review the suggestions and discuss how to proceed. He appreciates that he can call individual panel members to discuss specific issues. The Expert Panel reviewed more than just the methodology in the last couple of meetings, by looking at the results of the analysis of projects being considered for the Integrated Plan, but he said he was glad SPU sought the Expert Panel's input on these issues.
- Mike Milne of Brown and Caldwell added that he thought the Expert Panel's input had added a lot to the Integrated Plan. Eric Strecker of Geosyntec and Rick Pleus of Intertox said the ability to ask questions of the Expert Panel was valuable, and the panel's input was extremely helpful.
- Nancy Ahern of SPU said that the utility has gotten a huge amount out of the Expert Panel's discussions.
  - SPU continues to be very excited about opportunity to do the Integrated Plan. The Integrated Plan is groundbreaking work that will allow SPU to make the case for implementing stormwater projects in the near-term and delaying regulatorily required, low-priority CSO projects.
  - The conclusions that might be simple in Seattle's context may be harder to derive in other contexts. She said she thought the Expert Panel has done a great service for other communities working on integrated planning processes.
  - Nancy Ahern thanked the Expert Panel, the SPU and consultant team working on the Integrated Plan, and the regulators observing the process.
- Bill Ross of Ross Strategic suggested that the Expert Panel would like to be kept informed about the Integrated Plan as SPU selects projects and as regulatory agencies review the Integrated Plan.
  - Bob Gearheart agreed and said that perhaps SPU could send a newsletter to update the Panel. He would like to see how the process turns out.
  - Nancy Ahern said that SPU would keep the Expert Panel informed about the outcomes of the Integrated Plan.

- Next steps identified at the meeting included:
    - SPU plans to convene the Expert Panel for a **conference call on October 23** to discuss the methodology and data for evaluating street sweeping alternatives for the Integrated Plan.
    - Ross Strategic will work with Bob Gearheart and other Expert Panel members to draft a letter summarizing the Expert Panel's observations about SPU's approach to the Integrated Plan.

Participants and Observers

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
Derek Booth	Adjunct Professor, Bren School of Environmental Science and Management, University of California Santa Barbara, Santa Barbara, CA
Kyle Dreyfuss-Wells	Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH
Bob Pitt	Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL
Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Nancy Ahern	Deputy Director, Utility Systems Management, SPU
Kevin Buckley	Integrated Plan Project Manager, SPU
Andrew Lee	Combined Sewer Overflow Program Manager, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic
Audience Members	
Jonathan Frodge	SPU
Ed Mirabella	SPU
Charles Oppelt	SPU
Beth Schmoyer	SPU
Tracy Tackett	SPU
Ingrid Wertz	SPU
Justin Twenter	Brown and Caldwell
Kurt Playstead	CH2M HILL
Theresa Wagner	City of Seattle, Attorney's Office
Rob Annear	Geosyntec Consultants
Eric Strecker	Geosyntec Consultants
Gretchen Bruce	Intertox
Rick Pleus	Intertox
Jennifer Tice	Ross Strategic
Rob Grandinetti	U.S. Environmental Protection Agency
Alison Evans	Washington State Department of Ecology
Mark Henley	Washington State Department of Ecology
Rachel McCrea	Washington State Department of Ecology

Seattle Public Utilities Integrated Plan Expert Panel
Meeting #6 (Webinar), October 23, 2013
Call Summary

Participants

The sixth meeting of Seattle Public Utilities (SPU) Integrated Plan Expert Panel, a web-enabled call on October 23, 2013, was attended by five Expert Panel members, SPU managers and staff, consultants, and observers. A full list of attendees is at the end of the summary.

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
Derek Booth	Adjunct Professor, Bren School of Environmental Science and Management, University of California Santa Barbara, Santa Barbara, CA
Kyle Dreyfuss-Wells	Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH
Bob Pitt	Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL
Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Kevin Buckley	Integrated Plan Project Manager, SPU
Andrew Lee	Combined Sewer Overflow Program Manager, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic

Meeting Objectives

The objectives for the Expert Panel meeting included:

- Provide an overview of SPU's street sweeping program and the potential street sweeping projects being considered as part of the Integrated Plan.
- Present and obtain Expert Panel feedback on SPU's methodology and use of data for estimating the pollutant load reductions from street sweeping projects being considered for the Integrated Plan.
- Provide an opportunity for final Expert Panel observations and recommendations on the Integrated Plan approach.

A summary of the meeting discussions, organized by the agenda topic, is below.

Summary

Introduction

At the beginning of the meeting, Kevin Buckley of SPU noted that this webinar was intended as a follow-up discussion following the September 16th Expert Panel meeting when several Expert Panel members and observers had had questions about the methodology and preliminary pollutant load reduction results for street sweeping projects.

- On October 17, two SPU staff in the street sweeping program, Louise Kulzer and Shelly Basketfield, had a conference call with Expert Panel member Bob Pitt so that they could hear his comments firsthand, as they had not attended the September 16th meeting. Notes from that call were distributed as part of the meeting materials for this webinar.
- Bob Pitt said that he had appreciated the opportunity to provide his comments to SPU.

Discussion of Methodology for Estimating Pollutant Load Reductions from Street Sweeping Projects Being Considered for the Integrated Plan

- Shelly Basketfield of SPU gave a presentation on SPU's street sweeping program, the two projects SPU is considering for the Integrated Plan, and how SPU is estimating the pollutant load reductions that could be anticipated from those projects. Her presentation covered:
  - The City's current street sweeping for water quality program and what it has achieved
  - The two projects being considered for the Integrated Plan ("phase 1" and "phase 2" street sweeping)
  - Assumptions SPU used to estimate the alternatives' water quality benefits (the assumptions related to street dirt washoff particle distribution, representative sample concentrations, representative pickup rates for Seattle, and representative pickup rates for alternatives)
  - The process to develop water quality benefit estimates based on street sweeper pickup rates and estimated washoff pollutant load and concentration reductions
- She noted that SPU had revised its methodology since the September Expert Panel meeting to produce more conservative estimates. The key changes to the methodology included using only wet season fecal coliform data (instead of wet and dry season data) and using particle washoff rates derived from a study in Bellevue, WA conducted by Bob Pitt, which reduced SPU's previous estimates of the percentage of particles picked up by the sweeper that would have been washed off.
- After Shelly Basketfield's presentation, Rob Annear of Geosyntec gave an overview of the pollutant load reduction estimates for the street sweeping projects in the context of other stormwater projects being considered for the Integrated Plan and potential CSO control projects to defer.
- Key changes the Integrated Plan team made to the results since the September meeting included:
  - Refining the effluent mean concentrations (EMCs) for different land uses
  - Narrowing the scope of the natural drainage system (NDS) partnering
  - Incorporating the assumptions discussed in September related to underdrains for NDS (50 percent of NDS will have underdrains, and for those NDS projects with underdrains, the assumption is that all pollutant removal occurs within the bioswale, so load reduction estimates are based on the estimated RCOC concentrations in the underdrains), and

    - Refining the estimates of street sweeping load reductions.
- These changes reduced the load reduction estimates for stormwater projects, but in general they still remained larger than those for most CSO projects being proposed for deferral. The exception to this trend was ammonia-nitrogen (ammonia-N), for which some of the CSO projects proposed for deferral showed greater load reductions than did many of the proposed stormwater projects.
    - This is consistent with the team's previous results, which indicated that the candidate CSO projects would provide greater ammonia-N load reductions than most stormwater projects. The new assumptions for the NDS Partnering and Piper's Creek Bioretention project resulted in lower ammonia-N load reductions for those projects.
- Draft results shown in the presentation included:
    - Volume treated/removed
    - Total suspended solid loads
    - Fecal coliform loads
    - Dissolved copper loads
    - PCB loads
    - Ammonia-nitrogen loads

Slides from Shelly Basketfield and Rob Annear's presentations were distributed with the materials for the webinar and contain more information about the above topics.

Expert Panel Comments and Responses

- Bob Gearheart asked whether there would be an increase in biological oxygen demand (BOD) and chemical oxygen demand (COD) over time as the material in the pile decomposed.
    - Rob Annear of Geosyntec said that there would be some decay that occurs in the 14-day window before samples are collected from the pile.
    - Bob Pitt said that BOD is not a stable component (it varies over time and that can complicate laboratory results), and that COD is a more consistent measure, although there is a lag time for evaluating COD. Because of the lag time provided in the pile, Bob Pitt said he thought that SPU would probably be okay with its analyses for BOD/COD.
- In answer to a question from Eric Strecker of Geosyntec about using COD to predict BOD using standard stormwater ratios, Bob Pitt said the delay time for evaluating COD is several days, not a few hours. He added that that the ultimate BOD value will be closer to the COD. To fully evaluate these relationships, a BOD rate study of 10-15 lab analyses would need to be done.
    - Rob Annear said that one of the representative constituents of concern (RCOCs) is BOD, so if SPU is unable to using the ratio of COD to BOD-5, it will need to look at BOD.
    - Following the webinar, Bob Pitt forwarded a chapter of a monitoring book to the Expert Panel and the Integrated Plan team that contained more information about studies of BOD in urban runoff. Research conducted by Dr. Pitt in 1979 showed that BOD from urban runoff after a 10-20 day incubation period can be 5-10 times greater than the BOD levels after 1-5 days.
- In answer to a question from Jean Zodrow, Rob Annear clarified that for dissolved copper, it is not necessarily the case that the street sweeping projects would have "no reduction" in dissolved

copper loads, but rather that SPU does not know what the load reduction would be so the SPU team assumed zero reductions to be conservative.

- Bob Gearheart commented that some of the projects could have synergistic or cumulative effects, and it was not clear whether the results accounted for any potential double-counting.
- Near the end of the discussion, Bill Ross of Ross Strategic asked each Expert Panel member to comment on his/her overall reactions to the street sweeping methodology and the draft pollutant load reduction results. Their responses were as follows.
    - Kyle Dreyfuss-Wells and Derek Booth both said that the methodology seemed reasonable, although they noted that this was not their area of expertise.
    - Bob Pitt said that the overall methodology for evaluating street sweeping project pollutant load reductions seemed fine, and that SPU was using reasonable assumptions and correct calculations. He encouraged SPU to conduct monitoring of street sweeping and any other stormwater projects that are implemented under the Integrated Plan.
    - Derek Booth added to Bob Pitt's comments that given the cost of this effort, monitoring would be worthwhile.
    - Jean Zodrow asked about the uncertainty in the estimates for street sweeping, and whether the adjustments had generally been overestimates or underestimates.
        - Aaron Poresky of Geosyntec said the Integrated Plan team looked at the variability in the monitoring data in the bins, characterized the uncertainty in that data, and used a Monte Carlo analysis to apply that uncertainty to the ranges of load reduction estimates for street sweeping projects. He added that SPU does not yet have a clear picture about the central tendency of the results.
        - Jean Zodrow said that that approach made logical sense to her.
    - Bob Gearheart noted the uncertainty/confidence ranges will be important for street sweeping, since there are less data for that type of project. In addition, there is an opportunity to monitor, sample, and add to the stock of knowledge regarding the efficacy of street sweeping programs, which would be of great benefit for other jurisdictions contemplating street sweeping.

Observer Comments and Responses

- Mark Henley of the Washington State Department of Ecology asked whether there would be bacterial regrowth in the wet season pile, and whether this would overestimate fecal coliform bacteria removal.
    - Shelly Basketfield of SPU said that when the overall runoff concentrations and SPU's assumptions are considered, she thinks that the results will still be conservative. However, the City plans to continue to look at the fecal coliform levels and do more sampling.
    - Overall, fecal coliform concentrations are low because SPU is only using wet season data.
- Mark Henley of Ecology asked how the volume treated was calculated for street sweeping projects, since the sweepers are not running all of the time it is raining.
    - The SPU team replied that it calculated the amount of land associated with the area being swept (streets and connected sidewalks) to estimate annual runoff volume of streets being swept.
- Mark Henley of Ecology said that the consent decree requires post-construction monitoring for options in the Integrated Plan, so he encouraged SPU not to overestimate load reductions since he

said they would need to be verified, and if load reductions were not as estimated, SPU may be required to construct additional stormwater projects to make up the difference.

Wrap Up and Next Steps

- Bob Gearheart said that the Expert Panel had worked with the support of Jennifer Tice of Ross Strategic to develop a letter summarizing the Expert Panel's observations and recommendations for SPU related to the Integrated Plan. He said that the Expert Panel would add anything relevant related to this call, and that they expected to finish the letter in a couple of weeks.
- Kevin Buckley of SPU thanked the Expert Panel for their participation in the process and their input on the Integrated Plan methodology. He said that although this was the final meeting of the Expert Panel, SPU plans to keep the Expert Panel informed about developments with the Integrated Plan.

Participants and Observers

Name	Organization
Expert Panel Members	
Bob Gearheart, Chair	Professor Emeritus, Humboldt State University, Arcata, CA
Derek Booth	Adjunct Professor, Bren School of Environmental Science and Management, University of California Santa Barbara, Santa Barbara, CA
Kyle Dreyfuss-Wells	Manager of Watershed Programs, Northeast Ohio Regional Sewer District, Cleveland, OH
Bob Pitt	Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL
Jean Zodrow	Project Toxicologist, ARCADIS U.S., Inc., Lakewood, CO
SPU and Consultant Participants at the Table	
Kevin Buckley	Integrated Plan Project Manager, SPU
Andrew Lee	Combined Sewer Overflow Program Manager, SPU
Mike Milne	Integrated Plan Consultant Team Project Manager, Brown and Caldwell
Bill Ross	Expert Panel Facilitator, Ross Strategic
Audience Members	
Shelly Basketfield	SPU
Margaret Bay	SPU
Rex Davis	SPU
Louise Kulzer	SPU
Rob Annear	Geosyntec Consultants
Aaron Poresky	Geosyntec Consultants
Eric Strecker	Geosyntec Consultants
Jennifer Tice	Ross Strategic
Alison Evans	Washington State Department of Ecology
Mark Henley	Washington State Department of Ecology
Rachel McCrea	Washington State Department of Ecology
Dino Marshalonis (phone only)	U.S. Environmental Protection Agency

Attachment D-3: Response to Expert Panel Comment Regarding Utility Curves

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Response to Expert Panel Comment Regarding Utility Curves

PREPARED FOR: Mike Milne, Brown and Caldwell

COPY TO: Kevin Buckley, SPU
Emiko Takahashi, SPU
Kurt Playstead/SEA

PREPARED BY: Pitzler, Dan/SEA

DATE: November 14, 2013

PROJECT NUMBER:

A recent letter to the SPU Director titled Expert Panel Comments and Recommendations on the Integrated Plan, dated November 12, 2013 included the following comment related to the multi-objective decision analysis (MODA) methodology used in the Integrated Plan:

In the final selection of stormwater projects for the Integrated Plan, we understand that SPU is considering the tradeoffs between potentially competing objectives through a systematic multi-objective decision analysis (MODA) process. We believe that this analysis would be stronger if it incorporated the concept of utility curves, which would allow normalization of the units and which would consider non-linear cause-and-effect relationships in the MODA criteria. If SPU does not choose to use utility curves in this analysis, it should document its rationale for this decision.

The normalization of units in the MODA evaluation did use the concept of utility curves, but it assumed that changes in value were linear within the range of the scale endpoints for each decision criterion. In this particular MODA, all measurement scales (excepting water quality) were constructed scales (i.e., qualitative) where words were used to define the midpoint and endpoints of 1-5 scales. Constructed scales were used because data were not available to develop more quantitative scales. It is our opinion that the changes in value resulting when moving along the constructed scales used in this analysis are generally linear in nature. Perhaps, an in-depth exploration of value scales would have uncovered some modest non-linear cause and effect relationships in some scales, but it was determined that the potential benefits of added scaling precision would be out-weighed by the time and complexity required to develop the scales with the multi-disciplinary team of staff and consultants that did the scoring.

For water quality, the MODA model used weighted changes in loads for three indicator parameters (fecal coliform, PCBs, and dissolved copper) to establish relative water quality scores for each project. In this case, the team believed that not enough was known about how these water quality parameters affected water quality in the different water bodies relevant to the projects to explore non-linear relationships in the scales.

Appendix E: Pollutant Reduction Estimation Method—Candidate LTCP Projects

Seattle Public Utilities

Protecting Seattle's Waterways

Volume 3 – Integrated Plan

Appendix E: POLLUTANT REDUCTION ESTIMATION METHOD—CANDIDATE LTCP PROJECTS

Final

May 29, 2015

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List of Abbreviations

Term	Definition
ac	acre(s)
BECV	best estimate control volume
BOD	biochemical oxygen demand
CFU	colony forming unit(s)
City	City of Seattle
COC	Constituent of Concern
CSO	combined sewer overflow
Cu	copper
DO	dissolved oxygen
L	liter(s)
LCL	lower confidence limit
LTCP	Long-Term Control Plan
mg	milligram(s)
MG	million gallon(s)
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
RCOC	Representative Constituent of Concern
TSS	total suspended solids
UCL	upper confidence limit
Zn	zinc

Summary

This appendix describes the process used for the determination of load reductions of various pollutants, as identified in the Consent Decree (United States, 2013), to Seattle's waterways from the implementation of the Long-Term Control Plan (LTCP) projects considered candidates for deferral under this Integrated Plan (referred to herein as "candidate LTCP projects"). The results of this analysis facilitate comparison of these candidate LTCP projects with candidate stormwater projects. LTCP project load reductions are a function of both the modeled combined sewer overflow (CSO) discharge volume reduction from the implementation of a given project and the concentration of each Representative Constituent of Concern (RCOC) assumed to be present in a particular CSO's effluent. The CSO Outfall 107 project is the major contributor to the overall load reductions from all of the candidate LTCP projects, with the rest of the projects contributing less than 23 percent of the total load reductions for all RCOCs. Refer to Attachment E-2 of this appendix for a summary of projected load reductions from the implementation of each LTCP project by RCOC. Refer to Attachments E-1 and E-2 of this appendix for a summary of each LTCP project's contribution (as a percentage of total) to load reductions from all candidate LTCP projects.

Introduction

This appendix accompanies the City of Seattle (City)'s Integrated Plan. It describes the process used for the determination of load reductions of various pollutants identified in the Consent Decree (United States, 2013) to Seattle's waterways from the implementation of the candidate LTCP projects. The results of this analysis facilitate comparison of these candidate LTCP projects with candidate stormwater projects.

Objectives

The objective of this analysis was to determine the load reductions for Constituents of Concern (COC) that would be achieved if the candidate LTCP projects were implemented. This analysis formed the basis for comparison of candidate LTCP projects with candidate stormwater projects proposed for implementation under the Integrated Plan. Candidate stormwater projects were required to complete a similar load-reduction analysis under the terms of the Consent Decree. Candidate LTCP and stormwater projects were objectively compared to demonstrate that candidate stormwater projects offered "significant benefits" relative to candidate LTCP projects (one of the terms for stormwater project implementation under the Consent Decree).

By estimating the quantities of various undesirable and/or harmful substances that would be kept out of Seattle's waterways through the implementation of certain projects, this analysis provides a relatively simple and straightforward metric for comparing candidate LTCP projects, both to one another and to candidate stormwater projects.

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CHAPTER 1

Methodology

Estimation of the pollutant discharge reduction from the implementation of a particular LTCP project required characterization of the following two parameters:

- the volume reduction of CSO discharge in a given time period (i.e., seasonally or annually)
- the concentration of a given pollutant assumed to be present in CSOs

This chapter describes the methodology used in the estimation of these parameters, as well as the calculation methodology behind how they were used to estimate load reductions for particular pollutants at specific CSOs.

1.1 Determination of Pollutant Concentrations

This section provides a summary of the background RCOCs and pollutant concentrations.

1.1.1 Background: Representative Constituents of Concern

Section V.B. paragraph 20 of the Consent Decree lists a number of specific constituents that the Integrated Plan must address. These include fecal coliform bacteria, total suspended solids (TSS), biochemical oxygen demand (BOD), ammonia, phosphorus, oil and grease, and pH. The Consent Decree also lists several general categories of constituents (e.g., metals, pesticides, and semi-volatile organic compounds).

Due to the very tight schedule for developing the Integrated Plan, it was not possible to collect new water quality data. Therefore, the City compiled and reviewed existing CSO water data in light of the Consent Decree requirements to develop a list of “Representative Constituents of Concern” (RCOCs). In some cases, the City identified surrogates to represent a category of constituents (e.g., dissolved copper [Cu] and dissolved zinc [Zn] for metals; polychlorinated biphenyls [PCBs] and polybrominated diphenyl ethers [PBDEs] for toxic organic compounds).

The Consent Decree listed numerous specific constituents as well as categories of constituents. For some of these constituents, little or no data were available for an adequate evaluation. Also, it was not feasible to model each COC given the available data and schedule. Therefore, the Integrated Plan team selected RCOCs with guidance from the Expert Panel. RCOCs were selected based on Consent Decree requirements, data availability, and professional judgment. Table 1-1 lists the COCs listed in the Consent Decree and the recommended RCOCs to be used in the pollutant load reduction evaluations.

Table 1-1. COCs Identified in the Consent Decree and Recommended RCOCs Used for Project Evaluations

COCs identified in the Consent Decree	Recommended RCOCs
Biochemical oxygen demand (BOD)	BOD
Semi-volatile organic compounds	Bis(2-ethylhexyl)phthalate
Pesticides	Dichlobenil
Pathogens (fecal coliform bacteria)	Fecal coliform bacteria
pH	H+
Nitrogen ammonia	Ammonia-N
Oil and grease	Oil and grease
Polybrominated diphenyl ethers (PBDEs)	PBDEs[a]
Projected dissolved oxygen (DO)	Projected DO
Polychlorinated biphenyls (PCBs)	PCBs[a]
Phosphorus	Phosphorus[a]
Total suspended solids (TSS)	TSS
Metals	Dissolved copper
	Dissolved zinc
	Total copper
	Total zinc

a. Total phosphorus, total PCBs, and total PBDEs were used as RCOCs.

1.1.2 RCOC Concentrations

Local CSO water quality data were used to develop concentrations for each RCOC. The City sampled CSO water quality at 15 locations between 2007 and 2010. Sites were sampled from one to four times. In addition, King County sampled CSO water quality at seven locations in the Duwamish area between 2007 and 2009. These sites were sampled from three to five times.

Using these water quality concentrations was advantageous because they were actual data from the City and King County CSO systems. In addition, the samples were analyzed for most of the COCs listed in the Consent Decree.

A challenge in using these water quality concentrations was the fact that only one of the six CSOs with candidate LTCP projects were included in the locations sampled for water quality by the City and King County. This challenge was addressed by showing comparability between locations with and without candidate LTCP projects—specifically, showing that tributary basin land uses and RCOC concentrations between the locations with and without projects were similar.

The City sampling locations included one CSO with a project proposed for deferral in the Integrated Plan (CSO Outfall 99). Showing similarity between tributary area land uses (of sampled and unsampled CSOs with candidate LTCP projects) is assumed to support use of sampled CSO water quality concentrations for the unsampled CSOs. The comparison of tributary area land uses showed that the sampled CSO was predominantly residential/commercial, which was similar to three of the remaining CSOs with candidate LTCP projects. This is shown on Figure 1-1 below. This result suggests that the sampled water quality concentrations from the one CSO (CSO Outfall 99) could be applied to the three CSOs with similar tributary land use (CSO Outfalls 138, 139, and

140). Note: the remaining two unsampled CSOs consisted of mostly industrial land use (CSO Outfalls 107 and 111).

In addition to the comparison described above, the tributary land uses for the remaining 13 CSOs sampled by the City (but not proposed for deferral by the City) were summarized. This showed that the predominant tributary land use for all 13 CSOs was residential/commercial. This is also shown in Figure 1-1 below. Therefore, pooling all the water quality data sampled by the City, and using this to describe the CSOs, with mostly residential/commercial land use, with candidate LTCP projects (CSO Outfalls 99, 138, 139, and 140), was considered a reasonable approach.

The idea of pooling all the City sampling data and using them for the four Integrated Plan LTCP projects with residential/commercial land use was further evaluated by reviewing the water quality data collected by the City. Figures 1-2 through 1-4 summarize data of TSS, fecal coliform, and copper. Table 2-1 presents this information in tabular form. The median TSS value for the Integrated Plan CSO sampled by the City are significantly higher than the median value of the pooled data, which may suggest that using only data from this CSO for the remaining Integrated Plan CSOs would over-predict TSS. Therefore, the TSS summary could be interpreted to support use of the pooled data for characterizing Integrated Plan CSO water quality. The fecal coliform and copper medians for the Integrated Plan CSO are similar to the medians for the pooled data, which supports the use of the pooled data for describing the water quality of the residential/commercial CSOs with candidate LTCP projects.

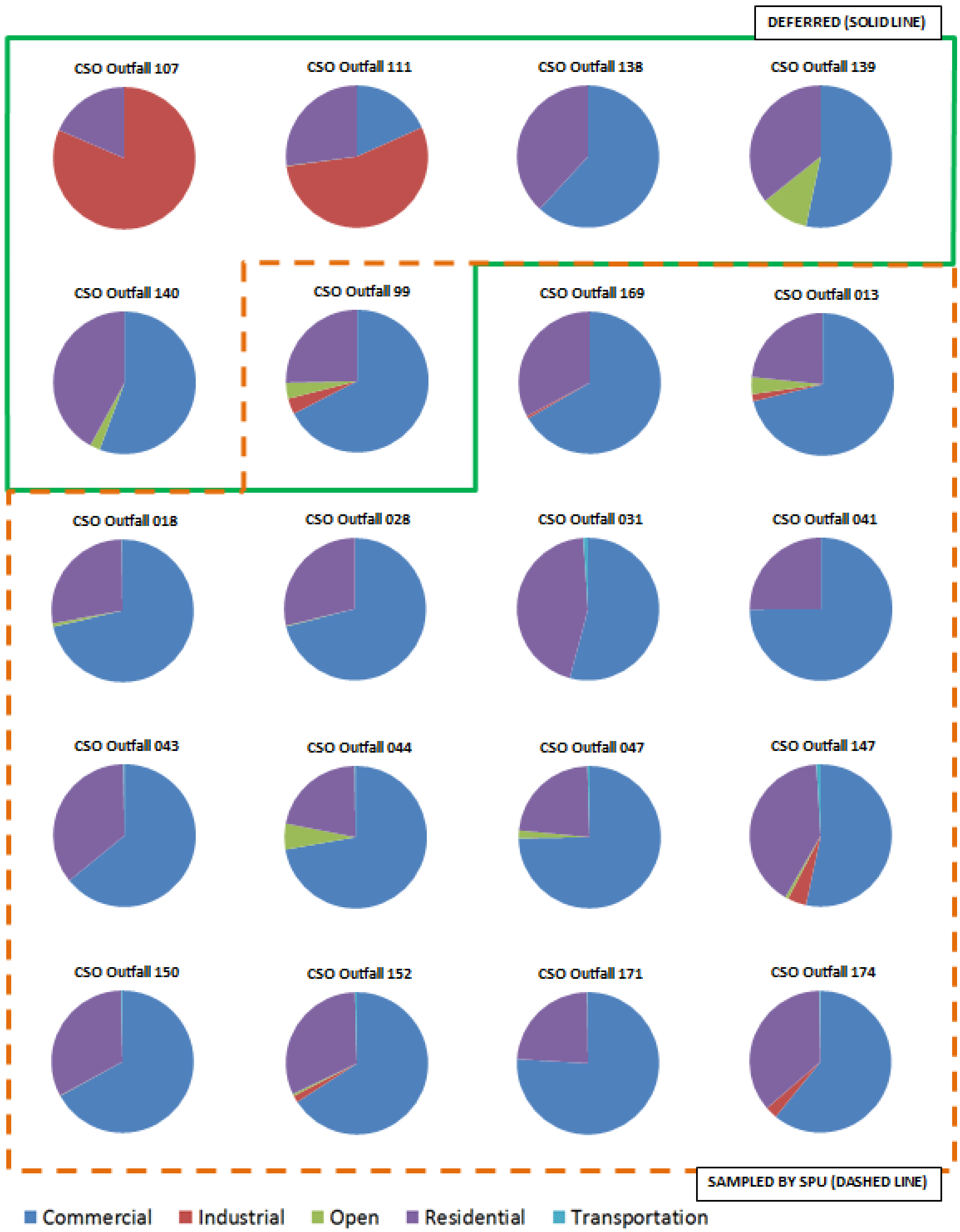

Figure 1-1. Tributary area land use for CSOs with candidate LTCP projects and CSOs sampled by the City

Table 1-2. Tributary Area Land Use for CSOs with Candidate LTCP Projects and CSOs Sampled by the City

CSO	Sampled by the City or proposed for deferral	Basin area (ac)	Percent of basin				
			Commercial	Industrial	Open	Residential	Transportation
013	Sampled	562	6.4%	0.1%	3.9%	66.4%	23.3%
018	Sampled	914	10.3%	0.0%	0.8%	61.2%	27.7%
028	Sampled	20	0.0%	0.0%	0.2%	71.1%	28.7%
031	Sampled	7	0.0%	0.0%	0.0%	54.7%	45.3%
041	Sampled	5	0.0%	0.0%	0.0%	74.9%	25.1%
043	Sampled	74	2.2%	0.0%	0.0%	62.1%	35.8%
044	Sampled	172	1.0%	0.0%	5.9%	71.3%	21.8%
047	Sampled	823	7.5%	0.3%	1.8%	67.5%	23.0%
147	Sampled	288	14.2%	1.3%	0.7%	42.9%	40.9%
150	Sampled	353	8.7%	0.1%	0.1%	58.4%	32.7%
152	Sampled	717	6.5%	1.1%	0.5%	60.2%	31.7%
171	Sampled	180	12.5%	0.0%	0.0%	63.6%	23.9%
169	Sampled	184	21.0%	0.1%	1.5%	54.8%	22.6%
174	Sampled	323	7.5%	1.3%	0.0%	55.0%	36.2%
99	Proposed for deferral and sampled	156	25.8%	1.7%	3.6%	43.5%	25.4%
107	Proposed for deferral	51	74.0%	7.5%	0.0%	0.0%	18.5%
111	Proposed for deferral	416	42.8%	15.8%	0.1%	13.3%	27.9%
138	Proposed for deferral	45	4.4%	0.0%	0.0%	57.4%	38.2%
139	Proposed for deferral	54	13.9%	0.0%	11.0%	39.4%	35.7%
140	Proposed for deferral	16	0.0%	0.0%	2.3%	55.7%	42.0%

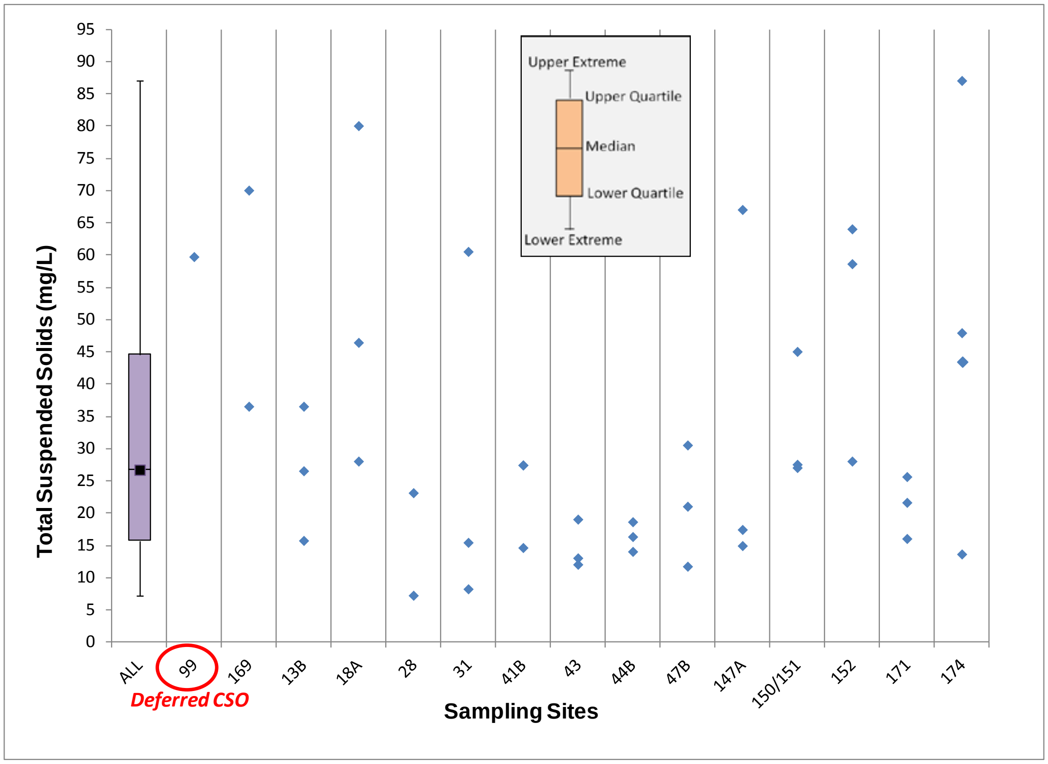

Figure 1-2. Total suspended solids, City sampling data

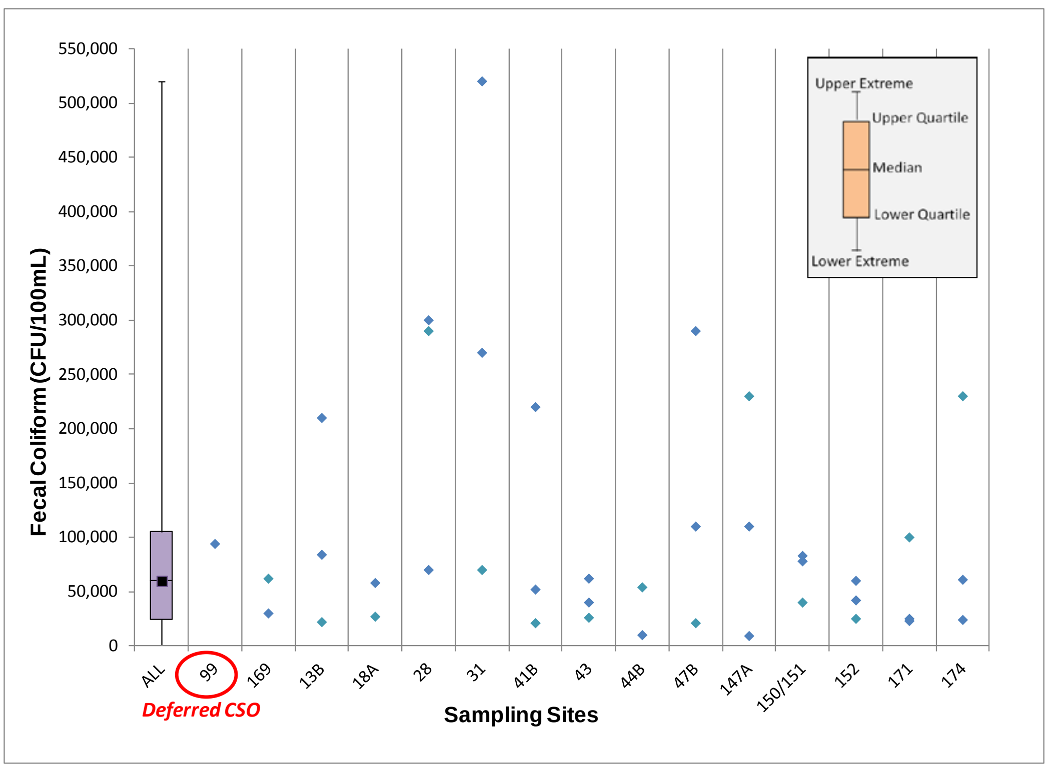

Figure 1-3. Fecal coliform, City sampling data

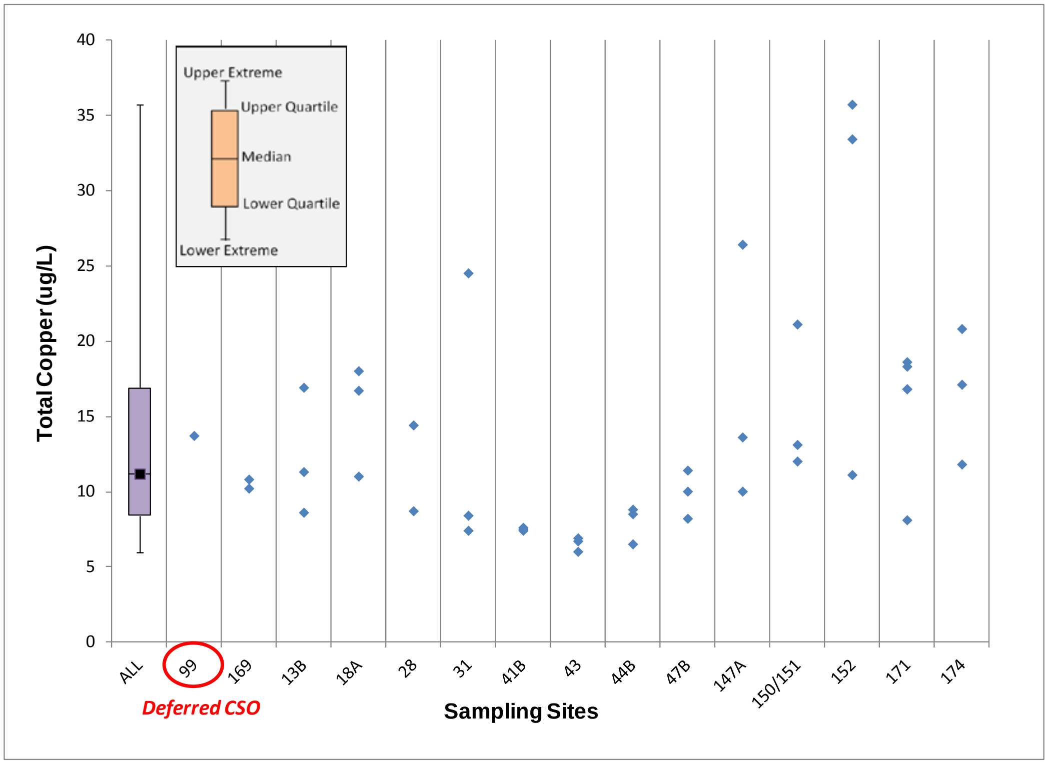

Figure 1-4. Total copper, City sampling data

Data for PCBs, PBDEs, and pesticides were not available from the City sampling data. Therefore, data from King County describing PCBs and PBDEs in CSO discharges (King County, 2011 and 2013) were used to fill the data gap. The Duwamish, Lander, Kingdome, and West Michigan sampling locations identified in the 2011 report were assumed to represent residential/commercial land use. Therefore, the PCB values for these locations, as reported in Table 4-3 of the report, were summarized for use in this analysis. The PBDE value used in this analysis is the median value reported by King County (2013) for all CSOs.

The two CSOs with candidate LTCP projects that were identified as having industrial land use (CSO Outfalls 107 and 111) are located in the Duwamish River basin. These CSO basins have similar land use as two CSOs, Brandon and Michigan, located nearby in the Duwamish River basin, which were sampled by King County (2011). Unlike the City data collection, the Michigan location was sampled in the combined sewer pipe (and not the overflow), during CSO or “near” CSO events. Three of the five events sampled at Michigan corresponded with recorded CSO events. The City pooled the King County water quality data from the two locations to estimate concentrations for the two CSOs with candidate LTCP projects.

The King County sample data included all RCOCs with the exception of the following parameters: BOD, fecal coliform bacteria, oil and grease, and H+. Residential/commercial (City sample data) values were used for industrial values to fill this data gap. PBDE concentrations were developed in the same way as described above.

Dichlobenil was used as a surrogate for the pesticide parameter because there were no CSO sampling data for pesticides. Dichlobenil was sampled in stormwater, as part of the state and federal requirements for CSO discharge required monitoring. The stormwater sampling provided concentrations of dichlobenil for residential, commercial, and industrial land uses. Therefore, median dichlobenil concentrations of each land use type were used to estimate a weighted concentration based on the land use of each CSO basin. This weighted concentration was factored by percentage of flow attributable to groundwater and stormwater within each CSO basin, based on the assumption that the pesticide is found only in stormwater and groundwater.

The RCOC concentrations used in this LTCP analysis were the mean of the data set, as calculated by the bootstrap method. The upper confidence limit (UCL) and lower confidence limit (LCL) were also estimated. This bootstrap method—used for deriving the mean, UCL, and LCL of the CSO water quality data set—was also applied to the data set used for the stormwater project evaluation, as discussed in the Integrated Plan and the stormwater project evaluation appendix.

For the results of this pollutant concentration analysis, see Section 2.1.

1.2 Determination of Volume Reductions

The methods used for estimating the reduction in CSO discharge volumes from the candidate LTCP projects entailed the use of the City's calibrated CSO flow models.

The City developed hydrologic and hydraulic models (EPA-SWMM 5 Build 5.0.022) for the currently uncontrolled CSO basins to support development of the LTCP. The models were developed to assess the performance of the existing system, predict wet weather flows, and estimate the frequency and volume of CSO events. The models were calibrated to flow monitoring data collected within each CSO basin. A full discussion of the modeling conducted for each of these CSO basins is provided within the LTCP reports, Volumes 2–10 (Brown and Caldwell, 2012).

These calibrated models were a good source of flow volume information for this LTCP pollutant reduction evaluation because they provide simulated, long-term time series of CSO events (detailing volume and duration). In addition, the models were used to develop estimates of control volumes (i.e., required storage) to limit the CSO to one or fewer overflows per year.

The basic steps involved in estimating volume reduction for each LTCP project were as follows:

1. Summarize the model results to determine the CSO events for the last 20 years of the simulation record. The past 20 years of the simulation record are used to correspond to the regulatory requirement of one allowable CSO per year, on average, for a 20-year period. Model results for a precipitation scaling factor near 1.00 are used. See below for more discussion regarding the scaling factor.

    a. Note: CSO Outfall 107 model results were summarized for the past 10 years of record because there was additional uncertainty regarding the past 20 years of record. The LTCP describes this in more detail.

2. Retrieve the best estimate control volume (BECV) developed for the candidate LTCP project. The BECV is the storage volume needed to bring an uncontrolled CSO basin into control (i.e., one overflow per year, on average), as determined by the modeling analysis.

3. Subtract the BECV from each pre-project CSO event volume to estimate post-project CSO volume for each event.

4. Summarize the average LTCP project reduction volume for a given time period (i.e., seasonally or annually). Two seasons were used for the seasonal summary: Season 1 represented the period between October and January and Season 2 represented the period between February and September. In general, a higher frequency and CSO volume is observed for events occurring in Season 1 while a lower frequency and CSO volume is observed for events in Season 2.

Uncertainty was represented in the calibrated model simulations by using precipitation scaling factors. The models were simulated 11 times with different scaled precipitation time series to produce results representing the range of uncertainty. The BECV was estimated as the mean of the control volumes from the 11 simulations. The precipitation scaling factor associated with the BECV, for the CSOs included in this analysis, ranged from 1.07 to 1.15.

Model results associated with a scaling factor of 1.00 were used for this LTCP pollutant reduction analysis. This scaling factor was used, in part, because the stormwater projects included in this analysis did not use scaled rainfall to account for uncertainty related to, among others, using historical rainfall to predict future conditions or the effects of climate change. Climate change effects, which would presumably occur in the future (after the proposed deferral has ended) were accounted for in the models by adding 0.06 to the scaling factor. Removing climate change from the scaling factors provided above would reduce many scaling factors to near 1.00.

For the results of this volume reduction analysis, see Section 2.2.

1.3 Load Reduction Calculations

Load reductions were calculated as a function of RCOC concentration and modeled CSO discharge volume reduction for every RCOC except fecal coliform using the following formula:

$$L_R = C \times V_R \times \left(\frac{10^6 gal}{MG}\right) \times \left(\frac{3.78541\ L}{gal}\right) \times \left(\frac{kg}{10^6 mg}\right)$$

Where:

$$L_R = Average\ load\ reduction\ for\ a\ given\ RCOC\ (except\ fecal\ coliform) over\ a\ given\ time\ period\ \left(\frac{kg}{time}\right)$$

$$C = Concentration\ of\ a\ given\ RCOC\ in\ effluent\ from\ a\ given\ CSO\ outfall\ \left(\frac{mg}{L}\right)$$

$$V_R = Modeled\ average\ CSO\ discharge\ volume\ reduction\ for\ a\ given\ time\ period\ \left(\frac{MG}{time}\right)$$

Note that V_R is defined as the modeled average CSO discharge volume per time (i.e., seasonally or annually) prior to the installation of a control measure (e.g., a large storage pipe) minus the modeled average CSO discharge volume per time after the installation an control measure. Also note that because concentrations for each RCOC other than fecal coliform were given in a variety of units, it was necessary to convert those units to $\frac{mg}{L}$ prior to applying the above formula.

When calculating fecal coliform load reductions, the following formula was used:

$$L_{RFC} = C \times V_R \times \left(\frac{10^6 gal}{MG}\right) \times \left(\frac{3.78541\ L}{gal}\right) \times \left(\frac{1000\ mL}{L}\right)$$

Where:

$L_{RFC} = Average\ load\ reduction\ for\ fecal\ coliform\ over\ a\ given\ time\ period\ \left(\frac{CFU}{time}\right)$

$C = Concentration\ of\ a\ given\ RCOC\ in\ effluent\ from\ a\ given\ CSO\ outfall\ \left(\frac{CFU}{mL}\right)$

$V_R = Modeled\ CSO\ discharge\ volume\ reduction\ for\ a\ given\ time\ period\ \left(\frac{MG}{time}\right)$

Note that because concentrations for fecal coliform were given in standard units of colony-forming units (CFU) per 100 mL $\left(\frac{CFU}{100\ mL}\right)$, it was nececessary to convert those units to $\frac{CFU}{mL}$ prior to applying the above formula.

For tables showing the assumed concentrations in CSO effluent of the various RCOCs and modeled volume reductions, consult Tables 2-1, 2-2, and 2-3. Note that CSO Outfalls 107, 111B, 111C, and 111H are classified as industrial and the rest of the LTCP projects are classified as residential/commercial, these data can be used with the above equations to recreate the load reduction results shown in Attachment E-2 (also note that for dichlobenil, Table 2-2 should be used instead of Table 2-1).

CHAPTER 2

Results

The pollutant (RCOC) concentration analysis and the volume reduction analysis form the "building blocks" of the load reduction analysis. Results of all three of these analyses are summarized in this chapter.

2.1 Pollutant Concentration Results

Table 2-1 shows the results of the pollutant concentration analysis.

Table 2-1. Mean, UCL, and LCL of RCOCs Applied to the Stormwater Volumes for Estimating Pollutant Reductions

Constituents of concern	Units	Residential/commercial			Industrial		
		Bootstrap mean	Bootstrap 95% lower confidence limit (LCL)	Bootstrap 95% upper confidence limit (UCL)	Boot-strap mean	Bootstrap 95% lower confidence limit (LCL)	Bootstrap 95% upper confidence limit (UCL)
Ammonia-N	mg/L	1.24	1.00	1.62	4.62	2.80	7.07
BOD	mg/L	19.5	15.3	24.7	19.5	15.3	24.7
Bis(2-ethylhexyl) phthalate	mg/L	0.0023	0.0018	0.0030	0.0083	0.0025	0.019
Dichlobenil	mg/L	Residential: 0.00012 Commercial: 0.000098	N/A	N/A	0.000070	N/A	N/A
Dissolved copper	mg/L	0.0051	0.0046	0.0057	0.0065	0.0041	0.011
Dissolved zinc	mg/L	0.019	0.018	0.021	0.032	0.022	0.046
Fecal coliform bacteria	CFU/100 mL	103,885	72,200	140,048	103,885	72,200	140,048
H+	mg/L	0.00012	0.000088	0.00017	0.00012	0.000088	0.00017
Oil and grease	mg/L	3.47	2.79	4.44	3.47	2.79	4.44
PBDEs	mg/L	0.000060	N/A	N/A	0.000060	N/A	N/A
PCBs	mg/L	0.000052	0.000040	0.000067	0.00011	0.000063	0.00020
Phosphorus	mg/L	0.60	0.44	0.75	1.57	1.23	2.12
Total copper	mg/L	0.013	0.011	0.016	0.053	0.034	0.068
TSS	mg/L	31.9	26.5	38.8	118.1	78.3	179.3
Total zinc	mg/L	0.042	0.038	0.048	0.14	0.10	0.19

Dichlobenil concentrations by LTCP project are shown in Table 2-2.

Table 2-2. Dichlobenil Concentration by LTCP Project

Outfall	Dichlobenil concentration (mg/L)
CSO Outfall 24	1.18E-04
CSO Outfall 25	1.17E-04
CSO Outfall 99	1.11E-04
CSO Outfall 107	7.00E-05
CSO Outfall 111B	7.00E-05
CSO Outfall 111C	7.00E-05
CSO Outfall 111H	1.15E-04
CSO Outfall 138	1.18E-04
CSO Outfall 139	1.18E-04
CSO Outfall 140	1.18E-04

2.2 Volume Reduction Results

Table 2-3 shows the results of the volume reduction analysis. The same information is also illustrated in Attachment E-3.

Table 2-3. Modeled Volume Reductions

Outfall	Season	Pre-project volume (MG/time period)	Post-project volume (MG/time period)	Volume reduction (MG/time period)
CSO Outfall 99	Annual	0.821	0.656	0.166
	Season 1 (Oct–Jan)	0.643	0.511	0.133
	Season 2 (Feb–Sep)	0.178	0.145	0.033
CSO Outfall 107	Annual	1.491	0.386	1.105
	Season 1 (Oct–Jan)	1.214	0.368	0.846
	Season 2 (Feb–Sep)	0.278	0.019	0.259
CSO Outfall 111	Annual	1.954	1.945	0.009
	Season 1 (Oct–Jan)	1.400	1.395	0.006
	Season 2 (Feb–Sep)	0.554	0.551	0.003

Table 2-3. Modeled Volume Reductions

Outfall	Season	Pre-project volume (MG/time period)	Post-project volume (MG/time period)	Volume reduction (MG/time period)
CSO Outfall 138	Annual	0.281	0.190	0.091
	Season 1 (Oct–Jan)	0.236	0.171	0.065
	Season 2 (Feb–Sep)	0.045	0.019	0.027
CSO Outfall 139	Annual	0.034	0.028	0.006
	Season 1 (Oct–Jan)	0.027	0.023	0.004
	Season 2 (Feb–Sep)	0.007	0.006	0.002
CSO Outfall 140	Annual	0.245	0.194	0.051
	Season 1 (Oct–Jan)	0.194	0.161	0.033
	Season 2 (Feb–Sep)	0.052	0.033	0.018

2.3 Load Reduction Calculation Results

Results of volume-reduction and load-reduction calculations are shown in tabular form in Attachment E-2 and are illustrated visually in Attachments E-3 (volume reductions), E-4 (load reductions, regular scale), and E-5 (load reductions, log scale). The total volume reduction from all candidate LTCP projects is approximately 1.4 million gallons (MG)/year. The CSO Outfall 107 project exhibits the greatest volume and average load reductions. This project constitutes 77 percent of the total annual volume reduction and 77 percent of the annual average total load reduction for all RCOCs, with the other CSOs making relatively minor contributions to total volume and load reductions. Relative contributions of each LTCP project to total load reductions from all candidate LTCP projects (by RCOC) are shown in Attachments E-1 (chart) and E-2 (table).

As stated previously, the two variables necessary for calculating load reductions for a given RCOC at a given LTCP project are volume reduced per time for the CSO and the concentration of a given RCOC assumed to be present in the LTCP project's effluent. Of these two variables, the volume reduced per time exhibits much greater variability between CSOs—often varying over several orders of magnitude—than assumed concentration (see Attachment E-3 for a visual comparison of the volume reductions between different candidate LTCP projects). Hence, the "driving force" behind variability in load reductions for a given RCOC between LTCP projects is volume reduction.

This idea is illustrated in Attachment E-1, which shows, as a percentage, the relative contributions of each candidate LTCP project to the total load reduction from all candidate LTCP projects (by RCOC). Note that the percentage contributions of each LTCP project to total load reductions for each RCOC closely parallel the percentage contributions of each LTCP project to total volume reduced, in general. The notable exception is CSO Outfall 107, which for certain RCOCs makes a significantly greater contribution to overall load reductions than might be expected from its contribution to volume reduction. For instance, CSO Outfall 107 is responsible for 77 percent of the overall volume reduction, yet contributes 92 percent to TSS reduction, 93 percent to total copper reduction, and 92 percent to bis(2-ethylhexyl)phthalate reduction. This is because this LTCP project is located in an industrial area, whereas most of the other LTCP projects are located in residential/commercial areas, and concentrations of suspended solids (i.e., TSS), metals (i.e. total copper), and semi-volatile organic compounds (i.e., bis(2-ethylhexyl)phthalate) would be expected to be higher in CSO discharge from industrial areas. See Table 2-1 for concentrations of RCOCs assumed to be present in effluent from the CSOs.

When applied to the CSO Outfall 111 project, however, the above comparison between concentrations of RCOCs in CSO effluent in commercial/residential areas and those in industrial areas also illustrates the primary importance of volume reduction in the load reduction calculations. Like CSO Outfall 107, CSO Outfall 111 has higher effluent concentrations of suspended solids, metals, and semi-volatile organic compounds than the LTCP projects in residential/commercial areas, yet because the volume reduction is relatively small (0.6 percent of the total volume reduction), they contribute only a very small amount to the overall load reduction for these constituents.

In summary, estimated load reductions are generally driven primarily by modeled volume reductions. CSO Outfall 107 has the greatest volume reduction and the greatest load reduction for all RCOCs. The remaining LTCP projects proposed for deferral collectively make a relatively small (<23 percent) contribution to overall load and volume reductions.

CHAPTER 3

Limitations

3.1 Pollutant Concentration Analysis

As discussed in Section 1.1.2, LTCP project CSO-sampling data were limited in number of samples and overall time period of sampling. However, the limited data used were specific to City and King County CSOs and covered the geographic extent of the candidate LTCP projects.

3.2 Volume Reduction Analysis

There is uncertainty associated with the model results used for this analysis. This uncertainty is explained, in detail, in the City LTCP hydraulic modeling reports (Brown and Caldwell, 2012).

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CHAPTER 4

References

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King County, 2011. Final. Duwamish River Basin Combined Sewer Overflow Data Report for Samples Collected from September 2007 to January 2010. Department of Natural Resources and Parks. Water and Land Resources Division.

King County, 2013. Draft. PCB/PBDE Loading Estimates for the Greater Lake Washington Watershed.

Seattle Public Utilities, 2013. Integrated Plan: Briefing Memorandum for April 29, 2013, Expert Panel Meeting. Briefing Memorandum on Stormwater and CSO Project Evaluation and Exposure Assessment Methods. April 22, 2013. Revised May 23.

United States of America and The State of Washington vs. The City of Seattle. 2013. Consent Decree. Civil Action No. 2:13-cv-678. July.

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Attachment E-1: Annual Volume and Load Reduction Summary Chart


Percentage of Total Candidate LTCP Project CSO Load Reduction by RCOC
Volume Reduced
12%
77%
1%
6%
0%
4%
Average (all RCOCs)
8%
84%
1%
5%
0%
3%
Total Zinc
4%
91%
Total suspended solids (TSS)
4%
92%
Total Copper
4%
93%
Phosphorus
5%
90%
3%
PCBs
6%
88%
PBDEs
Oil and grease
H+
Fecal coliform bacteria
Dissolved Zinc
85%
Dissolved Copper
9%
81%
Dichlobenil
16%
68%
9%
5%
Bis(2-Ethylhexyl)Phthalate
Biochemical oxygen demand
Ammonia-N
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
CSO Outfall 99
CSO Outfall 107
CSO Outfall 111
CSO Outfall 138
CSO Outfall 139
CSO Outfall 140

Attachment E-2: Annual Volume and Load Reduction Summary Tables

Attachment E-2: Annual Volume and Load Reduction Summary Tables

Annual Volume and Load Reductions (Values)

Project	Ammonia-N (kg)	Biochemical oxygen demand (kg)	Bis(2-ethylhexyl) phthalate (kg)	Dichlobenil (kg)	Dissolved copper (kg)	Dissolved zinc (kg)	Fecal coliform bacteria (billion CFU)	H+ (kg)	Oil and grease (kg)	PBDEs (kg)	PCBs (kg)	Phosphorus (kg)	Total copper (kg)	Total suspended solids (TSS) (kg)	Total zinc (kg)	Volume reduced (MG)
CSO Outfall 99	0.78	12	0.0015	0.00007	0.0032	0.012	651	0.000073	2.2	0.000038	0.000032	0.37	0.0084	20	0.026	0.17
CSO Outfall 107	19	82	0.035	0.00029	0.027	0.14	4,346	0.00049	15	0.00025	0.00046	6.6	0.22	494	0.57	1.1
CSO Outfall 111	0.15	0.64	0.00027	0.000003	0.00021	0.0011	34	0.0000038	0.11	0.0000020	0.0000036	0.05	0.0017	4	0.0044	0.0086
CSO Outfall 138	0.43	6.8	0.00081	0.000041	0.0018	0.0067	360	0.000040	1.2	0.000021	0.000018	0.21	0.0046	11	0.015	0.091
CSO Outfall 139	0.027	0.42	0.000050	0.000003	0.00011	0.00042	22	0.0000025	0.075	0.0000013	0.0000011	0.013	0.00029	0.69	0.00090	0.0057
CSO Outfall 140	0.24	3.8	0.00045	0.000023	0.0010	0.0038	201	0.000023	0.67	0.000012	0.000010	0.12	0.0026	6	0.0081	0.051
TOTAL	**21**	**106**	**0.038**	**0.00043**	**0.034**	**0.16**	**5,614**	**0.00063**	**19**	**0.00032**	**0.00053**	**7.3**	**0.24**	**536**	**0.63**	**1.4**

Annual Volume and Load Reductions (Percent of Total from All Candidate LTCP Projects)

Project	Ammonia-N (kg)	Biochemical oxygen demand (kg)	Bis(2-ethylhexyl) phthalate (kg)	Dichlobenil (kg)	Dissolved copper (kg)	Dissolved zinc (kg)	Fecal coliform bacteria (billion CFU)	H+ (kg)	Oil and grease (kg)	PBDEs (kg)	PCBs (kg)	Phosphorus (kg)	Total copper (kg)	Total suspended solids (TSS) (kg)	Total zinc (kg)	Average (all RCOCs)	Volume reduced
CSO Outfall 99	3.72%	11.60%	3.89%	16.16%	9.49%	7.61%	11.60%	11.60%	11.60%	11.60%	6.16%	5.11%	3.54%	3.74%	4.20%	8.11%	11.60%
CSO Outfall 107	92.23%	77.41%	91.90%	67.79%	81.37%	84.91%	77.41%	77.41%	77.41%	77.41%	87.64%	89.62%	92.57%	92.20%	91.32%	83.91%	77.41%
CSO Outfall 111	0.72%	0.60%	0.71%	0.71%	0.63%	0.66%	0.60%	0.60%	0.60%	0.60%	0.68%	0.70%	0.72%	0.72%	0.71%	0.66%	0.60%
CSO Outfall 138	2.05%	6.41%	2.15%	9.46%	5.24%	4.20%	6.41%	6.41%	6.41%	6.41%	3.40%	2.82%	1.95%	2.06%	2.32%	4.51%	6.41%
CSO Outfall 139	0.13%	0.40%	0.13%	0.59%	0.33%	0.26%	0.40%	0.40%	0.40%	0.40%	0.21%	0.18%	0.12%	0.13%	0.14%	0.28%	0.40%
CSO Outfall 140	1.15%	3.59%	1.20%	5.30%	2.94%	2.35%	3.59%	3.59%	3.59%	3.59%	1.91%	1.58%	1.09%	1.16%	1.30%	2.53%	3.59%

Attachment E-3: Volume Reductions by Candidate LTCP Project

This attachment contains the following figures:

- Figure E-3a. Average volume of water treated or reduced by the candidate LTCP projects
- Figure E-3b. Average volume of water treated or reduced by the candidate LTCP projects (Log Scale)

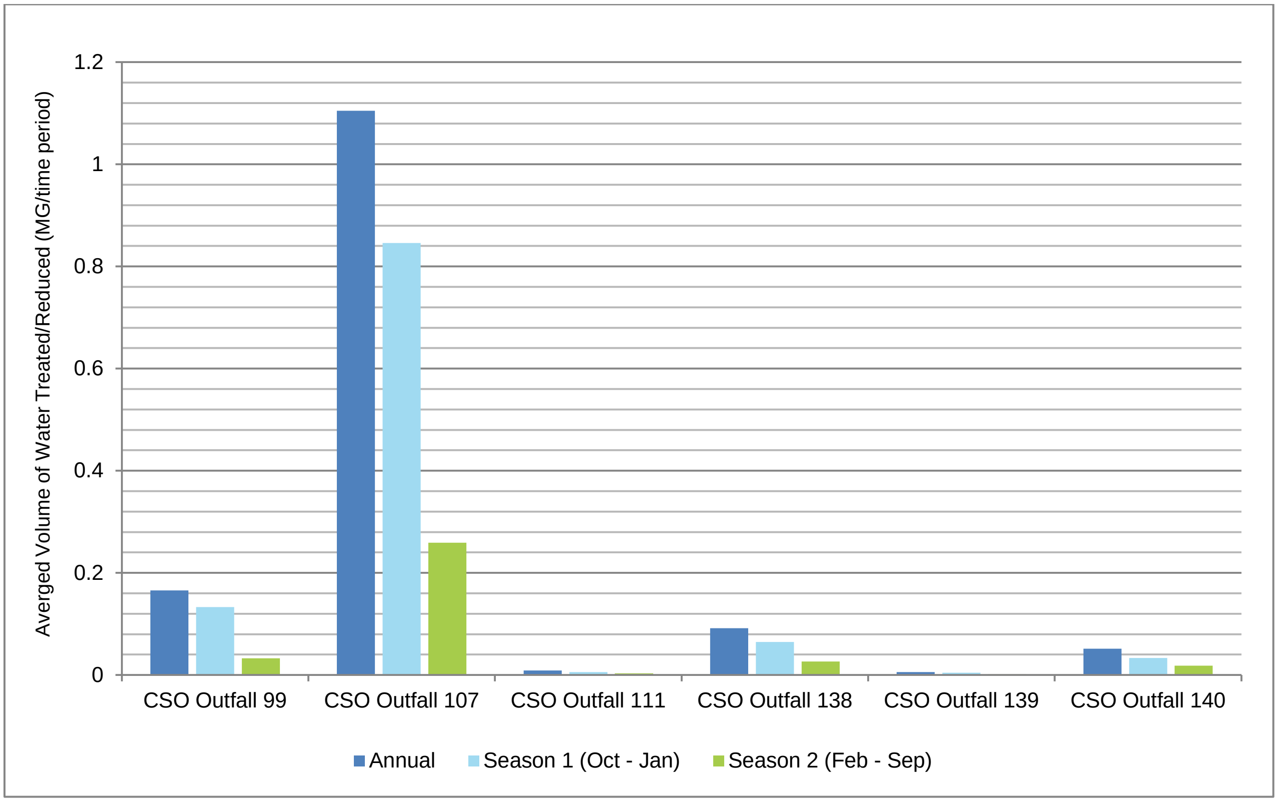

Figure E-3a. Average volume of water treated or reduced by the candidate LTCP projects

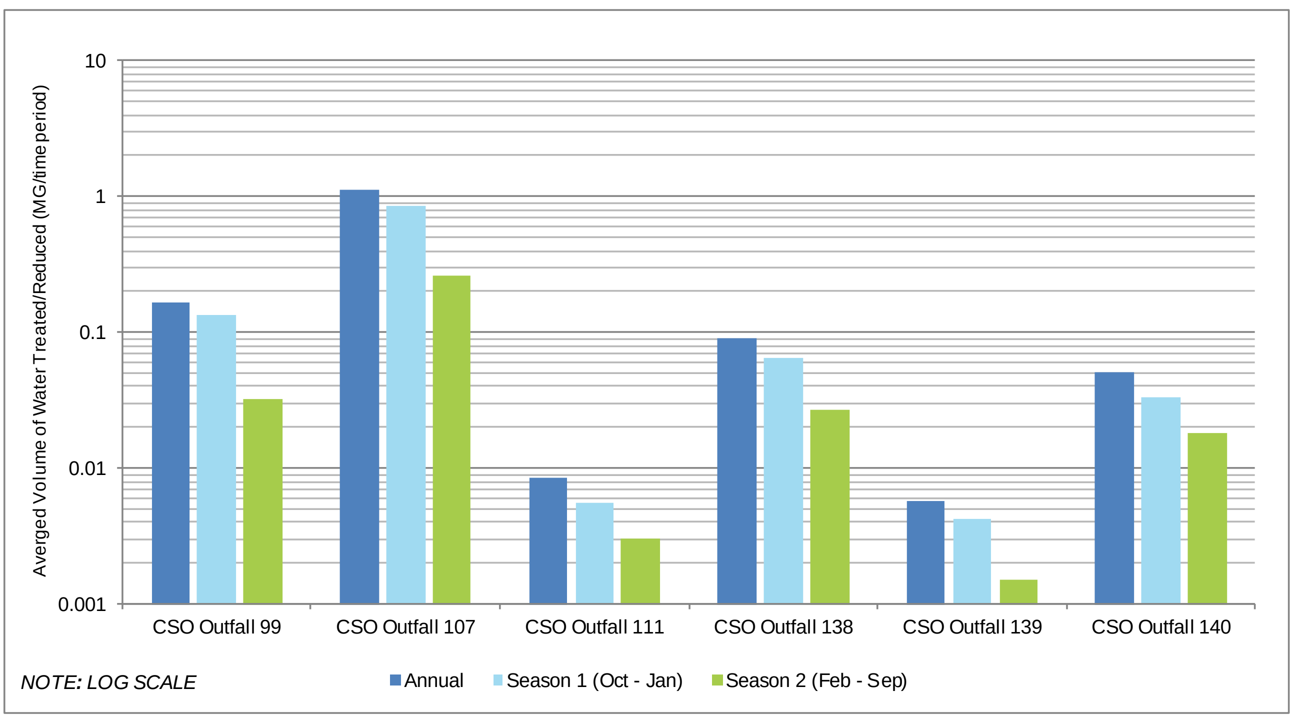

Figure E-3b. Average volume of water treated or reduced by the candidate LTCP projects (Log Scale)

Attachment E-4: Load Reductions by Candidate LTCP Project (Regular Scale)

This attachment contains the following figures:

- Figure E-4a. Average ammonia-N load reduction from the candidate LTCP projects (regular scale)
- Figure E-4b. Average BOD load reduction from the candidate LTCP projects (regular scale)
- Figure E-4c. Average Bis(2-Ethylhexyl)Phthalate load reduction from the candidate LTCP projects (regular scale)
- Figure E-4d. Average dichlobenil load reduction from the candidate LTCP projects (regular scale)
- Figure E-4e. Average dissolved copper load reduction from the candidate LTCP projects (regular scale)
- Figure E-4f. Average dissolved zinc load reduction from the candidate LTCP projects (regular scale)
- Figure E-4g. Average fecal coliform bacteria load reduction from the candidate LTCP projects (regular scale)
- Figure E-4h. Average H+ load reduction from the candidate LTCP projects (regular scale)
- Figure E-4i. Average oil and grease load reduction from the candidate LTCP projects (regular scale)
- Figure E-4j. Average PBDEs load reduction from the candidate LTCP projects (regular scale)
- Figure E-4k. Average PCBs load reduction from the candidate LTCP projects (regular scale)
- Figure E-4l. Average phosphorus load reduction from the candidate LTCP projects (regular scale)
- Figure E-4m. Average total copper load reduction from the candidate LTCP projects (regular scale)
- Figure E-4n. Average TSS load reduction from the candidate LTCP projects (regular scale)
- Figure E-4o. Average total zinc load reduction from the candidate LTCP projects (regular scale)

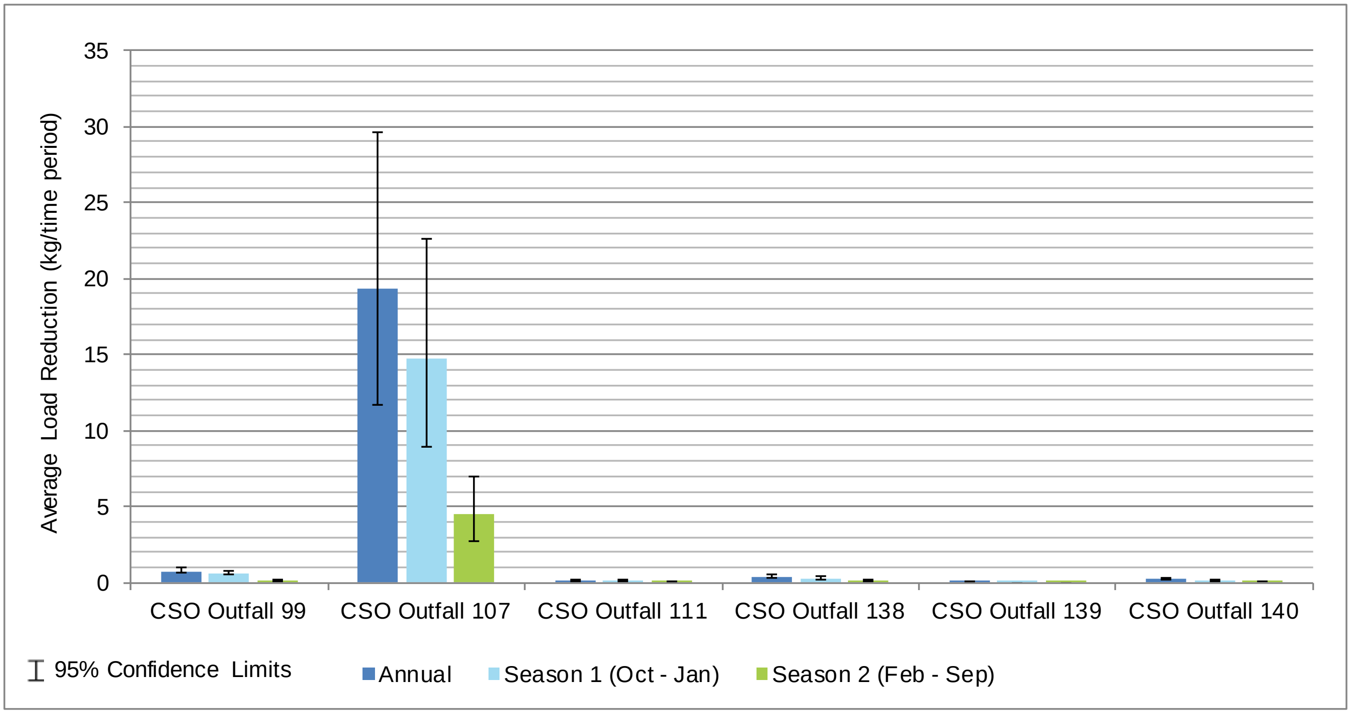

Figure E-4a. Average ammonia-N load reduction from the candidate LTCP projects (regular scale)

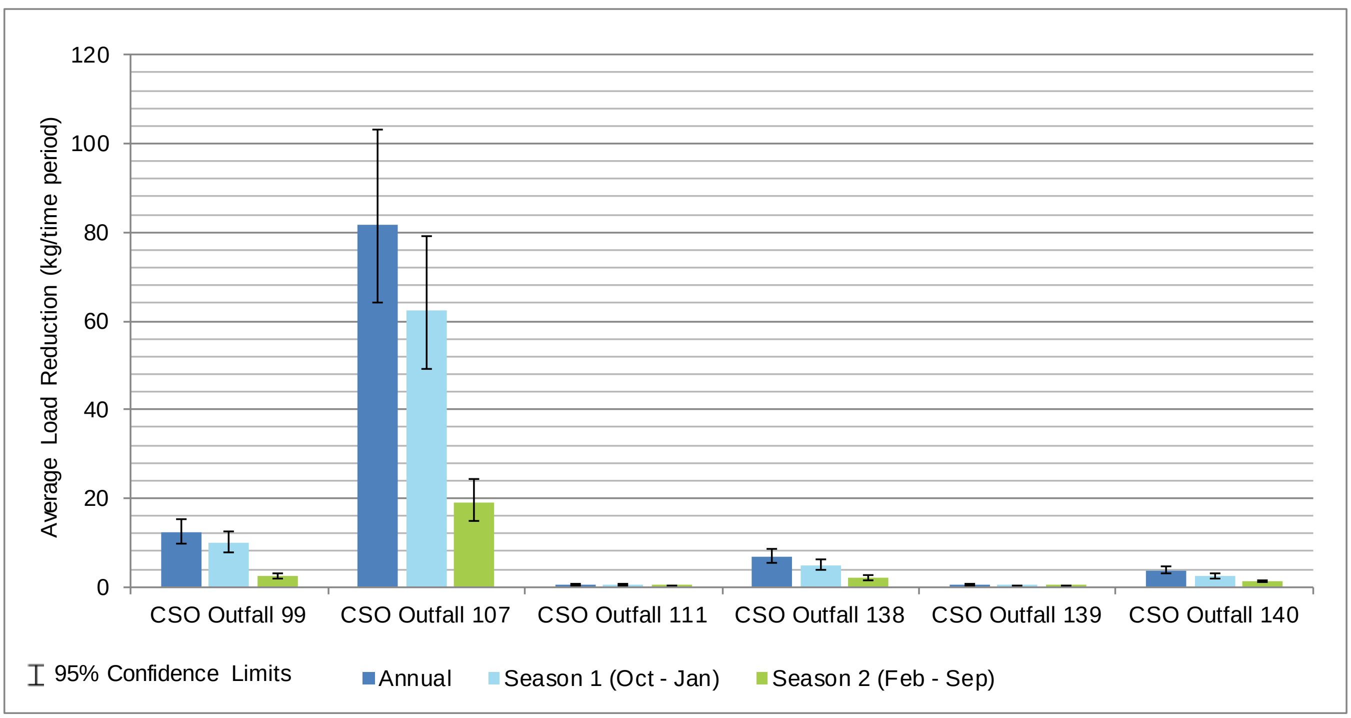

Figure E-4b. Average BOD load reduction from the candidate LTCP projects (regular scale)

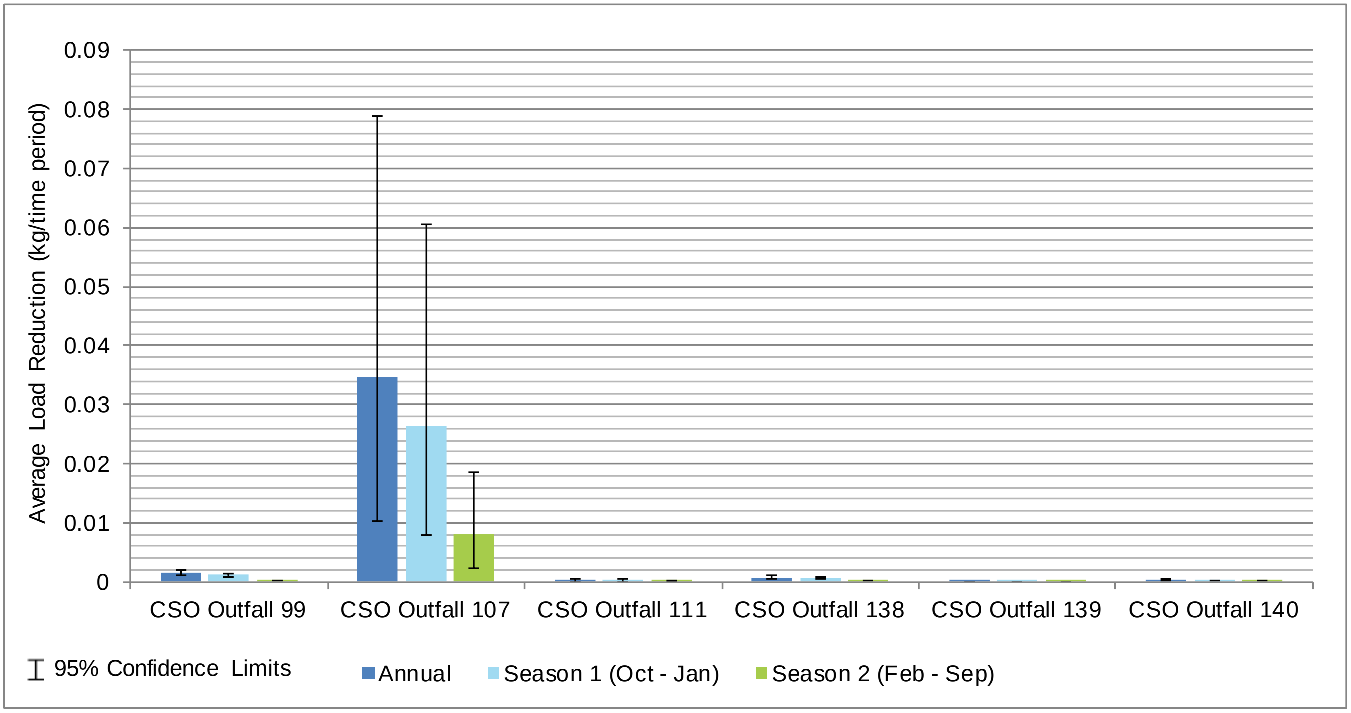

Figure E-4c. Average bis(2-Ethylhexyl)Phthalate load reduction from the candidate LTCP projects (regular scale)

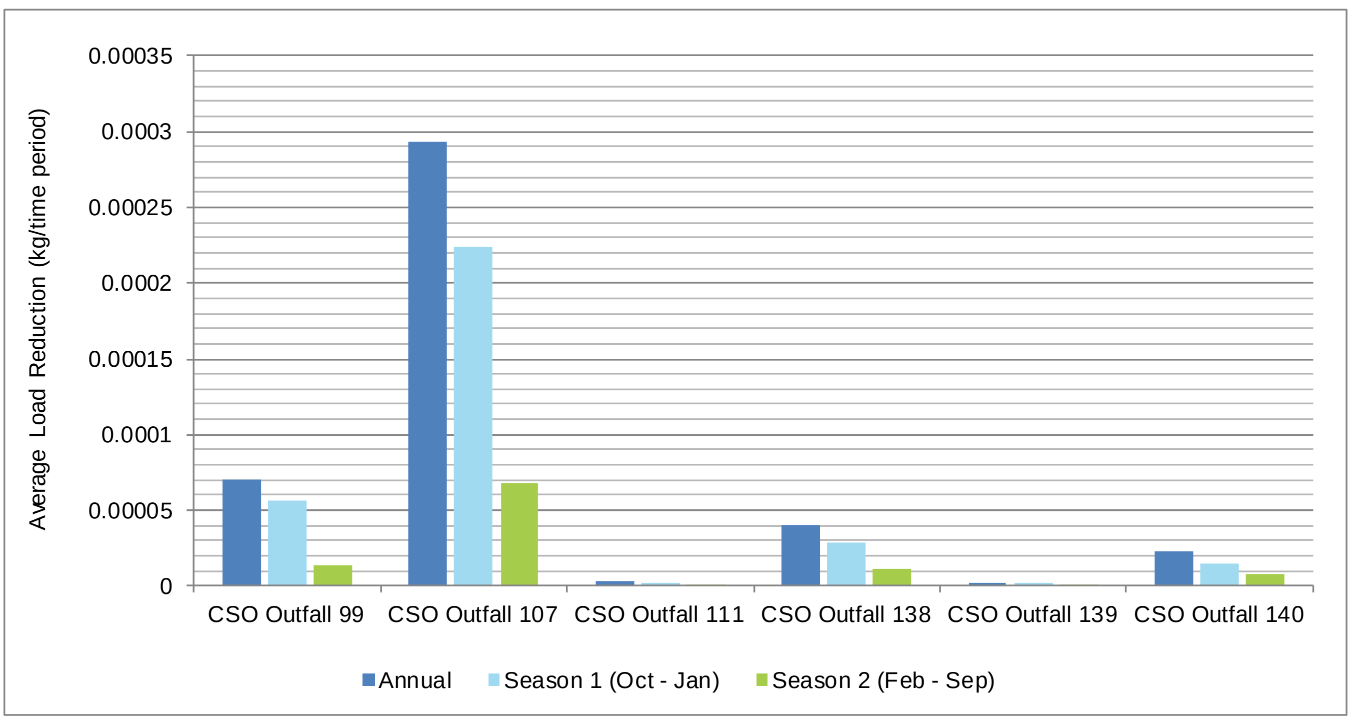

Figure E-4d. Average dichlobenil load reduction from the candidate LTCP projects (regular scale)

Note that for dichlobenil, there was insufficient data to calculate the UCLs and LCLs

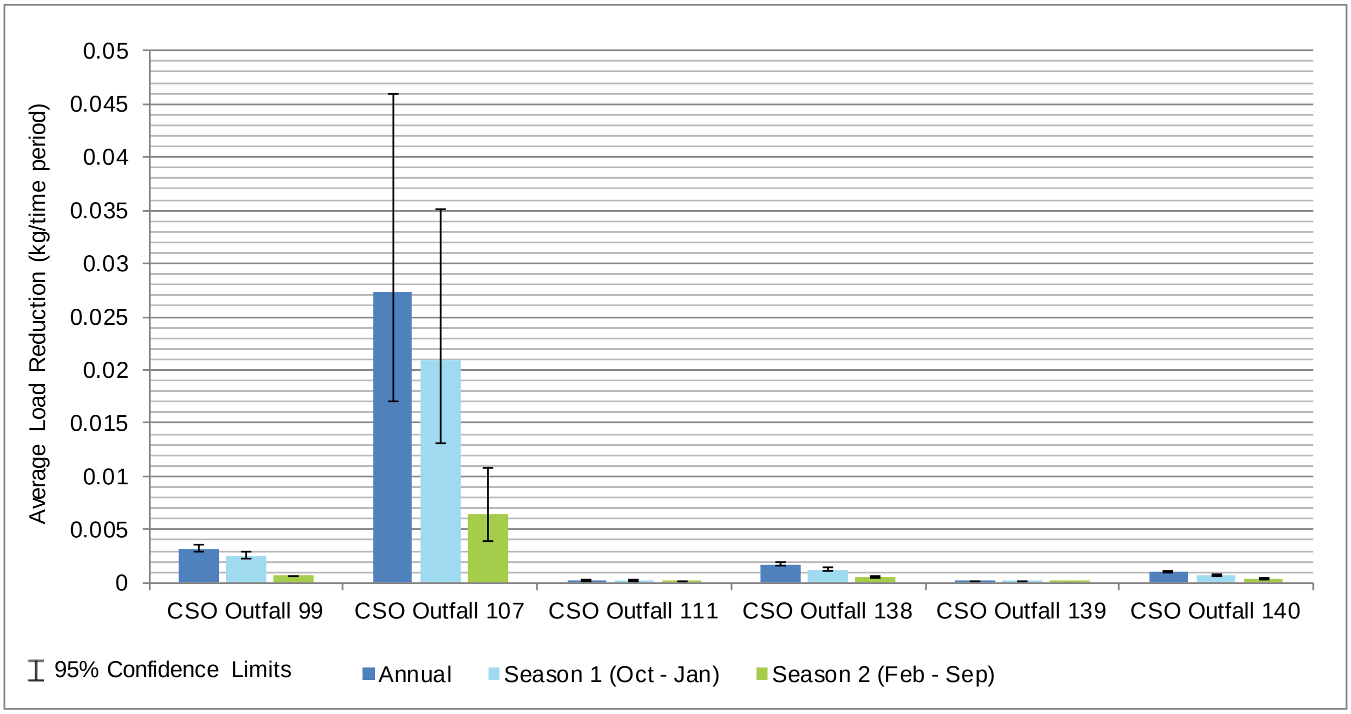

Figure E-4e. Average dissolved copper load reduction from the candidate LTCP projects (regular scale)

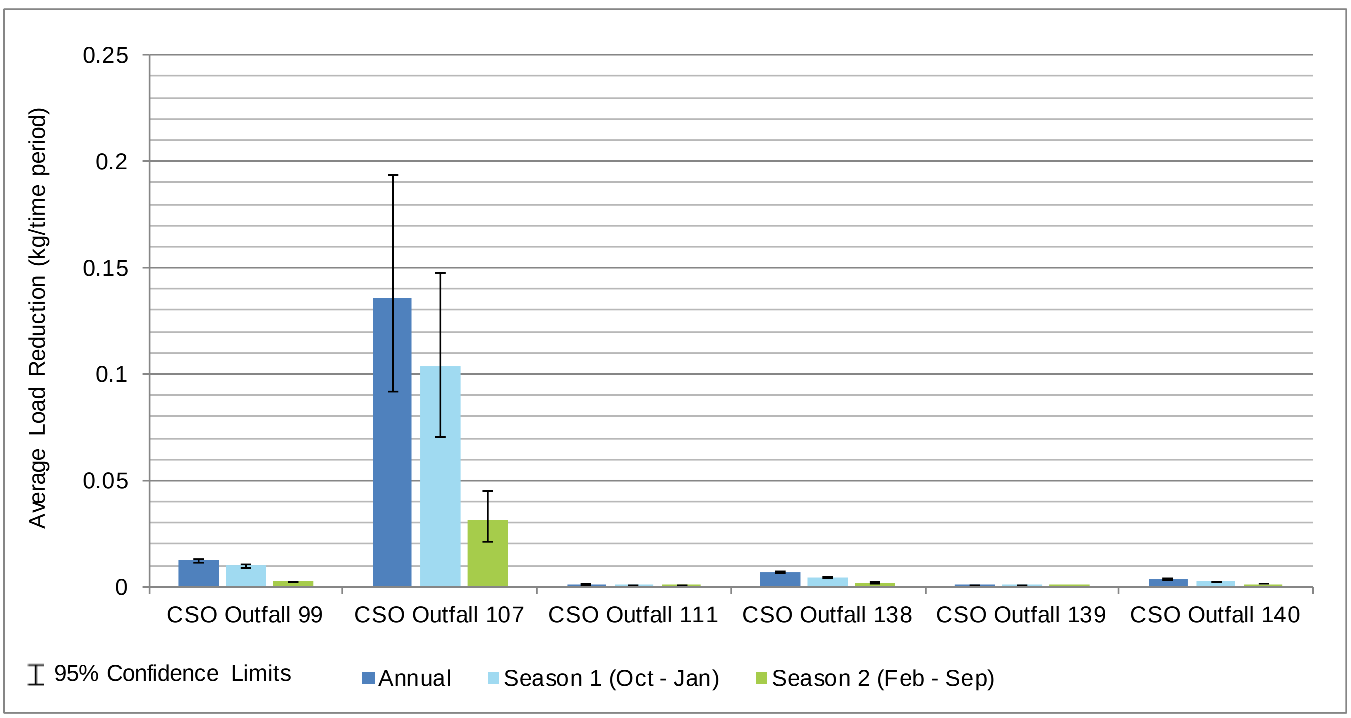

Figure E-4f. Average dissolved zinc load reduction from the candidate LTCP projects (regular scale)

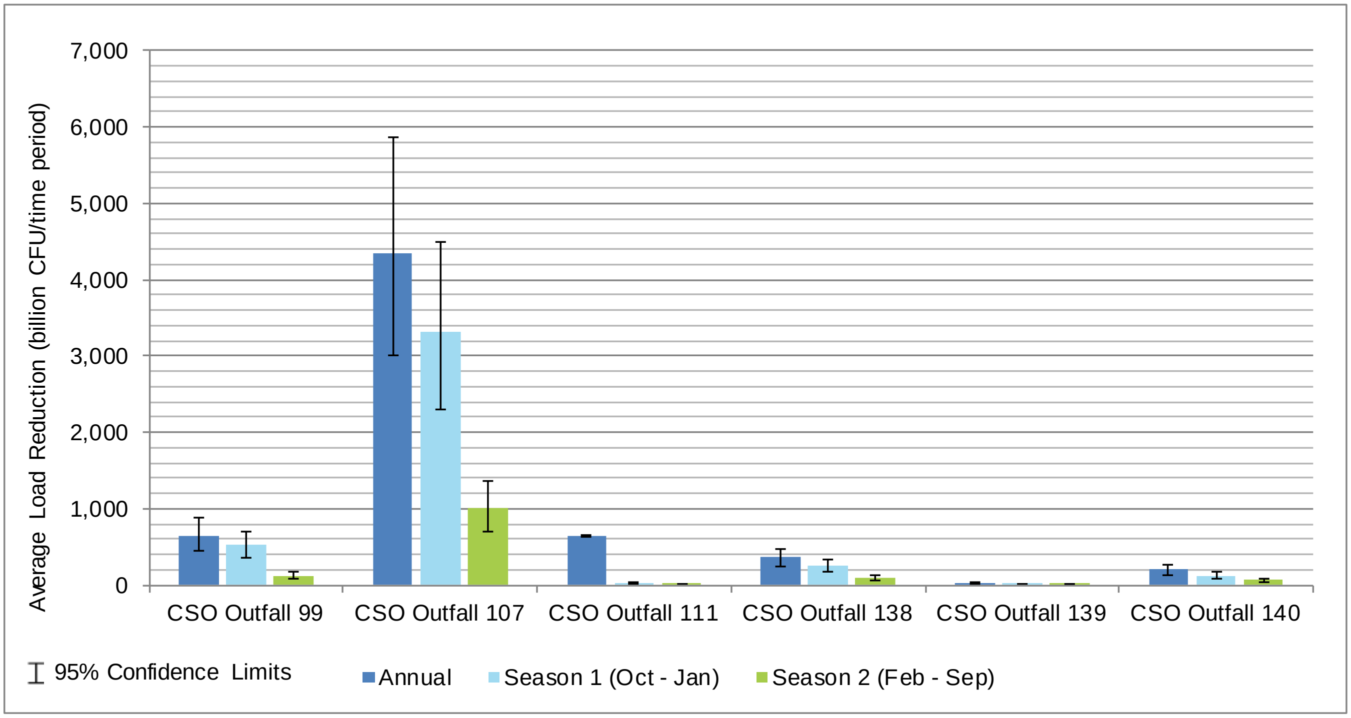

Figure E-4g. Average fecal coliform load reduction from the candidate LTCP projects (regular scale)

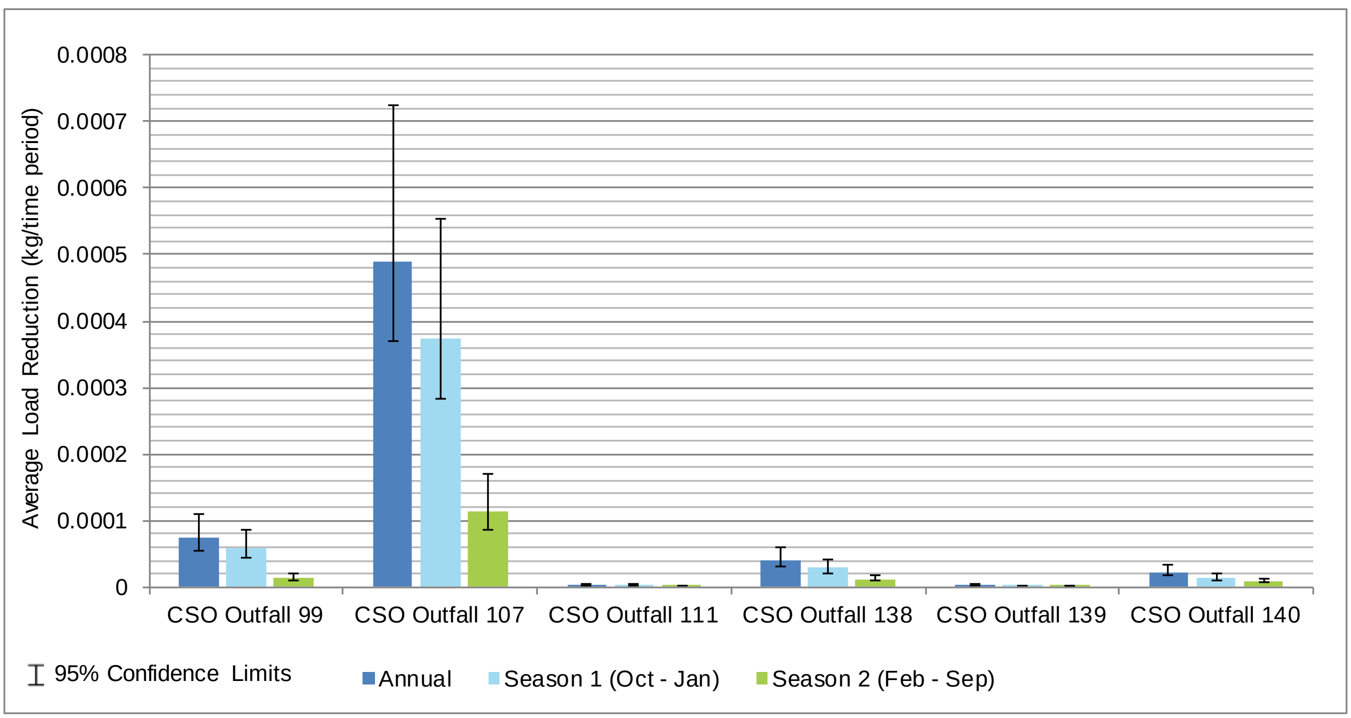

Figure E-4h. Average H+ load reduction from the candidate LTCP projects (regular scale)

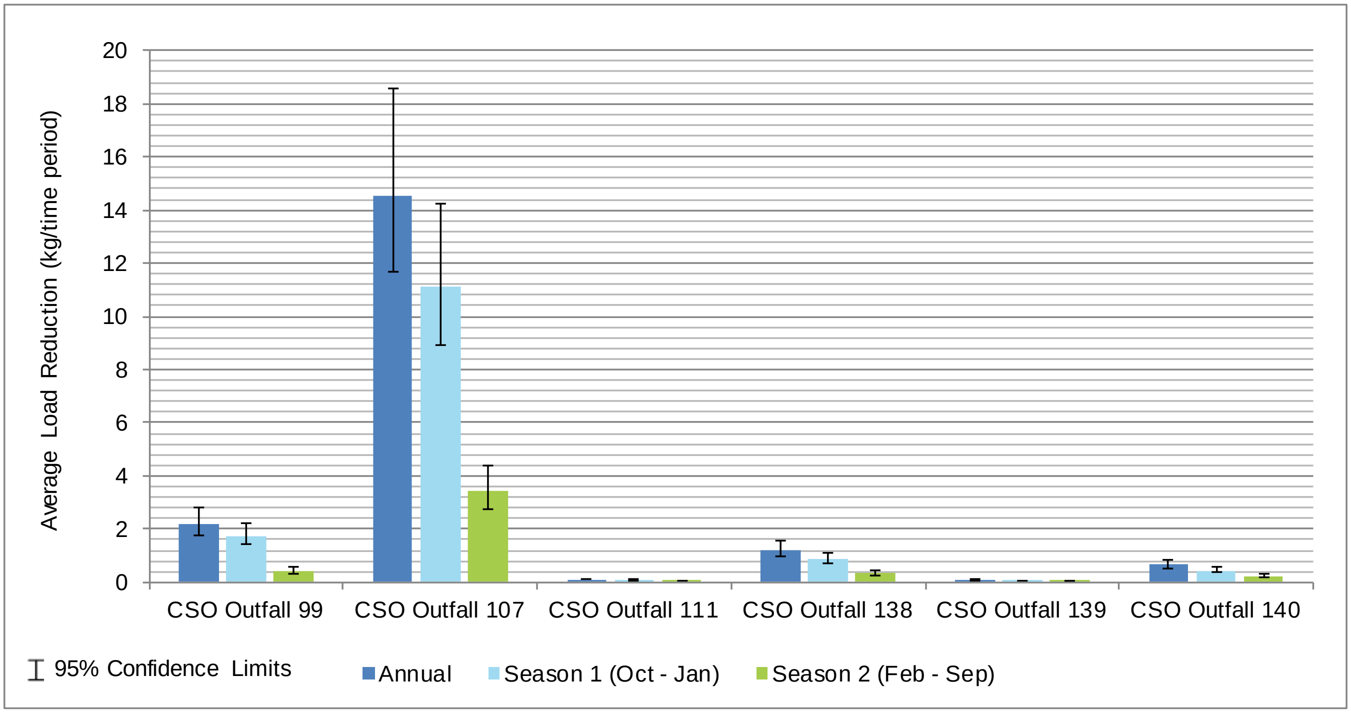

Figure E-4i. Average oil and grease load reduction from the candidate LTCP projects (regular scale)

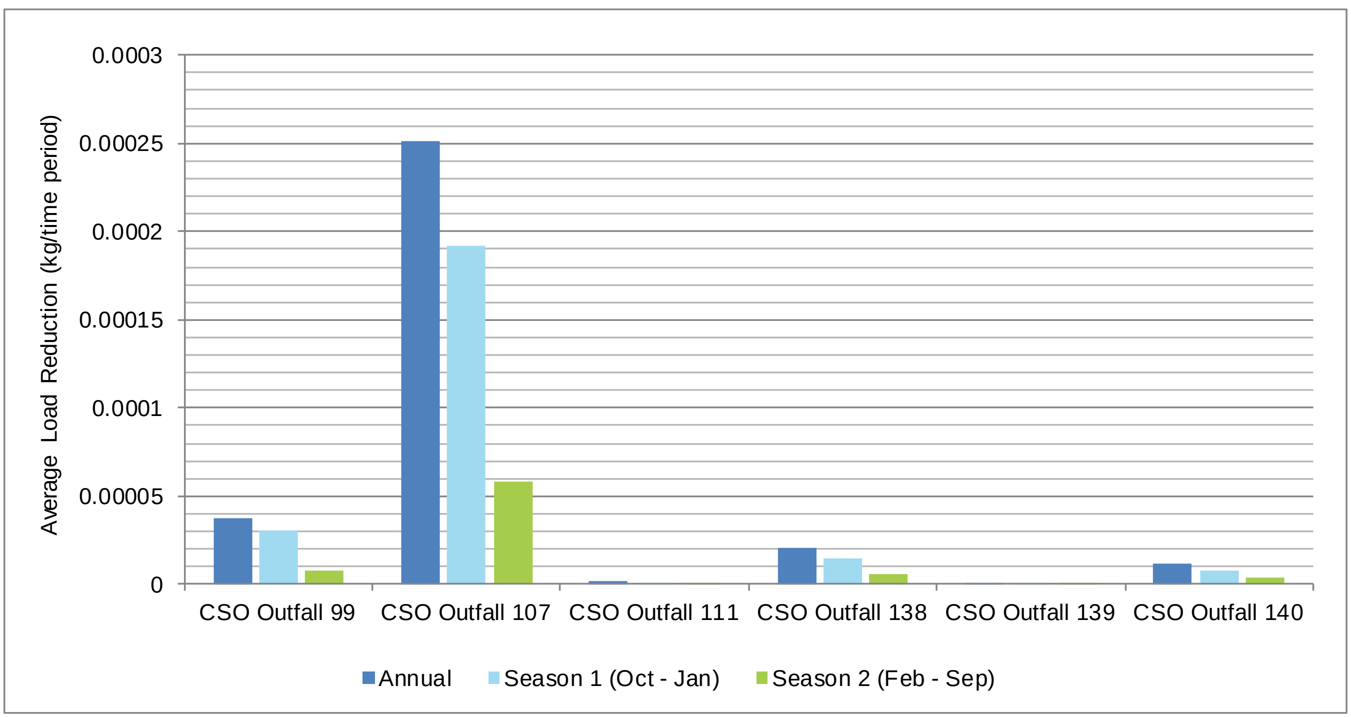

Figure E-4j. Average PBDEs load reduction from the candidate LTCP projects (regular scale)

Note that for PBDEs, there was insufficient data to calculate the UCLs and LCLs

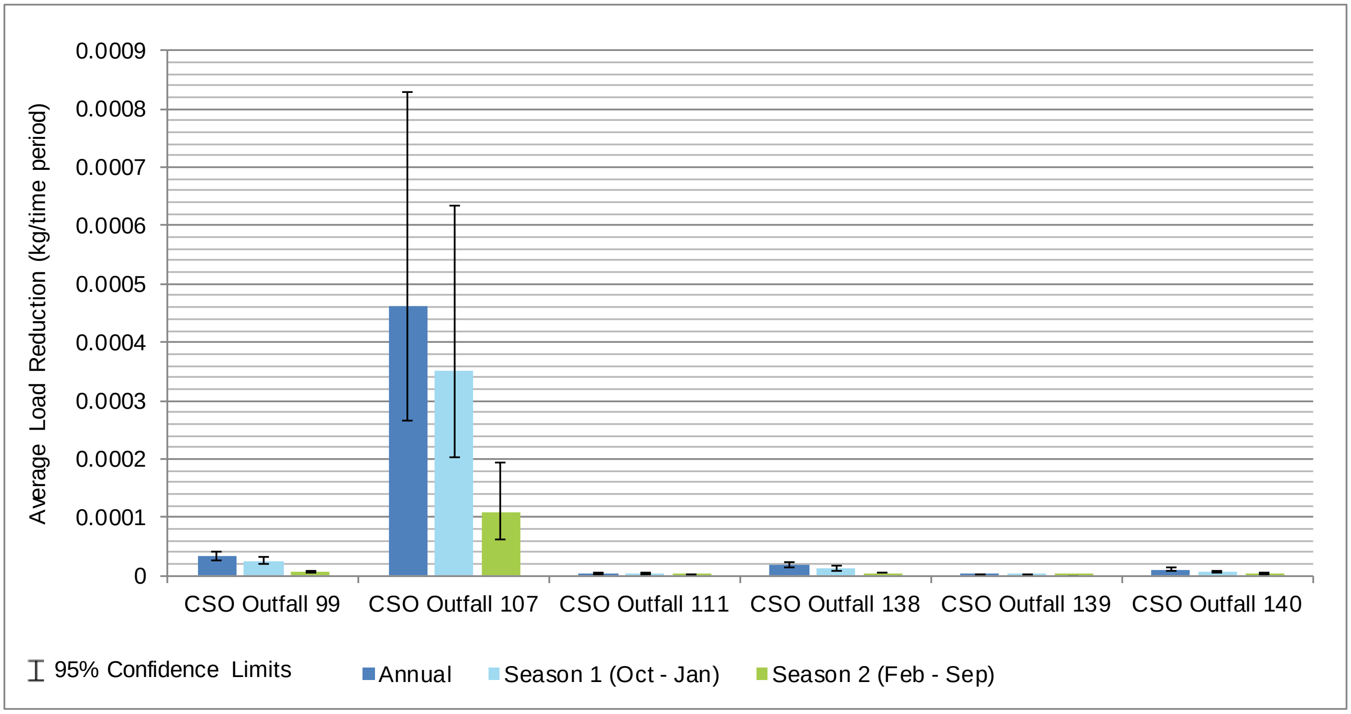

Figure E-4k. Average PCBs load reduction from the candidate LTCP projects (regular scale)

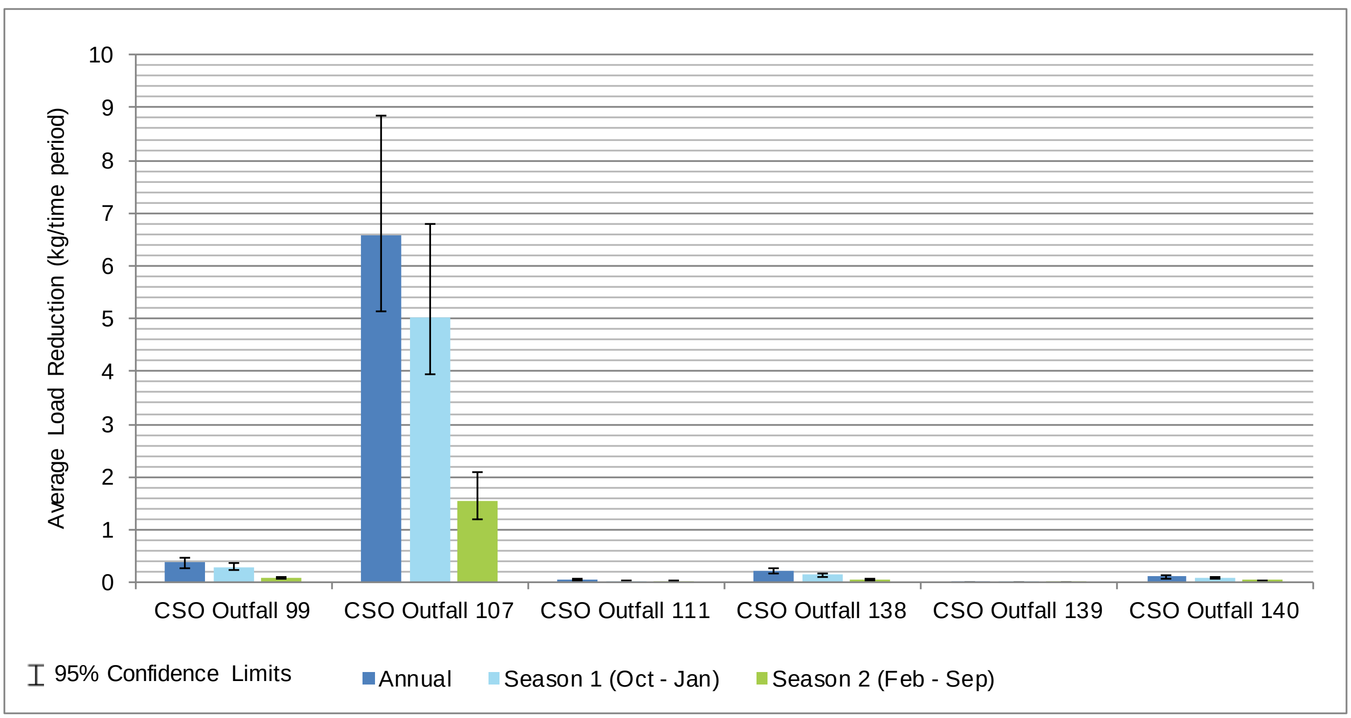

Figure E-4l. Average phosphorus load reduction from the candidate LTCP projects (regular scale)

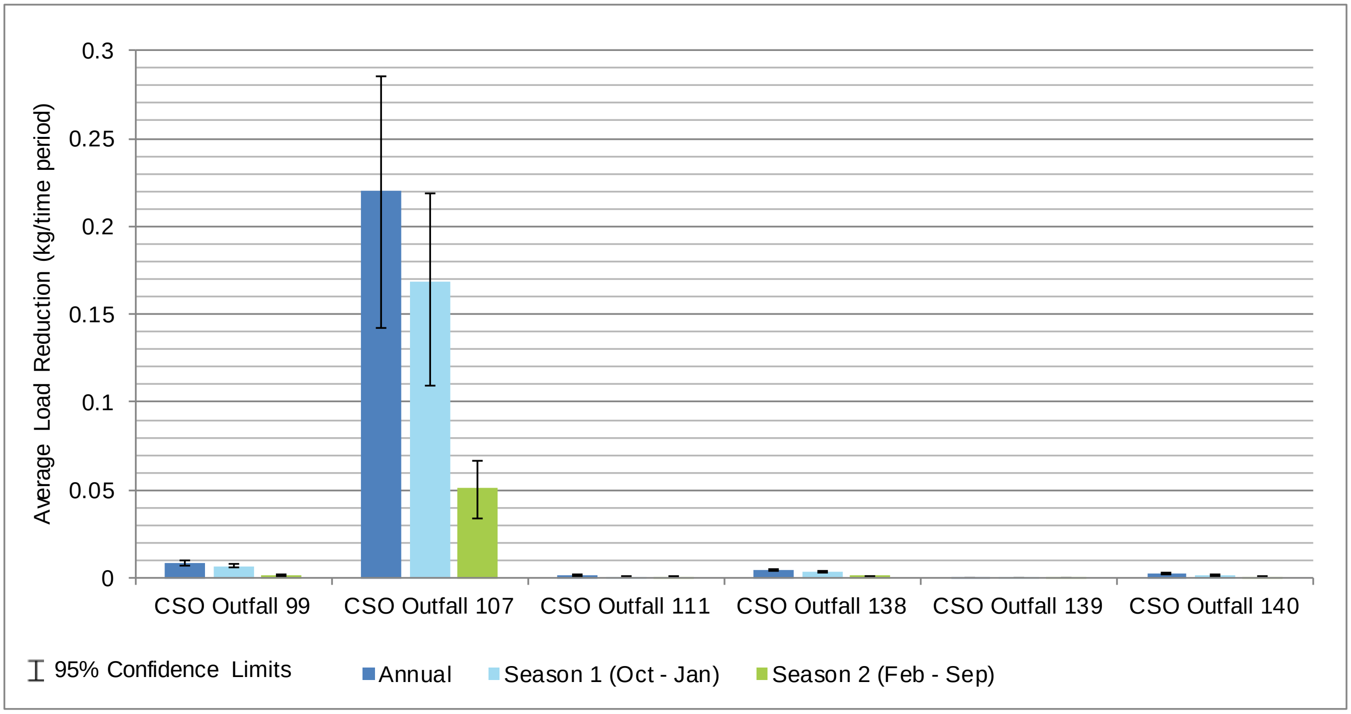

Figure E-4m. Average total copper load reduction from the candidate LTCP projects (regular scale)

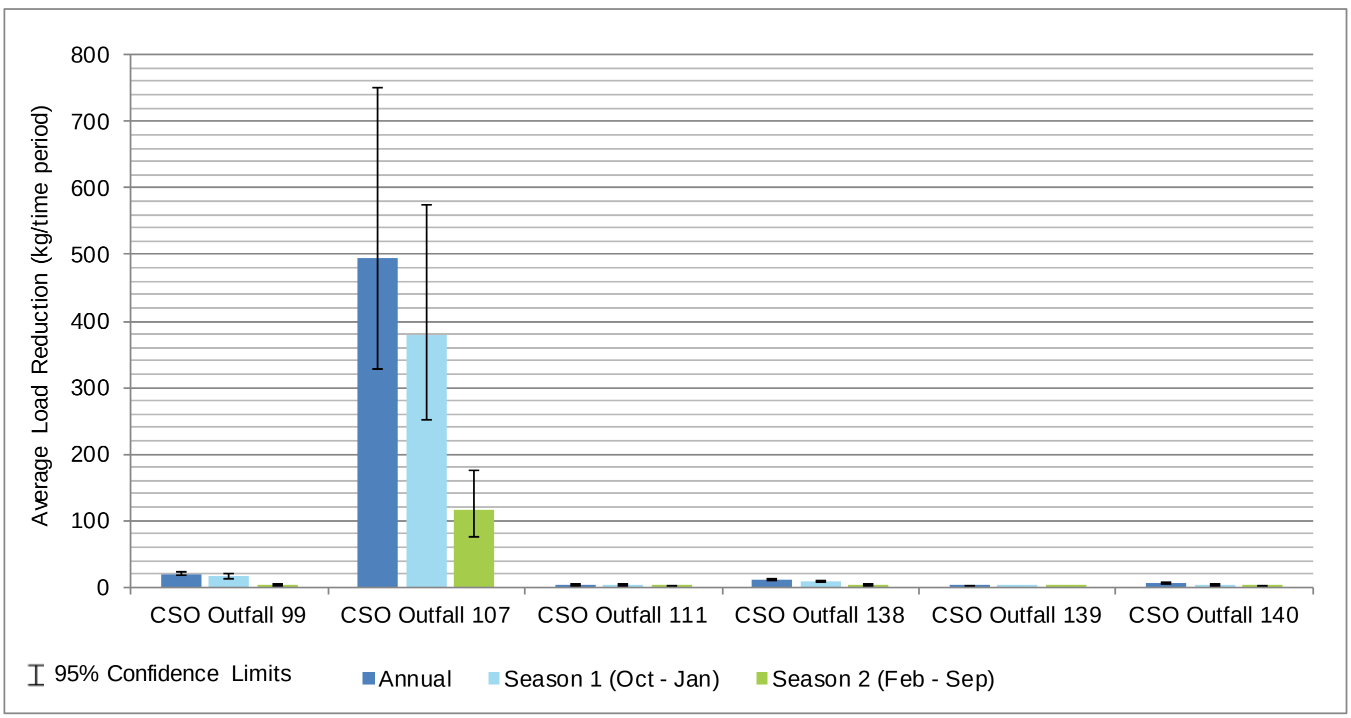

Figure E-4n. Average TSS load reduction from the candidate LTCP projects (regular scale)

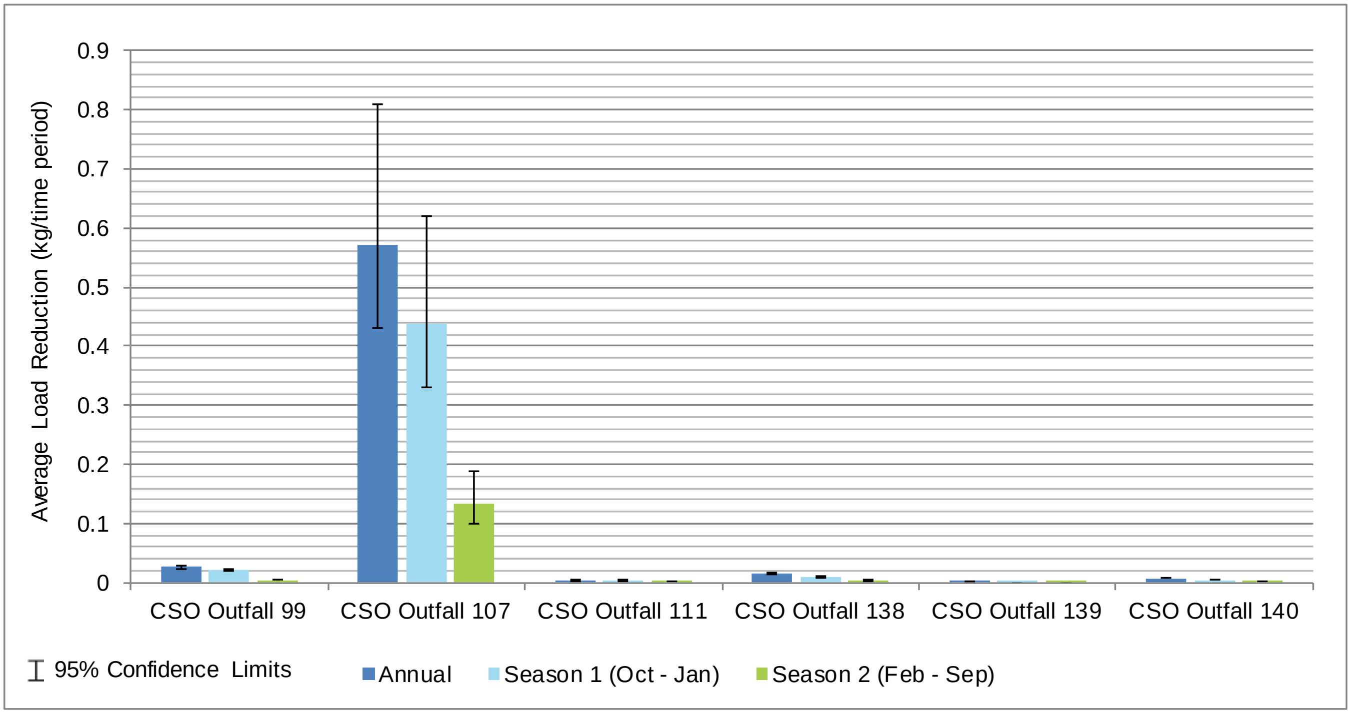

Figure E-4o. Average total zinc load reduction from the candidate LTCP projects (regular scale)

Attachment E-5: Load Reductions by Candidate LTCP Project (Log Scale)

This attachment contains the following figures:

- Figure E-5a. Average ammonia-N load reduction from the candidate LTCP projects (log scale)
- Figure E-5b. Average BOD load reduction from the candidate LTCP projects (log scale)
- Figure E-5c. Average Bis(2-Ethylhexyl)Phthalate load reduction from the candidate LTCP projects (log scale)
- Figure E-5d. Average dichlobenil load reduction from the candidate LTCP projects (log scale)
- Figure E-5e. Average dissolved copper load reduction from the candidate LTCP projects (log scale)
- Figure E-5f. Average dissolved zinc load reduction from the candidate LTCP projects (log scale)
- Figure E-5g. Average fecal coliform bacteria load reduction from the candidate LTCP projects (log scale)
- Figure E-5h. Average H+ load reduction from the candidate LTCP projects (log scale)
- Figure E-5i. Average oil and grease load reduction from the candidate LTCP projects (log scale)
- Figure E-5j. Average PBDEs load reduction from the candidate LTCP projects (log scale)
- Figure E-5k. Average PCBs load reduction from the candidate LTCP projects (log scale)
- Figure E-5l. Average phosphorus load reduction from the candidate LTCP projects (log scale)
- Figure E-5m. Average total copper load reduction from the candidate LTCP projects (log scale)
- Figure E-5n. Average TSS load reduction from the candidate LTCP projects (log scale)
- Figure E-5o. Average total zinc load reduction from the candidate LTCP projects (log scale)

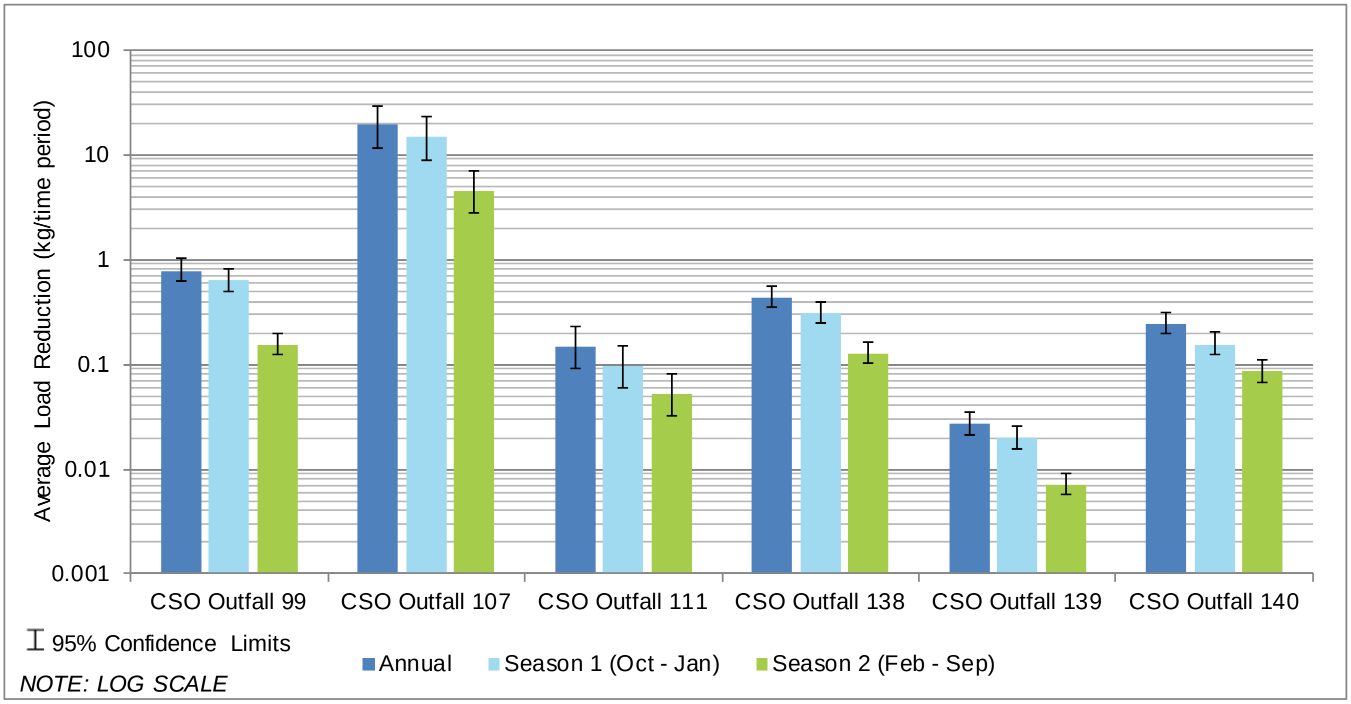

Figure E-5a. Average ammonia-N load reduction from the candidate LTCP projects (log scale)

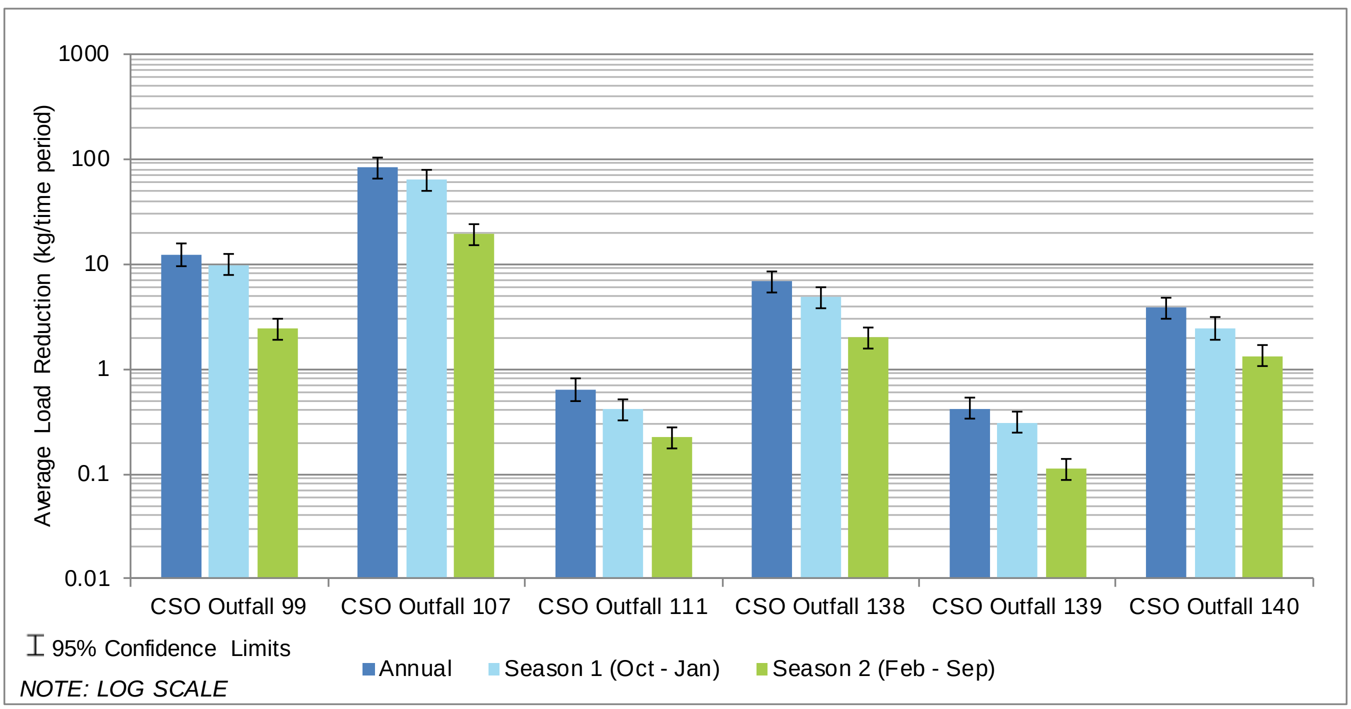

Figure E-5b. Average BOD load reduction from the candidate LTCP projects (log scale)

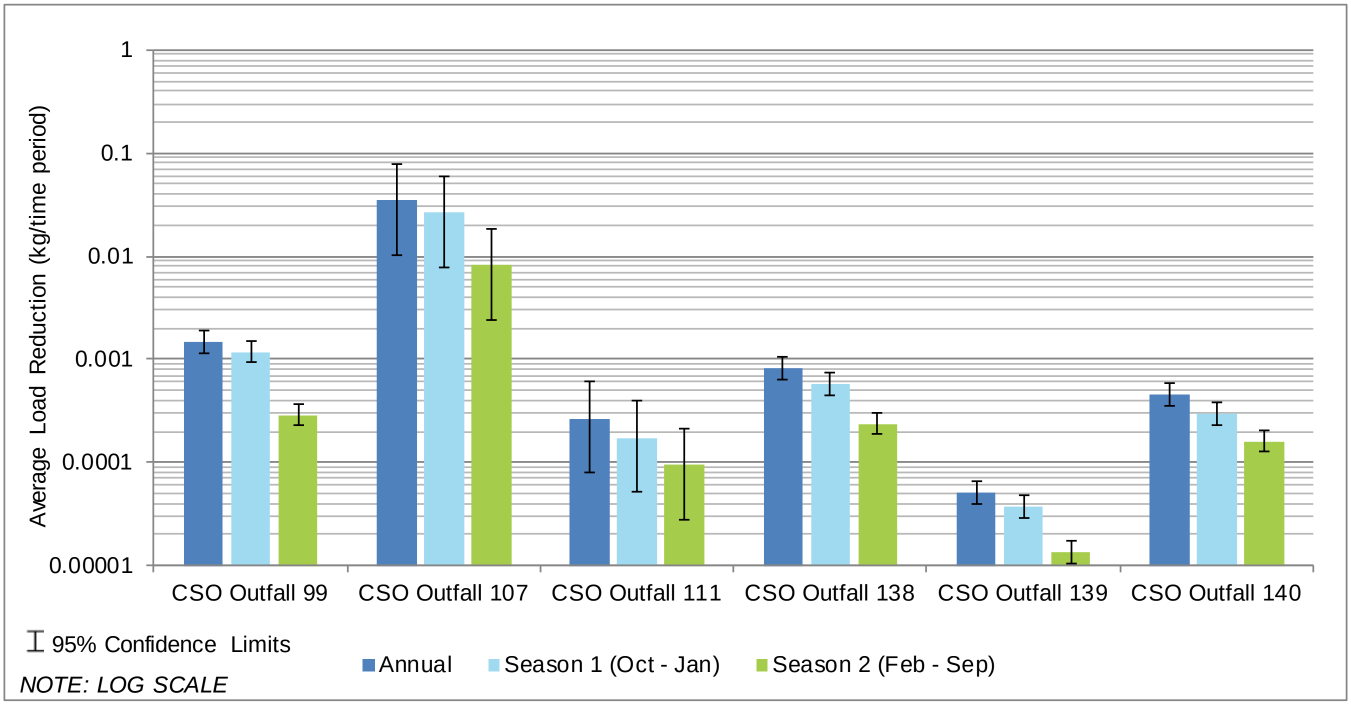

Figure E-5c. Average Bis(2-Ethylhexyl)Phthalate load reduction from the candidate LTCP projects (log scale)

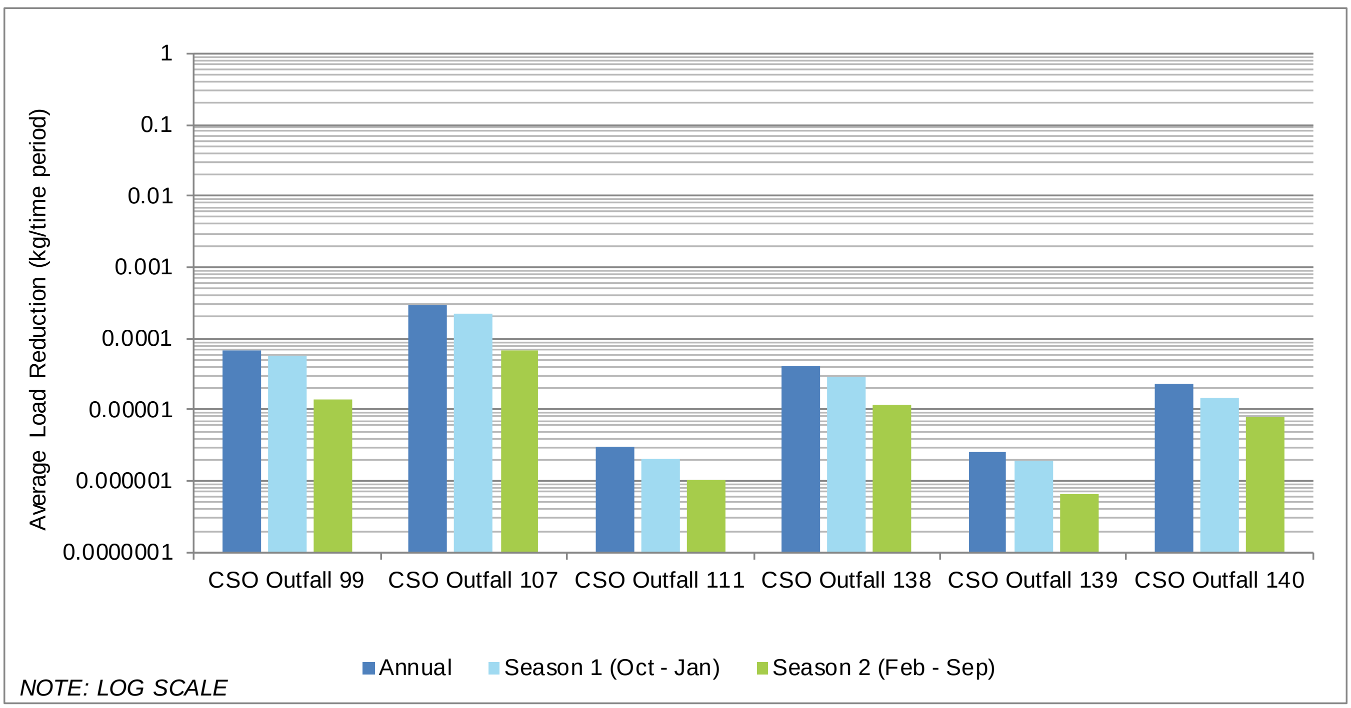

Figure E-5d. Average dichlobenil load reduction from the candidate LTCP projects (log scale)

Note that for dichlobenil, there was insufficient data to calculate the UCLs and LCLs

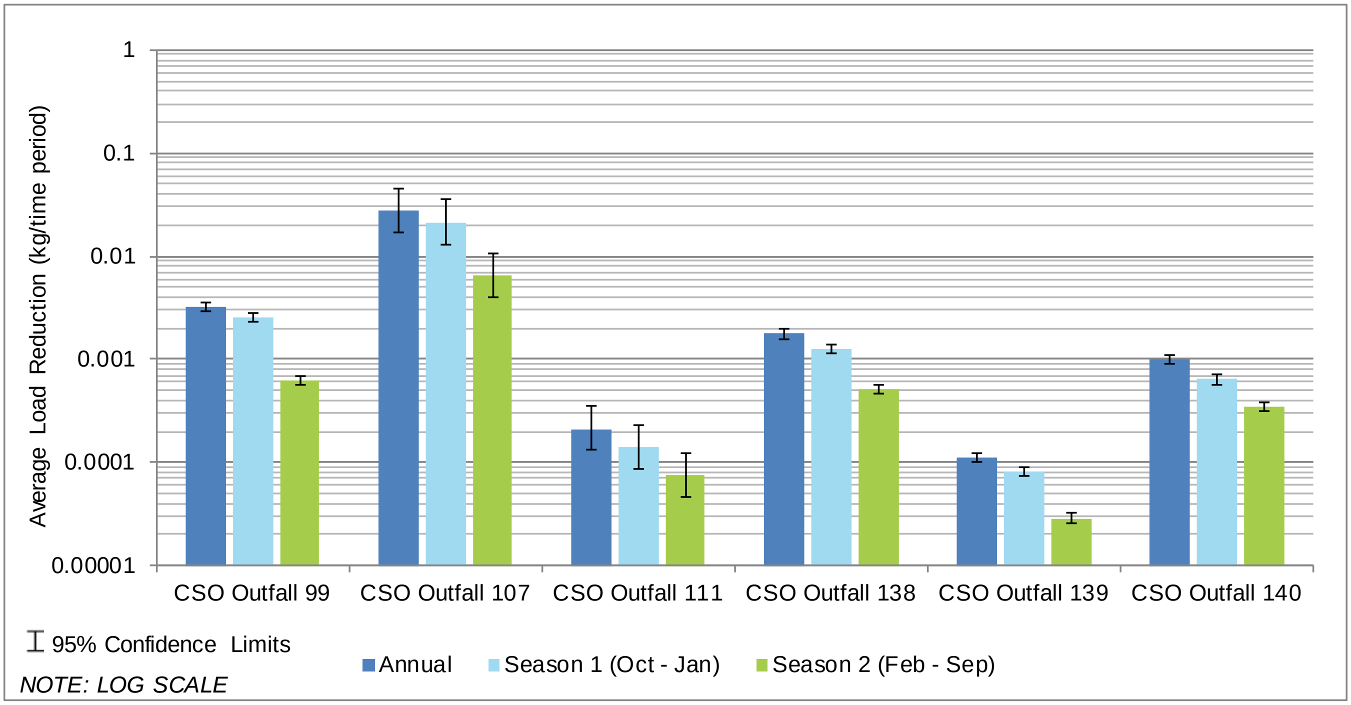

Figure E-5e. Average dissolved copper load reduction from the candidate LTCP projects (log scale)

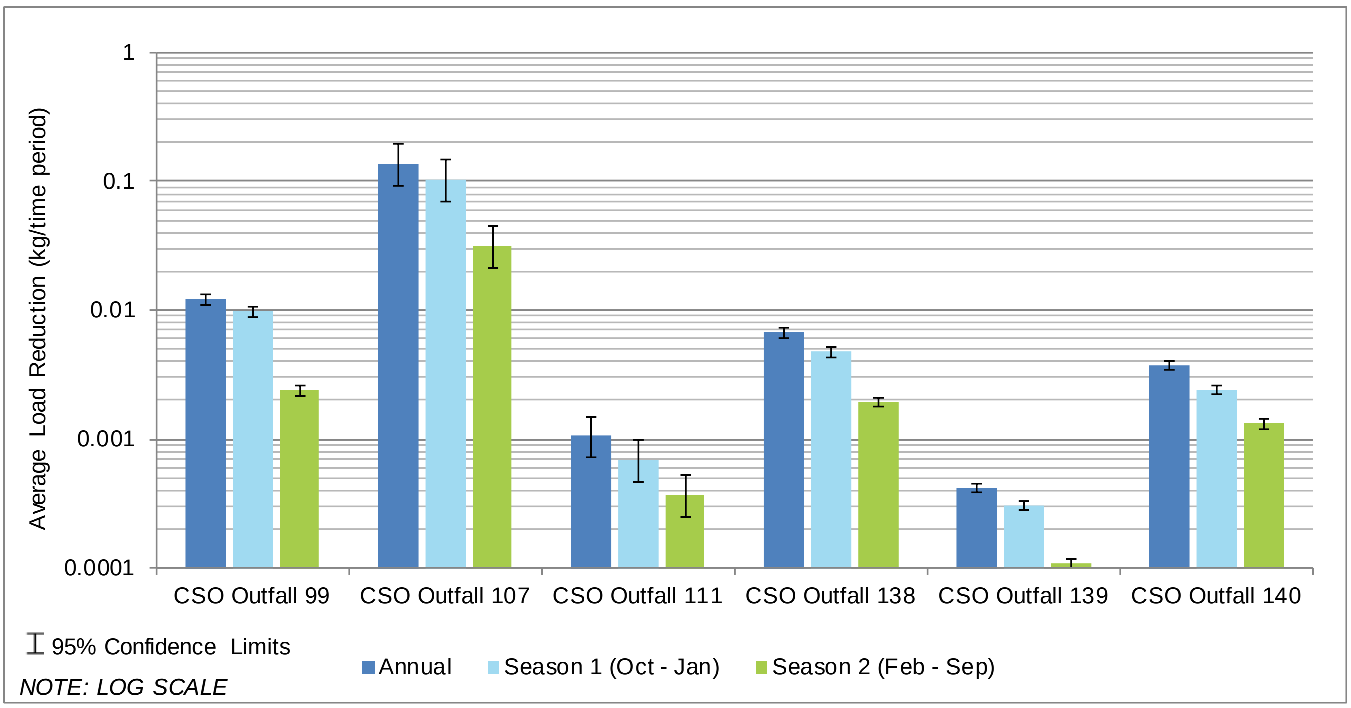

Figure E-5f. Average dissolved zinc load reduction from the candidate LTCP projects (log scale)

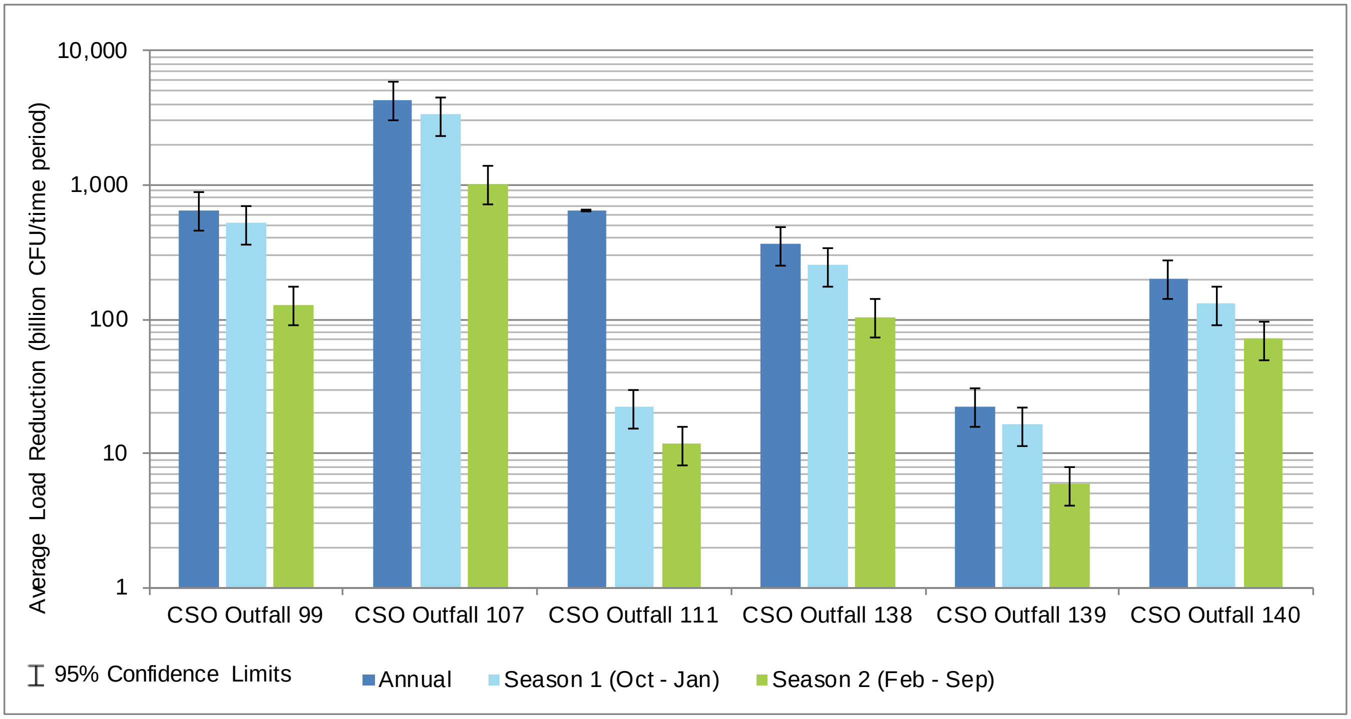

Figure E-5g. Average fecal coliform load reduction from the candidate LTCP projects (log scale)

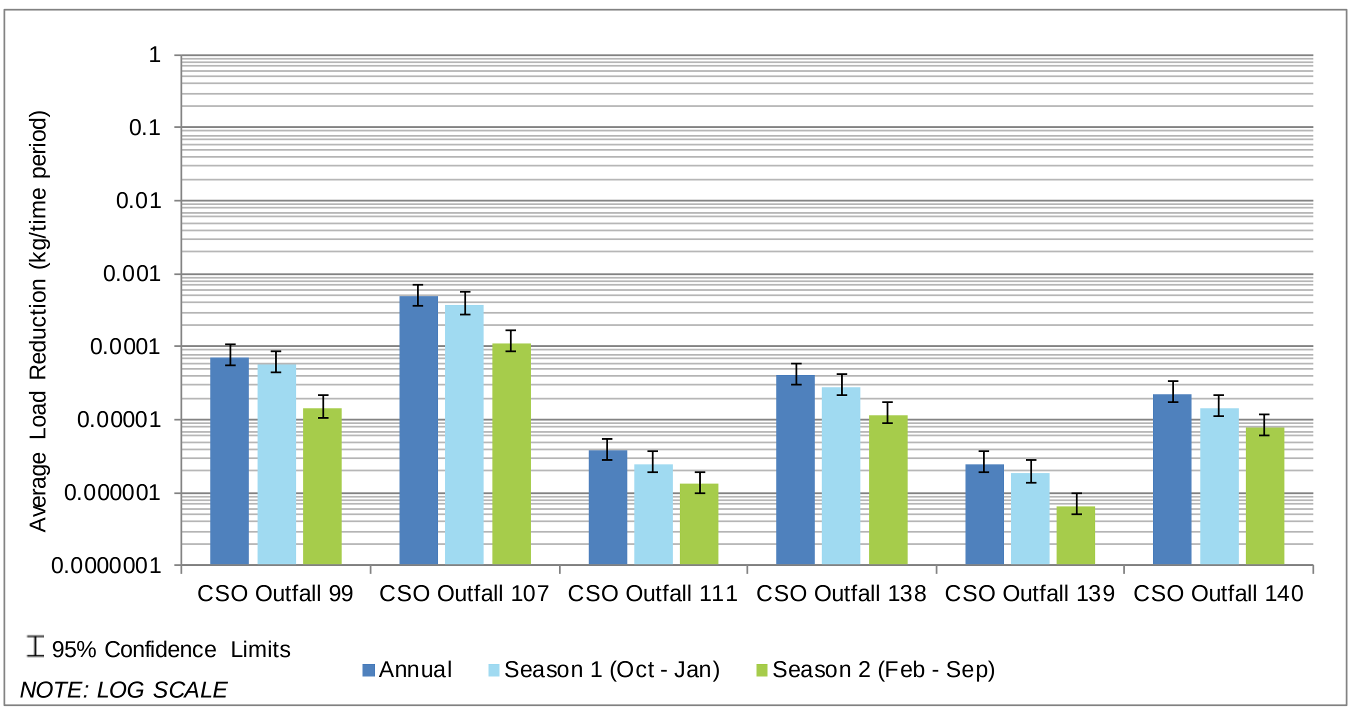

Figure E-5h. Average H+ load reduction from the candidate LTCP projects (log scale)

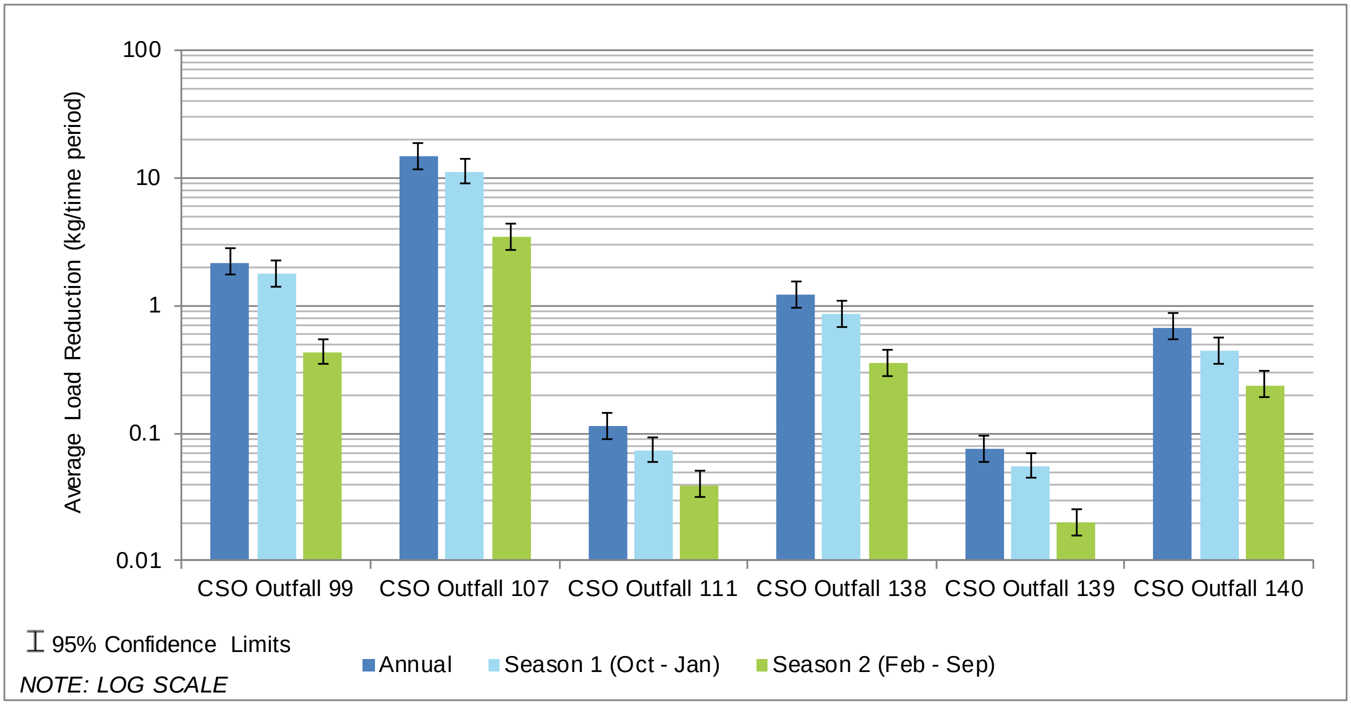

Figure E-5i. Average oil and grease load reduction from the candidate LTCP projects (log scale)

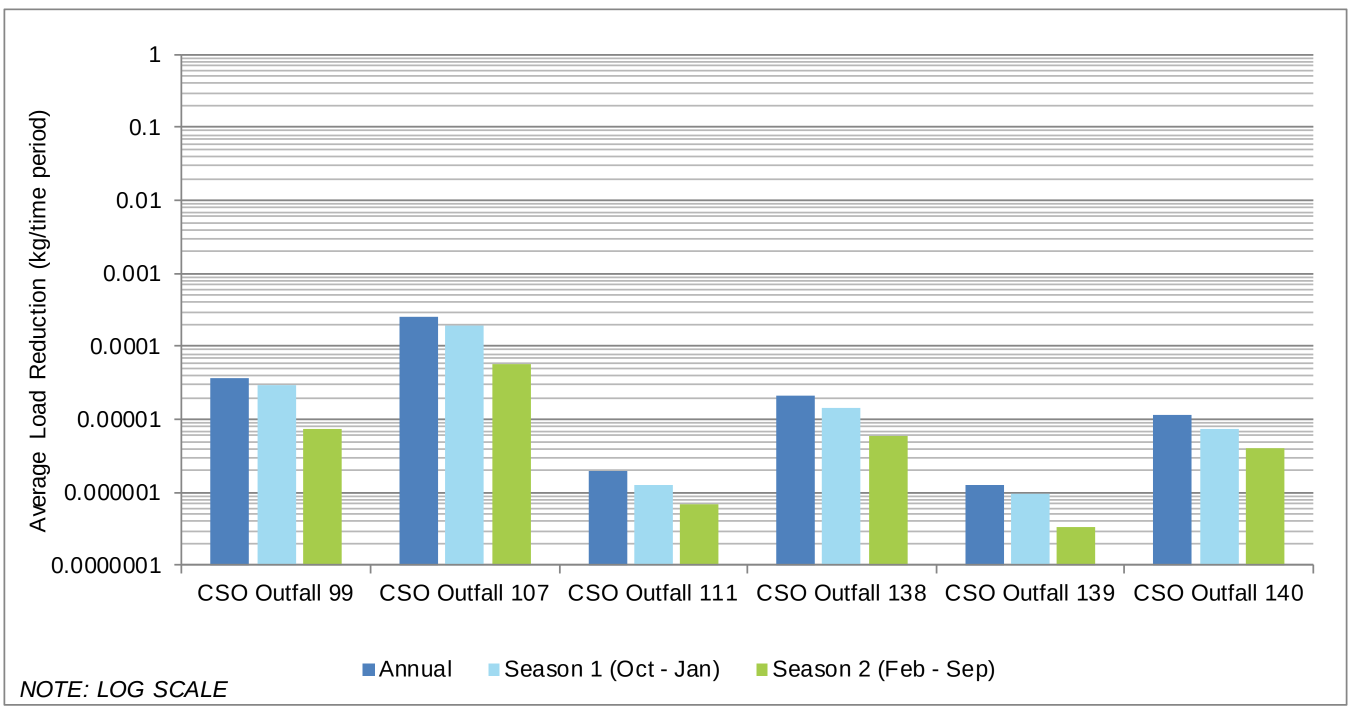

Figure E-5j. Average PBDEs load reduction from the candidate LTCP projects (log scale)

Note that for PBDEs, there was insufficient data to calculate the UCLs and LCLs

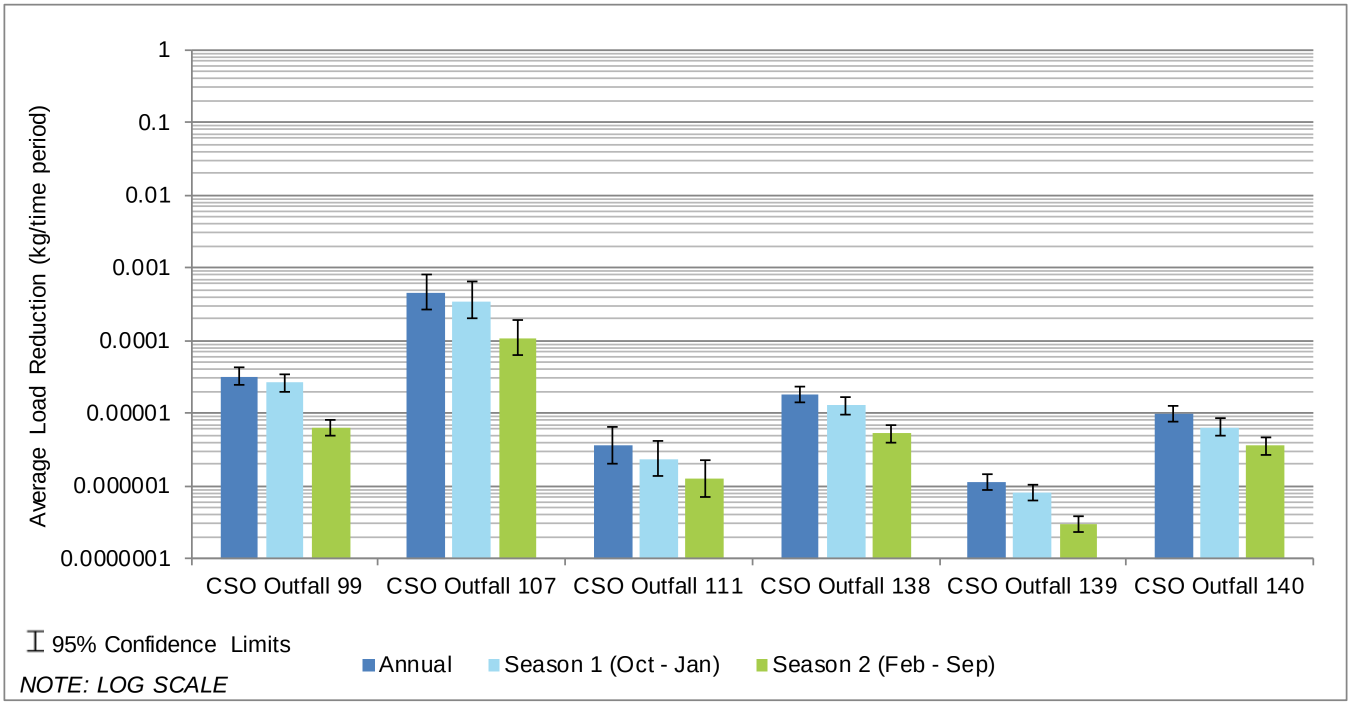

Figure E-5k. Average PCBs load reduction from the candidate LTCP projects (log scale)

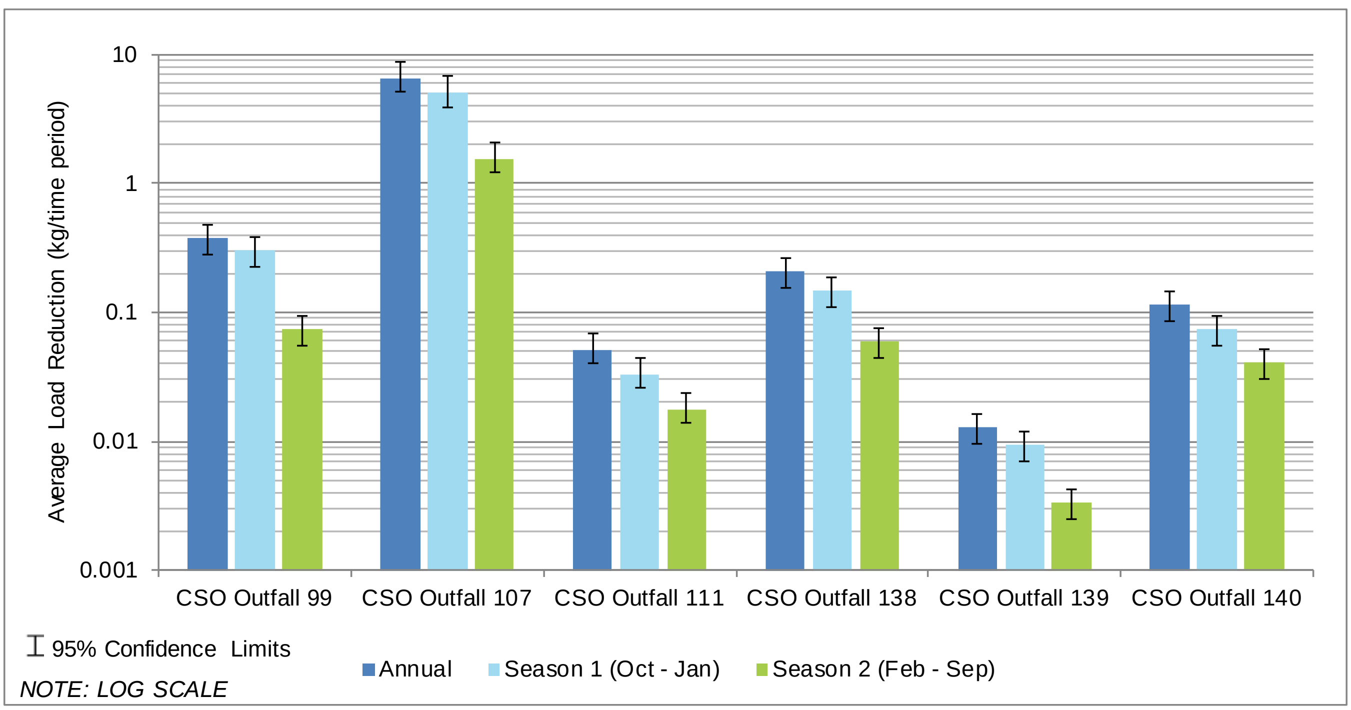

Figure E-5l. Average phosphorus load reduction from the candidate LTCP projects (log scale)

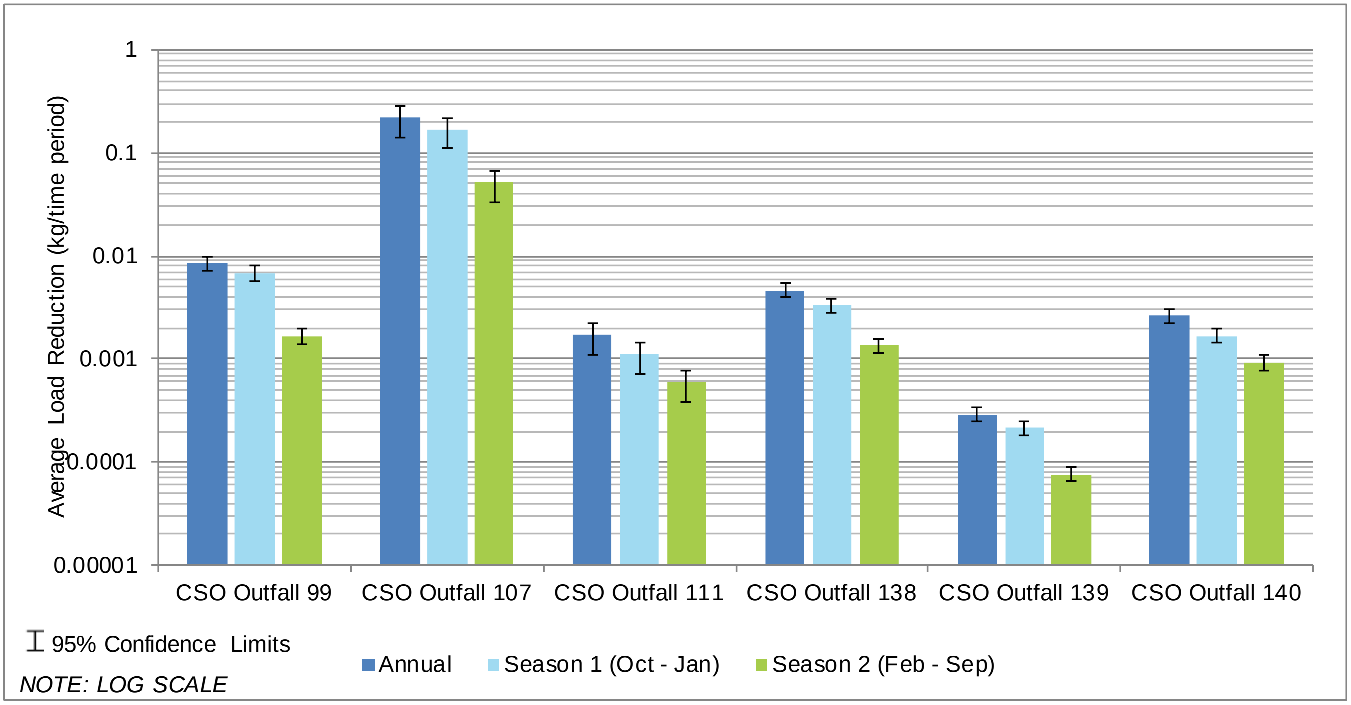

Figure E-5m. Average total copper load reduction from the candidate LTCP projects (log scale)

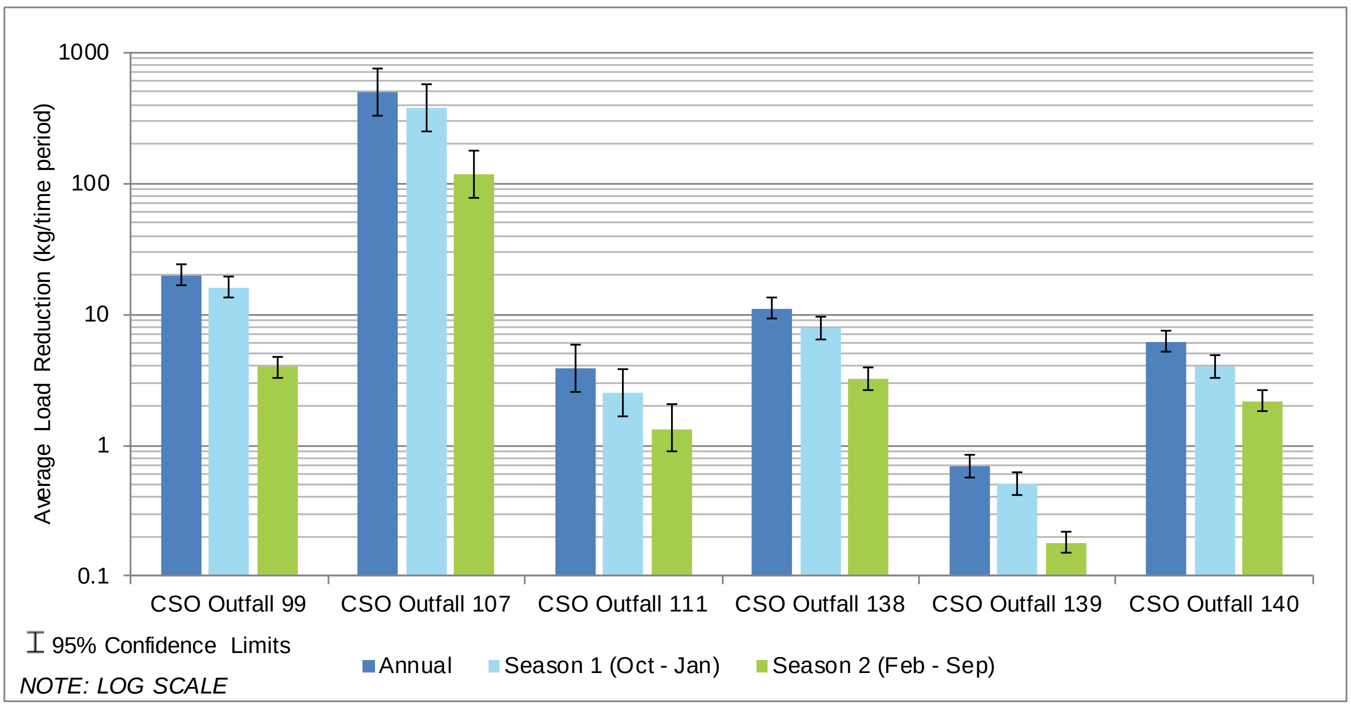

Figure E-5n. Average TSS load reduction from the candidate LTCP projects (log scale)

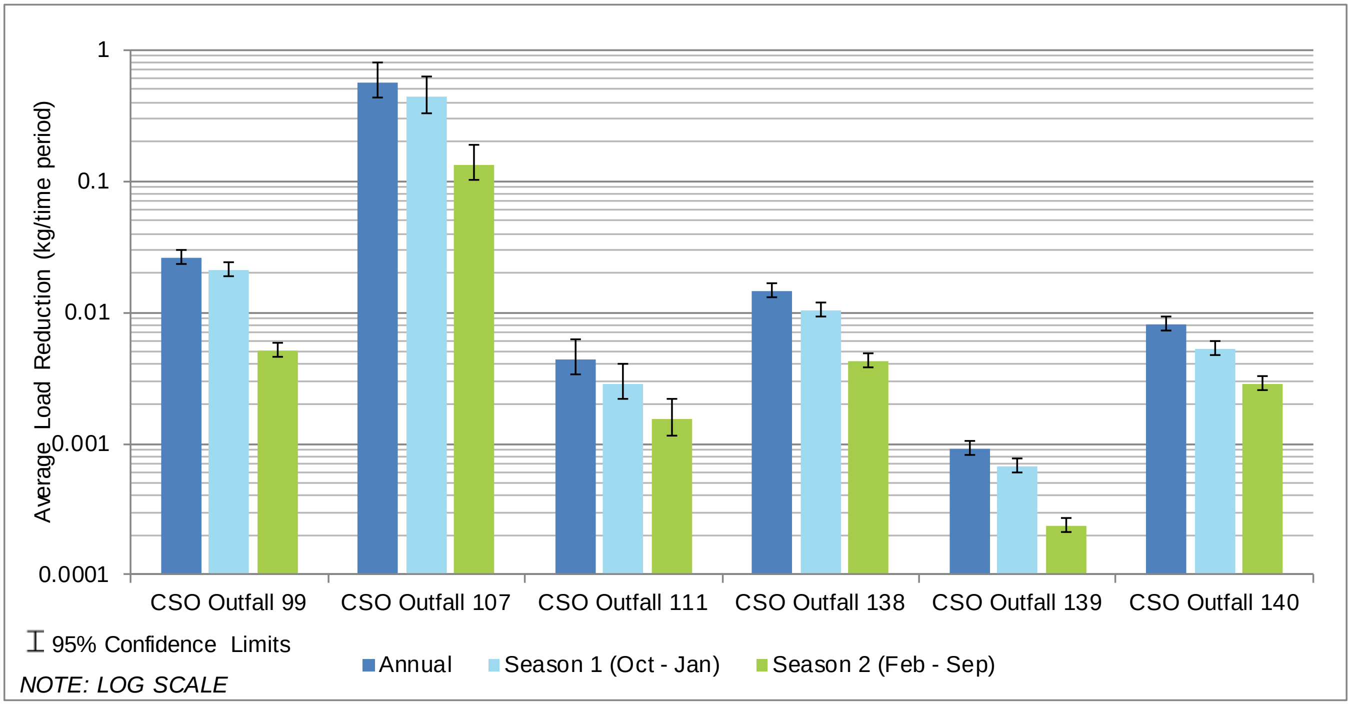

Figure E-5o. Average total zinc load reduction from the candidate LTCP projects (log scale)

Attachment E-6a: Supplementary LTCP Data—Overall Summary

Supplementary LTCP Data—Overall Summary

LTCP project	Analysis type	Precipitation scaling factor	Analysis period range	Analysis period (years)	Pre-project		BECV (MG)	Post-project	
					# of overflow events	Total overflow (MG)		# of overflow events	Total overflow (MG)
CSO Outfall 99	Model	1.0079	Jan 1992–Dec 2011	20	27	1.64E+01	1.71E-01	14	1.31E+01
CSO Outfall 107	Model	1.0	Jan 2003–Dec 2012	10	57	1.49E+01	5.00E-01	9	3.86E+00
CSO Outfall 111B	Model	1.0	Jan 1992–Dec 2011	20	21	2.90E+00	3.21E-03	15	2.84E+00
CSO Outfall 111C	Model	1.0	Jan 1992–Dec 2011	20	21	2.90E+00	3.21E-03	15	2.84E+00
CSO Outfall 111H	Model	1.0	Jan 1992–Dec 2011	20	17	2.95E+00	2.00E-03	11	2.92E+00
CSO Outfall 138	Model	1.0	Jan 1992–Dec 2011	20	13	3.32E+01	6.97E-03	13	3.31E+01
CSO Outfall 139	Model	1.0	Jan 1992–Dec 2011	20	29	5.63E+00	1.06E-01	11	3.80E+00
CSO Outfall 140	Model	1.0	Jan 1992–Dec 2011	20	22	6.80E-01	7.00E-03	13	5.66E-01

Note: Some LTCP projects have less than one overflow per year in the 20-year analysis period, which suggests compliance with current regulations. However, this is a result of using model results for precipitation scaling factor = 1.00.

Attachment E-6b: Supplementary LTCP Data—Monthly and Seasonal Summary

Monthly and Seasonal Summary for CSO Outfall 99			
Month	**Pre-project volume (MG/time period)**	**Post-project volume (MG/time period)**	**Volume reduction (MG/time period)**
1	1.07E-02	0.00E+00	1.07E-02
2	9.04E-02	7.96E-02	1.08E-02
3	6.08E-02	4.76E-02	1.32E-02
4	2.67E-02	1.81E-02	8.55E-03
5	0.00E+00	0.00E+00	0.00E+00
6	0.00E+00	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	0.00E+00	0.00E+00
9	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.00E+00	0.00E+00
11	1.86E-01	1.29E-01	5.79E-02
12	4.46E-01	3.82E-01	6.44E-02
Season			
Oct–Jan	6.43E-01	5.11E-01	1.33E-01
Feb–Sep	1.78E-01	1.45E-01	3.26E-02
Annual	8.21E-01	6.56E-01	1.66E-01

Monthly and Seasonal Summary for CSO Outfall 107			
Month	**Pre-project volume (MG/time period)**	**Post-project volume (MG/time period)**	**Volume reduction (MG/time period)**
1	1.85E-01	3.68E-02	1.49E-01
2	8.10E-03	0.00E+00	8.10E-03
3	9.94E-02	1.17E-02	8.77E-02
4	2.70E-02	0.00E+00	2.70E-02
5	6.48E-02	0.00E+00	6.48E-02
6	0.00E+00	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00
8	2.14E-02	0.00E+00	2.14E-02
9	5.70E-02	6.99E-03	5.00E-02
10	1.74E-01	7.26E-03	1.67E-01
11	4.42E-01	9.09E-02	3.52E-01
12	4.11E-01	2.33E-01	1.79E-01
Season			
Oct–Jan	1.21E+00	3.68E-01	8.46E-01
Feb–Sep	2.78E-01	1.87E-02	2.59E-01
Annual	1.49E+00	3.86E-01	1.11E+00

Monthly and Seasonal Summary for CSO Outfall 111B			
Month	**Pre-project volume (MG/time period)**	**Post-project volume (MG/time period)**	**Volume reduction (MG/time period)**
1	6.80E-03	6.48E-03	3.21E-04
2	1.46E-02	1.44E-02	1.60E-04
3	4.40E-03	4.04E-03	3.60E-04
4	5.00E-05	0.00E+00	5.00E-05
5	4.00E-04	2.40E-04	1.60E-04
6	3.50E-04	1.90E-04	1.60E-04
7	0.00E+00	0.00E+00	0.00E+00
8	1.50E-03	1.24E-03	2.60E-04
9	0.00E+00	0.00E+00	0.00E+00
10	1.13E-02	1.09E-02	3.71E-04
11	1.58E-02	1.56E-02	1.60E-04
12	8.98E-02	8.90E-02	8.02E-04
Season			
Oct–Jan	1.24E-01	1.22E-01	1.65E-03
Feb–Sep	2.13E-02	2.01E-02	1.15E-03
Annual	1.45E-01	1.42E-01	2.81E-03

Monthly and Seasonal Summary for CSO Outfall 111C			
Month	**Pre-project volume (MG/time period)**	**Post-project volume (MG/time period)**	**Volume reduction (MG/time period)**
1	3.10E-03	3.00E-03	1.00E-04
2	1.44E-02	1.43E-02	1.00E-04
3	1.50E-04	0.00E+00	1.50E-04
4	0.00E+00	0.00E+00	0.00E+00
5	0.00E+00	0.00E+00	0.00E+00
6	4.00E-04	3.00E-04	1.00E-04
7	0.00E+00	0.00E+00	0.00E+00
8	1.70E-03	1.60E-03	1.00E-04
9	0.00E+00	0.00E+00	0.00E+00
10	1.10E-02	1.07E-02	3.00E-04
11	1.23E-02	1.22E-02	1.00E-04
12	1.04E-01	1.04E-01	3.00E-04
Season			
Oct–Jan	1.31E-01	1.30E-01	8.00E-04
Feb–Sep	1.67E-02	1.62E-02	4.50E-04
Annual	1.47E-01	1.46E-01	1.25E-03

Monthly and Seasonal Summary for CSO Outfall 111H			
Month	**Pre-project volume (MG/time period)**	**Post-project volume (MG/time period)**	**Volume reduction (MG/time period)**
1	2.22E-02	2.18E-02	3.49E-04
2	1.80E-01	1.80E-01	3.49E-04
3	3.17E-02	3.13E-02	3.49E-04
4	1.67E-01	1.66E-01	3.49E-04
5	0.00E+00	0.00E+00	0.00E+00
6	0.00E+00	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00
8	1.38E-01	1.37E-01	3.49E-04
9	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.00E+00	0.00E+00
11	2.64E-01	2.63E-01	1.05E-03
12	8.60E-01	8.58E-01	1.74E-03
Season			
Oct–Jan	1.15E+00	1.14E+00	3.14E-03
Feb–Sep	5.16E-01	5.14E-01	1.39E-03
Annual	1.66E+00	1.66E+00	4.53E-03

Monthly and Seasonal Summary for CSO Outfall 138			
Month	**Pre-project volume (MG/time period)**	**Post-project volume (MG/time period)**	**Volume reduction (MG/time period)**
1	9.50E-03	0.00E+00	9.50E-03
2	9.50E-03	4.20E-03	5.30E-03
3	1.20E-02	6.55E-03	5.40E-03
4	2.90E-03	0.00E+00	2.90E-03
5	8.10E-03	4.50E-04	7.65E-03
6	1.00E-04	0.00E+00	1.00E-04
7	0.00E+00	0.00E+00	0.00E+00
8	1.26E-02	7.30E-03	5.30E-03
9	0.00E+00	0.00E+00	0.00E+00
10	1.98E-02	1.45E-02	5.30E-03
11	4.82E-02	2.39E-02	2.43E-02
12	1.59E-01	1.33E-01	2.57E-02
Season			
Oct–Jan	2.36E-01	1.71E-01	6.48E-02
Feb–Sep	4.52E-02	1.85E-02	2.67E-02
Annual	2.81E-01	1.90E-01	9.15E-02

Monthly and Seasonal Summary for CSO Outfall 139			
Month	**Pre-project volume (MG/time period)**	**Post-project volume (MG/time period)**	**Volume reduction (MG/time period)**
1	3.50E-04	0.00E+00	3.50E-04
2	5.00E-05	0.00E+00	5.00E-05
3	5.00E-05	0.00E+00	5.00E-05
4	1.50E-04	0.00E+00	1.50E-04
5	3.30E-03	2.40E-03	9.00E-04
6	0.00E+00	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00
8	3.55E-03	3.20E-03	3.50E-04
9	0.00E+00	0.00E+00	0.00E+00
10	3.00E-03	1.60E-03	1.40E-03
11	4.01E-03	2.96E-03	1.05E-03
12	1.96E-02	1.82E-02	1.40E-03
Season			
Oct–Jan	2.69E-02	2.27E-02	4.20E-03
Feb–Sep	7.10E-03	5.60E-03	1.50E-03
Annual	3.40E-02	2.83E-02	5.70E-03

Monthly and Seasonal Summary for CSO Outfall 140			
Month	**Pre-project volume (MG/time period)**	**Post-project volume (MG/time period)**	**Volume reduction (MG/time period)**
1	1.35E-03	0.00E+00	1.35E-03
2	1.10E-03	0.00E+00	1.10E-03
3	1.85E-03	0.00E+00	1.85E-03
4	1.80E-03	0.00E+00	1.80E-03
5	2.56E-02	1.87E-02	6.97E-03
6	2.00E-03	0.00E+00	2.00E-03
7	0.00E+00	0.00E+00	0.00E+00
8	1.77E-02	1.48E-02	2.93E-03
9	1.45E-03	0.00E+00	1.45E-03
10	2.26E-02	1.54E-02	7.25E-03
11	3.10E-02	1.96E-02	1.13E-02
12	1.39E-01	1.26E-01	1.32E-02
Season			
Oct–Jan	1.94E-01	1.61E-01	3.31E-02
Feb–Sep	5.15E-02	3.34E-02	1.81E-02
Annual	2.45E-01	1.94E-01	5.12E-02

Appendix F: Pollutant Reduction Estimation Method—Candidate Stormwater Projects

Seattle Public Utilities

Protecting Seattle's Waterways

Volume 3 – Integrated Plan

Appendix F: POLLUTANT REDUCTION ESTIMATION METHOD—CANDIDATE STORMWATER PROJECTS

Final

May 29, 2015

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List of Abbreviations

Term	Definition
ACWA	(Oregon) Association of Clean Water Agencies
BC	Brown and Caldwell
BEHP	Bis(2-ethylhexyl)phthalate
BMP	best management practice
BOD	biochemical oxygen demand
CBODU	Ultimate Chemical and Biological Oxygen Demand
CESF	chitosan-enhanced sand filter
CFU	colony forming unit(s)
CI	confidence interval
City	City of Seattle
CSO	combined sewer overflow
CSS	combined sewer system
Cu	copper
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
EMC	event mean concentration
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
gpd	gallon(s) per day
GSI	green stormwater infrastructure
GULD	General Use Level Designation
[H+]	hydrogen ion
LCL	lower confidence limit
LTCP	Long-Term Control Plan
MG	million gallon(s)
mg/L	milligram(s) per liter
mL	milliliter(s)
MPN	most probable number
MS4	municipal separate storm sewer system
NBF	North Boeing Field
NBOD	Nitrogenous Biochemical Oxygen Demand
NDS	Natural Drainage System
NSQD	National Stormwater Quality Database
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
PLM	pollutant load model
RCOC	Representative Constituent of Concern
RG	rain gauge
ROS	Regression on Order Statistics
SMMWW	Stormwater Management Manual for Western Washington, version 2012
SS4WQ	Street Sweeping for Water Quality
TAPE	Technology Assessment Protocol – Ecology
TP	total phosphorus
TSS	total suspended solids
UCL	upper confidence limit
WWHM	Western Washington Continuous 2012 Simulation Hydrology Model, version 2012
yr	year(s)
Zn	zinc

Summary

This appendix documents the pollutant load model (PLM) analysis for stormwater projects conducted as part of the City of Seattle (City) Integrated Plan. Geosyntec conducted this analysis to help the City develop the Integrated Plan, which is an alternative in the City's Long-Term Control Plan (LTCP) for combined sewer overflows (CSOs).

Geosyntec estimated the pollutant load reductions of the 14 candidate stormwater projects identified by the City (Table 1-1). The load reduction analysis focused on the constituents of concern identified in the Consent Decree. Where the Consent Decree identified categories of pollutants (e.g., metals, pathogens, semi-volatile organic compounds, and pesticides), Representative Constituents of Concern (RCOCs) were identified in consultation with the City and the Expert Panel.

Model Overview

The general approach for assessing pollutant load reductions relies on the use of existing information and a relatively simple spreadsheet model. Although the PLM was not calibrated to site-specific conditions, local information provided by the City where possible (e.g., local stormwater runoff study data and local precipitation data) was used in the model. Information from literature and the International Stormwater Best Management Practices (BMP) Database (www.bmpdatabase.org) was also used for parameterizing the PLM.

The Pre-Project component of the model is based on observed and literature-developed rainfall/runoff relationships and estimated pollutant concentrations in stormwater runoff. The volume of stormwater runoff is estimated using a simple volumetric runoff coefficient, an empirical expression that relates runoff volume to the rainfall depth and the basin characteristics such as imperviousness and soil infiltration characteristics. The pollutant concentration in stormwater runoff is represented by an expected average pollutant concentration, developed based on analysis of event mean concentrations (EMC). The EMCs used in this analysis were obtained from available monitoring data and are dependent on the land use type.

The Post-Project component of the model utilizes the Pre-Project concentrations and runoff volumes and applies project performance estimates for stormwater treatment projects. The modeled performance of projects depends on three factors: (1) the fraction of average long-term stormwater runoff volume receiving treatment (referred to hereafter as "capture efficiency"), (2) the pollutant removal achieved in the project by virtue of surface runoff reduction via infiltration and/or evapotranspiration (generically referred to as "volume reduction"), and (3) the pollutant removal achieved in the treatment project by virtue of improved water quality of treated runoff. The flow chart in Figure S-1 provides an overview of the Post-Project modeling component.

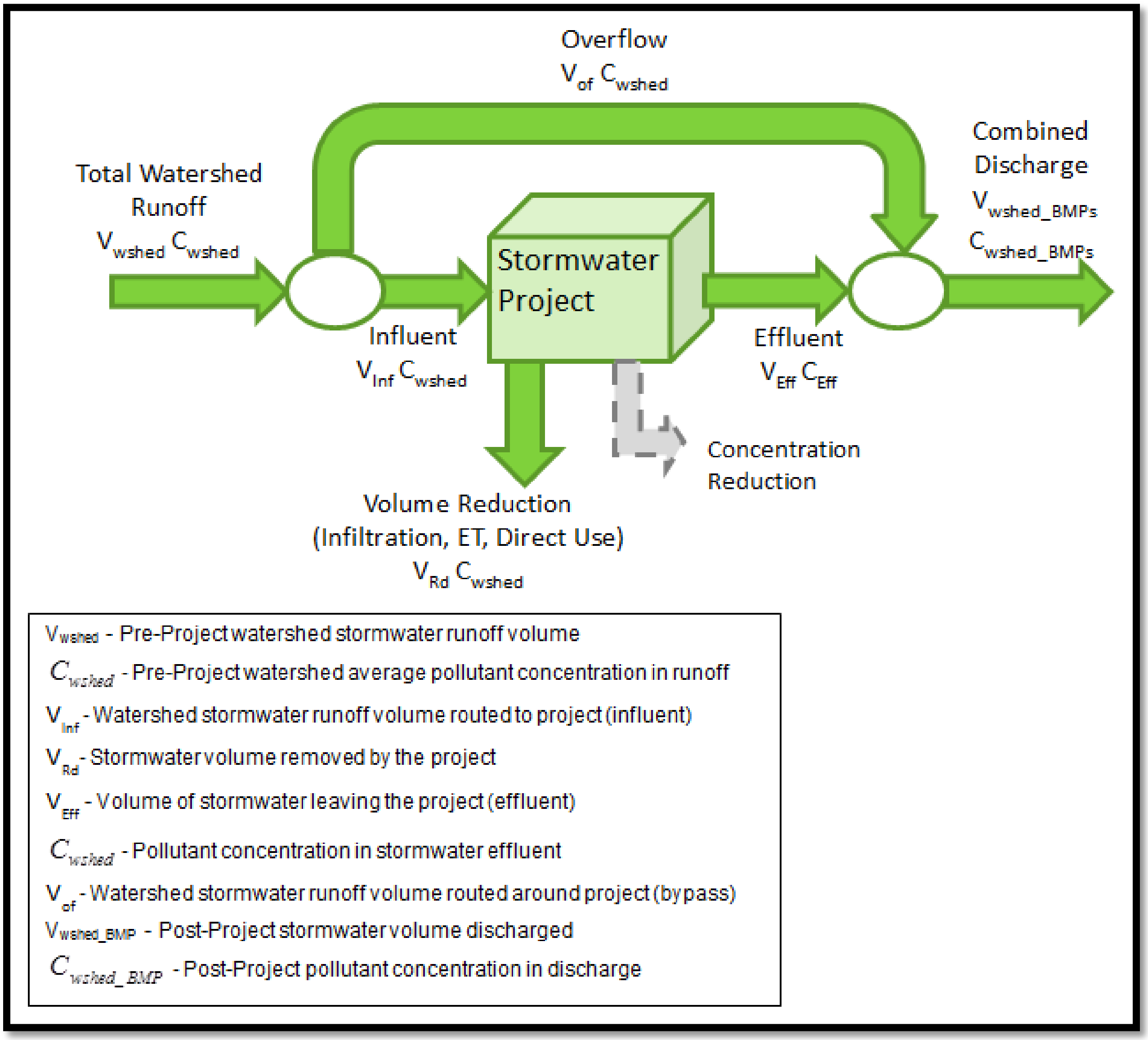

Figure S-1. Conceptual diagram of PLM Post-Project component

Uncertainty in Input Parameters

There is an inherent level of uncertainty in the stormwater sampling data, watershed characteristics, geographic information system (GIS) data, stormwater project performance data, and other data sets that were used to help understand the water quality benefits of stormwater projects. Therefore, understanding and quantifying these sources of uncertainty and incorporating them into the PLM creates a more robust analysis. A statistical modeling approach (Monte Carlo Analysis) was employed to allow the uncertainty in input parameters to be reflected in model inputs and to provide an indication of the average characteristics and variability of the stormwater concentrations and loadings in model results. For each Monte Carlo iteration, the PLM randomly selects a value between the lower and upper bounds for each key parameter to develop a unique estimate of average long-term conditions. The calculation is repeated for a large number of iterations, resulting in a large distribution of different estimates of potential long-term runoff volume, pollutant concentrations, and pollutant loadings results from each of the project tributary areas.

Geosyntec first developed a lower and upper bound for each of the parameters that is sensitive in the analysis and can be meaningfully quantified. When possible, the model expressed these input parameters in terms of a 95 percent confidence interval (CI) on the long-term average (i.e., bounded by the lower confidence limit [LCL] and the upper confidence limit [UCL]). CIs were developed for the land use runoff concentrations, project effluent concentrations, and street sediment concentrations using the bootstrap approach in combination with Regression on Order Statistics (ROS). Additionally, when the underlying data sets did not allow for the explicit estimation of CIs, the LCL and UCL for each key model input parameter were estimated using other methods, such as modeling calculations, data analysis, literature, or best professional judgment as described in Chapter 3.

The PLM is intended to estimate long-term average annual conditions for a given location and project. The PLM does not seek to describe the temporal variability that is inherent in stormwater pollutant loading. Additionally, the PLM is not intended to predict conditions for a given storm event or monitoring period.

Street Sweeping Model Overview

The City has implemented the Street Sweeping for Water Quality (SS4WQ) program, and as part of this, street solids are monitored to determine pollutant removal. Because the City has the SS4WQ program and the monitoring data, a separate PLM was developed to characterize long-term average pollutant loading reductions and concentration reductions for the City Integrated Plan street sweeping stormwater programs. This model uses a rate of pollutant removed by sweeping per curb-mile (pick-up rate) calculated from data measured during the City's current street sweeping program. The pick-up rate is then applied to the area that will receive enhancements to the street sweeping program to generate the total pollutant mass removed. Adjustments were applied to the total pollutant mass removed to convert this mass into a portion that would have been expected to be washed off the street during rain events and discharged at stormwater outfalls. A detailed discussion of the street sweeping analysis is included in Appendix G of the City's Integrated Plan report. The methodology and data provided by the City was then used to characterize the uncertainty inherent in the street sweeping data, as described below, and run with the Monte Carlo iterations.

Model Input Parameters

The PLM input parameters for the Pre-Project pollutant loadings include precipitation, stormwater project drainage area, runoff coefficients, and land use runoff concentrations. The PLM input parameters for the Post-Project pollutant loadings include project performance parameters, including capture efficiency, volume reduction, and effluent quality and/or other expressions of treatment efficiency. The PLM was modified to allow estimation of uncertainty in model predictions and seasonal variations.

Precipitation Characteristics

The annual and seasonal average precipitation in the Seattle area, as well as uncertainty in long-term average precipitation, were characterized based on an analysis of the City's network of 12 active rain gauges (RGs), which span a period of 35 years from 1978 to 2012. RG20 was selected as the central representative gauge. Spatial variability was used to estimate the range of long-term averages that may exist across the city. Table 3-1 presents the average precipitation and CIs used in the PLM for the three modeling time periods. These three modeling periods (annual, Season 1 [October–January], and Season 2 [February–September]) were selected based on an evaluation of the magnitude and frequency of CSO events.

Stormwater Projects Drainage Areas

The City identified and mapped the potential extent of the drainage area for each of the 14 candidate stormwater projects (Table 1-1 and Figure 3-1). The PLM calculated the “effective” drainage area, runoff coefficient, and land use pollutant runoff concentrations based on the conveyance class (e.g., informal vs. formal), surface type (e.g., roofs vs. lawns), and land use within each stormwater project drainage area. Other parameters also influence runoff and pollutant loads (e.g., soils, source area type, slope); however, these parameters were not as well supported by available data. The variability introduced by these parameters was considered to be encompassed within the overall uncertainty applied to the other parameters. Additionally, the stormwater project drainage area for several projects includes greater area than it may be possible to completely address by projects, and therefore the degree of implementation was also considered as a model parameter.

Effective Drainage Area Adjustments

A portion of the storm flow from a drainage basin may be “lost” during conveyance and not discharge from the municipal separate storm sewer system (MS4) outfall, due to two separate components of the conveyance system: (1) the type of conveyance system the area is connected to (i.e., excluding the areas in which flow is routed into the sanitary sewer system), and (2) the losses within the conveyance system (e.g., infiltration). To account for these losses, a connection factor was used to adjust the effective area of the drainage basin. The connection factor was estimated using the following equation:

*Connection factor = area connect to MS4 (%) * [1 – conveyance losses (%)]*

The City developed estimates based on citywide conditions. Significant catchment-specific and watershed-specific variations in system types and system losses are considered likely. Therefore, it was assumed that the estimated connection factors have a plus or minus 25 percent upper and lower bound of uncertainty. Table 3-3 lists the connection factor and the range of uncertainty for each land surface type in the partially separated and fully separated areas. Because it is assumed that zero percent of the combined sewer system (CSS) areas are connected to the MS4, the connection factor for all the land surface types in those areas is zero.

Degree of Project Implementation

All of the stormwater projects, excluding the green stormwater infrastructure (GSI) bioretention alternatives, are planned to be fully implemented for the watersheds identified. The GSI bioretention projects underwent a desktop GIS evaluation to establish a broad range of potentially feasible areas for implementation. However, due to site-specific conditions (e.g., actual infiltration rates) and social considerations (e.g., neighborhood concerns), many locations may not be suitable for implementation following site investigations. To account for these potential constraints, the estimated degree of implementation of these projects and therefore the Integrated Plan stormwater project drainage area was adjusted (Table 3-4).

Runoff Coefficients

The Western Washington Continuous Simulation Hydrology Model (WWHM, 2012) was applied to estimate runoff coefficients for each land surface type based on various soil types and surface slopes (Table 3-5). The range of long-term runoff coefficients estimated from this analysis was interpreted to develop Seattle-specific LCLs and UCLs for each land surface type (e.g., roofs, lawns, parking, streets, etc.). Note that while land surface types were used to estimate runoff coefficients in the PLM, data were not available to characterize pollutant runoff concentrations at the scale of discrete land surface types/source areas. Instead, land use-based information was used to estimate pollutant runoff concentrations.

Land Use Runoff Concentrations

The process of developing land use runoff concentrations included compiling stormwater runoff data from multiple sources (including local, regional, and national data sets), developing criteria for applying these data sets (e.g., attempt to represent Pacific Northwest runoff quality), and developing an approach for interpreting the data.

Using the runoff data, criteria, and approach described in Section 3.4, the upper and lower bound for each land use concentration was selected from summary statistics presented in Attachment F-1 of this appendix. The CIs and selected ranges for each EMC are graphically depicted in Attachment F-2 of this appendix. Final land use runoff concentration values are summarized in Table 3-7.

Project Performance

Project performance was modeled as a function of three elements: (1) the capture efficiency, discussed in Section 3.5.1; (2) the volume reduction, discussed in Section 3.5.2; and (3) the pollutant removal, discussed in Section 3.5.3.

Project Capture Efficiency

The City selected the preliminary design criteria for most of the stormwater projects to achieve a capture efficiency of 91 percent of the runoff volume. However, due to size and cost limitations or the availability of land for construction, several of the stormwater projects have preliminary designs with lower capture efficiencies (Table 3-8). No uncertainty is associated with the capture efficiency of the stormwater projects, because the projects will be further designed and built to satisfy the assumed capture efficiency criteria, with appropriate margins of safety, as needed.

Project Volume Reduction

The majority of the stormwater projects are treatment projects that do not infiltrate runoff; however, the bioretention and biofiltration projects are designed to reduce surface flow via infiltration. Preliminary planning of the GSI bioretention projects assumes that site-specific conditions will allow 50 percent of the captured volume to be infiltrated into native soils while the remaining 50 percent will be discharged after treatment to the receiving waters via underdrains. For the South Myrtle St. Shoulder Stabilization project, a range of volume reductions was developed that accounts for uncertainty arising from a lack of site-specific design conditions (e.g., infiltration rate) and variability in biofiltration performance (Table 3-9).

Project Pollutant Removal

The pollutant removals for the stormwater projects (excluding street sweeping) were estimated based on available data, using (1) an effluent quality-based approach, derived from the International Stormwater BMP Database (Table 3-10); (2) correlating pollutant removal to total suspended solids (TSS) reduction based on pollutant characteristics; or (3) other methods based on available data and best professional judgment. When using the effluent quality-based approach (which was preferred), project performance data from the International Stormwater BMP Database were also analyzed to evaluate whether there is a statistically significant difference between influent and effluent concentrations. Where there was not a statistically significant difference between influent and effluent concentrations, no concentration reduction was assumed.

For the NDS Partnering project where some of the treated stormwater infiltrates into native soils and some may be treated but discharged through an underdrain, the PLM calculates the pollutant removal by considering both pathways: the mass of pollutants removed from the infiltrated water and the mass of pollutants removed based on the treatment and then discharged where there is an underdrain present.

Street Sweeping

The City has been monitoring street sediment mass and quality in conjunction with its SS4WQ program. The data collected through this program, including street sediment removed, curb-miles swept, and concentrations of RCOC in street sediment, directed the development of the model estimating the potential load reductions resulting from enhancements to the street sweeping program.

The discussion of each of the necessary model inputs along with the resulting values can be found in Appendix G of the City Integrated Plan document: Pollutant Reduction Estimation Method—Candidate Stormwater Street Sweeping Programs. Additionally, quantifiable uncertainty was estimated for the seasonal precipitation, sample variability, and sweeper productivity (Section 3.6).

Model Methodology

Calculate the Pre-Project stormwater runoff volume:

1. Calculate the implemented effective drainage area for each land use type within the candidate stormwater project drainage basin based on the degree of project implementation, land use (e.g., residential, commercial, industrial), surface type (e.g., street, building, sidewalk, landscaped area), and drainage system connection factors (see Section 3.2).
2. Estimate the runoff coefficient for each land use type within the candidate stormwater project drainage basin based on land use, surface type, and surface type runoff coefficients (see Section 3.3).
3. Select the rainfall depth for the time period to be evaluated (annual, wet and dry seasons; see Section 3.1) to calculate the stormwater runoff volume from each land use type within the candidate stormwater project drainage area and then sum the volumes to calculate the Pre-Project runoff volume.

Calculate the Pre-Project pollutant loads and concentrations:

4. Select a pollutant concentration in stormwater runoff for each land use type and each RCOC (see Section 3.4) and multiply by the runoff volume to calculate the Pre-Project load from each discrete land use type in the project drainage basin and then sum the loads for each RCOC to calculate the Pre-Project RCOC loads.
5. Divide each Pre-Project RCOC load by the Pre-Project volume to calculate the Pre-Project average concentration for each RCOC.

Calculate the Post-Project stormwater runoff volume, pollutant loads, and concentrations:

6. Calculate the Post-Project runoff volume by summing the bypass volume (Pre-Project volume multiplied by 1 minus the capture efficiency [see Section 3.5.1]) and the project effluent volume (Pre-Project volume multiplied by capture efficiency and 1 minus the project volume reduction [see Section 3.5.2]).

7. Calculate the Post-Project load by summing the bypass load (bypass volume multiplied by the Pre-Project concentration) and the project effluent load (project effluent volume multiplied by the project effluent concentration [see Section 3.5.3]). This calculation assumes complete removal of all RCOCs in the fraction of the captured stormwater that infiltrates the native soils beneath the facility (e.g. NDS Partnering facilities with no underdrains).
8. Divide each Post-Project RCOC load by the Post-Project volume to calculate the Post-Project average concentration for each RCOC.

Calculate the stormwater runoff volume, pollutant load, and concentration reductions:

9. Calculate the Post-Project average volume reduction, concentration reduction, and load reduction for each RCOC based on the difference between Pre-Project and Post-Project results.

Calculate the distribution of results:

10. Repeat steps 1–9 a total of 1,000 times for each RCOC and time period, recording the Pre-Project, Post-Project, and reduction model results for each iteration.

Model Methodology Assumptions

The following key assumptions are made for the Monte Carlo water quality modeling methodology:

1. The stormwater projects were modeled to only remove pollutants and not act as a source.
2. The stormwater projects were modeled so that the dissolved fraction of RCOCs were always less than or equal to their respective total RCOC.

Street Sweeping Model

The PLM was modified to be able to quantify the uncertainty and estimate the seasonal RCOC concentrations and loads for the street sweeping data provided by the City.

Model Results

The PLM results are summarized in a series of box-and-whisker charts (Attachment F-3). Each chart displays the long-term average concentration or load reduction for an RCOC during the annual time period. Each candidate Integrated Plan stormwater project is included on the x-axis with the estimated reduction on the y-axis, the median reduction is indicated by the horizontal line within the box, the top and bottom of the box represents the 25th and 75th percentile average long-term reductions, respectively, and the top and bottom whiskers represent the 95th and 5th percentile average long-term reductions, respectively.

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CHAPTER 1

Introduction

This appendix documents the pollutant load model (PLM) analysis for stormwater projects conducted as part of developing the City of Seattle (City) Integrated Plan. The Integrated Plan is an alternative in the City's Long-Term Control Plan (LTCP) for combined sewer overflows (CSOs). Geosyntec conducted the pollutant load analysis in partnership with the City and Brown and Caldwell to help develop the Integrated Plan.

Geosyntec developed a PLM to estimate the pollutant load reductions of the candidate stormwater projects identified by the City. The City identified 14 potential candidate stormwater projects based on Step 2[1] of the Integrated Planning process, as listed in Table 1-1. The *Stormwater Treatment Project Screening Technical Memorandum* (SPU, 2013) includes a planning-level description of each project and describes the best management practice (BMP) selection process, which consisted of the following steps:

- **Step 2.1**: Identify characteristics of the priority ranked basins
- **Step 2.2**: Identify receiving water body and its primary pollutant(s) of concern
- **Step 2.3**: Estimate pollutant loading and flow for each basin
- **Step 2.4**: Conduct stormwater project feasibility screening
- **Step 2.5**: Estimate costs

Table 1-1. Potential Integrated Plan Stormwater Projects

Name	Total tributary drainage area (acres)	Project type	Treatment type	Receiving water body
Blue Dog Pond/Pretreatment	242	Swirl concentrator	Basic (particle separation)	Duwamish Waterway
Longfellow Cascades	68	Bioretention with routing to infiltration	Flow control/basic (vegetated media filtration/sorption)	Longfellow Creek
Minor Ave./Cascades Filterras	56	Media filter	Basic (media filtration/sorption)	Lake Union
Minor Ave./I-5 StormFilter Vault	140	Cartridge media filter	Basic (media filtration)	Lake Union
NDS Partnering	Piper's Creek: 684 Thornton Creek: 2,703 Longfellow Creek: 557	Bioretention with routing to infiltration	Flow control/basic (vegetated media filtration/sorption)	Piper's Creek Thornton Creek Longfellow Creek

[1] See City's Integrated Plan report, Figure 1-2 for the steps taken in the Integrated Planning approach.

Table 1-1. Potential Integrated Plan Stormwater Projects

Name	Total tributary drainage area (acres)	Project type	Treatment type	Receiving water body
Piper's Cascades	159	Bioretention with routing to infiltration	Flow control/basic (vegetated media filtration/sorption)	Piper's Creek
South Myrtle St. Shoulder Stabilization	3.2	Biofiltration swale	Basic (vegetated filtration)	Duwamish Waterway
South Myrtle St. StormFilter Vault	8.5	Cartridge media filter	Basic (vegetated media filtration/sorption)	Duwamish Waterway
South Park WQ Facility	254	Active treatment (CESF)	Chitosan-enhanced sand filtration system	Duwamish Waterway
Street Sweeping Expansion Arterials	1,736	Street sweeping	Regenerative air street sweeper	Varies/multiple
Street Sweeping Expansion Residential	1,120	Street sweeping	Regenerative air street sweeper	Varies/multiple
SW Hinds SD StormFilter Vault	29	Cartridge media filter	Basic (media filtration/sorption)	Duwamish Waterway
U Village Filterras	5.4	Media filter	Basic (media filtration/sorption)	Lake Washington
Webster Pond/Pretreatment	366	Swirl concentrator	Basic (particle separation)	Longfellow Creek

1.1 Objectives

The objective of this PLM analysis was to assess pollutant load reductions for those stormwater projects and programs identified in Step 2 of the Integrated Planning process.

This assessment was performed using the constituents of concern identified in the Consent Decree the City recently entered into with the U.S. Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), and United States Department of Justice (e.g., metals, pathogens, semi-volatile organic compounds, and pesticides). Representative Constituents of Concern (RCOCs) carried forward in the loading analyses were identified in consultation with the City and the Expert Panel. The RCOCs were selected with consideration for known environmental concerns and data availability. For example, copper and zinc were selected as representative of metals because copper and zinc are the most common and well-known toxicants characterized by multiple stormwater runoff studies. Table 1-2 identifies the complete list of RCOCs.

Table 1-2. Representative Constituents of Concern

Constituents identified in Consent Decree	Selected RCOC
Biochemical oxygen demand (BOD)	BOD[a]
Semi-volatile organic compounds	Bis(2-ethylhexyl)phthalate
Pesticides	Dichlobenil
Pathogens	Fecal coliform bacteria
pH	[H+][b]
Nitrogen ammonia	Ammonia-N[c]
Oil and grease	Oil and grease[d]
Polybrominated diphenyl ethers (PBDE)	Total PBDEs
Fecal coliform bacteria	Fecal coliform bacteria
Projected dissolved oxygen (DO)	Projected DO[e]
Polychlorinated biphenyls (PCB)	Total PCBs
Phosphorus	Total phosphorus (TP)
Total suspended solids (TSS)	TSS
Metals	Dissolved copper Dissolved zinc Total copper Total zinc

a. BOD = 5-day biochemical oxygen demand (BOD_5).

b. H+ = hydrogen ion concentration.

c. Ammonia-N = nitrogen-ammonia

d. Oil and grease analyzed using a combination of EPA 1664A and earlier comparable methods (EPA 1664, EPA 413.1, etc.).

e. Projected DO = change in DO deficit.

1.2 Methodology

The general approach for assessing pollutant load reductions relies on the use of existing information and a relatively simple spreadsheet model. Although the PLM was not calibrated to site-specific conditions, local information provided by the City was used where possible (e.g., local stormwater quality data and local precipitation data). Information from literature reviews and the International Stormwater BMP Database was also used for parameterizing the PLM.

The project (City and consultant team) team consulted with the Expert Panel via three full-day face-to-face panel meetings and two conference calls to reach consensus on model inputs and methodology. The Expert Panel reviewed the stormwater project evaluation methodology and provided feedback on data used, assumptions, and the proposed methods for developing the baseline PLM and the performance of the potential candidate stormwater projects. Their feedback was valuable for selecting an appropriate list of RCOCs to meet the Consent Decree requirements, assessing the most appropriate land use and project performance data, and the statistical method selected for demonstrating project performance and uncertainty. The Expert Panel also provided feedback and insight into specific considerations such as addressing PCBs in the Duwamish Waterway and how to refine the performance of street sweeping.

Appendix D of the City's Integrated Plan report contains a summary of the Expert Panel meetings and their findings.

CHAPTER 2

Model Overview

2.1 Pollutant Load Model Overview

The PLM was developed to characterize long-term average[2] pollutant concentrations and loadings (total mass of pollutants) for each RCOC from each candidate stormwater project drainage area prior to project implementation (Pre-Project) and after project implementation (Post-Project) on an annual and seasonal basis. It was also used to develop estimates of the variability in performance. This empirical, volume-based PLM is generally applicable in the planning and evaluation stages of a project[3].

The Pre-Project component of the model is based on simple rainfall/runoff relationships and estimated pollutant concentrations in stormwater runoff. The volume of stormwater runoff is estimated using a simple runoff coefficient method, an empirical expression that relates runoff volume to the rainfall depth and the basin characteristics such as the amount of impervious land cover. The pollutant concentration in stormwater runoff is represented by an expected average pollutant concentration, which was developed based on analysis of the event mean concentrations (EMC). EMCs were obtained from available monitoring data and are dependent on the land use type (e.g., commercial, industrial, and residential).

The Post-Project component of the model utilized the Pre-Project concentrations and runoff volumes and applied project performance parameters to estimate Post-Project conditions. The performance of projects was modeled as a function of three factors: (1) the fraction of average long-term stormwater runoff volume receiving treatment (referred to hereafter as “capture efficiency”), (2) the long-term average pollutant removal achieved in the project by virtue of surface runoff reduction via infiltration and/or evapotranspiration (generically referred to as “volume reduction”), and (3) the long-term average pollutant removal achieved in the treatment project by virtue of improved water quality of treated runoff. The flow chart in Figure 2-1 provides an overview of the Post-Project modeling component.

[2] The long-term average condition is a more reliable indication of total long-term loading (considering the influence of both normal and extreme events), while the long-term median condition is a more reliable indicator of conditions that occur most frequently.

[3] The model does not incorporate the hydraulics or detailed hydrology of the site, which would be appropriate for subsequent design stages and requires additional data and more sophisticated modeling.

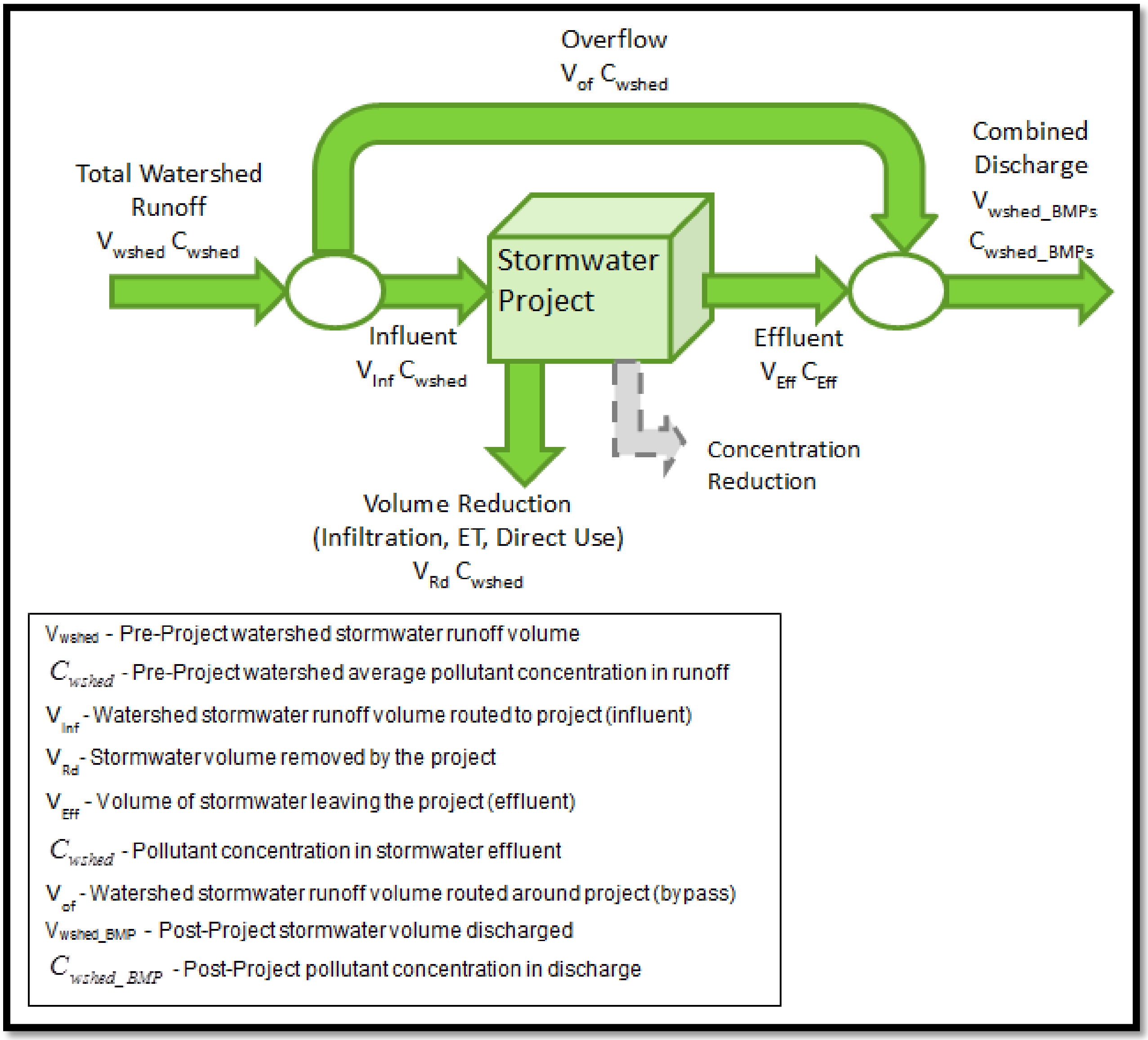

Figure 2-1. Conceptual diagram of PLM Post-Project model component

Runoff volumes, stormwater quality characteristics, and project performance are highly variable. Therefore, a statistical modeling approach (Monte Carlo Analysis) was employed to allow the uncertainty in input parameters to be reflected in model inputs and to provide an indication of the average characteristics and variability of the stormwater concentrations and loadings in the model results. For each Monte Carlo iteration, the PLM randomly selects a value from between the lower and upper bounds for each key parameter to develop a unique estimate of average long-term conditions. The calculation is repeated for a large number of iterations, resulting in a large distribution of different estimates of potential long-term runoff volume, pollutant concentrations, and pollutant loading results from each of the stormwater project drainage areas.

Using the model methodology described in further detail in Chapter 4, the PLM estimates a distribution of the long-term average annual runoff loadings for each RCOC and time period for the following eight outputs (each expressed as an average long-term estimate):

1. Pre-Project Runoff: The runoff volume from the stormwater project drainage basins prior to stormwater project implementation
2. Post-Project Runoff: The runoff volume from the stormwater project drainage basins after the implementation of the stormwater project
3. Pre-Project Concentration: The concentrations of the RCOCs in runoff from the stormwater project drainage basins prior to the stormwater project implementation
4. Post-Project Concentration: The concentrations of the RCOCs in runoff from the stormwater project drainage basins after the implementation of the stormwater project
5. Concentration Reduction: The concentration reductions of the RCOCs in the runoff from stormwater project drainage basins as a result of the implementation of the stormwater project
6. Pre-Project Load: The loadings of the RCOCs from the stormwater project drainage basins prior to the stormwater project implementation
7. Post-Project Load: The loadings of the RCOCs from the stormwater project drainage basins after the implementation of the stormwater project
8. Load Reduction: The load reductions of the RCOCs in runoff from the stormwater project drainage basins after the implementation of the stormwater project

An additional PLM was developed to characterize long-term average pollutant loading reductions and concentration reductions for the City Integrated Plan proposed enhanced street sweeping stormwater projects. This model uses a rate of pollutant removed by sweeping per curb-mile (pick-up rate) calculated from data measured during the City's current street sweeping program. The pick-up rate is then applied to the area that will receive enhanced street sweeping (more frequent and more miles) to the current street sweeping program to generate the total pollutant mass removed. Adjustments were applied to the total pollutant mass removed to convert this mass into a portion that would have been expected to be washed off the street during rain events and discharged at stormwater outfalls. A detailed discussion of the street sweeping analysis is included in Appendix G of the City's Integrated Plan report. The street sweeping methodology was used with the data provided by the City to characterize the uncertainty inherent in the street sweeping data and run using the Monte Carlo iterations.

2.2 Uncertainty in Input Parameters

There is an inherent level of uncertainty in the stormwater quality data, watershed characteristics, basin boundary delineations, stormwater project performance data, and other information that was used to help understand the water quality benefits of the proposed stormwater projects. Therefore, it is important to understand the sources of uncertainty so that they can be quantified and incorporated into the PLM to create a more robust analysis. Below are described the sources of uncertainty and a brief discussion of the main approaches for characterizing the uncertainty of the model input parameters. Additionally, Chapter 3 discusses in greater detail the uncertainty analysis and results for each individual model input parameter.

2.2.1 Sources of Uncertainty

The sources of uncertainty relating to the PLM input parameters arise from, but are not limited to, the following:

- representativeness of data from studies conducted in other areas that were used in the analysis (e.g., runoff concentrations)
- general uncertainty in any stormwater data due to measurements, field protocols, data quality, and data accuracy
- stormwater volume estimating methods that rely on empirical relationships between annual rainfall and runoff
- spatial uncertainty in watershed/site conditions (e.g., imperviousness, soils, runoff parameters), as they relate to the certainty that can be had regarding hydrologic conditions at a given location

It is important to note that the PLM does not seek to describe the temporal variability that is inherent in stormwater pollutant loading. The PLM is intended to estimate long-term average conditions for a given location and project. At this scale, temporal variability (e.g., storm-to-storm, year-to-year) is not relevant. Additionally, the PLM is not intended to predict conditions for a given storm event or monitoring period.

2.2.2 Characterizing Uncertainty

A lower and upper bound was developed for each of the most important and sensitive model input parameters that can be meaningfully quantified. When possible, the model expressed these input parameters in terms of a 95 percent confidence interval (CI) on the long-term average (i.e., bounded by the lower confidence limit [LCL] and the upper confidence limit [UCL]). CIs were developed for the land use runoff concentrations, project effluent concentrations, and street sediment concentrations using the bootstrap approach (Singh et al., 1997) in combination with Regression on Order Statistics (ROS). Additionally, when underlying data sets did not allow for the explicit estimation of CIs, the LCL and UCL for each key model input parameter were estimated using other methods such as modeling calculations, data analysis, literature, or best professional judgment as described in Chapter 3. Table 2-1 summarizes the model input parameters with the uncertainty quantified and the method of quantification employed.

2.2.2.1 Method for Dealing with Multiple Detection Limits

To account for the multiple detection limits in the censored data sets, an ROS method was employed. ROS is a category of robust methods for estimating descriptive statistics of censored data sets that utilize the normal scores for the order statistics (Shumway et al., 2002). The plotting position method by Hirsch and Stendinger (1987) (summarized by Helsel and Cohn, 1988) was used. In this method, plotting positions are based on conditional probabilities and ranks, where the ranks of the censored (below detection) and uncensored (above detection) data related to each detection limit are ranked independently. The method is summarized in the equations below.

After plotting positions for the censored and uncensored values have been calculated, the uncensored values are plotted against the z-statistic corresponding to the plotting position and the best-fit line of the known data points is derived. Using this line and the plotting positions for the uncensored data, the values for the uncensored data are extrapolated.

$$pe_j = pe_{j+1} + \frac{A_j}{(A_j+B_j)} \times \left(1 - pe_{j+1}\right) \qquad (1)$$

Where:

A_j = the number of uncensored observations above the j detection limit and below the j +1 detection limit

B_j = the number of censored and uncensored observations less than or equal to the j detection limit

pe_j = the probability of exceeding the j threshold for j = m, m -1, … 2, 1 where m is the number of thresholds; by convention $pe_{m+1} = 0$

Equation 2 was used for plotting the uncensored data and equation 3 was used for plotting the censored data; the plotting positions of the data were calculated using the Weibull plotting position formula (Weibull, 1951).

$$p(i) = (1 - pe_j) + \frac{(pe_j - pe_{j+1}) \times r}{(A_j + 1)} \qquad (2)$$

Where:

p(i) = the plotting position of the uncensored i data point

r = the rank of the i^{th} observation of the A_j observations above the j detection limit

$$pc(i) = \frac{(1 - pe_j) \times r}{(n_j + 1)} \qquad (3)$$

Where:

pc(i) = the plotting position of the censored i data point

R = the rank of the i^{th} observation of the n_j censored values below the j detection limit

2.2.2.2 Method for Calculating Descriptive Statistics

After replacement values were estimated for censored data (or for data sets without non-detects), descriptive statistics were computed using the bootstrap method (Singh et al., 1997). The bootstrap method samples from the data set with replacement[4] several thousand times and calculates the desired descriptive statistics from the sampled data. The steps of the bootstrap estimation method are described below.

1. Take a sample of size *n* with replacement (the sampled data point remains in the data set for subsequent sampling) from the existing data set (Singh et al. (1997) recommends that *n* be the same size as the original

[4] The data point selected for the bootstrap analysis remains in the data set and is allowed to be selected more than one time, rather than a single time, which is known as "sampling without replacement."

data set, this recommendation was followed for the analysis) and compute the descriptive statistic, θ_i (e.g., mean), from the sampled data.

2. Repeat Step 1 independently N times (10,000 for this analysis) each time calculating a new estimate for θ_i.
3. Calculate the bootstrap estimate, θ_B, by averaging the θ_i's for i=1 to N.

Fundamentally, the bootstrap procedure is based on the Central Limit Theorem, which suggests that even when the underlying population distribution is non-normal, averaging produces a distribution more closely approximated with normal distribution than the sampled distribution (Devore, 1995).

Table 2-1. Uncertainty and Methods in Input Parameters

Parameter	Lower and upper bounds of uncertainty[a]	Characterization source
Average Annual and Seasonal Precipitation	Plus or minus 10% of the arithmetic mean	Best professional judgment based on analysis of spatial variability of rainfall across the city
Effective Drainage Area	Plus or minus 25% of the mean	Best professional judgment
Runoff Coefficient	Varied	Analyzed using WWHM with different inputs for soil type and slope conditions
Land Use Runoff Concentrations	95% confident interval on the long-term average	Statistical analysis of various land use runoff concentration data sets
Project Volume Reduction[b]	Biofiltration swale: 18%–32%	Statistical analysis of International Stormwater BMP Database
Project Effluent Concentrations or Concentration Reductions	95% confident interval on the long-term average	Statistical analysis of International Stormwater BMP Database; supplemental information, where available; best professional judgment where necessary to fill data gaps
Street Sediment Concentrations	95% confident interval on the long-term average	Statistical analysis of raw street sediment concentrations
Street Sweeper Productivity	Plus or minus 25% of the mean	Best professional judgment

a. Many parameters had extenuating circumstances in which different lower and/or upper bounds were used. A detailed explanation of the uncertainty in every parameter input is included in Chapter 3.

b. The bioretention projects had volume reductions as well; however, there was no quantifiable uncertainty for the volume reduction of these projects.

CHAPTER 3

Model Input Parameters

The PLM simulates pollutant loadings into (Pre-Project) and out of (Post-Project) each candidate stormwater project. PLM input parameters for the Pre-Project pollutant loadings include precipitation, stormwater project drainage area, runoff coefficients, and land use runoff concentrations. The PLM input parameters for the Post-Project pollutant loadings include project performance parameters, including capture efficiency, volume reduction, and effluent quality and/or other expressions of treatment efficiency. A discussion of these model input parameters is provided below. Additionally, there is a separate discussion of the model input parameters for street sweeping.

Many parameters that can affect pollutant loads and concentrations vary spatially and may not be adequately represented by stormwater monitoring data collected at discrete locations. Examples include specific high or low source concentrations, topography, soil types, and precipitation characteristics, among others, all of which can influence the buildup and mobilization of pollutants. The following model input parameters represent the best data currently available for representation of existing and developed site conditions in the water quality model (PLM).

3.1 Precipitation Characteristics

Annual and seasonal average precipitation in the Seattle area, as well as uncertainty in long-term annual average precipitation, was characterized according to the water year based on the City's network of 12 active rain gauges (RGs), which span a period of 35 years from 1978 to 2012. Based on this network, a single rain gauge (RG20), was selected for purposes of parameterizing the PLM. RG20 is believed to be representative of the City's network of rain gauges for the reasons listed below:

- RG20's mean annual precipitation value (33.8 inches) approximates the mean annual precipitation value across all stations (33.6 inches).
- RG20's 95 percent CI about the mean overlapped the 95 percent CIs for all other stations with the exception of RG11, which had the lowest annual precipitation value (29.5 inches).
- RG20 is centrally located in the city of Seattle.

Table 3-1 presents the average precipitation and CIs used in the PLM for the three modeling time periods. These three modeling periods were selected based on an evaluation of the magnitude and frequency of CSO events.

Table 3-1. Cumulative Precipitation Estimates Used in the PLM
(Based on Water Year, Rain Gauge RG20, and n=34)

Period	Average (inches)	Confidence interval[a] (inches)
Annual	33.8	30.4–37.2
October–January (Season 1)	18.3	16.5–20.1
February–September (Season 2)	15.5	14.0–17.1

a. Confidence interval is defined as plus or minus 10% of the average based on best professional judgment of an analysis of general spatial variability of precipitation data across the city.

3.2 Stormwater Projects Drainage Areas

The City identified and mapped the drainage area for each of the 14 candidate stormwater projects (Table 1-1 and Figure 3-1). The PLM then calculated the “effective” drainage area, runoff coefficient, and land use pollutant runoff concentrations based on the conveyance class (e.g., informal vs. formal), surface type (e.g., roofs vs. lawns), and land use within each candidate stormwater project drainage area. Other parameters are also understood to influence runoff and pollutant loads (e.g., soils, source area type, and slope); however, these parameters were not as well supported by available data. The variability introduced by these parameters is considered to be encompassed within the overall uncertainty applied to the other parameters. Additionally, the candidate stormwater project drainage areas for several of the projects include larger drainage areas than possible to completely be addressed by the projects; therefore, the degree of implementation was also considered as a model parameter.

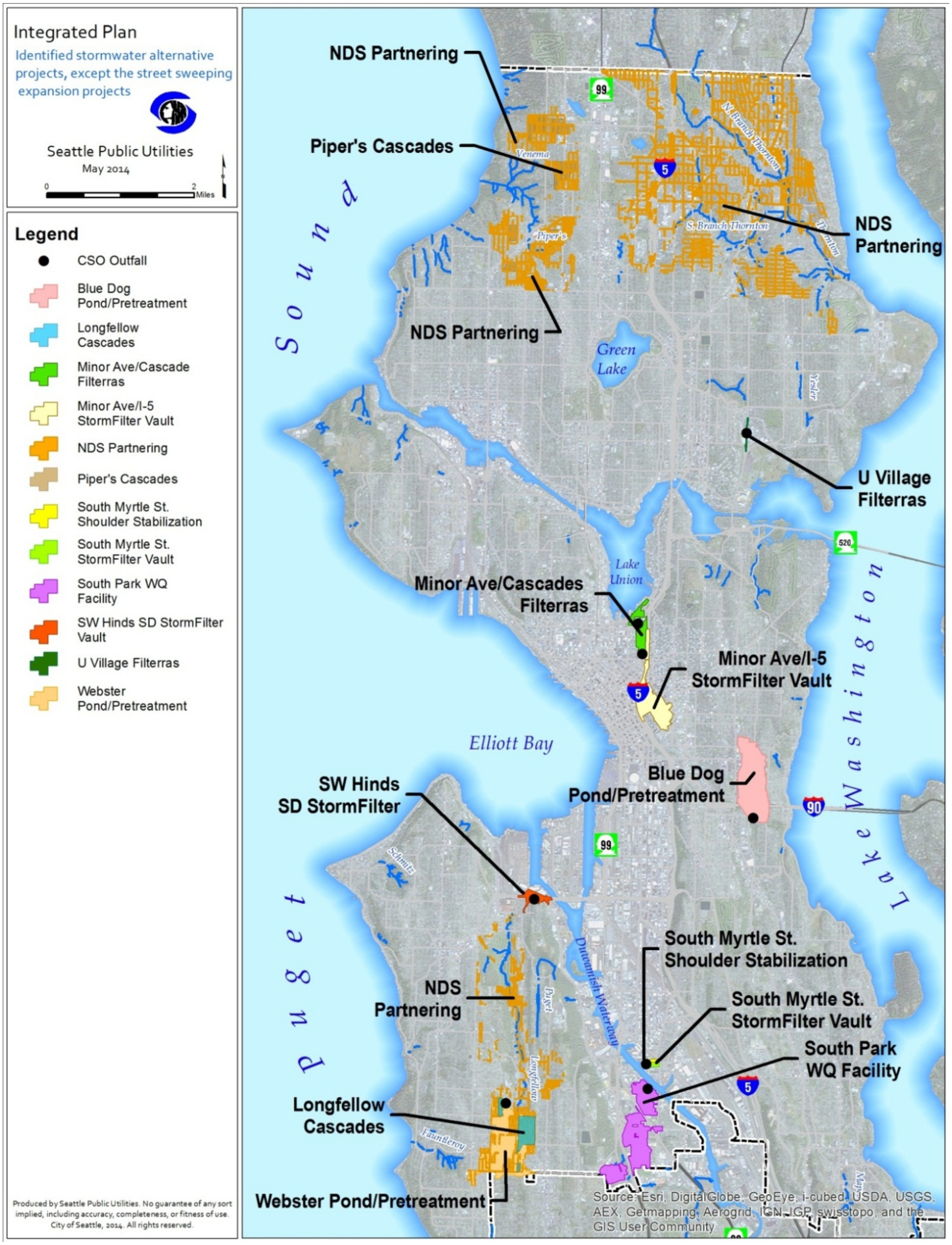

Figure 3-1. Identified stormwater alternative projects, except the street sweeping expansion projects
(tributary watershed and discharge point are shown for each)

3.2.1 Conveyance Class, Surface Type, and Land Use

The drainage areas for the candidate stormwater projects (excluding street sweeping) were characterized by conveyance class, surface type, and land use in a geographic information system (GIS) by intersecting the respective City GIS layers (Table 3-2). Conveyance classes, surface types, and land uses are described below.

Table 3-2. GIS Layers Used for Characterizing Conveyance Class, Surface Type, and Land Use

GIS layer	File name
Project drainage area	IPAlternativeBndry.lpk
Conveyance class	Combined_updated feature class from IPtoBNC.gdb
Surface type	SurfaceType feature class from IP_PLE.gdb
Land uses	LNDUSEZONING feature class from IP_PLE.gdb

Source: City of Seattle

Conveyance Class. The stormwater conveyance systems found within the candidate stormwater project drainage areas determines whether stormwater is directed into a municipal separate storm sewer system (MS4) or the combined sewer system (CSS) (Figure 3-2). The conveyance class GIS layer is classified into the following three classes:

- <u>Combined sewer systems:</u> Areas where stormwater and sanitary sewage are collected and conveyed to the wastewater treatment plant in a single pipe. Most of the older sections of Seattle are served by combined sewers.
- <u>Municipal separate storm sewer systems:</u> Areas where stormwater and sewage are collected and conveyed in totally separate systems (e.g., MS4s and sanitary sewers). Stormwater is discharged directly to the nearest receiving water body and sewage is conveyed to the wastewater treatment plant.
- <u>Partially separated systems:</u> Areas where combined sewer and MS4 systems overlap. These systems typically exist in areas where the City has separated stormwater from the combined system to reduce CSOs. In these areas, runoff from the streets is generally collected and conveyed in a separate storm drain system, but runoff from the adjacent parcels may or may not continue to be connected to the CSS. The degree of separation on private parcels depends on the ease with which these areas could be connected to the storm drain system during construction.

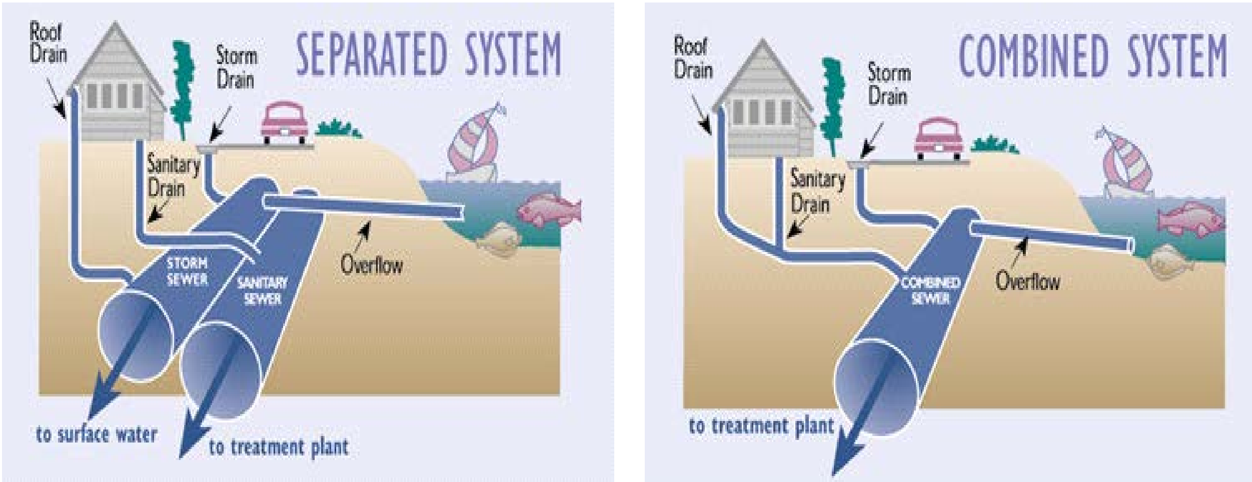

Figure 3-2. Schematic of separated and combined sewer systems

The conveyance class layer was used to estimate the portion of the candidate stormwater project's drainage area that would produce runoff to an MS4 outfall (see description of effective area in Section 3.2.2).

Surface Type. The City created the surface type GIS layer utilizing three data sources, starting with the most precise layer and filling in missing areas with the less precise layers to produce a comprehensive representation of the various ground covers found within the Integrated Plan stormwater project drainage areas (see description in the Pollutant Loading Estimation Technical Memorandum by the City on April 18, 2013 [SPU, 2013(b)]). The surface type GIS layer is classified into the following eight classes:

- Building
- Driveway/Parking Lot
- Other Impervious
- Pervious Landscape
- Sidewalk
- Street
- Trees/Scrub
- Water

The surface type GIS layer was used primarily to estimate the volume of runoff generated from the Integrated Plan stormwater project drainage area based on empirical rainfall-runoff relationships developed for areas characterized by different levels of imperviousness (see Section 3.3 and Section 4.1). However, surface type also came into play in the estimates of effective drainage area as the connection factors developed for areas served by partially and fully separated systems varied depending on surface type (e.g., streets are more likely to be connected to the MS4 than roofs in partially separated systems), discussed in Section 3.2.2.

Land Uses. Land use in the candidate project drainage areas was divided into the following six categories using King County parcel GIS information:

- Commercial
- Industrial
- Open Space
- Residential
- Vacant/Unknown
- Water

The land use GIS layer was used in the PLM to characterize pollutant runoff concentrations expected from those land uses based upon observed data in Seattle as well as regional and national land use runoff quality data sets, discussed in Section 3.4.

3.2.2 Effective Drainage Area Adjustments

A significant portion of the flow that leaves a drainage basin may not discharge out of an MS4 outfall, due to two separate components of the conveyance system: (1) the type of conveyance system the area is connected to, and (2) the losses within the conveyance system. To account for these losses, a connection factor was used to adjust the effective area of the drainage basin. The connection factor was estimated using the following equation:

*Connection factor = area connect to MS4 (%) * [1 – conveyance losses (%)]*

3.2.2.1 Conveyance Class Adjustment

The drainage basin areas were reduced to represent only the percent of the area connected to the MS4 (i.e., excluding the areas in which flow is routed into the sanitary sewer system). It is assumed that in areas of MS4 and CSS all runoff flows to the respective system, while in the partially connected systems only a portion of the area flows to the MS4. For these partially separated areas, the degree of separation from the combined system and connection to the MS4 is based on the City's knowledge of how these separation projects were designed and constructed. As explained above, for most separation projects, runoff from the streets was separated from the CSS and routed to the separated storm drain system (i.e., MS4). However, runoff from areas adjacent to the right-of-way was not as easily separated. Therefore, runoff from the adjacent parcels often continues to flow to the CSS. Table 3-3 lists the estimated area connected to the MS4 in the partially separated areas for each surface type. Additionally, it is assumed that 100 percent of the MS4 areas and zero percent of the CSS areas are connected to the MS4.

3.2.2.2 Conveyance System Losses Adjustment

Flow can be lost from certain drainage systems due to factors such as soil infiltration in the informal drainage areas served by ditches and culverts and pipe exfiltration through leaking joints and cracks in the formal piped drainage system. These losses are represented in the PLM as a percent of the area contributing flow (i.e., flow from X percent of the area is lost within the conveyance system). The informal conveyance systems experience higher losses due to the nature of the system (e.g., greater infiltration in the bottom of unlined open channels). Partially separated areas are assumed to have a formal conveyance, because it was previously part of the combined system. The fully separated areas are assumed to have an informal conveyance north of 85th Street. In the rest of the city, fully separated systems are piped. Conveyance losses in these areas are zero. The City's experience at the surface type level within formal and informal conveyance areas informs the estimated percent of the typical flow that is lost. Table 3-3 lists the estimated losses occurring within the formal and informal conveyance systems for each surface type. Note that because the open land use areas calibrated conditions may already account for some of these losses, the overall assumed losses may be somewhat conservative (i.e., baseline loadings may be underestimated). When estimating pollutant load reductions, it is considered conservative to make assumptions that underestimate baseline runoff volumes and pollutant loads.

3.2.2.3 Connection Factor Uncertainty

The City developed estimates based on citywide conditions. Significant catchment-specific and watershed-specific variations in system types and system losses are considered likely. Therefore, it was assumed that the estimated connection factors have a plus or minus 25 percent lower and upper bound of uncertainty. For connection factors that are estimated to be 100 percent, the uncertainty ranges from 80 to 100 percent. Table 3-3 lists the connection factor and the range of uncertainty for each surface type in the partially separated and fully separated areas. Because it is assumed that none of the CSS areas are connected to the MS4, all of the surface types in those areas were assigned a connection factor of zero.

Table 3-3. Surface Type Connection Factors[a]

Surface type	Partially separated areas			Fully separated areas (MS4)		
	Area connected to MS4 (%)	Loss in formal conveyance (%)	Connection factor (%) [low–high]	Area connected to MS4 (%)	Loss in informal conveyance (%)	Connection factor (%) [low–high]
Street	100	0	100 [80–100]	100	0	100 [80–100]
Driveway/ Parking Lot	75	0	75 [50–100]	100	50	50 [25–75]
Building (Roof)	60	0	60 [35–80]	100	65	35 [10–60]
Sidewalk	100	10	90 [80–100]	100	20	80 [60–100]
Other Impervious	100	0	75 [50–100]	100	50	50 [25–75]
Water	100	0	100 [80–100]	100	0	100 [80–100]
Landscape Area	100	0	100 [80–100]	100	0	100 [80–100]
Tree/scrub	100	0	100 [80–100]	100	0	100 [80–100]

a. Very small GIS slivers of land use areas are found with no surface type and/or no conveyance type defined. To be conservative these areas are assigned a connection factor of 0%. When estimating pollutant load reductions, it is considered conservative to make assumptions that underestimate baseline runoff volumes and pollutant loads.

3.2.3 Degree of Project Implementation

All of the candidate stormwater projects, excluding the green stormwater infrastructure (GSI) bioretention alternatives, are planned to be fully implemented. The GSI bioretention projects underwent a desktop GIS evaluation to establish a broad area potentially feasible for implementation. However, due to site-specific conditions (e.g., actual infiltration rates) and social considerations (e.g., neighborhood concerns), many locations may not be suitable for implementation following site investigations. To account for these potential constraints, the estimated degree of implementation of these projects, and therefore the stormwater project drainage area, was adjusted (Table 3-4).

Table 3-4. Degree of Implementation for Stormwater Projects

Alternative name	Project implementation
Longfellow Cascades	60%
NDS Partnering	4%[a]
Piper's Cascades	60%
All other stormwater projects	100%

a. The design implementation level provided by the City. Although significantly higher percentages are feasible, this implementation level is reasonable within the confines of the potential budget allocation.

3.3 Runoff Coefficients

The Western Washington Continuous Simulation Hydrology Model (WWHM, 2012) was used to estimate Seattle-specific runoff coefficients for each surface type. The WWHM (2012) utilizes long-term 15-minute precipitation data, measured evaporation data, and other region-specific data sets in a continuous-simulation hydrology model to calculate annual precipitation volumes and runoff and other loss volumes.

To simulate the runoff from the various Seattle surface types, the WWHM program was set to the precipitation file "VLPRECIP 15 min." [5] This gauge, located in north Seattle, provides representative rainfall for the stormwater projects. RG20, used in the overall analysis of annual rainfall amounts, has only hourly data and therefore could not be used for this more detailed analysis. Additionally, the use of WWHM was intended only to develop a unitless fraction of stormwater runoff, and not to provide an absolute estimate of runoff volumes; therefore, minor differences in rainfall depths between these gauges were not important.

[5] The precipitation gauge RG20, used to establish the precipitation values for the PLM, is not calibrated in the WWHM program. Therefore, the VLPRECIP gauge was chosen as a similar precipitation file.

The eight surface types classified in the City GIS layer were combined into four groups for analysis and modeled with a closely matching WWHM category:

- Building (WWHM category roof)
- Driveway/Parking Lot, Other Impervious, Sidewalk, Street, and Water (WWHM categories Driveways, Sidewalks, Parking)
- Pervious Landscape (WWHM category Lawn)
- Trees/Scrub (WWHM category Forest)

Each of the four WWHM categories was modeled as 1-acre drainage areas. To characterize the lower and upper bounds of uncertainty relating to site-specific conditions, the following soil and slope attributes were used:

- soil type A/B and flat slope (LCL)
- soil type C and steep slope (UCL)

WWHM uses these input definitions to estimate the volume of annual precipitation, surface runoff, and interflow (pervious areas only). The surface runoff and interflow (when applicable) were divided by the annual precipitation to calculate the runoff coefficients for the four groups of surface types. The LCL and UCL for each surface type group are listed in Table 3-5.

Table 3-5. WWHM Surface Type Runoff Coefficients

Surface type	LCL	UCL
Pervious Landscape	0.0	0.40
Pervious Trees/Scrub	0.0	0.18
Impervious Land Cover[a]	0.82	0.87

a. The WWHM Roof category produced the same runoff volumes as the Driveways, Sidewalk, and Parking category; therefore, they are reported simply as impervious.

3.4 Land Use Runoff Concentrations

Land use runoff concentrations representative of each RCOC were developed to estimate Pre-Project loadings. The process of developing land use runoff concentrations included compiling stormwater runoff data from multiple sources (Table 3-6), developing criteria for selecting appropriate data sets, and developing an approach for interpreting the data. This process and the final land use runoff concentrations used in the PLM are described below.

3.4.1 EMC Data Compilation

Stormwater runoff data from multiple data sources were evaluated to estimate the land use runoff concentrations upper and lower bounds using identified EMC values for each RCOC (Table 3-6). Prior to the analysis, the stormwater data were compiled into a single database. Attributes in the compiled database include data source, land use, date, parameter, units, data qualifier (e.g., non-detected values), and value (both censored/non-detect and uncensored).

Stormwater data were excluded from the compiled database if the assigned land uses were inconsistent with the modeled land use categories (e.g., residential, commercial, industrial, open space, and vacant). Exceptions were made for PCB and PBDE, in which cases land use was not a consideration of the PLM for the following reasons:

- PBDE data were limited to King County and Spokane, Washington. Land use information was not available from these data sources.
- PCB data were limited to King County, Washington; Portland, Oregon; the City of Seattle, Washington; and data from Ecology. Land use information was not available from King County or Ecology.
- The amount of PBDE and PCB data were limited. Pooling the data into a single land use category made for a more robust data set (a special exception is described below).

Total PBDEs and PCBs concentrations were calculated by summing the detected congeners and Aroclor sample results. Where all congeners and Aroclors are non-detect, an uncensored value equal to the minimum detection limit was assigned. This approach helps to avoid overestimates of PCB and PBDE loads that could occur by summing half of the detection limit for each of the respective congeners/Aroclors. It also helps to avoid a case where a sample with all non-detects could be considered to be higher than a sample with one detection. However, by taking the full detection limit of the lowest congener/Aroclor, this approach also recognizes that the sum of many congeners/Aroclors that are each below detection could still sum to more than half of the lowest detection limit of any one congener. The [H+] (hydrogen concentration for calculating pH) was calculated using pH sample results using the following equation: 10^(-1*pH)*(1.0079)*(1,000).

Prior to calculating descriptive statistics, the raw data were uncensored using the robust ROS method described in Section 2.2.2. If there were three or fewer detect values or if a sample set exceeded 80 percent non-detect, a simple substitution of half the reporting limit was used.

Table 3-6. EMC Data Sources

Agency	Data set description	Available RCOCs	Reference
City of Seattle	Stormwater samples collected between February 2009 and July 2012 from three locations	[H+], ammonia-N, bis(2-ethylhexyl)phthalate, BOD_5, D-Cu, T-Cu, dichlobenil, fecal coliform, PCB, TP, TSS, D-Zn, T-Zn	City's stormwater characterization monitoring conducted for NPDES permit (SPU, 2013c)
City of Tacoma	Samples collected between November 2001 and June 2012 from six stations in the Thea Foss and Wheeler-Osgood Waterways	[H+], BOD_5, D-Cu, T-Cu, dichlobenil, fecal coliform, TP, TSS, D-Zn, T-Zn	The Thea Foss and Wheeler-Osgood Waterways Annual Source Control and Water Year Stormwater Monitoring Report (Tacoma, 2013)
King Co.	Stormwater samples collected from seven locations in the Lake Washington watershed between November 2011 and April 2012	PCB, PBDE	2013 study for PCB/PBDE Loading Estimates for the Greater Lake Washington Watershed (King County, 2013)

Table 3-6. EMC Data Sources

Agency	Data set description	Available RCOCs	Reference
ACWA	Samples collected between May 1991 and May 1996 from 23 stations throughout Oregon	[H+], ammonia-N, BOD_5, D-Cu, T-Cu, fecal coliform, oil and grease, TP, TSS, D-Zn, T-Zn	Oregon Association of Clean Water Agencies (ACWA): ACWA stormwater database (ACWA, 2013)
NSQD	Samples collected between March 1980 and November 2008 from 347 stations across the country	[H+], ammonia-N, BOD_5, D-Cu, T-Cu, fecal coliform, oil and grease, TP, TSS, D-Zn, T-Zn	National Stormwater Quality Database: Version 3 (NSQD, 2013)
City of Spokane	Stormwater samples collected between May and June 2007 from 10 stations in the Spokane River basin	PBDE, dioxins/furans	2009 Washington Department of Ecology study: PBDE and Dioxin/Furans in Spokane Stormwater (Ecology, 2009)
City of Portland	Stormwater samples collected between May 1993 and April 2008 from 241 stations around the city	[H+], bis(2-ethylhexyl)phthalate, D-Cu, T-Cu, oil and grease, PCB, TP, TSS, D-Zn, T-Zn	Portland stormwater sample database (Portland, 2013)
Ecology	Stormwater samples collected between January 2011 and May 2011 from nine stations	PCB	Washington Department of Ecology's Lower Duwamish database (Ecology, 2013)

3.4.2 Land Use Runoff Concentration Upper/Lower Bounds Selection

This section provides a summary of the goals and approach used for developing land use runoff concentration upper and lower bounds for input into the PLM.

3.4.2.1 Goals

The compiled stormwater runoff data were evaluated to define a reasonable range of land use runoff concentrations LCL and UCL for input into the PLM. To that end, the data set was assessed to:

- include data that account for various development conditions, age, and types, with potential for pollutant sources and magnitudes to vary from site to site
- define statistics that are valid for pollutant load modeling (i.e., means) rather than frequency analysis (i.e., medians)
- reasonably represent the anticipated quality of stormwater runoff in the Integrated Plan project drainage areas recognizing the uncertainty associated with using data from other similar areas, particularly when the available data are associated with a limited number of or only one sampling station
- attempt to preserve expected relative trends in pollutant concentrations between land uses, where supported by data
- attempt to reduce potential for unreasonably high upper ends of runoff concentration ranges, which could result in a high bias estimate of pollutant load reduction

3.4.2.2 Approach

The approach in the land use runoff concentration selection process consisted of (1) defining the mean, LCL, and UCL for each RCOC by data source and land use, and (2) selecting a lower and upper bound for each RCOC by land use from the summary statistics. As the default approach, the bounding range of land use concentration was defined to the lowest LCL and highest UCL on long-term average from all the data sets. Various additional restrictions and considerations are discussed below.

Filter Data Sets with Known Potential for High Bias. Data from Portland industrial and residential data sets were identified as having a potential for a high bias. The Portland industrial data are primarily from heavy industrial sites, which may over-predict loads from the industrial areas located in stormwater project drainage areas, which could be characterized more as light industrial rather than heavy industrial. The Portland residential data are also prone to broader CIs because of the small sample size. Finally, one residential site in the ACWA database (Portland-R-1) was anomalous and had been identified as an outlier in the original analyses of these data by Woodward-Clyde (1997); therefore, this site was removed.

Consider City Industrial Monitoring Station Data on a Case-by-Case Basis. The City industrial monitoring site would likely result in a low bias in industrial load estimates based on the actual distribution of land use. Land use in this area is only 37 percent industrial with the rest comprising 32 percent residential, 13 percent commercial, and 18 percent open space uses. The City industrial monitoring site data were used only where needed to provide a “second opinion” to increase the upper end of the bounded range.

Give Preference to Pacific Northwest Data Sets Where Reasonable. Data from the Pacific Northwest data sets (e.g., Seattle, Tacoma, ACWA) are likely more representative of stormwater runoff in the Seattle area than from a national data set (e.g., NSQD). Therefore, by default, the long-term average range was developed by the lowest LCL and highest UCL from the Seattle, Tacoma, and ACWA data sets. Where Pacific Northwest data are higher than NSQD, the upper bound was adjusted to the NSQD UCL. The result of this approach is that the highest study is not used where estimates are available from all four sources (Seattle, Tacoma, ACWA, NSQD).

Where the Mean of the Second-highest Study is Higher than UCL95 of Other Studies, Set the Upper Range to the Mean of the Second-highest Study. The intent of this guideline is to truncate the actual range to reduce the potential for high bias in loading estimates.

Apply Concentrations from a Comparable Land Use if Data Are Absent for a Particular Land Use. Data sets were not available for the vacant land use category. Additionally, dichlobenil data were not available from the open space land use category. In these instances, the land use runoff concentrations were set equal to the residential land use category based on an evaluation of surface types. The surface type evaluation showed that “Pervious Landscape” and “Trees/Scrub” predominantly characterize open space (88 percent), vacant (65 percent), and residential (54 percent) land uses in the stormwater project drainage areas. This is in contrast to commercial and industrial land uses (61 percent and 75 percent, respectively), which are predominantly characterized by the surface types “Driveway/Parking Lot,” “Street,” and “Building.” Any potential bias introduced by equating vacant and open space with residential land use will have minimal impacts on the final results as open space and vacant land use categories represent a small fraction (5 percent and 4 percent, respectively) of the stormwater drainage areas.

Apply Special Considerations for Defining PCB Concentration for Projects in the Duwamish Watershed. Stormwater PCB runoff concentrations are likely higher in the Duwamish watershed than elsewhere in the Seattle area as this watershed contains several known sources of PCBs. Therefore, the PCB data from Ecology's Lower Duwamish database (Ecology, 2011) were used exclusively for defining PCB concentrations in the Duwamish watershed. For the remaining drainage areas, the standard approach described in this section was used to estimate concentrations.

3.4.2.3 Final Selections

Using the goals and approach described above, an upper and lower bound was selected for each land use concentration from summary statistics presented in Attachment F-1. The CIs and selected ranges for each RCOC/land use combination are graphically depicted in Attachment F-2. Final land use runoff concentration characteristic values are summarized below in Table 3-7.

Table 3-7. Land Use Runoff Concentrations: Selected Upper and Lower Bounds
(Assumed 95% Confidence Levels on Long-Term Averages)

RCOC	Units	Residential		Commercial		Industrial		Open space		Vacant	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
BOD_5	mg/L	2.88	11.53	3.39	17.56	2.30	16.82	1.39	3.51	2.88	11.53
Fecal coliform	CFU/100 mL	1,184	30,106	4,068	32,323	2,965	66,589	658	24,406	1,184	30,106
TSS	mg/L	44.51	93.12	58.33	106.28	58.24	176.89	6.86	105.70	44.51	93.12
Oil and grease	mg/L	2.27	5.89	2.87	9.50	2.84	10.07	0.49	2.79	2.27	5.89
[H+]	mg/L	8.97E-05	3.32E-04	6.32E-05	4.62E-04	7.75E-05	1.33E-03	2.65E-05	1.65E-04	8.97E-05	3.32E-04
Total copper	µg/L	9.0	19	21	44	14	39	1.0	16	9.0	19
Dissolved copper	µg/L	3.0	7.0	7.0	16	3.0	10	1.0	5.0	3.0	7.0
Total zinc	µg/L	47	129	124	204	133	258	9.0	45	47	129
Dissolved zinc	µg/L	13	40	44	124	133	258	2.0	25	13	40
Ammonia-N	µg/L	83	151	127	311	184	297	123	229	83	151
TP	µg/L	97	343	93	330	114	383	28	202	97	343
Total PCBs	ng/L	4.226	28.982	4.226	28.982	4.226[a]	28.982[a]	4.226	28.982	4.226	28.982
Total PBDEs	ng/L	1.958	52.218	1.958	52.218	1.958	52.218	1.958	52.218	1.958	52.218
Bis(2-ethylhexyl)phthalate	µg/L	1.154	3.152	3.201	6.644	2.445	3.491	0.632	3.435	1.154	3.152
Dichlobenil	µg/L	0.0532	0.1123	0.0250	0.0581	0.0236	0.0390	0.0000	0.0000	0.0532	0.1123

a. The total PCB concentrations for the industrial areas draining to the Duwamish used higher LCL and UCL (25.63 and 97.56) as described above.

3.5 Project Performance

The candidate stormwater projects identified by the City encompass seven types of projects:

1. Active treatment (chitosan-enhanced sand filter [CESF])
2. Biofiltration swale
3. Bioretention with infiltration
4. Cartridge media filter
5. Media filter
6. Street sweeping
7. Swirl concentrator

The project performance of each project and RCOC were modeled for the purpose of estimating Post-Project loadings. The project performance was modeled as a function of three factors: (1) the capture efficiency, discussed in Section 3.5.1; (2) the volume reduction, discussed in Section 3.5.2; and (3) the pollutant removal, discussed in Section 3.5.3.

3.5.1 Project Capture Efficiency

The percent of the annual runoff volume a stormwater project will be capable of treating/managing is referred to as capture efficiency. Projects are typically designed in such a way that the flow exceeding the capture efficiency volume or flow rate will be routed around the project and will receive no treatment or in some cases where on-line and overflow occurs, minimal treatment (assumed to be zero in this modeling effort).

The City selected the preliminary design criteria for most of the candidate stormwater projects to achieve a capture efficiency of 91 percent[6]. However, due to size and cost limitations or the availability of land for construction, several of the candidate stormwater projects have preliminary designs with lower capture efficiencies (Table 3-8). No uncertainty is associated with the capture efficiency of the stormwater projects, because the projects will be further designed and built to satisfy the assumed capture efficiency criteria, with appropriate margins of safety, as needed. For example, the NDS Partnering Project is expected to have 80% of the stormwater entering the facilities captured and 20% is expected to be bypassed.

Table 3-8. Project Capture Efficiency

Alternative name	Capture efficiency
Longfellow Cascades	80%
NDS Partnering	80%
Piper's Cascades	80%
South Park WQ Facility	83%
Webster Pond/Pretreatment: Swirl Concentrator	86%

[6] The Stormwater Management Manual for Western Washington (SMMWW) lists the target capture efficiency for most new and re-development BMP as 91 percent of the total runoff estimated using an approved continuous model. The City's stormwater projects are retrofit projects and therefore are not subject to new and re-development based capture efficiency targets. However, the City will strive to maximize the efficiency of individual projects, considering size and cost considerations.

Table 3-8. Project Capture Efficiency

Alternative name	Capture efficiency
All other stormwater projects, except sweeping programs	91%[a]

a. This design criteria level was provided by the City.

3.5.2 Project Volume Reduction

In addition to treating the stormwater through physical and biological processes, some stormwater projects (e.g., biofiltration and bioretention systems) may infiltrate and/or evapotranspirate the flow when site conditions are favorable (e.g., high infiltration rates, low groundwater table). In these facilities the volume of water that is infiltrated is considered removed and the associated pollutant load is reduced to zero. The volume reduction refers to the percent of the captured flow the project is estimated to lose via infiltration and/or evapotranspiration. For the other types of projects considered (e.g., media filtration, swirl concentrators, and active treatment), it is assumed that there will be no reduction in stormwater volume.

Preliminary planning of the GSI bioretention projects assumes the site-specific conditions will allow 50 percent of the captured volume to be infiltrated into native soils while the remaining 50 percent will be discharged after treatment to the receiving waters via an underdrain. Bioretention projects with underdrains have pollutant load reductions based on the pollutant removal performance discussed in Section 3.5.3. No uncertainty is associated with the volume reduction of the GSI bioretention projects, because the projects will be sited, designed, and built at later phases to ensure that they achieve at least 50 percent volume reduction, with appropriate margins of safety, as needed.

For the South Myrtle St. Shoulder Stabilization project, a range of volume reductions was developed to account for uncertainty arising from a lack of site-specific design conditions (e.g., infiltration rate) and variability in biofiltration performance. An analysis of 13 studies of biofiltration swales in the International Stormwater BMP Database with paired inflow and outflow volumes resulted in volume reductions ranging from 35 to 65 percent (Geosyntec Consultants and Wright Water Engineers, Inc., 2011). This reported range is intended to be useful at a planning level, recognizing that it represents performance that could be expected over a range of conditions and design standards. However, to add an additional level of conservativeness, half the range of reported volume reductions was used in the PLM. The estimated LCL and UCL for the project volume reductions for all projects are included in Table 3-9.

Table 3-9. Stormwater Project Volume Reduction

Candidate stormwater project	Volume reduction
Longfellow Cascades	50%[a]
NDS Partnering	50%[a]
Piper's Cascades	50%[a]
South Myrtle St. Shoulder Stabilization	LCL: 18% UCL: 32%
All other projects, except sweeping programs	0%

a. The City set the minimum design criteria; therefore, this volume reduction is considered conservative and no uncertainty is necessary.

3.5.3 Project Pollutant Removal

The pollutant removals for the stormwater projects (excluding street sweeping) were estimated based on available data, using: (1) an effluent quality-based approach, derived from the International Stormwater BMP Database, (2) correlating pollutant removal to TSS reduction based on pollutant characteristics, or (3) other methods based on available data and best professional judgment. Each of these approaches is described below.

3.5.3.1 International Stormwater BMP Database

Project effluent quality, like land use EMCs, is highly variable. To account for this variability, effluent quality data from the International Stormwater BMP Database were analyzed and the 95 percent CIs about the mean effluent concentrations (representing the LCLs and UCLs) were calculated. Similar to the estimation of land use EMCs, the final project effluent values used were determined using a combination of ROS and the bootstrap method. A log-normal distribution was assumed for the project effluent concentrations analysis. Table 3-10 includes the LCL and UCL for each RCOC and candidate stormwater project combinations in the International Stormwater BMP Database meeting all of the criteria for analysis.

The International Stormwater BMP Database is a comprehensive source of project performance information. It consists of carefully examined data from a peer-reviewed collection of studies that have monitored the effectiveness of a variety of projects in treating water quality pollutants for a variety of land use types. Research on characterizing project performance suggests that effluent quality rather than percent removal is more reliable in modeling stormwater treatment (Strecker et al., 2001).

The stochastic modeling approach of the PLM helps account for the uncertainty of not knowing the relationship between influent and effluent concentrations because the confidence limits of the average project effluent concentrations are based on a variety of project studies with a wide range of influent concentrations, representing a variety of drainage area land use characteristics. The Monte Carlo model accounts for pollutant reductions only if the predicted influent is greater than the achievable effluent quality estimated for the modeled project (i.e., effluent equals influent [or land use-based] concentrations up until the influent concentration exceeds the effluent concentration). Therefore, influent (or land use runoff-based) concentrations are considered by the model because they are directly used to determine whether treatment occurs.

The steps below were followed to ensure that the appropriate data from the International Stormwater BMP Database were selected in estimating the LCL and UCL of the effluent concentrations for each RCOC and candidate stormwater project combination:

1. Matching candidate stormwater projects to similar categories of stormwater projects in the International Stormwater BMP Database
2. Retrieving appropriate effluent concentrations to characterize each RCOC and candidate stormwater project combination
3. Calculating whether the influent and effluent concentrations are statistically significantly different

Select Analogous International Stormwater BMP Database Categories. Each project category in the International Stormwater BMP Database was carefully reviewed to select an equivalent or comparable project to each of the candidate stormwater projects. The International Stormwater BMP Database subcategory of Cartridge Media Filter was selected to represent candidate stormwater projects using media filters and cartridge media filters. No single stormwater project in the International Stormwater BMP Database was analogous to the Active

Treatment process planned for the South Park WQ Facility project. Project performance for this project was analyzed separately and the assumptions used are included in Section 3.5.3.3.

Criteria for Effluent Concentrations to Be Included in the Analysis. Only RCOC and candidate stormwater project combinations in the International Stormwater BMP Database with at least three separate studies, each of which had at least three effluent concentrations, were included for further analysis. The International Stormwater BMP Database did not have sufficient studies meeting these criteria for:

- Any candidate stormwater project treating bis(2-ethylhexyl)phthalate, dichlobenil, total PCBs, or total PBDEs. The project reduction performance for these combinations was determined using local monitoring studies and TSS correlation as described in Section 3.5.3.2.
- The effluent concentrations of BOD and fecal coliform from media filter projects. To be conservative, the analysis of the International Stormwater BMP Database for these RCOCs was performed based on sand filter projects.
- The effluent concentration of oil and grease from swirl concentrator projects. Oil and grease effluent concentrations were determined from the oil and grease subcategory of manufactured devices.
- The effluent concentration of BOD from bioretention projects. BOD concentrations were analyzed using sand filter project results.
- The effluent concentrations of fecal coliform from bioretention projects. To be conservative, the LCL was analyzed as the E. coli effluent concentrations from bioretention, with a 1.59 multiplier to convert to fecal coliform. The 1.59 multiplier is based on the EPA REC-1 Criterion of 200 most probable number (MPN) per 100 milliliters (mL) for fecal coliform versus 126 MPN/100 mL for E. coli. This is believed to provide a conservatively high estimate of fecal coliform, as studies have found that ratios are typically lower than 1.59 (Rasmussen, 2003). The UCL was analyzed using the fecal coliform effluent concentrations from sand filter projects.

Check if Influent/Effluent Concentrations Are Statistically Significantly Different. The Mann-Whitney rank-sum test, which is based on the alternative hypothesis that the influent and effluent medians differ, compared each RCOC and candidate stormwater project combination that fulfilled the analysis criteria. This non-parametric test applies to two independent data sets. A p-value less than 0.05 indicates that the influent and effluent median concentrations are statistically significantly different at the 95 percent confidence level. The RCOC and candidate stormwater project combinations that were not statistically significantly different are identified in Table 3-10. Additionally, the following combinations had concerns that led to the use of an alternative analysis of the International Stormwater BMP Database:

- Bioretention studies for dissolved copper contain 66 pairs of influent and effluent concentrations from three studies, but do not show significant removal. However, sand filter studies contain 134 pairs of influent and effluent concentrations from 10 studies and do show a significant removal. It is anticipated that the candidate bioretention projects will be as good as or better than sand filter projects with appropriate media selection. Therefore, the dissolved copper effluent concentrations from sand filter projects were substituted in place of bioretention projects.
- Statistical significance of oil and grease in the Bioretention category is limited by a high number of non-detect samples in both the influent and effluent. Therefore, the oil and grease effluent concentrations from sand filter projects were substituted in place of bioretention projects. It is anticipated that candidate bioretention projects will be as good as or better than sand filter projects with appropriate media selection.

Table 3-10. International Stormwater BMP Database 95 Percent Confidence Intervals about the Mean Effluent Concentrations for Modeling

RCOC	Units	Media filter		Swirl concentrator		Bioretention		Biofiltration swale	
		LCL	UCL	LCL	UCL	LCL	UCL	LCL	UCL
BOD	mg/L	3.83	5.86	NSD	NSD	3.83	5.86	3.68	5.58
Fecal coliform	CFU/100 mL	4,783	9,131	NSD	NSD	937	9,131	NSD	NSD
TSS	mg/L	20.37	27.07	69.08	102.30	17.35	33.06	23.08	30.37
Oil and grease	mg/L	4.71	7.88	2.03	3.54	2.51	3.29	3.50	7.27
[H+]	mg/L	1.02E-04	2.03E-04	NSD	NSD	2.06E-04	8.05E-04	1.76E-04	5.22E-04
Total copper	mg/L	0.010	0.022	0.013	0.018	0.011	0.020	0.0089	0.011
Dissolved copper	mg/L	0.0048	0.010	NSD	NSD	0.0047	0.0065	0.0079	0.011
Total zinc	mg/L	0.058	0.084	0.076	0.123	0.023	0.038	0.031	0.038
Dissolved zinc	mg/L	0.028	0.041	NSD	NSD	0.022	0.034	0.026	0.039
Ammonia-N	mg/L	NSD	NSD	0.482	0.971	0.297	0.588	NSD	NSD
TP	mg/L	0.099	0.166	0.241	0.399	NSD[a]	NSD[a]	0.25	0.31

NSD: Analysis demonstrated that project pollutant effluent concentration was not statistically significantly different from the influent concentration.

a. Soil amendments will be considered and evaluated to ensure that phosphorus is not increased as a result of the bioretention projects.

Washington Department of Ecology, Technology Assessment Protocol – Ecology (TAPE) Certification. Swirl concentrators, Filterra® tree box units and StormFilter® cartridge filtration units have been approved by Ecology for general use. To be accepted, these devices have undergone extensive lab and field testing under the state's TAPE protocols. All of these systems, except swirl concentrators, are approved for basic stormwater treatment. Swirl concentrators are approved for use only as pretreatment devices. The TSS reductions reported in the International Stormwater BMP Database and the TAPE certification goals are shown in Table 3-11. The pretreatment designation for swirl concentrators establishes TSS removal goals significantly higher than the reductions reported from the International Stormwater BMP Database. Utilizing the regionally specific TAPE monitoring results, while still being conservative, a reduction in TSS was applied to the swirl concentrators in place of the International Stormwater BMP Database effluent concentrations.

Table 3-11. Comparison of TSS Effluent Concentrations (or Percent Reductions) Reported in the International Stormwater BMP Database versus TAPE Certification Goals (Ecology, 2013b) and Assumptions Used in the PLM

Integrated Plan project	Ecology TAPE (2013)		International Stormwater BMP Database		Assumptions used in PLM	
	LCL	UCL	LCL	UCL	LCL	UCL
Swirl concentrators[a]	50%	80%	0%	44%	30%	50%
Media filter (Filterra® tree box units)[b]	20 mg/L		20 mg/L	27 mg/L	20 mg/L	27 mg/L
Media filter (StormFilter® vault)[b]	20 mg/L		20 mg/L	27 mg/L	20 mg/L	27 mg/L

a. Ecology TAPE Pretreatment LCL and UCL are intended to achieve 50% removal of fine (50-micron mean size) (LCL) and 80% removal of coarse (125-micron mean size) TSS.

b. Ecology TAPE Basic treatment is intended to achieve an effluent goal of 20 mg/L based on influent TSS concentrations less than 100 mg/L, which would likely occur in stormwater runoff from the proposed Integrated Plan project sites.

Bioretention. The expected performance of bioretention projects was reinforced by comparing values from the International Stormwater BMP Database with those reported in Roseen and Stone (2013). Roseen and Stone (2013) present summary statistics on effluent concentrations from constructed bioretention systems based on a literature review of multiple sources including the International Stormwater BMP Database, the City of Seattle bioretention projects (NW 110th Cascade), and many other sources (of projects). Roseen and Stone (2013) reported CIs about the study median concentrations (Table 3-12). These CIs could not be used directly in the PLM, which is based on CIs about the population mean (Table 3-10). It is important to note that the effluent LCL and UCL concentrations listed in Table 3-10 are means based on all data within a category, while the Roseen and Stone (2013) and International Stormwater BMP Database effluent LCL and UCL concentrations listed in Table 3-12 are medians (of summaries of individual studies). However, a comparison of equivalent statistics (including effluent concentration medians and the CIs about the medians) from the International Stormwater BMP Database and Roseen and Stone (2013) suggest that the two data sources have comparable effluent concentrations (Table 3-12). Therefore, the limitations of using the smaller data set from the International Stormwater BMP Database were considered to be offset by the ability to extract statistics from the International Stormwater BMP Database that were more suitable for pollutant load modeling purposes (i.e., averages rather than medians).

Table 3-12. Comparison of Bioretention Median Effluent Concentrations Reported in the International Stormwater BMP Database versus Roseen and Stone (2013)

Parameter	Units	Roseen and Stone (2013)				International Stormwater BMP Database			
		# of data points (studies)	Median	LCL	UCL	# of data points (samples)	Median	LCL	UCL
Fecal coliform	CFU/ 100 mL	7	290	1[a]	5,000[a]	N/A	N/A	N/A	N/A
TSS	mg/L	31	8	6	14	193	8.3	5.6	9.0
Oil and grease	mg/L	8	0.28	0.163	2.5	N/A	N/A	N/A	N/A
Total Cu	mg/L	19	0.006	0.005	0.016	56	0.0077	0.0049	0.0099
Dissolved Cu[b]	mg/L	6	0.011	0.0029[a]	0.020[a]	186	0.0044	0.0036	0.0051
Total Zn	mg/L	23	0.018	0.013	0.035	99	0.018	0.0077	0.025
Dissolved Zn[b]	mg/L	5	0.025	0.019[a]	0.026[a]	185	0.012	0.0083	0.017
Ammonia-N	mg/L	19	0.04	0.03	0.055	184	0.067	0.052	0.08
TP	mg/L	41	0.1	0.06	0.14	249	0.089[c]	0.073[c]	0.1[c]

N/A: The International Stormwater Database did not have sufficient studies for this RCOC/candidate stormwater project combination as discussed earlier in this section. The mean values were approximated based on representative RCOC/ stormwater project combinations; therefore, median concentrations are not available at this time.

a. *Sample size less than 8. Minimum and maximum values reported in lieu of LCL and UCL, respectively.*

b. *The median, LCL, and UCL for dissolved copper and zinc were calculated (for comparison only) based on sample results for the Media Filter category in the International Stormwater BMP Database. The Media Filter category is largely dominated by the Sand Filter category, which was the category used to approximate the LCL and UCL of the mean concentrations for these RCOCs in the Bioretention category, as discussed previously.*

c. *The Mann-Whitney rank-sum test (discussed above) revealed that effluent concentrations of TP are not significantly different from influent concentrations; removal of TP by bioretention was not simulated.*

3.5.3.2 TSS Correlated Pollutant Reductions

The International Stormwater BMP Database did not have sufficient data to accurately characterize the effluent concentrations of bis(2-ethylhexyl)phthalate, dichlobenil, total PCBs, or total PBDEs. Therefore, a secondary approach was used to estimate the removal based on TSS removals by taking into account the physiochemical properties of these RCOCs. Each RCOC was examined to estimate the percent dissolved in the stormwater (dissolved fraction) and the percent associated with the suspended solids (particulate fraction). Because bis(2-ethylhexyl)phthalate, total PCBs, and total PBDEs are highly hydrophobic chemicals (i.e., repelled by water and tend to bond to solids), the dissolved fraction is assumed to be negligible and therefore these RCOCs are assumed to be associated only with the particulate fraction. The dissolved /particulate fractionation for dichlobenil is highly uncertain. Therefore, to be conservative, it was assumed that dichlobenil would not be effectively removed by any of the proposed treatment devices; e.g., zero removal (but may still be removed via volume reduction).

An attempt was made to correlate the removal of the particulate fraction for bis(2-ethylhexyl)phthalate, total PCBs, and total PBDEs based on the stormwater project removal of each suspended solid particle size and the RCOC particle size relationship (i.e., the mass of the RCOC associated with each particle size removed by the project). However, an investigation of data and literature revealed no evidence upon which to assume particle size relationship in stormwater for these RCOCs. Therefore, the removal of these RCOCs was set equal to the removal of TSS. Table 3-13 shows potential TSS removal for the various projects with a representative influent concentration.

Table 3-13. Stormwater Project TSS Removal Efficiency (Concentration Reduction) for Representative Influent Concentration Scenarios

Project type	LCL	UCL
Media filter[a]	49%	78%
Swirl concentrator	30%	50%
Bioretention[a,b]	36%	81%
Biofiltration swale[a,b]	41%	75%
Active treatment (South Park WQ Facility project)	88%	98%

a. *This removal efficiency is for example only. These removal efficiencies are dependent on the influent stormwater concentration and the effluent concentration reported in the International Stormwater BMP Database. Because the influent concentration varies with land use, the removal efficiencies will fluctuate based on various project land use influent scenarios; however, the relative magnitudes between projects is expected to be similar. The LCL and UCL reported here are the minimum LCL and maximum UCL of TSS reduction based on 1,000 Monte Carlo iterations of a representative land use scenario.*

b. *Excluding TSS load reduction resulting from the volume reduction.*

Several regional monitoring data sets were available to compare TSS removals with bis(2-ethylhexyl)phthalate and total PCBs (Table 3-14). The South Park electrocoagulation pilot test (SPU, 2012a) and data reported in the literature that were compiled for the South Park business case (SPU, 2012b) demonstrated similar removal rates between TSS and PCBs. However, the TSS removal rates were approximately two to four times higher than the measured removal rates for bis(2-ethylhexyl)phthalate from the City's South Park electrocoagulation pilot test and StormFilter® field tests conducted by the City of Tacoma and Seattle (City of Tacoma and Taylor Associates, 2008). Therefore, to be conservative, the candidate stormwater project TSS removal rates were reduced by two (UCL) to four (LCL) times before being applied to bis(2-ethylhexyl)phthalate concentrations.

Table 3-14. Monitoring Data TSS, Bis(2-ethylhexyl)phthalate, and Total PCBs Removal

Monitoring data set	TSS	Bis(2-ethylhexyl)phthalate	Total PCBs
South Park electrocoagulation pilot test[a]	47%–94%	9%–44%	78%–86%
South Park business case[b]	79%–97%	N/A	87%
StormFilter®[c]	27%–91%	13%–36%	N/A

a. SPU (2012a). Performance testing conducted during seven storm events on stormwater from the South Park drainage basin that was passed through a 6-cell treatment unit.

b. SPU (2012b). Results from multiple field and bench tests on urban and industrial stormwater, as well as municipal wastewater conducted by various vendors, were compiled to evaluate the performance of a variety of active treatment systems, including electrocoagulation, chitosan-enhanced sand filtration, ballasted sedimentation, and chemically enhanced primary treatment.

c. City of Tacoma and Taylor Associates (2008). Field tests were conducted between 2003 and 2005 on an 11-cartridge StormFilter® vault installed at the Washington State Department of Transportation's BMP testing facility in Seattle. Testing was conducted during 17 storm events on runoff from I-5 and adjacent areas.

3.5.3.3 Active Treatment System

The pollutant removal for the South Park WQ Facility active treatment system was estimated using a combination of the following approaches: (1) removal estimates from the full-scale monitoring at North Boeing Field (NBF) CESF (North Boeing Field, 2013)[7], (2) effluent concentrations for a comparable stormwater project category in the International Stormwater BMP Database that includes similar unit processes, or (3) correlating pollutant removal to TSS reduction based on pollutant characteristics. Table 3-15 discusses the assumed range of effluent quality or removal efficiency and the source of the assumption.

Table 3-15. Active Treatment Assumptions

RCOC	Effluent concentration / percent removal estimates[a]		Assumption source
	LCL	UCL	
BOD_5 (mg/L)	3.83	5.86	No data from full-scale monitoring, use effluent based on Sand Filter category from International Stormwater BMP Database.
Fecal coliform (CFU/100 mL)	4,783	9,131	Data not available from NBF CESF; assumed that disinfection will not be provided. Assumed effluent quality based on International Stormwater BMP Database analysis based on Sand Filter category.

[7] Six paired influent/effluent sampling results from December 2011 to July 2013 at the long-term stormwater treatment systems installed at the North Boeing Field facility in Seattle. Treatment was installed to reduce PCB loads prior to cleanup of contaminated sediment at the Slip 4 Early Action Area in the Lower Duwamish Waterway.

Table 3-15. Active Treatment Assumptions

RCOC	Effluent concentration / percent removal estimates[a]		Assumption source
	LCL	UCL	
TSS (mg/L)	1.7	6.8	Full-scale CESF at NBF showed excellent removal for all influent up to 107 mg/L. Lower bound: median effluent observed in the first year of the full-scale NBF CESF monitoring Upper bound: 2x the highest observation
Total Cu	85%	61%	10th and 90th percentile from CESF at NBF[b]
Dissolved Cu	57%	15%	10th and 90th percentile from CESF at NBF[b]
Total Zn	88%	52%	10th and 90th percentile from CESF at NBF[b]
Dissolved Zn	61%	12%	10th and 90th percentile from CESF at NBF[b]
Oil and grease (mg/L)	2.51	3.29	Based on International Stormwater BMP Database Sand Filter category
[H+] (moles/L)/pH	0%	0%	No significant change
Ammonia-N	0%	0%	No significant change
TP (mg/L)	Assumed 75% of TP is particulate bound and removed at same rate as TSS		Based on analysis of typical ratio of orthophosphate to TP concentrations measured in stormwater characterization samples collected by the City for its NPDES permit.
Total PCBs	80%	50%	Based on findings from CDM (2010) for chemically enhanced primary treatment[c]. Should be as good or better for CESF based on better removal of finer particle sizes.
Total PBDEs	80%	50%	Assume same as total PCBs based on similar K_{OW}
Bis(2-ethylhexyl)phthalate	Percent removal is 2 times less than TSS removal	Percent removal is 4 times less than TSS removal	Based on analysis of South Park electrocoagulation pilot test and the StormFilter tests (Table 3-14).
Dichlobenil	0%	0%	No removal
Projected DO	Dependent on BOD and ammonia		Based on the Streeter-Phelps equation

a. Ranges indicate 95% confidence interval except where noted.

b. Chose to use percent removal methodology because the average influent concentrations to this study appear to be lower-than-average influent concentrations expected to occur at the South Park WQ Facility. Therefore, effluent quality could over-predict removal.

c. Results from pilot test conducted by King County at West Point wastewater treatment facility. Multiple scenarios were tested using different system loading rates and chemical coagulants. Listed values are for results from tests conducted using system loading rates similar to those expected to be used in full-scale operation.

3.5.3.4 Dissolved Oxygen

In order to characterize the impact of pollutant load reductions on receiving water dissolved oxygen (DO) concentrations a simplified approach for calculating DO based on the Streeter-Phelps equation was used to estimate the change in projected DO concentration associated with each candidate stormwater project. The Streeter-Phelps equation calculates the average daily DO deficit (i.e., difference between DO at saturation and actual DO) as follows:

$$[D]_t = D_0 e^{-k_a t} + \left(\frac{k_d L_0}{k_a - k_d}\right)(e^{-k_d t} - e^{-k_a t}) + \left(\frac{k_n N_0}{k_a - k_n}\right)(e^{-k_n t} - e^{-k_a t})$$

where: D_t = average daily DO deficit at time t downstream of a point source, mg/L

D_0 = initial DO deficit, mg/L

L_0 = initial carbonaceous BOD, mg/L

N_0 = initial nitrogenous BOD, mg/L

k_a = re-aeration rate constant (day^{-1})

k_d = CBODU deoxygenation rate constant (day^{-1})

k_n = NBOD deoxygenation rate constant (day^{-1})

t = time, days

The Streeter-Phelps equation does not implicitly account for flow. As CSO improvements are quantified by reductions in flow and not by decreases in pollutant concentrations, improvements in BOD concentrations are first normalized to account for changes in loading[8]. Using a common normalizing volume, equal to the maximum flow from all the stormwater and CSO projects (e.g., 140.457 million gallons per year [MG/yr]), allowed for a comparison between stormwater and CSO projects. Ultimate Chemical and Biological Oxygen Demand (CBODU) and Nitrogenous Biochemical Oxygen Demand (NBOD) concentrations were normalized by multiplying by the specific project volume and dividing by the normalizing volume.

Using the Street-Phelps equation, the Pre- and Post-Project maximum DO deficit was calculated based on the normalized NBOD and CBODU concentrations. These deficit values were used to calculate the reduction in normalized DO deficit between the Pre-Project condition and the Post-Project condition in milligrams per liter (mg/L).

The assumptions described below were applied to all projects equally (i.e., site-specific rates and conversion factors were not calculated for individual projects).

1. For each project, three DO projections were calculated (annual, October–January [Season 1], February–September [Season 2]).

[8] Most of the proposed CSO control projects use storage to reduce the frequency and volume of CSO events.

2. BOD_5 = $CBOD_5$. *Rationale:* The CBOD is exerted immediately, whereas the majority of NBOD reactions occur at a slower rate (Thomann and Mueller, 1987).
3. 5-day: ultimate conversion factor = 0.45. *Rationale:* The conversion factor represents the approximate average of primary and secondary treatment (Chapra, 1997).
4. NBOD = 4.57 x [ammonia concentration]. *Rationale*: The approximation is based on stoichiometry (Thomann and Mueller, 1987 and Chapra, 1997).
5. CBODU decay rate @ 20° = 0.2, corrected for temperature θ = 1.047 (EPA, 1980). *Rationale*: The decay rate represents the approximate average of primary and secondary treatment (Thomann and Mueller, 1987).
6. NBOD nitrification = 0.3 @ 20°, corrected for temperature θ = 1.08 (EPA, 1980). *Rationale*: Best professional judgment.
7. Re-aeration @ 20° = 3, corrected for temperature θ = 1.024 (EPA, 1980). *Rationale*: Best professional judgment.
8. Temperature = modeled value (if available) or estimated from existing data. *Rationale*: Best professional judgment.
9. Time = travel time through proposed project (if available from model) or estimated length of storm event. *Rationale*: Best professional judgment.

3.6 Street Sweeping

Since 2011, the City has been conducting monitoring to track the performance of its street sweeping program for water quality. The data collected through this program, including street sediment removed, curb-miles swept, and concentrations of RCOCs in street sweepings, directed the development of the model used for estimating the potential load reductions resulting from enhancements to street sweeping. Additional inputs necessary for the model include:

- precipitation volume
- runoff coefficient
- route details of street sweeping enhancements (e.g., schedule, street area, distance, percent draining to MS4)
- percent of sweeping schedule that the sweeper will be available (i.e., utilization)
- rate of street sediment accumulation
- percent of street sediment mobilized to an MS4 outfall during storm events
- factor of safety applied to load reductions (i.e., decrease residential load reductions by 50 percent and arterial load reductions by 25 percent, refer to Appendix G)

The discussion of each of these model inputs along the resulting values can be found in Appendix G of the City's Integrated Plan report. Additionally, the following sections include a discussion of how uncertainty in input data sets was developed relating to the seasonal precipitation, sample variability, and sweeper productivity.

3.6.1 Seasonal Precipitation

A description of the development of the annual precipitation used in the street sweeping model is included in Appendix G of the City's Integrated Plan report. To maintain consistency with the PLM, the seasonal precipitation used in the street sweeping model maintains the same proportions to the annual rainfall as the proportions calculated for the PLM discussed in Section 3.1. Additionally, the LCLs and UCLs for the street sweeping model precipitation were determined in the same fashion as in the PLM (i.e., plus or minus 10 percent of the average) (Table 3-16).

Table 3-16. Cumulative Precipitation Estimates Used in the Street Sweeping Model

Time period	Average (inches)	Confidence interval[a] (inches)
Annual[b]	37.2	33.5–40.9
October–January (Season 1)	20.1	18.1–22.1
February–September (Season 2)	17.1	15.3–18.8

a. Confidence interval is defined as plus or minus 10% of the average (consistent with the assumption in Section 3.1).

b. The annual average precipitation for the street sweeping model (see Appendix G of the City's Integrated Plan report) was based on a different rain gauge from the analysis for the other stormwater projects analyzed in this appendix (see Section 3.1); therefore, precipitation amounts differ.

3.6.2 Sample Variability

As with stormwater EMCs, the variability of RCOC concentrations in street sweepings is significant[9]. To account for this variability, City street sweepings RCOC concentration data were analyzed and descriptive statistics were generated using the bootstrap method, similar to what was used to generate land use runoff concentrations and program effluent concentrations (see Section 2.2.2). The descriptive statistics generated, including the mean and 95th percentile CIs on the mean (LCL and UCL), were converted into relative percent differences (i.e., mean minus LCL divided by mean), which were then used to quantify the uncertainty of the pick-up rates[10] (Table 3-17).

City street sweepings have not been analyzed for total PBDEs. Therefore, the LCL and UCL for total PBDEs was developed based on the relative percent difference of the mean stormwater concentration LCL and UCL (see Section 3.4 and Attachment F-1). The relative percent difference for the mean stormwater concentration LCL and UCL is assumed to be similar to the relative percent difference for the mean street sweepings concentration LCL and UCL.

[9] For example, the total copper sample concentrations in the analysis of sweeper sweepings <250 µm ranged from 87 to 321 mg/kg.

[10] Pickup rates represent the mass of pollutant removed per mile swept and were calculated directly within the City eSweep software program using the RCOC street sediment concentration (Appendix G).

Table 3-17. Street Sweepings Concentration Relative Percent Difference from Mean: Upper and Lower Confidence Intervals on Mean

RCOC	LCL[a]	UCL[b]
BOD_5	19%	18%
Fecal coliform	67%	143%
TSS	6%	5%
Oil and grease	9%	10%
[H+]	N/A	N/A
Total copper	9%	15%
Dissolved copper	N/A	N/A
Total zinc	9%	10%
Dissolved zinc	N/A	N/A
Ammonia-N	N/A	N/A
TP	14%	12%
Total PCBs	21%	26%
Total PBDEs[c]	38%	113%
Bis(2-ethylhexyl)phthalate	9%	8%
Dichlobenil	N/A	N/A

N/A: Analysis was not performed for the street sweeping load reductions for these RCOCs at this time due to insufficient data or uncertainty in the washoff characteristics. See Appendix G for additional details.

a. *Mean street sweepings concentration minus LCL divided by mean.*

b. *Street sweepings UCL concentration minus mean divided by mean.*

c. *The LCL and UCL for total PBDEs are actually land use concentration relative percent differences. However, it is assumed applicable.*

3.6.3 Sweeper Productivity

The actual curb-miles swept in an MS4 drainage area on an annual basis are susceptible to a wide range of factors, including but not limited to sweeper and operator availability, weather conditions, and parking compliance. Several of these variables have already had safety factors applied. However, to account for additional uncertainty, the LCL and UCL of the annual MS4 curb-miles are plus and minus 25 percent, respectively, of the mean value.

CHAPTER 4

Model Methodology

Each iteration of the PLM uses input parameters randomly selected from between the LCL and UCL values (discussed in detail in Chapter 3) to calculate a unique estimate of the potential long-term average stormwater runoff volume, pollutant concentration, and pollutant loading for the Pre- and Post-Project condition for each RCOC and each of the stormwater projects. A large number of iterations are run to develop an extensive distribution of different estimates of the potential long-term average Pre-Project and Post-Project results, which can be used to characterize the median estimated value and the uncertainty (LCL and UCL) associated with each project. The general steps of the PLM are as follows, with each step described in more detail in Sections 4.1 through 4.5:

Calculate the Pre-Project stormwater runoff volume:

1. Calculate the implemented effective drainage area for each land use type within the candidate stormwater project drainage basin based on the degree of project implementation, land use (e.g., residential, commercial, industrial), surface type (e.g., street, building, sidewalk, landscaped area), and drainage system connection factors (see Section 3.2).
2. Estimate the runoff coefficient for each land use type within the candidate stormwater project drainage basin based on land use, surface type, and surface type runoff coefficients (see Section 3.3).
3. Select the rainfall depth for the time period to be evaluated (annual, wet and dry seasons; see Section 3.1) to calculate the stormwater runoff volume from each land use type within the candidate stormwater project drainage area and then sum the volumes to calculate the Pre-Project runoff volume.

Calculate the Pre-Project pollutant loads and concentrations:

4. Select a pollutant concentration in stormwater runoff for each land use type and each RCOC (see Section 3.4) and multiply by the runoff volume to calculate the Pre-Project load from each discrete land use type in the project drainage basin and then sum the loads for each RCOC to calculate the Pre-Project RCOC loads.
5. Divide each Pre-Project RCOC load by the Pre-Project volume to calculate the Pre-Project average concentration for each RCOC.

Calculate the Post-Project stormwater runoff volume, pollutant loads, and concentrations:

6. Calculate the Post-Project runoff volume by summing the bypass volume (Pre-Project volume multiplied by 1 minus the capture efficiency [see Section 3.5.1]) and the project effluent volume (Pre-Project volume multiplied by capture efficiency and 1 minus the project volume reduction [see Section 3.5.2]).
7. Calculate the Post-Project load by summing the bypass load (bypass volume multiplied by the Pre-Project concentration) and the project effluent load (project effluent volume multiplied by the project effluent concentration [see Section 3.5.3]).
8. Divide each Post-Project RCOC load by the Post-Project volume to calculate the Post-Project average concentration for each RCOC.

<u>Calculate the stormwater runoff volume, pollutant load, and concentration reductions:</u>

9. Calculate the Post-Project average volume reduction, concentration reduction, and load reduction for each RCOC based on the difference between Pre-Project and Post-Project results.

<u>Calculate the distribution of results:</u>

10. Repeat steps 1–9 a total of 1,000 times for each RCOC and time period, recording the Pre-Project, Post-Project, and reduction model results for each iteration.

4.1 Pre-Project Stormwater Runoff Volume (Steps 1–3)

<u>Step 1:</u> Calculate the implemented effective drainage area for each land use type (EA_{lu}) within the candidate stormwater project drainage area using the following equation:

$$EA_{lu} = I \, \Sigma_{st} \, (A_{lu\ st} \, CF_{st\ cl}) \qquad (1)$$

where:

I = the degree of implementation for the candidate stormwater project, a function of potential feasibility

Σ_{st} = the sum of the effective drainage area (i.e., drainage area multiplied by the connection factor) for each surface type ($_{st}$) within a land use type

$A_{lu\ st}$ = the land use and surface type specific drainage area (e.g., acres of roads within residential land use), calculated by merging the GIS surface type and land use layers

$CF_{st\ cl}$ = the surface type and conveyance class ($_{cl}$) specific connection factor, randomly selected from within the defined LCL and UCL

<u>Step 2:</u> Estimate the runoff coefficient for each land use type ($R_{v\ lu}$) within the candidate stormwater project drainage area using the following equation:

$$R_{v\ lu} = A_{lu\ i} \, R_i + A_{lu\ pl} \, R_{pl} + A_{lu\ pt} \, R_{pt} \qquad (2)$$

where:

$A_{lu\ i}$ = the land use specific impervious drainage area (i.e., acres of roads, sidewalks, roofs, etc. within each land use type), calculated by merging the City GIS surface type and land use layers and selecting the impervious areas

R_i = the impervious runoff coefficient, randomly selected from within the defined LCL and UCL

$A_{lu\ pl}$ = the land use specific pervious landscape drainage area, calculated by merging the City GIS surface type and land use layers and selecting the pervious landscape areas

R_{pl} = the pervious landscape runoff coefficient, randomly selected from within the defined LCL and UCL

$A_{lu\ pt}$ = the land use specific pervious trees drainage area, calculated by merging the City GIS surface type and land use layers and selecting the pervious trees areas

R_{pt} = the pervious trees runoff coefficient, randomly selected from within the defined LCL and UCL

Step 3A: Estimate the stormwater runoff volume from each land use type (V_{lu}) within the candidate stormwater project drainage area (e.g., million gallons of stormwater runoff from residential land use) using the following equation:

$$V_{lu} = P_{tp}\ A_{lu}\ R_{v\ lu} \qquad (3)$$

where:

P_{tp} = the rainfall depth for the time period ($_{tp}$), randomly selected from within the defined LCL and UCL. It is assumed that rain falls uniformly over all land uses in the Integrated Plan stormwater project drainage area.

EA_{lu} = the land use specific implemented effective drainage area, calculated using equation (1)

$R_{v\ lu}$ = the land use specific runoff coefficient, calculated at the surface type level using equation (2)

Step 3B: Calculate the Pre-Project stormwater runoff volume (V_{wshed}) for the Integrated Plan stormwater project drainage area, as the sum (Σ_{lu}) of runoff volume from each land use type:

$$V_{wshed} = \Sigma_{lu}\ V_{lu} = \Sigma_{lu}\ (P_{tp}\ A_{lu}\ R_{v\ lu}) \qquad (4)$$

4.2 Pre-Project Pollutant Loads and Concentrations (Steps 4 and 5)

Step 4: Calculate the Pre-Project pollutant load (L_{wshed}) from the candidate stormwater project drainage area by:

$$L_{wshed} = \sum V_{lu} C_{lu} \qquad (5)$$

where:

C_{lu} = the runoff concentration from each individual land use area (e.g., mg/L of copper from residential land use), randomly selected from within the defined LCL and UCL

Step 5: Calculate the Pre-Project average pollutant concentration in runoff (C_{wshed}) from the Integrated Plan stormwater project drainage area, by dividing the Pre-Project load (Step 4, Eq. 5) by the Pre-Project runoff volume (Step 3B, Eq. 4):

$$C_{wshed} = L_{wshed} / V_{wshed} \tag{6}$$

4.3 Post-Project Stormwater Runoff Volume, Pollutant Loads, and Concentrations (Steps 6–8)

Step 6: Calculate the Post-Project runoff volume (V_{wshed_BMPs}) from the candidate stormwater project drainage area by:

$$V_{wshed\_BMPs} = \left[Cap_{\%} \times V_{wshed} \times (1 - VR\%)\right] + \left[(1 - Cap_{\%}) \times V_{wshed}\right] \tag{7}$$

where:

$Cap_{\%}$ = the capture efficiency of the project

VR% = the percent reduction in effluent volume achieved by the project, randomly selected from within the defined LCL and UCL

V_{wshed} and C_{wshed} were calculated per Steps 3B (Eq. 4) and 5 (Eq. 6), respectively

Step 7: Calculate the Post-Project pollutant load (L_{wshed_BMPs}) from the candidate stormwater project drainage area by:

$$L_{wshed\_BMPs} = \left[Cap_{\%} \times V_{wshed} \times C_{eff} \times (1 - VR\%)\right] + \left[(1 - Cap_{\%}) \times V_{wshed} \times C_{wshed}\right] \tag{8}$$

where:

$Cap_{\%}$ = the capture efficiency of the project

VR% = the percent reduction in effluent volume achieved by the project, randomly selected from within the defined LCL and UCL

C_{eff} = the effluent concentration from the project, randomly selected from within the defined LCL and UCL

V_{wshed} and C_{wshed} were calculated per Steps 3B (Eq. 4) and 5 (Eq. 6), respectively

Step 8: Calculate the Post-Project average pollutant concentration in stormwater runoff (C_{wshed_BMPs}) from the candidate stormwater project drainage area by dividing the Post-Project load (Step 7, Eq. 8) by the Post-Project runoff volume (Step 6, Eq. 7):

$$C_{wshed\_BMPs} = L_{wshed\_BMPs} / V_{wshed\_BMPs} \qquad (9)$$

4.4 Stormwater Runoff Volume, Pollutant Load, and Concentration Reductions (Step 9)

Step 9A: Calculate the stormwater runoff volume reduction (VR_{wshed}) for the candidate stormwater project drainage area by subtracting the Post-Project volume (Step 6, Eq. 7) from the Pre-Project volume (Step 4, Eq. 5):

$$VR_{wshed} = V_{wshed} - V_{wshed\_BMPs} \qquad (10)$$

Step 9B: Calculate the pollutant load reduction (LR_{wshed}) for the candidate stormwater project drainage area by subtracting the Post-Project load (Step7, Eq. 8) from the Pre-Project load (Step 4, Eq. 5):

$$LR_{wshed} = L_{wshed} - L_{wshed\_BMPs} \qquad (11)$$

Step 9C: Calculate the pollutant concentration reduction (CR_{wshed}) for the candidate stormwater project drainage area by subtracting the Post-Project concentration (Step 8, Eq. 9) from the Pre-Project concentration (Step 5, Eq. 6):

$$CR_{wshed} = C_{wshed} - C_{wshed\_BMPs} \qquad (12)$$

4.5 Distribution of Results (Step 10)

Steps 1–9 were repeated a total of 1,000 times for the annual time period, recording the Pre-Project, Post-Project, and reduction runoff volume; pollutant concentration; and load from each iteration. The process is repeated again for both Season 1 and Season 2. The resultant distributions can be used to present a frequency distribution for pollutant concentrations and loads using statistics calculated from the 1,000 Monte Carlo iterations (Attachment F-3). Each of the 1,000 iterations represents a different estimate of long-term average conditions, within the range of possibility based on the established CIs on input parameters. Interpretation of the frequency distribution allowed CIs on results to be developed.

4.6 Model Methodology Assumptions

The following key assumptions are made for the Monte Carlo water quality modeling methodology:

1. The stormwater projects were modeled to only remove pollutants and not act as a source.
2. The stormwater projects were modeled so that the dissolved fraction of RCOCs were always less than or equal to their respective total RCOC.

The implications of each of these assumptions to the water quality projections are discussed below.

Project Performance: the Stormwater Projects Are Not a Source of Pollutants. In instances when the randomly determined project effluent concentration exceeds the modeled influent concentration, no pollutant removal occurs and the effluent concentration is modified to equal the influent concentration. This prevents projects from acting as a source of pollutants in the water quality modeling (PLM). The commitment to regular and effective maintenance of the stormwater projects provides support for this assumption.

Project Performance: the Stormwater Dissolved Fraction Must Be Less Than Total. In instances when the randomly determined project effluent concentration for a dissolved RCOC exceeds the randomly determined project effluent concentration for a total RCOC, the effluent concentration of the dissolved RCOC is modified to equal the effluent concentration of the total RCOC. This prevents illogical loading and concentration scenarios, resulting from natural statistical variability associated with overlapping confidence limits.

4.7 Street Sweeping Model

As discussed previously, the City developed a separate PLM to characterize long-term average pollutant loading reductions and concentration reductions for the candidate street sweeping stormwater projects. This model uses a rate of pollutant removed by sweeping per curb-mile (pick-up rate) calculated from data measured during the City's current street sweeping program. The pick-up rate is then applied to the area that will receive enhancements to the street sweeping program to generate the total pollutant mass removed. The methodology and data provided by the City were then used to characterize the uncertainty inherent in the street sweeping data, as described below, and run with the Monte Carlo iterations.

The model methodology was originally developed without the capabilities of quantifying the uncertainty inherent in the street sweeping model inputs or estimating the RCOC concentrations and loads for the seasonal time periods. The original model was modified to be able to quantify the uncertainty and estimate the seasonal RCOC concentrations and loads using the following steps (see Appendix G of the City's Integrated Plan report for a detailed description of the original model):

1. Report the mean long-term annual average concentration and load reduction directly from the original model[11].
2. Calculate the LCL_{pr} and UCL_{pr} using equations 1 and 2 for the wet and dry season pick-up rates (PR_w and PR_d) from the original model. Then randomly select new wet and dry season pick-up rates from the LCL_{pr} and UCL_{pr}:

$$LCL_{pr} = PR - (PR * LCL_{\%\ diff}) \qquad (1)$$

$$UCL_{pr} = PR + (PR * UCL_{\%\ diff}) \qquad (2)$$

where:

$LCL_{\%\ diff}$ and $UCL_{\%\ diff}$ = the relative percent difference for street sediment concentrations developed in Section 3.6.2.

3. Randomly select an equivalent swept distance in the MS4 from the defined LCL and UCL developed in Section 3.6.3.
4. Calculate the average annual pollutant load reduction for each RCOC by multiplying the selected equivalent distance in the MS4 by the selected pick-up rates (same calculation as in the original model).
5. Calculate the average annual runoff volume by multiplying a randomly selected precipitation depth from the defined LCL and UCL in Table 3-16 by the original street and sidewalk area and runoff coefficient (same calculation as the original model).
6. Calculate the average annual concentration reduction by dividing the average annual load reduction by the average annual runoff volume (same calculation as the original model).
7. Estimate the RCOC load reduction (L_s) for each Integrated Plan season based on the cleaning season (e.g., wet, dry, leaf) pick-up rates and the percent of the cleaning season in the Integrated Plan season (Table 4-1) using the following equation:

$$Ls = PRw * IPs\ w + PRd * IPs\ d + PRl * IPs\ l \qquad (3)$$

where:

IPs w = percent of the wet cleaning season in the Integrated Plan season

IPs d = percent of the dry cleaning season in the Integrated Plan season

IPs l = percent of the leaf cleaning season in the Integrated Plan season

8. Calculate the average seasonal runoff volume by multiplying a randomly selected rainfall depth from the defined LCL and UCL in Table 3-16 by the original street and sidewalk area and runoff coefficient (same calculation as the original model).

[11] Skewedness in the underlying distribution of some of the RCOC input parameters and the use of the fixed mean from the original model, created LCL and UCL results that were skewed low for several of the RCOC.

Table 4-1. Street Cleaning Seasons in Integrated Plan Seasons

Street cleaning season	Percent in Integrated Plan Season 1 (Oct–Jan)	Percent in Integrated Plan Season 2 (Feb–Sept)
Wet (Jan–April)	25%	75%
Dry (May–Sept)	0%	100%
Leaf (Oct–Dec)	100%	0%

9. Calculate the seasonal concentration reduction by dividing the seasonal load reduction by the average seasonal runoff volume (same calculation as the original model).
10. Repeat steps 1–9 a total of 1,000 times for each RCOC and time period, recording the estimated pollutant concentration and load reduction for each iteration. The resultant distributions can be used to present a frequency distribution for pollutant concentrations and loads using statistics calculated from the 1,000 Monte Carlo iterations (Attachment F-3).

4.8 Model Reliability

Overall, the model is considered to be reliable for long-term planning and providing an approximate estimate of anticipated concentration and load reductions. Nonetheless, uncertainties exist that cannot be quantified and may influence the reliability of modeling results. Uncertainties in estimated performance are mitigated in part through the commitment to an adaptive operation approach, monitoring and maintenance, and the incorporation of flexibility in the design.

CHAPTER 5

Model Results

Box-and-whisker charts of the PLM results (pollutant load or concentration reductions) are included as Attachment F-3. Each chart displays the long-term average annual concentration or load reduction for each RCOC. The candidate stormwater projects are included on the x-axis with the estimated long-term average annual reduction on the y-axis, the median of long-term average annual reduction (selected from the distribution of the 1,000 Monte Carlo iterations) is indicated by a horizontal line within the box, the top and bottom of the box represents the 25th and 75th percentile reductions, respectively, and whiskers represent the minimum and maximum reductions. Due to limited data availability, the concentration and load reductions from some candidate stormwater project and RCOC combinations were not calculated at this time (discussed in Section 3.5.3) and therefore are not included on the charts.

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CHAPTER 6

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Attachment F-1: Stormwater Concentration Data Table

The number of studies, the mean runoff concentration, and the LCL and UCL (the 95th CI on the mean calculated as described in Section 2.2.2) are included below each RCOC, land use, and data source combination. A discussion of each data source is included in Section 3.4.

Table F-1-1. Stormwater Runoff Concentration Summary Statistics by Data Source and Land Use

Parameter	Units	Land use	Source	n	Mean	LCL	UCL
[H+]	mg/L	Commercial	ACWA	60	1.68E-04	***6.32E-05***[L]	4.09E-04
[H+]	mg/L	Commercial	NSQD	266	2.66E-04	1.19E-04	6.11E-04
[H+]	mg/L	Commercial	Seattle	32	1.15E-04	9.20E-05	1.43E-04
[H+]	mg/L	Commercial	Tacoma	224	3.23E-04	2.49E-04	***4.62E-04***[U]
[H+]	mg/L	Industrial	ACWA	36	4.91E-04	***7.75E-05***[L]	***1.33E-03***[U]
[H+]	mg/L	Industrial	NSQD	371	1.23E-03	1.14E-04	4.24E-03
[H+]	mg/L	Industrial	Portland	40	1.25E-03	3.02E-04	3.64E-03
[H+]	mg/L	Industrial	Seattle	34	5.93E-05	4.96E-05	7.15E-05
[H+]	mg/L	Industrial	Tacoma	274	1.92E-04	1.66E-04	2.25E-04
[H+]	mg/L	Open Space	NSQD	19	6.46E-05	***2.65E-05***[L]	1.26E-04
[H+]	mg/L	Open Space	Portland	6	1.17E-04	8.31E-05	***1.65E-04***[U]
[H+]	mg/L	Residential	ACWA	35	1.30E-04	***8.97E-05***[L]	1.79E-04
[H+]	mg/L	Residential	NSQD	579	2.06E-03	1.01E-03	3.28E-03
[H+]	mg/L	Residential	Portland	1	2.42E-04	--	--
[H+]	mg/L	Residential	Seattle	35	2.35E-04	1.84E-04	3.03E-04
[H+]	mg/L	Residential	Tacoma	113	2.68E-04	2.12E-04	***3.32E-04***[U]
Ammonia-N	mg/l	Commercial	NSQD	417	0.659	0.579	0.747
Ammonia-N	mg/l	Commercial	Seattle	24	0.192	***0.127***[L]	***0.311***[U]
Ammonia-N	mg/l	Industrial	NSQD	376	0.572	0.506	0.664
Ammonia-N	mg/l	Industrial	Seattle	24	0.233	***0.184***[L]	***0.297***[U]

Table F-1-1. Stormwater Runoff Concentration Summary Statistics by Data Source and Land Use

Parameter	Units	Land use	Source	n	Mean	LCL	UCL
Ammonia-N	mg/l	Open Space	NSQD	35	***0.229***	***0.123*** L	0.388
Ammonia-N	mg/l	Residential	NSQD	774	0.431	0.395	0.471
Ammonia-N	mg/l	Residential	Seattle	24	0.113	***0.083*** L	***0.151*** U
Bis(2-ethylhexyl) phthalate	ug/l	Commercial	Seattle	34	3.857	***3.201*** L	4.433
Bis(2-ethylhexyl) phthalate	ug/l	Commercial	Tacoma	224	5.344	4.494	***6.644*** U
Bis(2-ethylhexyl) phthalate	ug/l	Industrial	Portland	45	1.904	1.400	2.459
Bis(2-ethylhexyl) phthalate	ug/l	Industrial	Seattle	33	2.186	1.659	2.970
Bis(2-ethylhexyl) phthalate	ug/l	Industrial	Tacoma	273	2.927	***2.445*** L	***3.491*** U
Bis(2-ethylhexyl) phthalate	ug/l	Open Space	Portland	9	1.803	***0.632*** L	***3.435*** U
Bis(2-ethylhexyl) phthalate	ug/l	Residential	Portland	6	3.778	2.233	5.216
Bis(2-ethylhexyl) phthalate	ug/l	Residential	Seattle	35	1.884	***1.154*** L	2.752
Bis(2-ethylhexyl) phthalate	ug/l	Residential	Tacoma	113	2.648	2.191	***3.152*** U
BOD_5	mg/L	Commercial	ACWA	77	11.00	8.39	14.85
BOD_5	mg/L	Commercial	NSQD	790	16.00	14.79	***17.56*** U
BOD_5	mg/L	Commercial	Seattle	33	14.95	11.62	19.04
BOD_5	mg/L	Commercial	Tacoma	15	4.16	***3.39*** L	5.01
BOD_5	mg/L	Industrial	ACWA	58	23.00	15.68	31.06
BOD_5	mg/L	Industrial	NSQD	628	14.78	13.12	***16.82*** U
BOD_5	mg/L	Industrial	Seattle	33	6.91	5.45	8.86
BOD_5	mg/L	Industrial	Tacoma	13	2.88	***2.30*** L	3.78
BOD_5	mg/L	Open Space	ACWA	10	2.27	***1.39*** L	***3.51*** U
BOD_5	mg/L	Open Space	NSQD	62	5.76	4.66	7.01
BOD_5	mg/L	Residential	ACWA	58	8.83	6.72	***11.53*** U
BOD_5	mg/L	Residential	NSQD	1507	13.15	12.09	14.61

Table F-1-1. Stormwater Runoff Concentration Summary Statistics by Data Source and Land Use

Parameter	Units	Land use	Source	n	Mean	LCL	UCL
BOD_5	mg/L	Residential	Seattle	35	4.92	3.92	6.17
BOD_5	mg/L	Residential	Tacoma	16	3.58	***2.88*** *L*	4.33
Copper, dissolved	mg/L	Commercial	ACWA	60	0.009	***0.007*** *L*	0.014
Copper, dissolved	mg/L	Commercial	NSQD	48	0.008	0.006	0.010
Copper, dissolved	mg/L	Commercial	Seattle	34	0.017	0.014	0.020
Copper, dissolved	mg/L	Commercial	Tacoma	43	0.013	0.011	***0.016*** *U*
Copper, dissolved	mg/L	Industrial	ACWA	50	0.008	0.006	***0.010*** *U*
Copper, dissolved	mg/L	Industrial	NSQD	42	0.009	0.007	0.011
Copper, dissolved	mg/L	Industrial	Portland	55	0.018	0.012	0.025
Copper, dissolved	mg/L	Industrial	Seattle	33	0.006	0.005	0.007
Copper, dissolved	mg/L	Industrial	Tacoma	34	0.005	***0.003*** *L*	0.006
Copper, dissolved	mg/L	Open Space	ACWA	9	0.004	0.003	***0.005*** *U*
Copper, dissolved	mg/L	Open Space	NSQD	7	0.003	0.002	0.004
Copper, dissolved	mg/L	Open Space	Portland	4	0.002	***0.001*** *L*	0.002
Copper, dissolved	mg/L	Residential	ACWA	34	0.005	0.004	0.007
Copper, dissolved	mg/L	Residential	NSQD	101	0.009	0.006	0.015
Copper, dissolved	mg/L	Residential	Portland	4	0.006	0.004	0.007
Copper, dissolved	mg/L	Residential	Seattle	35	0.006	0.004	***0.007*** *U*
Copper, dissolved	mg/L	Residential	Tacoma	36	0.003	***0.003*** *L*	0.004
Copper, total	mg/L	Commercial	ACWA	80	0.027	***0.021*** *L*	0.036
Copper, total	mg/L	Commercial	NSQD	798	0.026	0.024	0.029
Copper, total	mg/L	Commercial	Seattle	34	0.049	0.043	0.054
Copper, total	mg/L	Commercial	Tacoma	43	0.036	0.030	***0.044*** *U*
Copper, total	mg/L	Industrial	ACWA	60	0.031	0.024	***0.039*** *U*

Table F-1-1. Stormwater Runoff Concentration Summary Statistics by Data Source and Land Use

Parameter	Units	Land use	Source	n	Mean	LCL	UCL
Copper, total	mg/L	Industrial	NSQD	637	0.032	0.027	0.038
Copper, total	mg/L	Industrial	Portland	96	0.069	0.054	0.087
Copper, total	mg/L	Industrial	Seattle	33	0.023	0.019	0.028
Copper, total	mg/L	Industrial	Tacoma	34	0.016	***0.014*** [L]	0.019
Copper, total	mg/L	Open Space	ACWA	10	0.004	0.003	0.005
Copper, total	mg/L	Open Space	NSQD	51	0.013	0.008	0.024
Copper, total	mg/L	Open Space	Portland	9	0.006	***0.001*** [L]	***0.016*** [U]
Copper, total	mg/L	Residential	ACWA	61	0.012	0.010	0.016
Copper, total	mg/L	Residential	NSQD	1772	0.023	0.021	0.025
Copper, total	mg/L	Residential	Portland	6	0.021	0.008	0.058
Copper, total	mg/L	Residential	Seattle	35	0.016	0.014	***0.019*** [U]
Copper, total	mg/L	Residential	Tacoma	36	0.011	***0.009*** [L]	0.013
Dichlobenil	ug/l	Commercial	Seattle	34	0.0369	***0.0250*** [L]	***0.0581*** [U]
Dichlobenil	ug/l	Commercial	Tacoma	54	0.1143	0.0762	0.1608
Dichlobenil	ug/l	Industrial	Seattle	33	0.0711	0.0386	0.1184
Dichlobenil	ug/l	Industrial	Tacoma	49	0.0301	***0.0236*** [L]	***0.0390*** [U]
Dichlobenil	ug/l	Residential	Seattle	35	0.0999	***0.0532*** [L]	0.1920
Dichlobenil	ug/l	Residential	Tacoma	36	0.0777	0.0536	***0.1123*** [U]
Fecal coliform	CFU/100mL	Commercial	ACWA	66	27846	5118	63325
Fecal coliform	CFU/100mL	Commercial	NSQD	312	23795	17681	***32323*** [U]
Fecal coliform	CFU/100mL	Commercial	Seattle	33	6240	***4068*** [L]	9882
Fecal coliform	CFU/100mL	Commercial	Tacoma	20	8089	4203	12984
Fecal coliform	CFU/100mL	Industrial	ACWA	54	79349	3640	281402
Fecal coliform	CFU/100mL	Industrial	NSQD	417	36541	19027	***66589*** [U]

Table F-1-1. Stormwater Runoff Concentration Summary Statistics by Data Source and Land Use

Parameter	Units	Land use	Source	n	Mean	LCL	UCL
Fecal coliform	CFU/100mL	Industrial	Seattle	33	4139	1048	12387
Fecal coliform	CFU/100mL	Industrial	Tacoma	19	6484	***2965*** ^{L}	11955
Fecal coliform	CFU/100mL	Open Space	ACWA	9	8588	***658*** ^{L}	***24406*** ^{U}
Fecal coliform	CFU/100mL	Open Space	NSQD	33	23366	12200	37693
Fecal coliform	CFU/100mL	Residential	ACWA	53	15562	6163	28761
Fecal coliform	CFU/100mL	Residential	NSQD	590	45835	28839	72938
Fecal coliform	CFU/100mL	Residential	Seattle	35	2953	***1184*** ^{L}	5808
Fecal coliform	CFU/100mL	Residential	Tacoma	21	14306	4856	***30106*** ^{U}
Oil and grease	mg/L	Commercial	ACWA	58	3.60	***2.87*** ^{L}	4.54
Oil and grease	mg/L	Commercial	NSQD	415	***9.50***	6.83	12.75
Oil and grease	mg/L	Industrial	ACWA	63	4.92	***2.84*** ^{L}	***10.07*** ^{U}
Oil and grease	mg/L	Industrial	NSQD	423	7.31	5.33	10.54
Oil and grease	mg/L	Industrial	Portland	5	2.50	2.50	2.50
Oil and grease	mg/L	Open Space	ACWA	10	0.59	***0.49*** ^{L}	0.72
Oil and grease	mg/L	Open Space	NSQD	30	1.65	0.86	***2.79*** ^{U}
Oil and grease	mg/L	Residential	ACWA	57	3.25	***2.27*** ^{L}	4.82
Oil and grease	mg/L	Residential	NSQD	652	***5.89***	4.22	8.22
PBDE	ng/L	Grouped	King Co	27	24.478	10.363	***52.218*** ^{U}
PBDE	ng/L	Grouped	Spokane	38	3.167	***1.958*** ^{L}	5.103
PCB	ng/L	Duwamish	Ecology	26	52.909	***25.628*** ^{L}	***97.563*** ^{U}
PCB	ng/L	Grouped	King Co	27	6.238	***4.226*** ^{L}	9.551
PCB	ng/L	Grouped	Portland	8	28.546	1.054	69.630
PCB	ng/L	Grouped	Seattle	28	18.798	12.186	***28.982*** ^{U}
PCB	ng/L	Industrial[a]	Portland	70	386.939	126.720	872.617

Table F-1-1. Stormwater Runoff Concentration Summary Statistics by Data Source and Land Use

Parameter	Units	Land use	Source	n	Mean	LCL	UCL
TP	mg/L	Commercial	ACWA	80	0.433	0.311	0.583
TP	mg/L	Commercial	NSQD	992	0.292	0.270	0.315
TP	mg/L	Commercial	Seattle	33	0.290	0.257	***0.330*** ^{U}
TP	mg/L	Commercial	Tacoma	24	0.125	***0.093*** ^{L}	0.164
TP	mg/L	Industrial	ACWA	58	0.494	0.405	0.621
TP	mg/L	Industrial	NSQD	715	***0.383*** ^{U}	0.339	0.427
TP	mg/L	Industrial	Portland	1	0.067	--	--
TP	mg/L	Industrial	Seattle	33	0.264	0.217	0.343
TP	mg/L	Industrial	Tacoma	21	0.140	***0.114*** ^{L}	0.172
TP	mg/L	Open Space	ACWA	9	0.164	0.131	***0.202*** ^{U}
TP	mg/L	Open Space	NSQD	127	0.264	0.125	0.615
TP	mg/L	Open Space	Portland	2	***0.028*** ^{L}	--	--
TP	mg/L	Residential	ACWA	61	***0.343*** ^{U}	0.251	0.481
TP	mg/L	Residential	NSQD	2456	0.383	0.362	0.413
TP	mg/L	Residential	Seattle	35	0.227	0.188	0.276
TP	mg/L	Residential	Tacoma	30	0.118	***0.097*** ^{L}	0.141
TSS	mg/L	Commercial	ACWA	80	85.97	67.21	***106.28*** ^{U}
TSS	mg/L	Commercial	NSQD	904	110.23	97.80	124.76
TSS	mg/L	Commercial	Seattle	34	71.60	60.01	86.27
TSS	mg/L	Commercial	Tacoma	215	66.25	***58.33*** ^{L}	73.91
TSS	mg/L	Industrial	ACWA	58	121.55	87.67	***176.89*** ^{U}
TSS	mg/L	Industrial	NSQD	703	159.00	141.31	179.34
TSS	mg/L	Industrial	Portland	259	75.99	***58.24*** ^{L}	103.80
TSS	mg/L	Industrial	Seattle	33	87.60	60.43	126.47

Table F-1-1. Stormwater Runoff Concentration Summary Statistics by Data Source and Land Use

Parameter	Units	Land use	Source	n	Mean	LCL	UCL
TSS	mg/L	Industrial	Tacoma	269	83.03	76.20	91.21
TSS	mg/L	Open Space	ACWA	10	52.27	21.80	***105.70***[U]
TSS	mg/L	Open Space	NSQD	120	88.74	58.86	122.27
TSS	mg/L	Open Space	Portland	7	23.74	***6.86***[L]	49.98
TSS	mg/L	Residential	ACWA	60	61.51	***44.51***[L]	***93.12***[U]
TSS	mg/L	Residential	NSQD	2339	119.65	110.37	129.53
TSS	mg/L	Residential	Portland	8	67.90	25.63	135.13
TSS	mg/L	Residential	Seattle	35	66.64	50.49	87.77
TSS	mg/L	Residential	Tacoma	111	65.15	57.11	75.23
Zinc, dissolved	mg/L	Commercial	ACWA	60	0.078	0.056	***0.124***[U]
Zinc, dissolved	mg/L	Commercial	NSQD	49	0.107	0.077	0.157
Zinc, dissolved	mg/L	Commercial	Seattle	34	0.053	***0.044***[L]	0.064
Zinc, dissolved	mg/L	Commercial	Tacoma	223	0.057	0.051	0.063
Zinc, dissolved[b]	mg/L	Industrial	ACWA	50	0.267	0.107	0.678
Zinc, dissolved[b]	mg/L	Industrial	NSQD	42	0.297	0.107	0.808
Zinc, dissolved[b]	mg/L	Industrial	Portland	55	0.215	0.111	0.375
Zinc, dissolved[b]	mg/L	Industrial	Seattle	33	0.047	0.040	0.055
Zinc, dissolved[b]	mg/L	Industrial	Tacoma	274	0.060	***0.053***[L]	0.070
Zinc, dissolved	mg/L	Open Space	ACWA	9	0.014	0.006	***0.025***[U]
Zinc, dissolved	mg/L	Open Space	NSQD	7	0.027	0.003	0.071
Zinc, dissolved	mg/L	Open Space	Portland	4	0.006	***0.002***[L]	0.010
Zinc, dissolved	mg/L	Residential	ACWA	34	0.046	0.035	0.057
Zinc, dissolved	mg/L	Residential	NSQD	98	0.033	0.027	***0.040***[U]
Zinc, dissolved	mg/L	Residential	Portland	4	0.035	0.020	0.057

Table F-1-1. Stormwater Runoff Concentration Summary Statistics by Data Source and Land Use

Parameter	Units	Land use	Source	n	Mean	LCL	UCL
Zinc, dissolved	mg/L	Residential	Seattle	35	0.015	***0.013***^{L}	0.017
Zinc, dissolved	mg/L	Residential	Tacoma	113	0.029	0.026	0.034
Zinc, total	mg/L	Commercial	ACWA	80	0.163	0.133	***0.204***^{U}
Zinc, total	mg/L	Commercial	NSQD	885	0.190	0.174	0.209
Zinc, total	mg/L	Commercial	Seattle	34	0.155	0.139	0.171
Zinc, total	mg/L	Commercial	Tacoma	224	0.134	***0.124***^{L}	0.147
Zinc, total	mg/L	Industrial	ACWA	60	0.372	0.205	0.708
Zinc, total	mg/L	Industrial	NSQD	703	0.223	0.202	***0.258***^{U}
Zinc, total	mg/L	Industrial	Portland	96	0.536	0.384	0.695
Zinc, total	mg/L	Industrial	Seattle	33	0.155	***0.133***^{L}	0.186
Zinc, total	mg/L	Industrial	Tacoma	274	0.152	0.139	0.166
Zinc, total	mg/L	Open Space	ACWA	10	0.023	***0.009***^{L}	***0.045***^{U}
Zinc, total	mg/L	Open Space	NSQD	56	0.053	0.036	0.077
Zinc, total	mg/L	Open Space	Portland	7	0.007	0.004	0.011
Zinc, total	mg/L	Residential	ACWA	61	0.098	0.077	***0.129***^{U}
Zinc, total	mg/L	Residential	NSQD	2042	0.115	0.102	0.135
Zinc, total	mg/L	Residential	Portland	6	0.143	0.038	0.329
Zinc, total	mg/L	Residential	Seattle	35	0.053	***0.047***^{L}	0.061
Zinc, total	mg/L	Residential	Tacoma	113	0.077	0.069	0.088

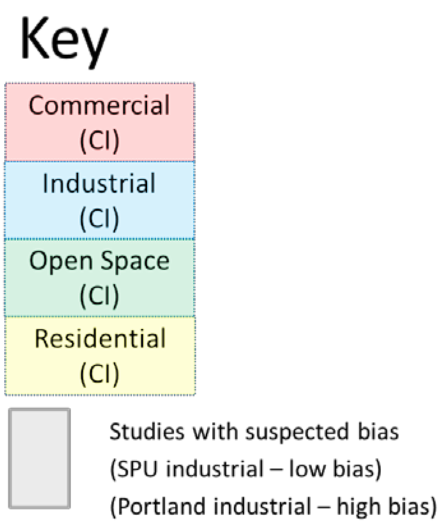
Notes: The upper and lower runoff concentration bounds selected as inputs to the PLM are denoted by values in bold italics. The lower and upper bounds are also denoted with an L and U superscript, respectively.

a. *The Portland industrial PCB data are not representative of Seattle and was not considered in defining the upper and lower bounds for PCB.*

b. *The industrial dissolved zinc values exceed some of the industrial total zinc values. Therefore, the UCL EMC bound for industrial dissolved zinc was set equal to the industrial total zinc UCL EMC bound.*

Attachment F-2: Stormwater Concentration Data Figures

The 95th percent CIs on the mean runoff concentration for each RCOC, land use, data source combination, developed using the approach described in Section 2.2.2, are graphically depicted below. The color-shaded regions represent the land use specific confidence bounds (CI) that were selected as inputs into the PLM as described in Section 3.4. Additionally, some of the studies had suspected bias and required special consideration. The following key illustrates the different land use shading of the select CI on the charts:



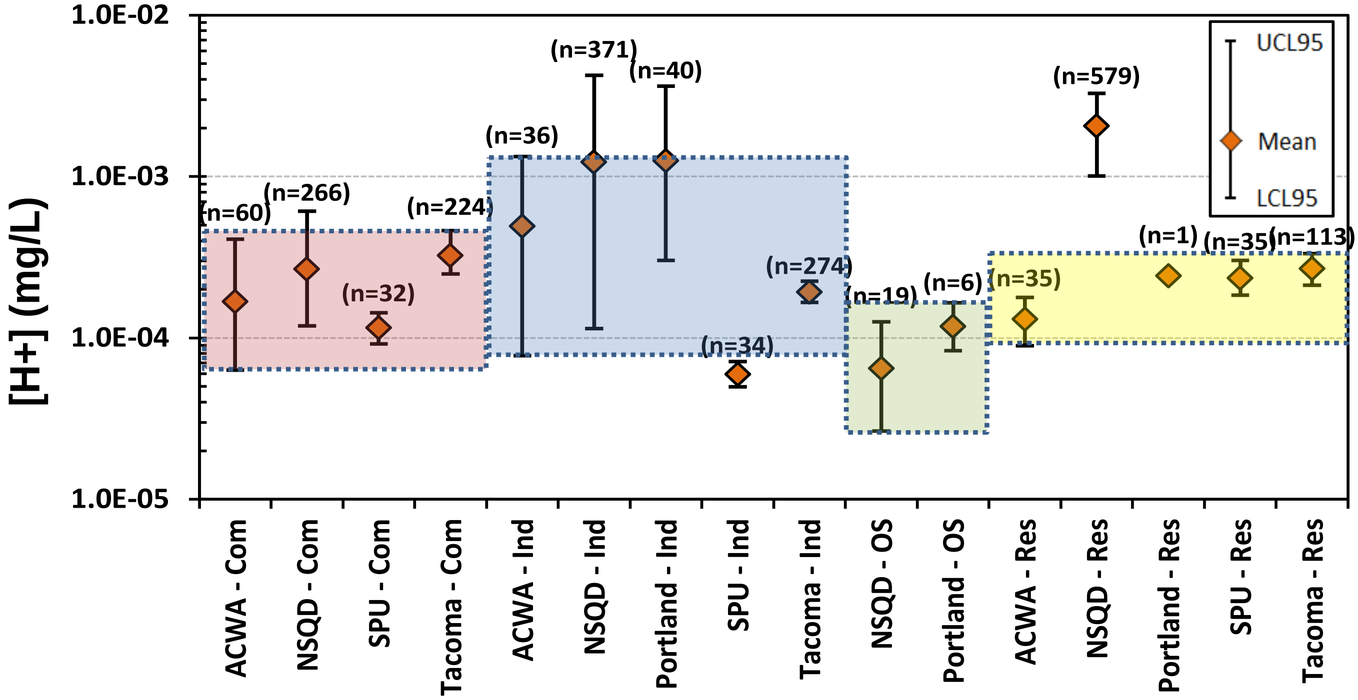


Figure F-2a. Confidence intervals for year-round hydrogen ion concentration stormwater data by source and land use

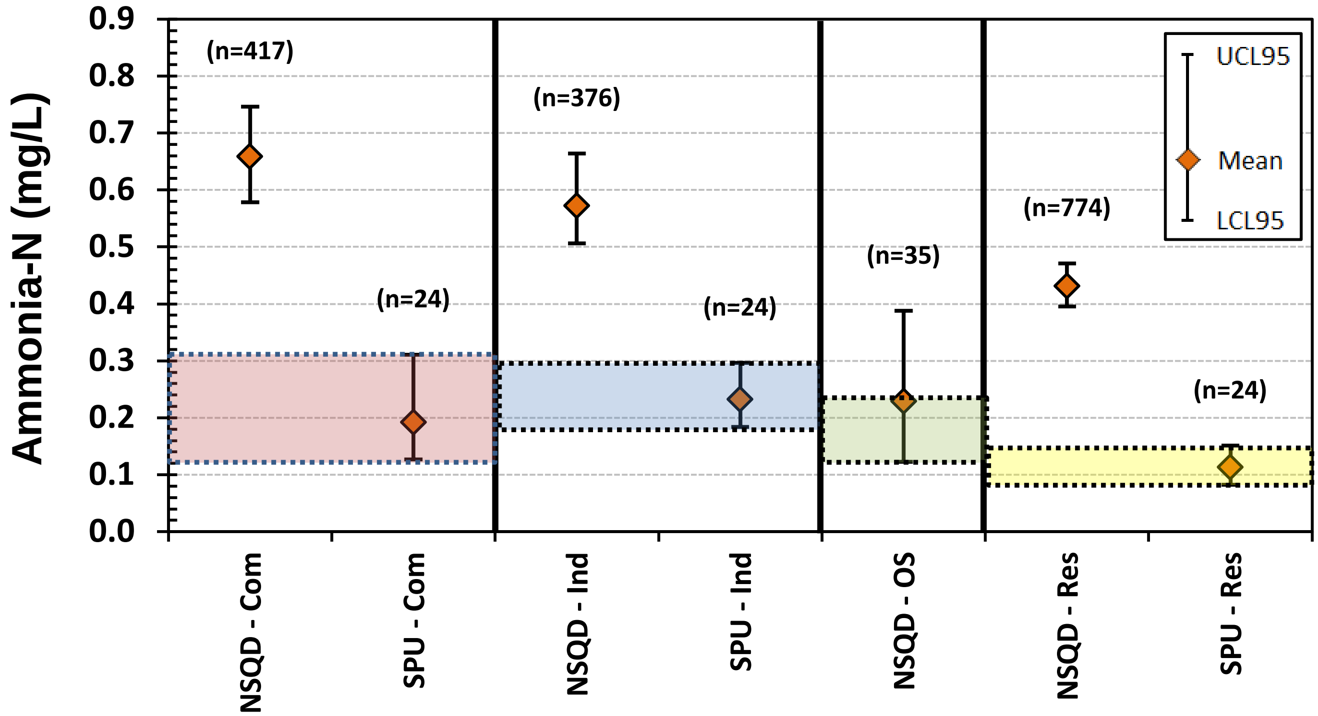


Figure F-2b. Confidence intervals for year-round ammonia-N stormwater data by source and land use

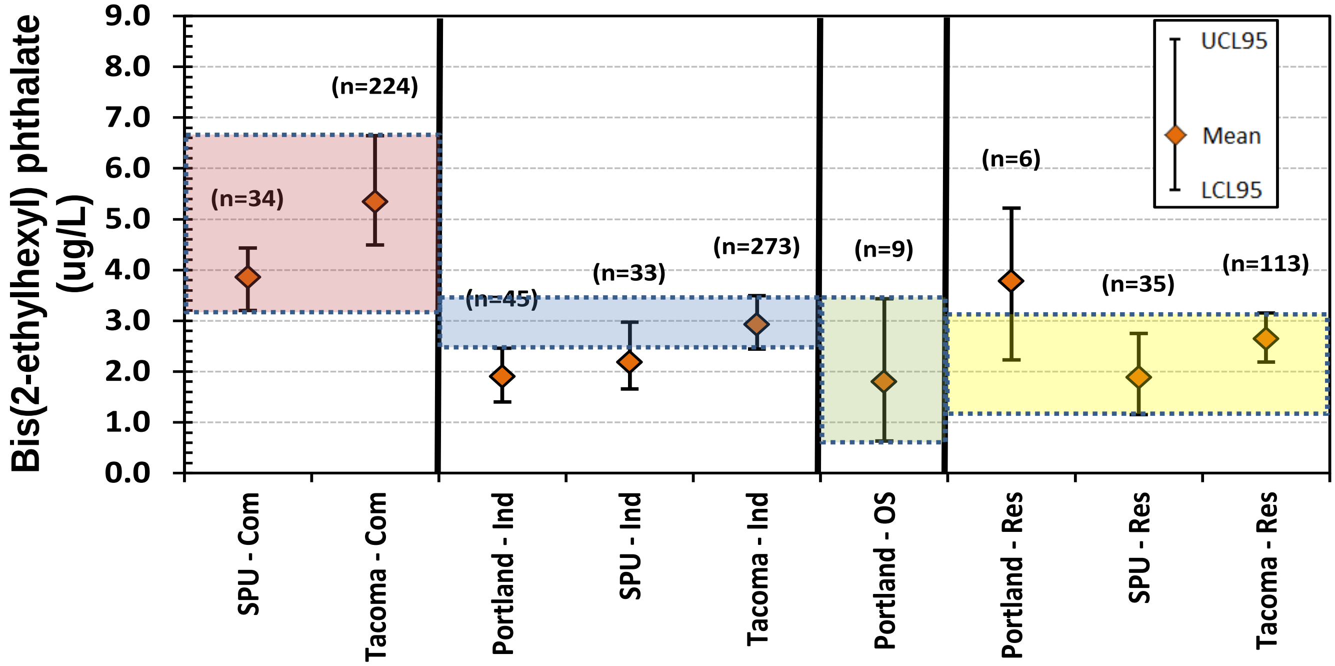


Figure F-2c. Confidence intervals for year-round bis(2-ethylhexyl)phthalate stormwater data by source and land use

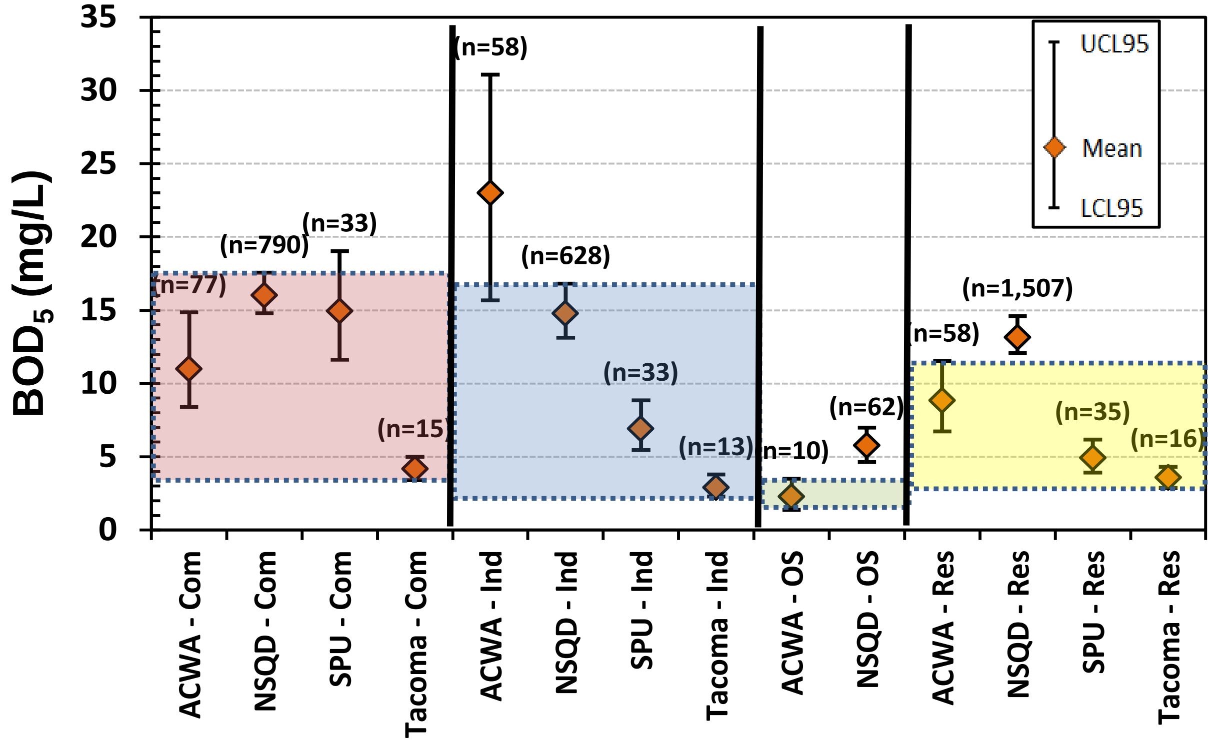


Figure F-2d. Confidence intervals for year-round 5-day BOD_5 data by source and land use

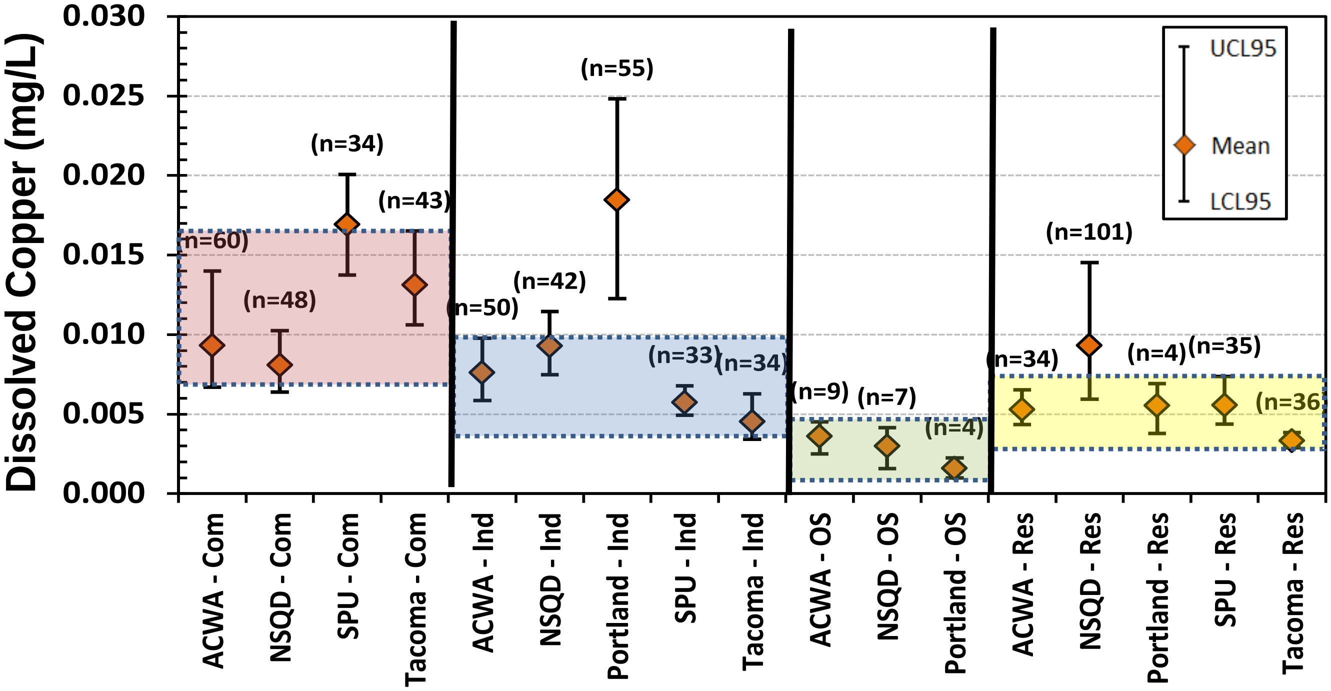


Figure F-2e. Confidence intervals for year-round dissolved copper stormwater data by source and land use

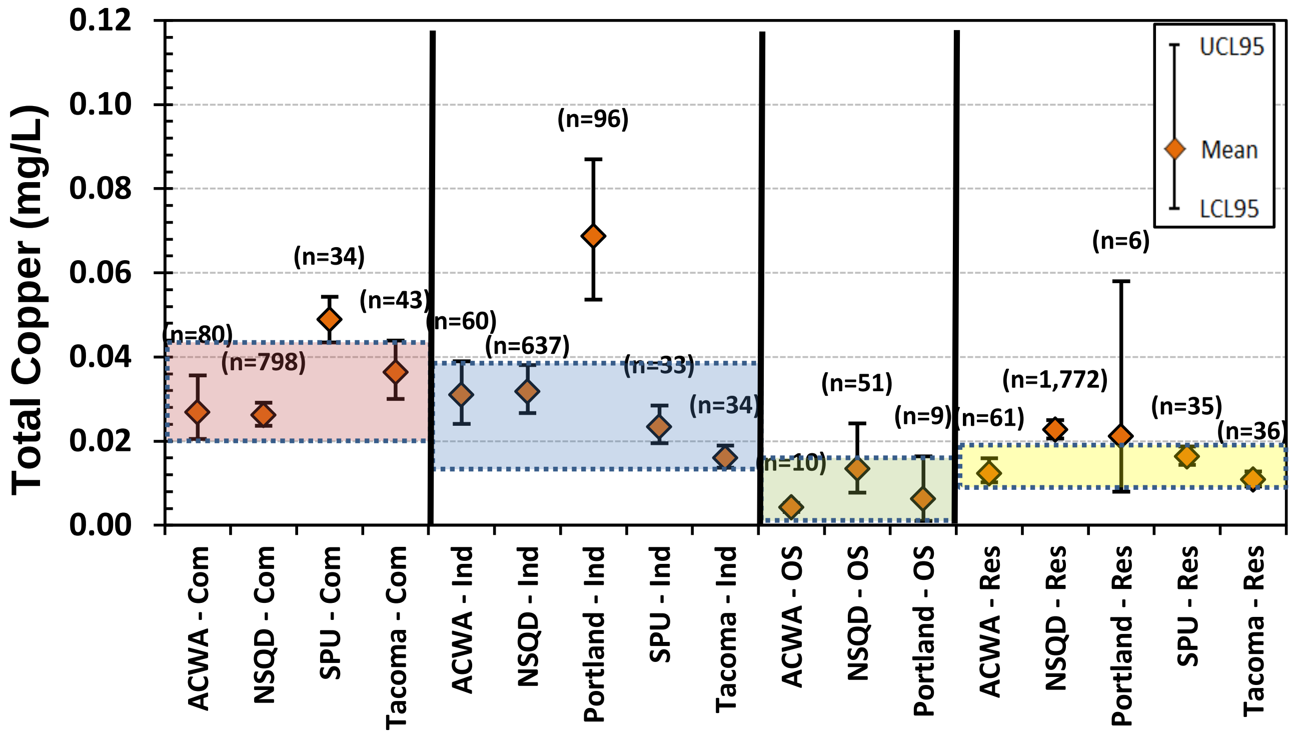


Figure F-2f. Confidence intervals for year-round total copper stormwater data by source and land use

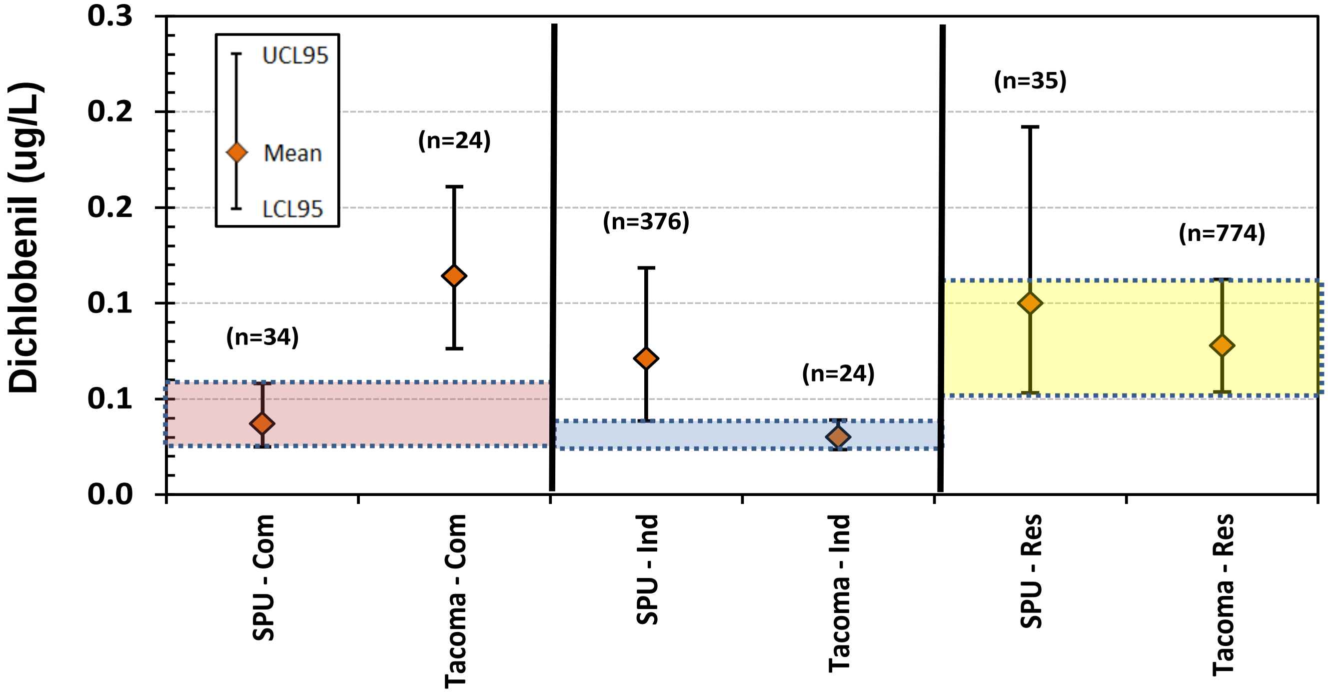


Figure F-2g. Confidence intervals for year-round 5-day dichlobenil stormwater data by source and land use

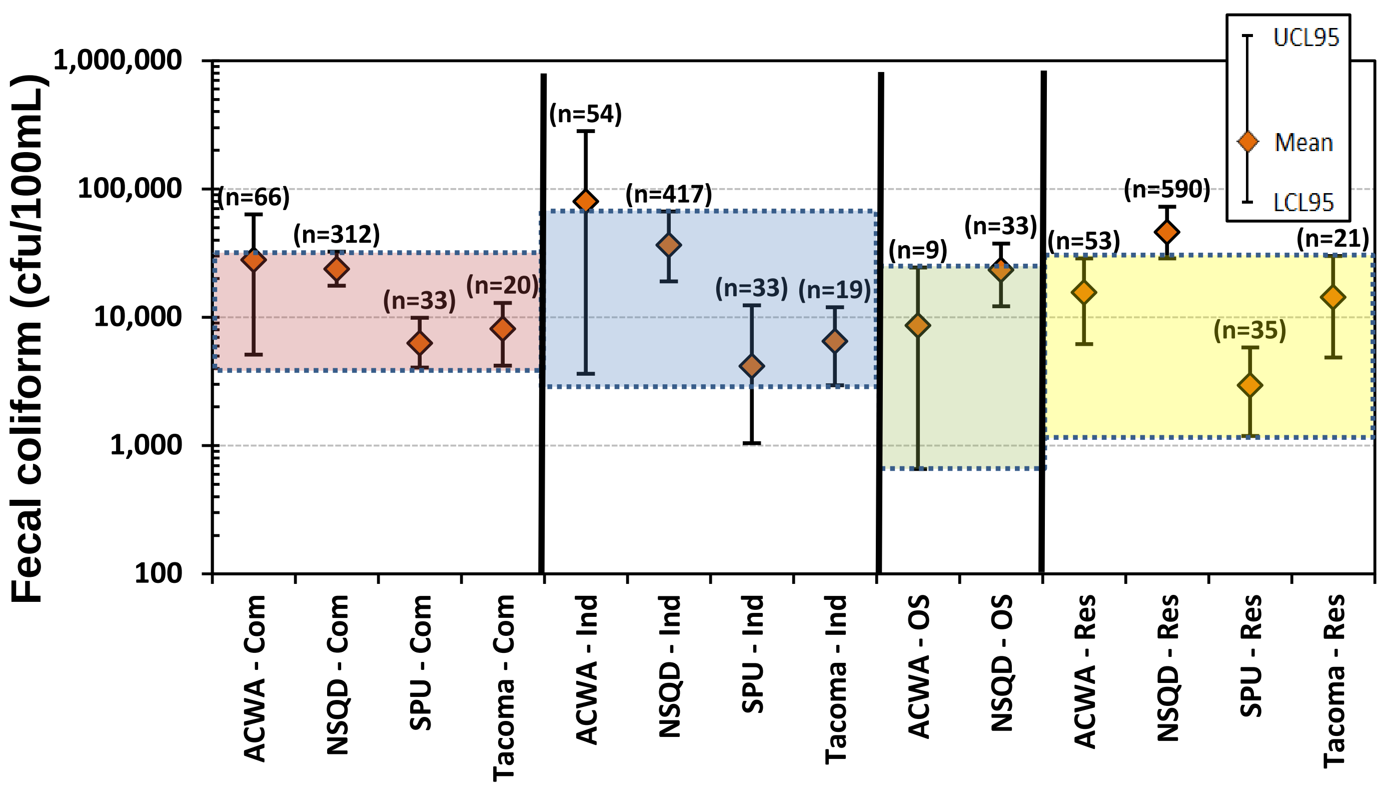


Figure F-2h. Confidence intervals for year-round fecal coliform data by source and land use

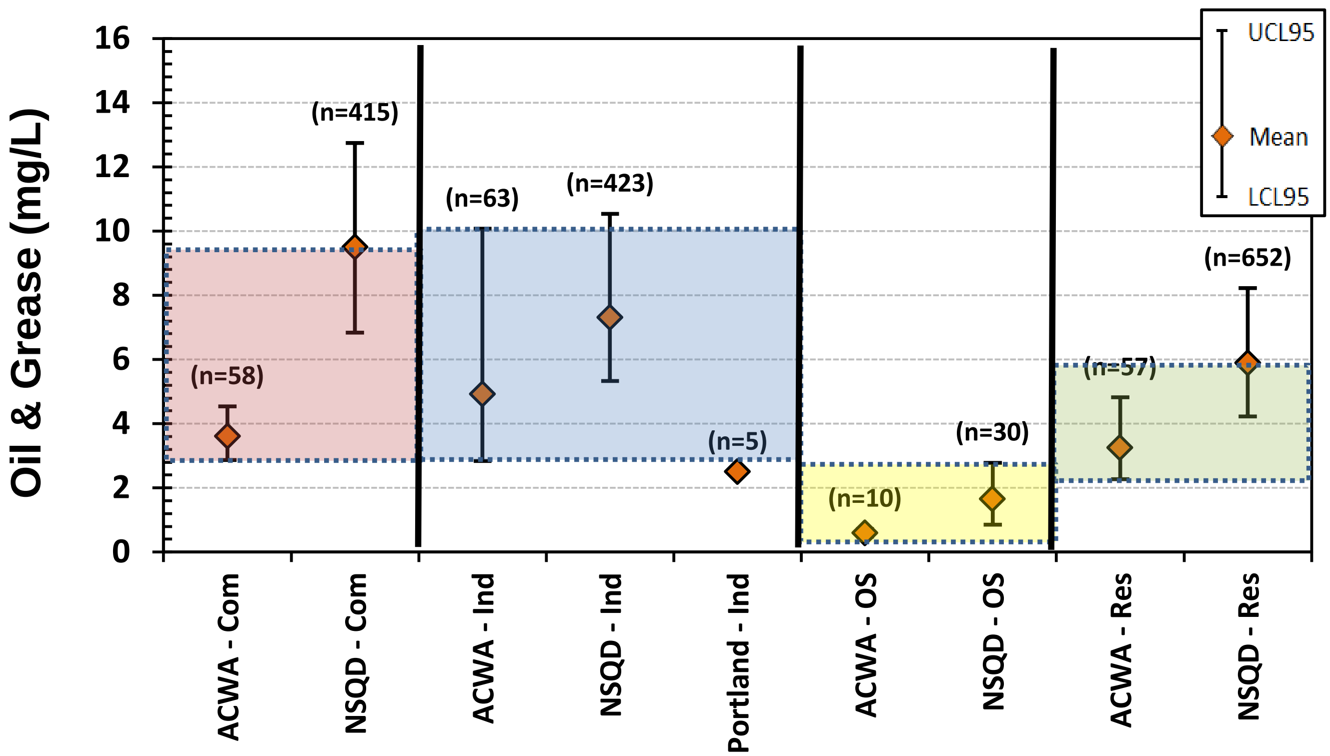


Figure F-2i. Confidence intervals for year-round oil and grease data by source and land use

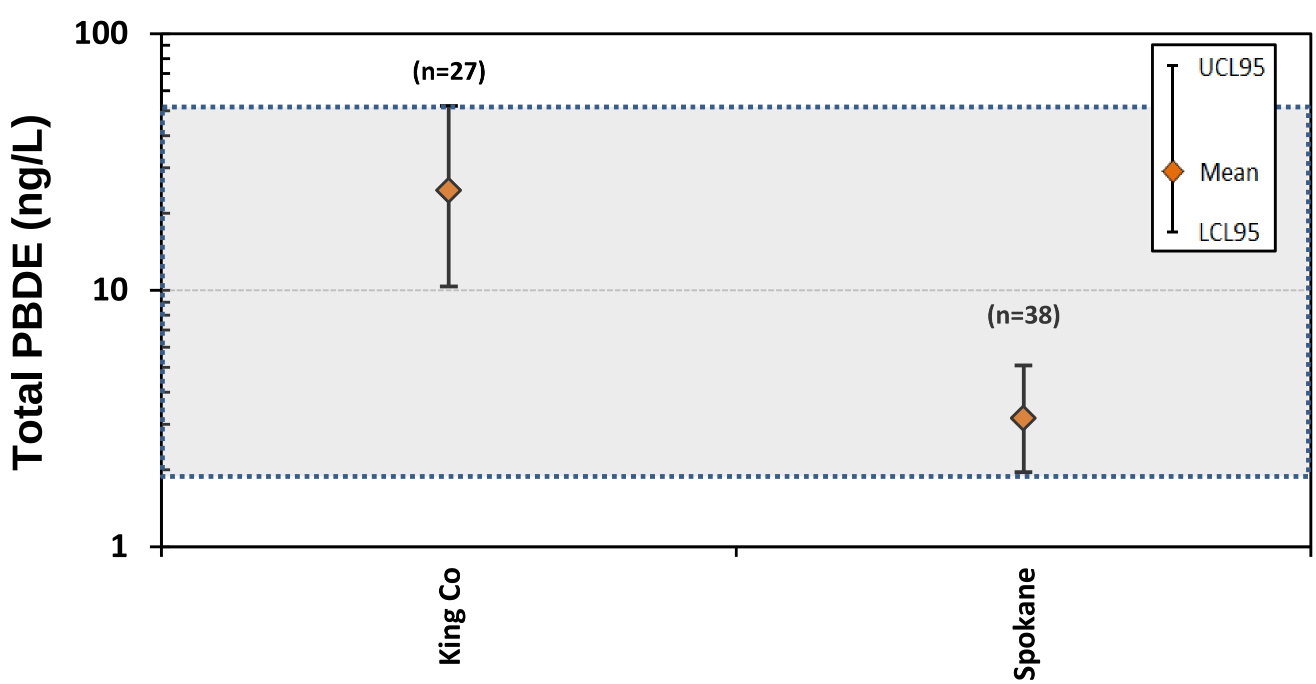


Figure F-2j. Confidence intervals for year-round total polybrominated diphenyl ethers stormwater data by source and land use

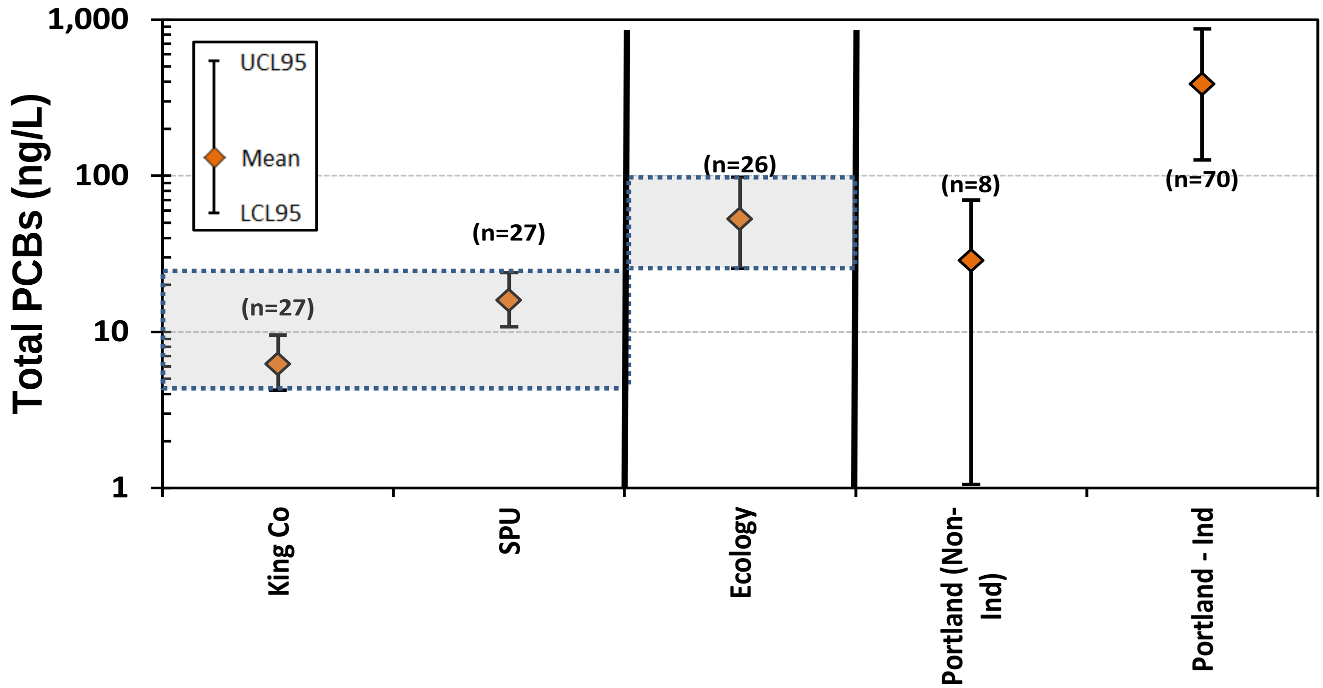


Figure F-2k. Confidence intervals for year-round total polychlorinated biphenyls stormwater data by source and land use

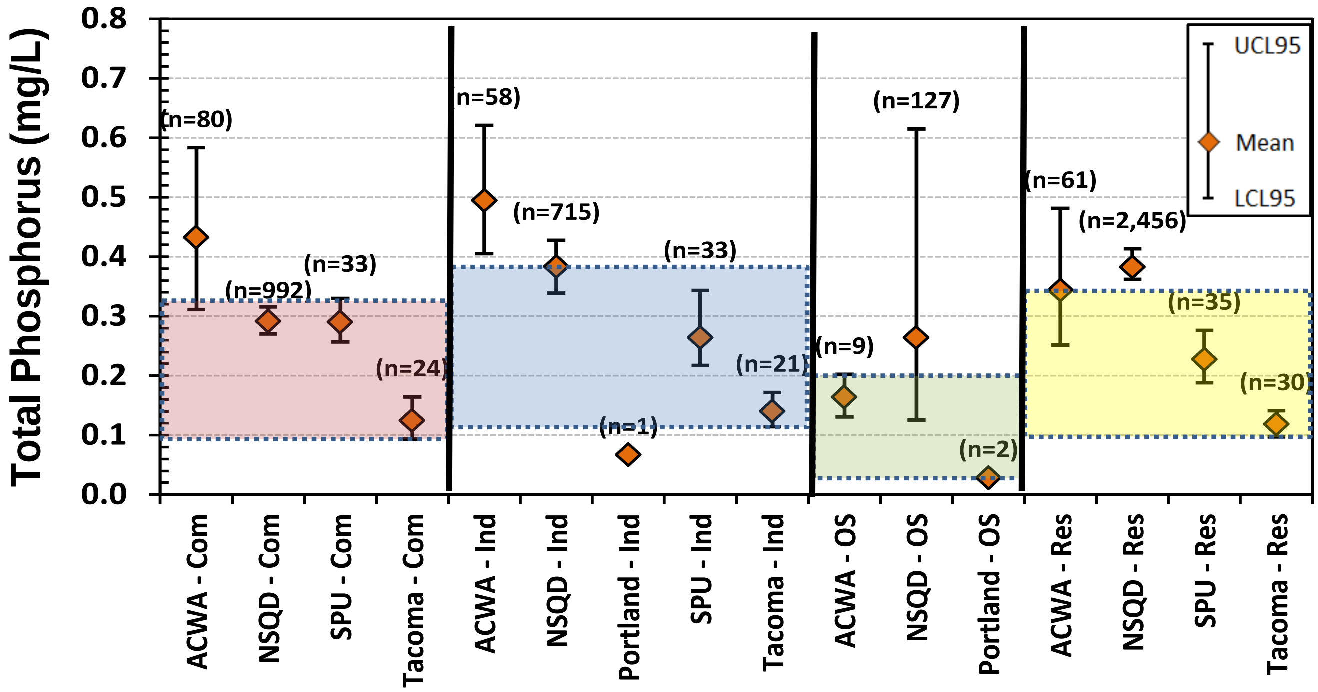


Figure F-2l. Confidence intervals for year-round total phosphorus stormwater data by source and land use

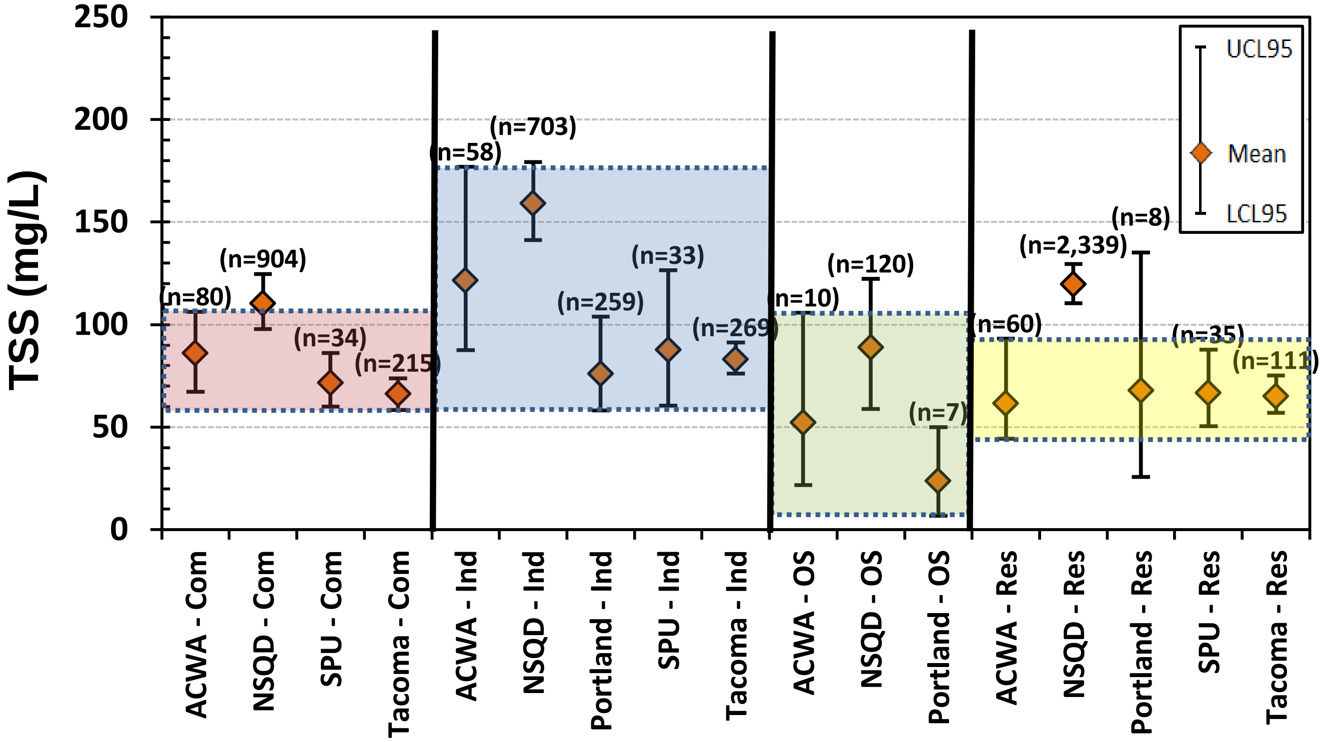


Figure F-2m. Confidence intervals for year-round total suspended solids data by source and land use

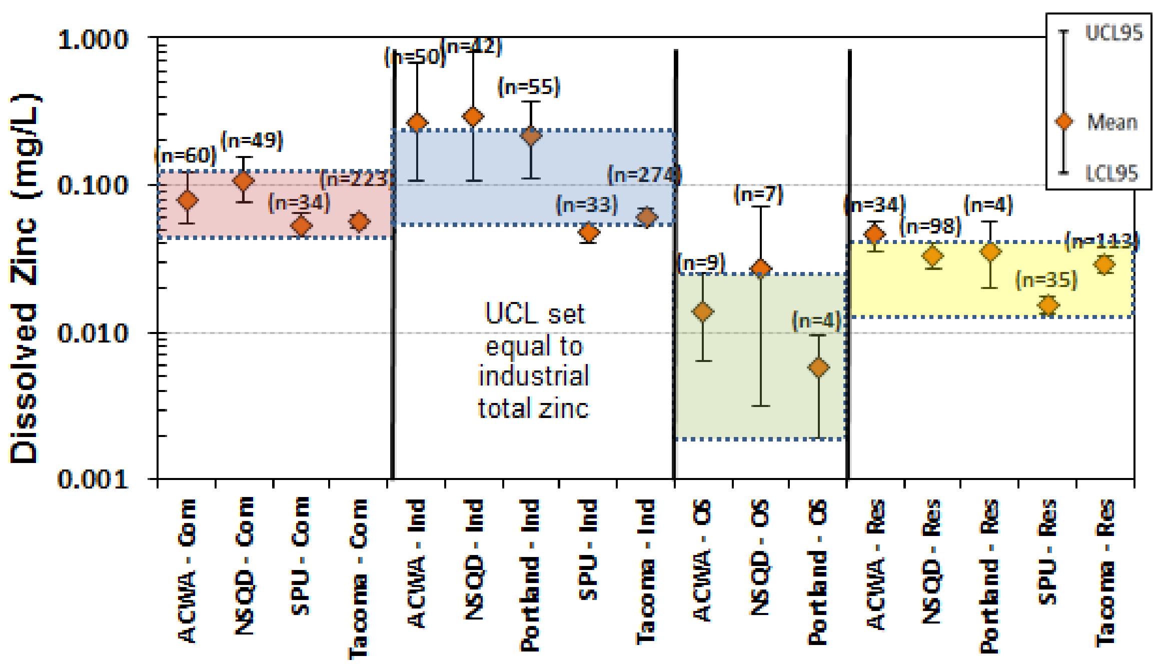


Figure F-2n. Confidence intervals for year-round dissolved zinc stormwater data by source and land use

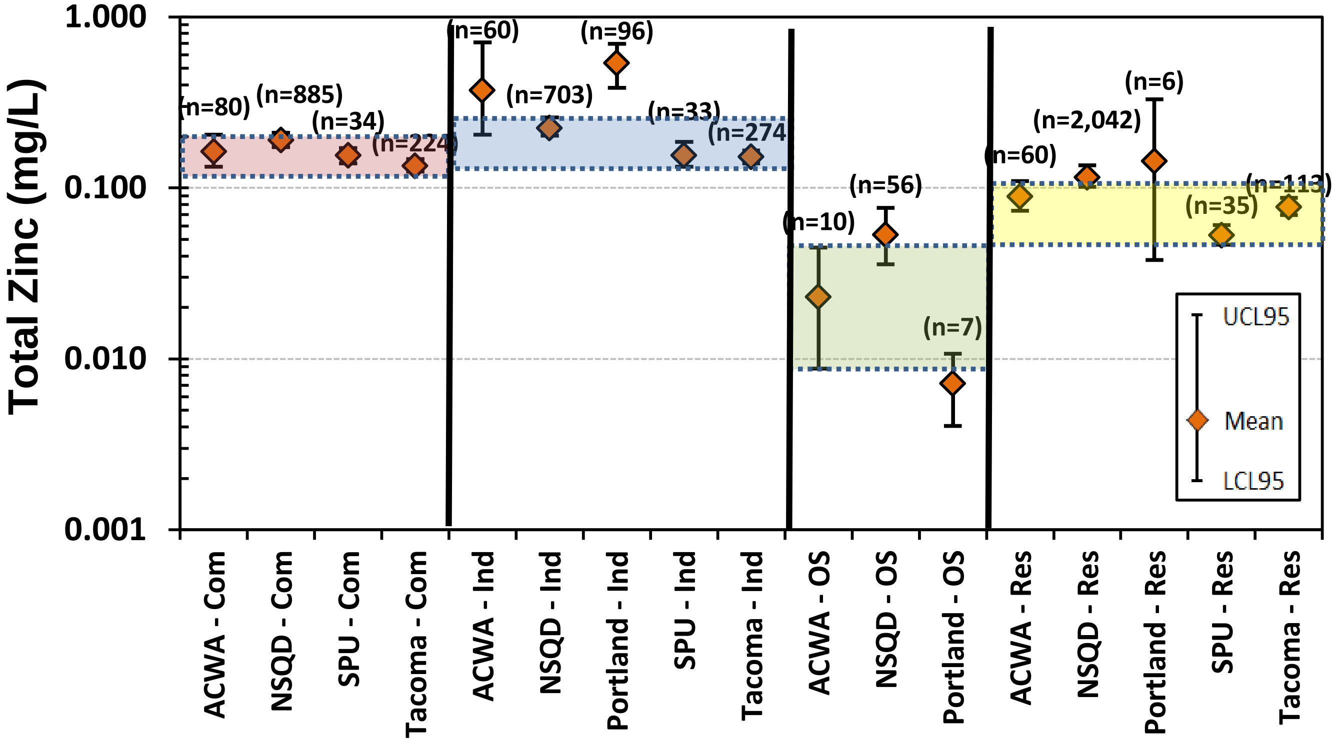


Figure F-2o. Confidence intervals for year-round total zinc stormwater data by source and land use

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Attachment F-3: Integrated Plan Stormwater Project Box and Whisker Results Charts

The box-and-whisker charts graphically present the PLM results. Each chart displays the long-term average annual concentration or load reduction for an RCOC. The candidate stormwater projects are included on the x-axis with the estimated long-term average annual reduction on the y-axis. The median of the long-term average annual reduction (selected from the distribution of the 1,000 Monte Carlo iterations) is indicated by a horizontal line within the box. The top and bottom of the box represent the 75th and 25th percentile reductions, respectively. The top and bottom whiskers represent the 95th and 5th percentile reductions, respectively (see key included within each figure). These percentiles represent the range of long-term average reductions that can be expected from a given project.

Due to limited data availability, the concentration and load reductions for some stormwater project and RCOC combinations were not calculated (discussed in Section 3.5.3). For example, due to limited data availability, concentration reductions for dichlobenil, dissolved copper, dissolved zinc, ammonia-N, [H+], and normalized DO deficit could not be calculated for the street sweeping programs and therefore are not presented. And, due to limited data availability, loads reductions for dichlobenil, dissolved copper, dissolved zinc, ammonia-N, and [H+] were not able to be calculated for the street sweeping projects at this time and therefore are not presented.

For street sweeping projects, the mean of the long-term average annual reductions are reported (not the median), as calculated by the original model.

The long-term average annual concentration reduction for dichlobenil was zero for every Integrated Plan stormwater project (except street sweeping) as described in Section 3.5.3.

The UCL of the land use runoff concentrations for ammonia-N (as described in Section 3.4) were lower than the LCL of the project effluent concentrations (as described in Section 3.5.3) for all of the Integrated Plan stormwater projects (except street sweeping). Therefore, the long-term average annual concentration reduction for ammonia-N was zero for every Integrated Plan stormwater project (except street sweeping).

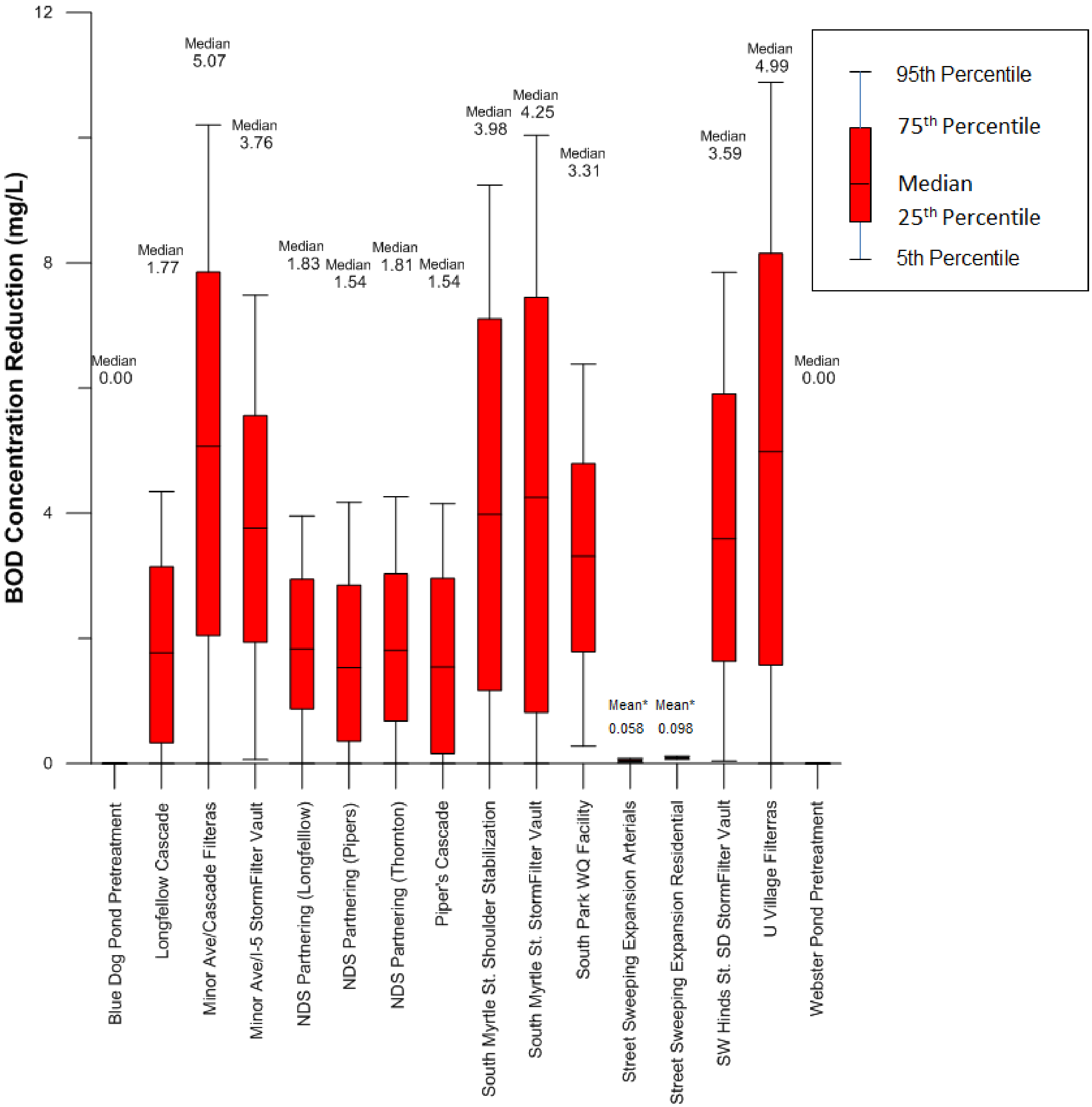

Figure F-3a. Long-term average annual concentration reduction for BOD_5

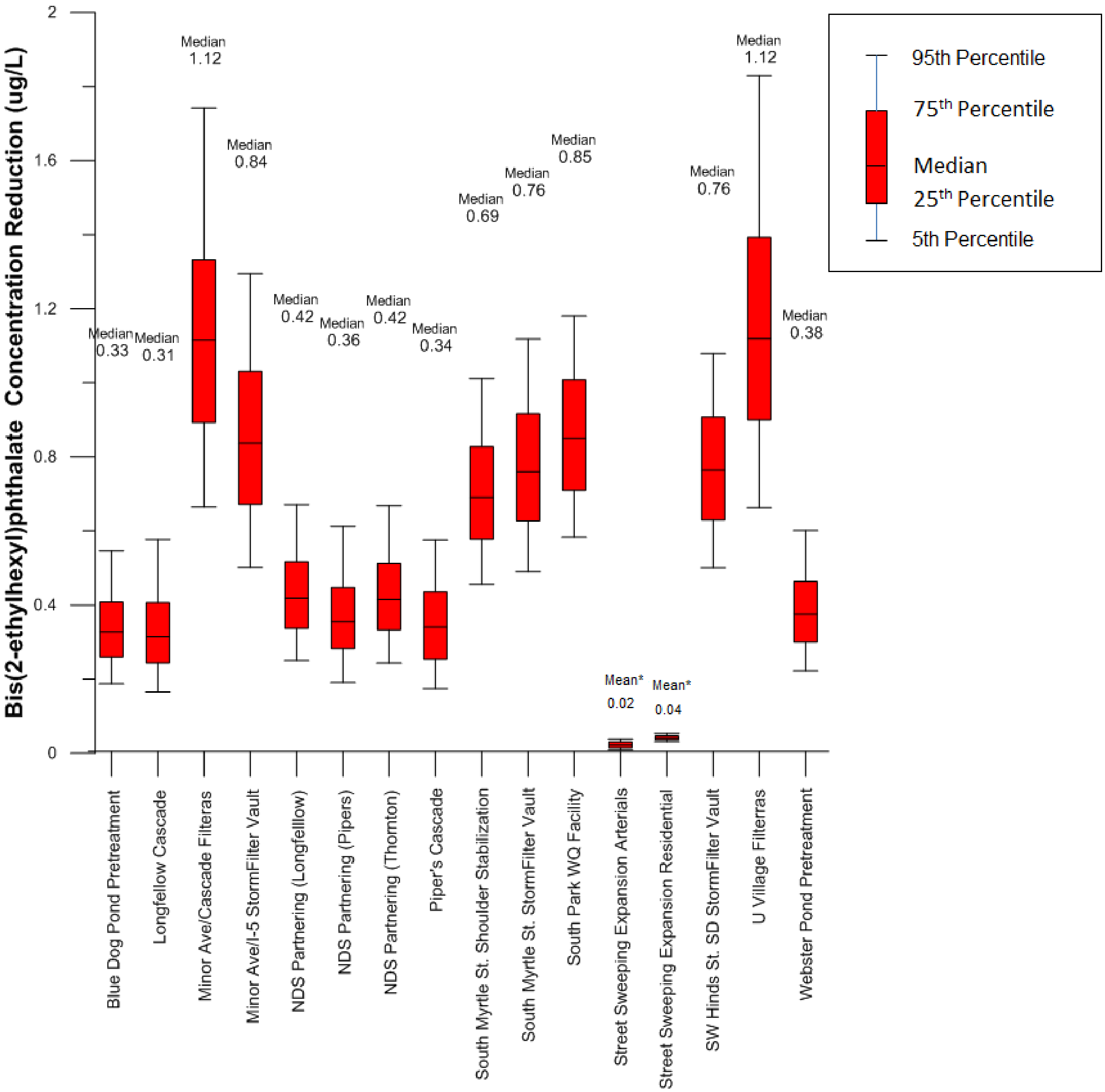

Figure F-3b. Long-term average annual concentration reduction for bis(2-ethylhexyl)phthalate

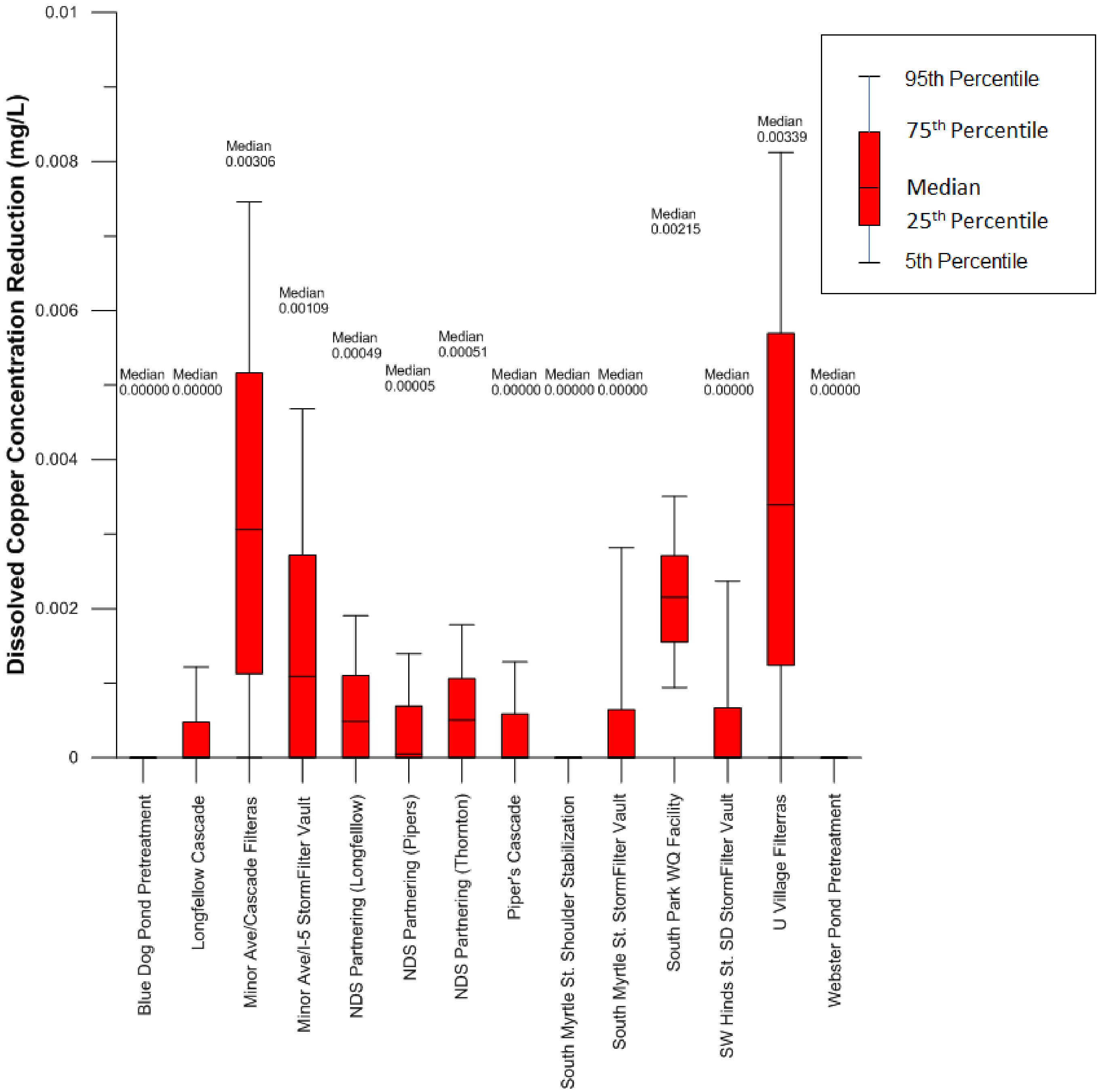

Figure F-3c. Long-term average annual concentration reduction for dissolved copper

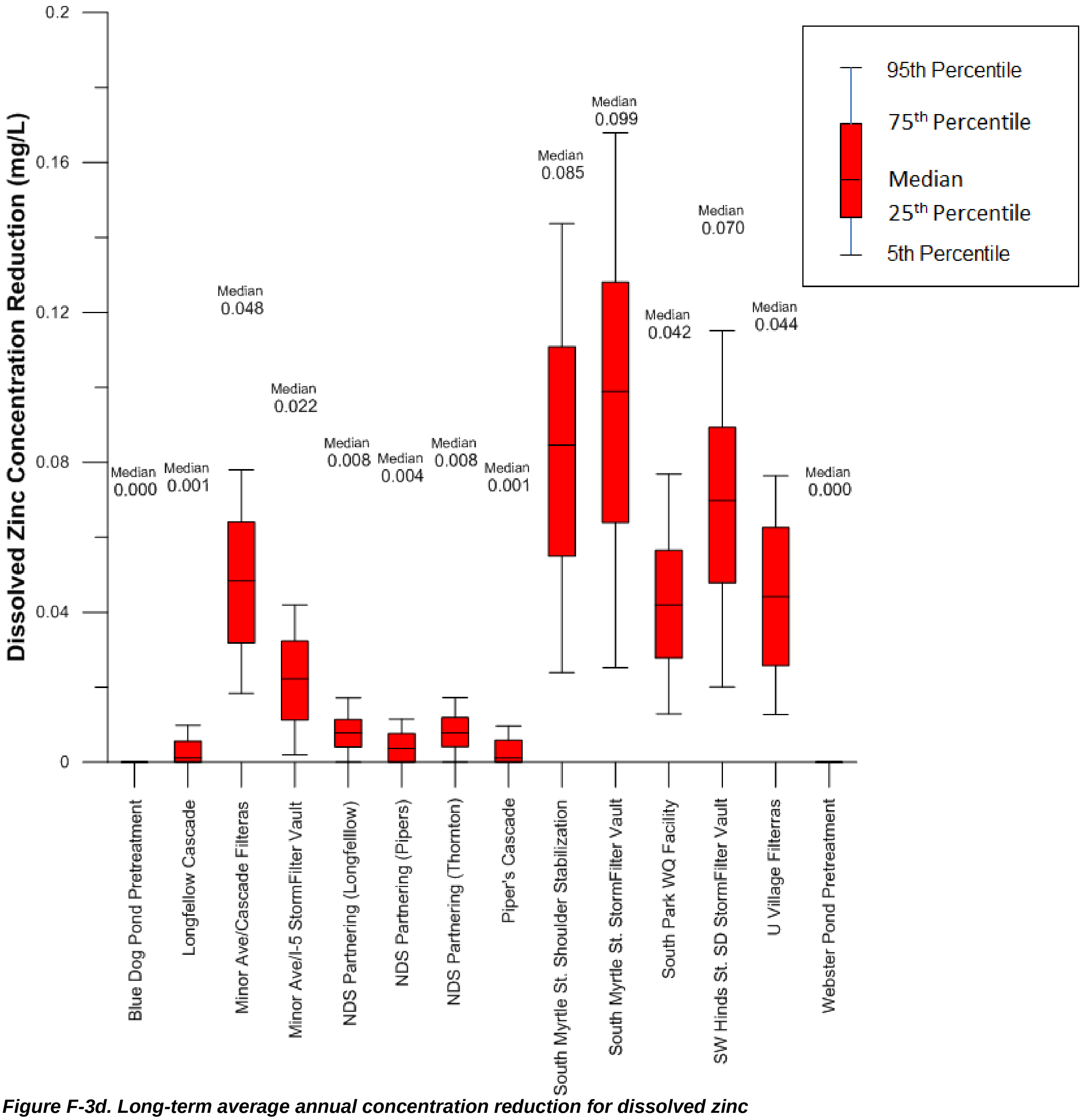

Figure F-3d. Long-term average annual concentration reduction for dissolved zinc

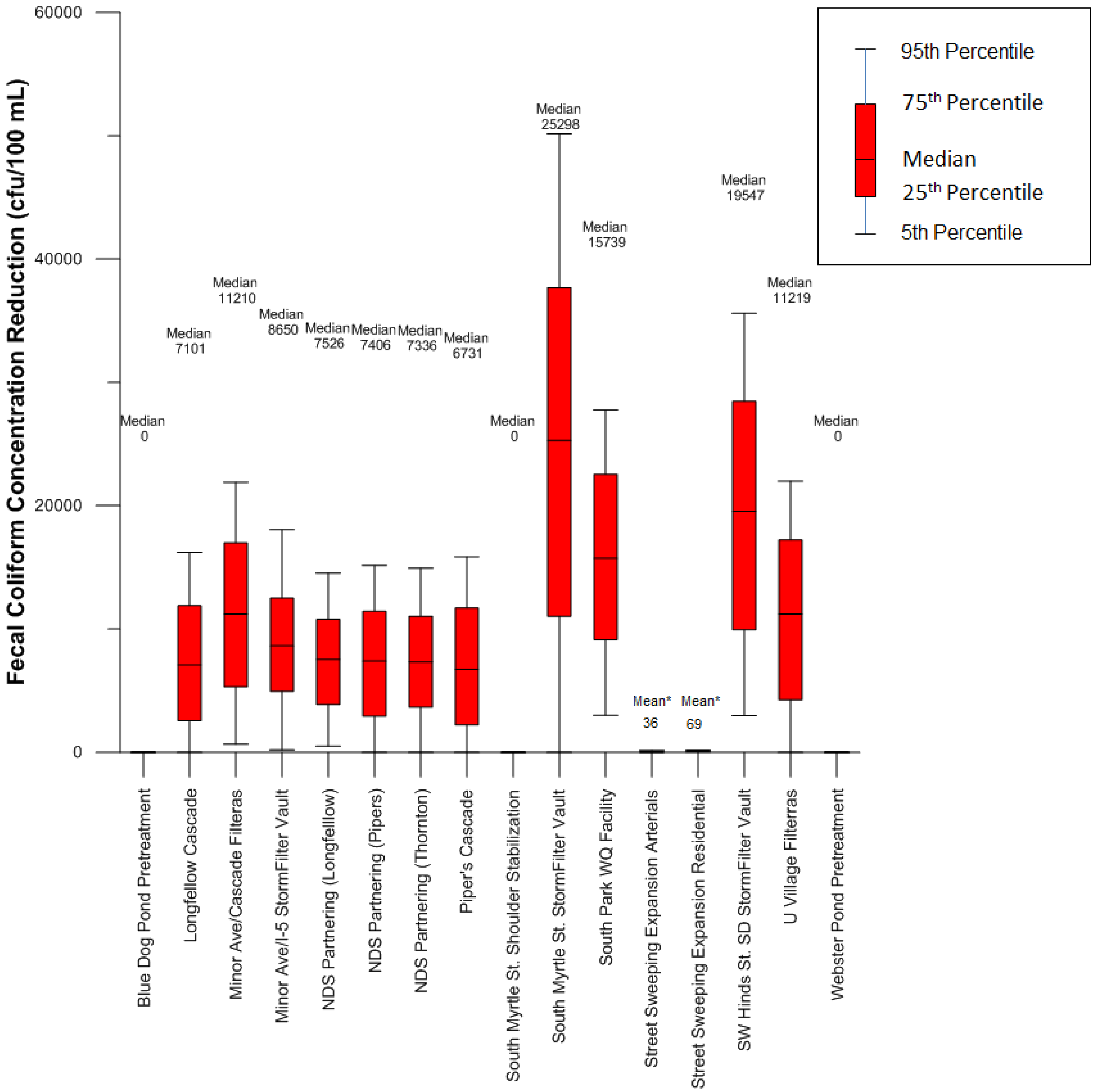

Figure F-3e. Long-term average annual concentration reduction for fecal coliform

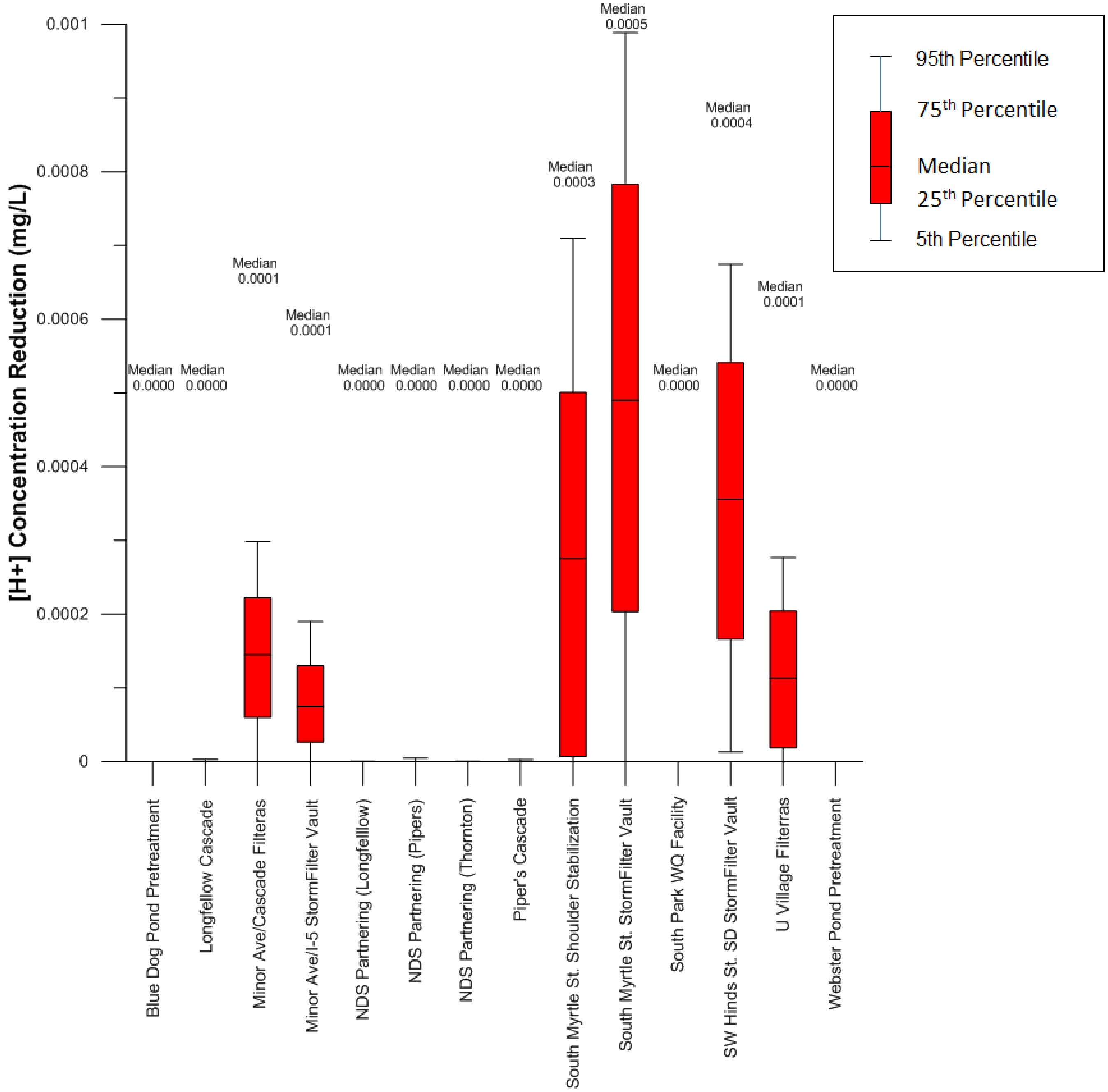

Figure F-3f. Long-term average annual concentration load reduction for [H+]

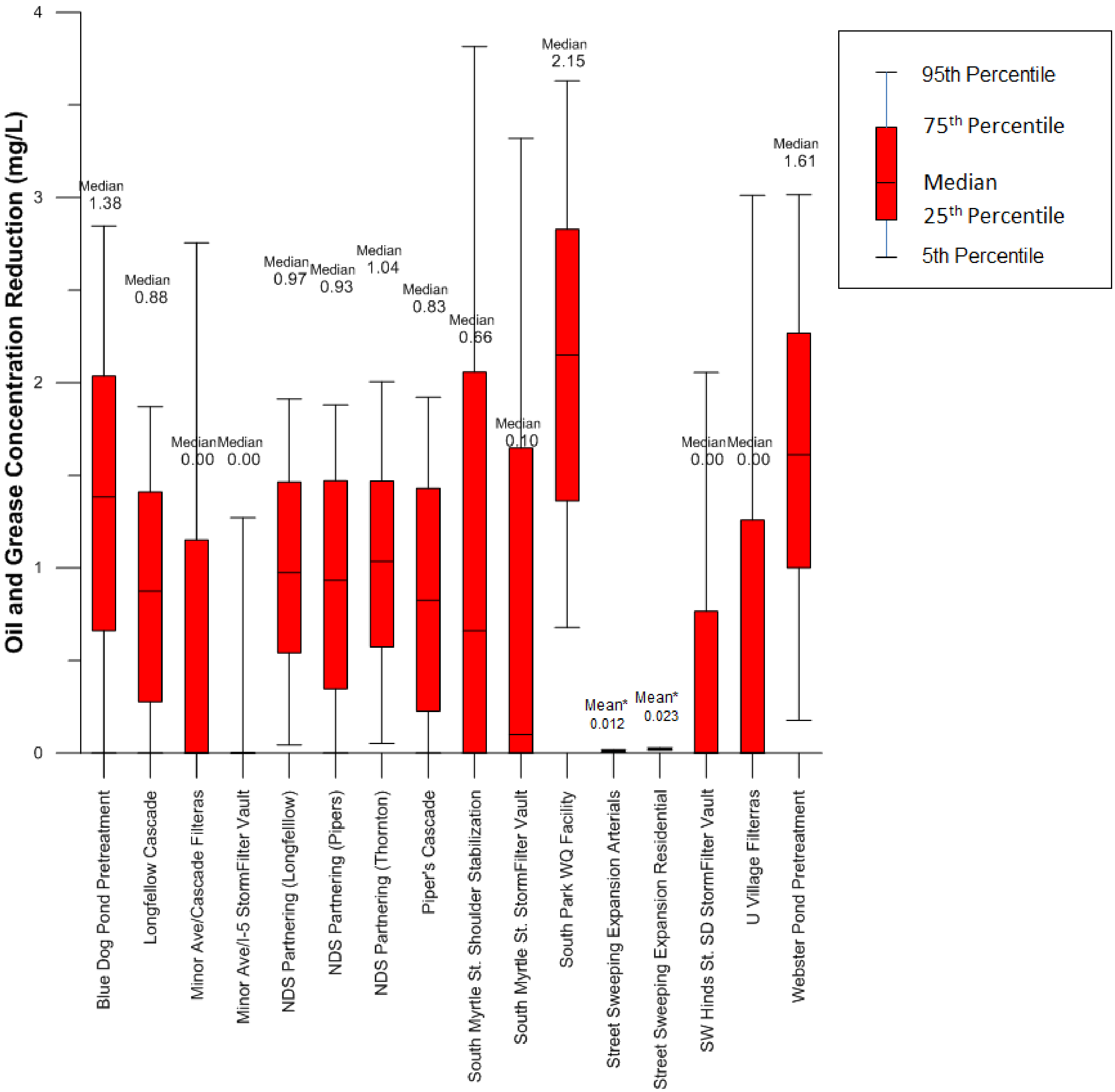

Figure F-3g. Long-term average annual concentration reduction for oil and grease

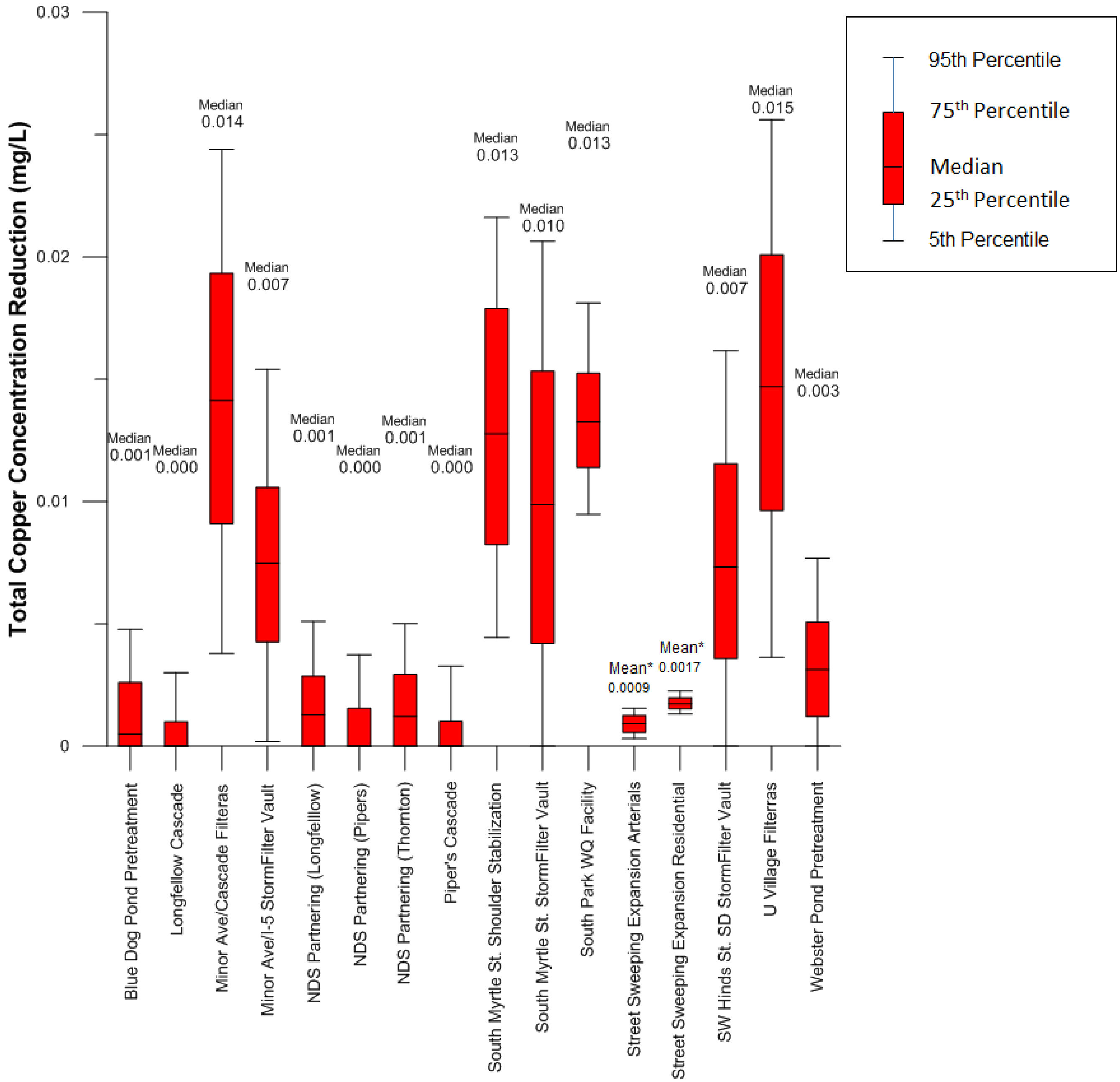

Figure F-3h. Long-term average annual concentration reduction for total copper

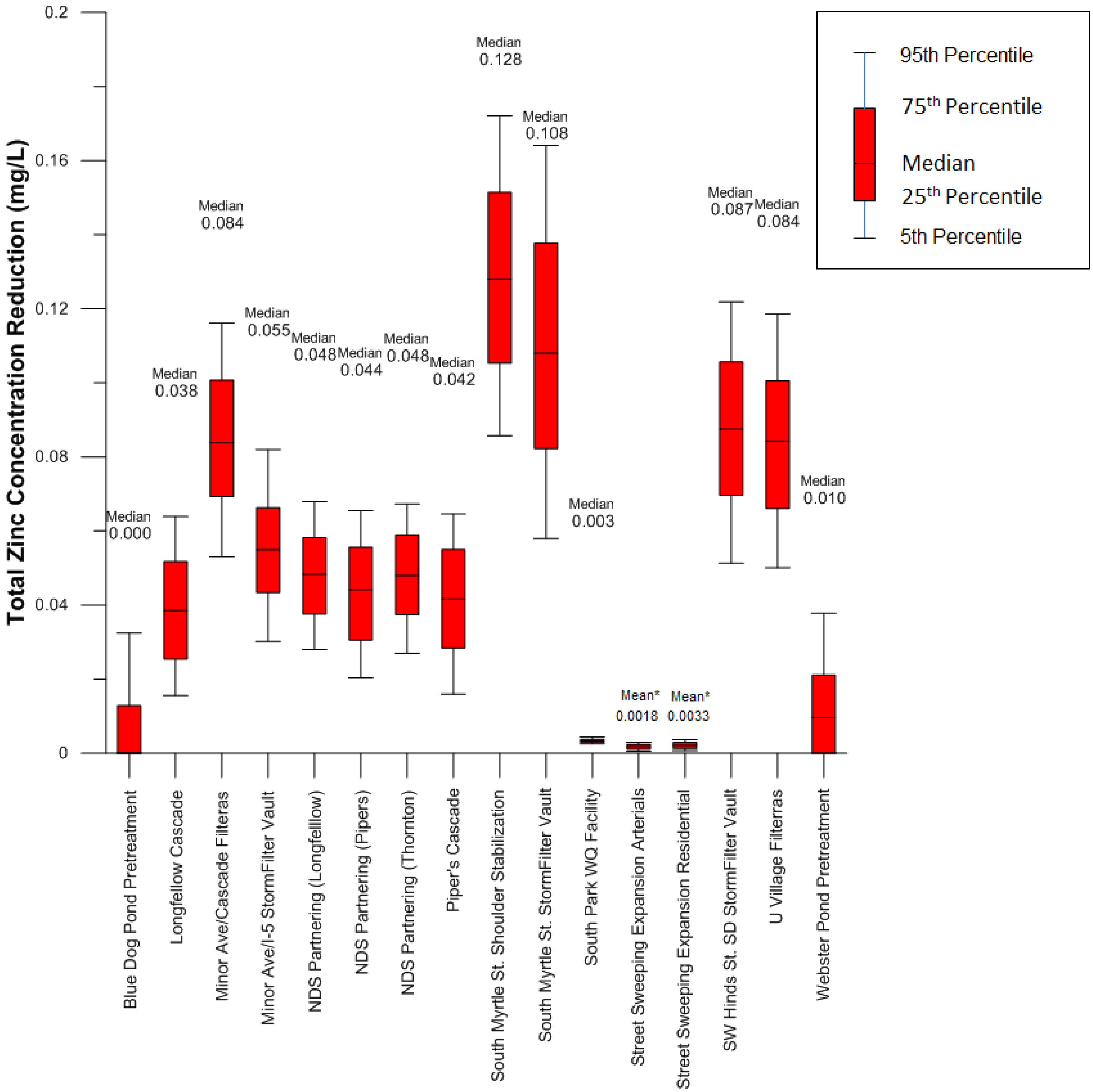

Figure F-3i. Long-term average annual concentration reduction for total zinc

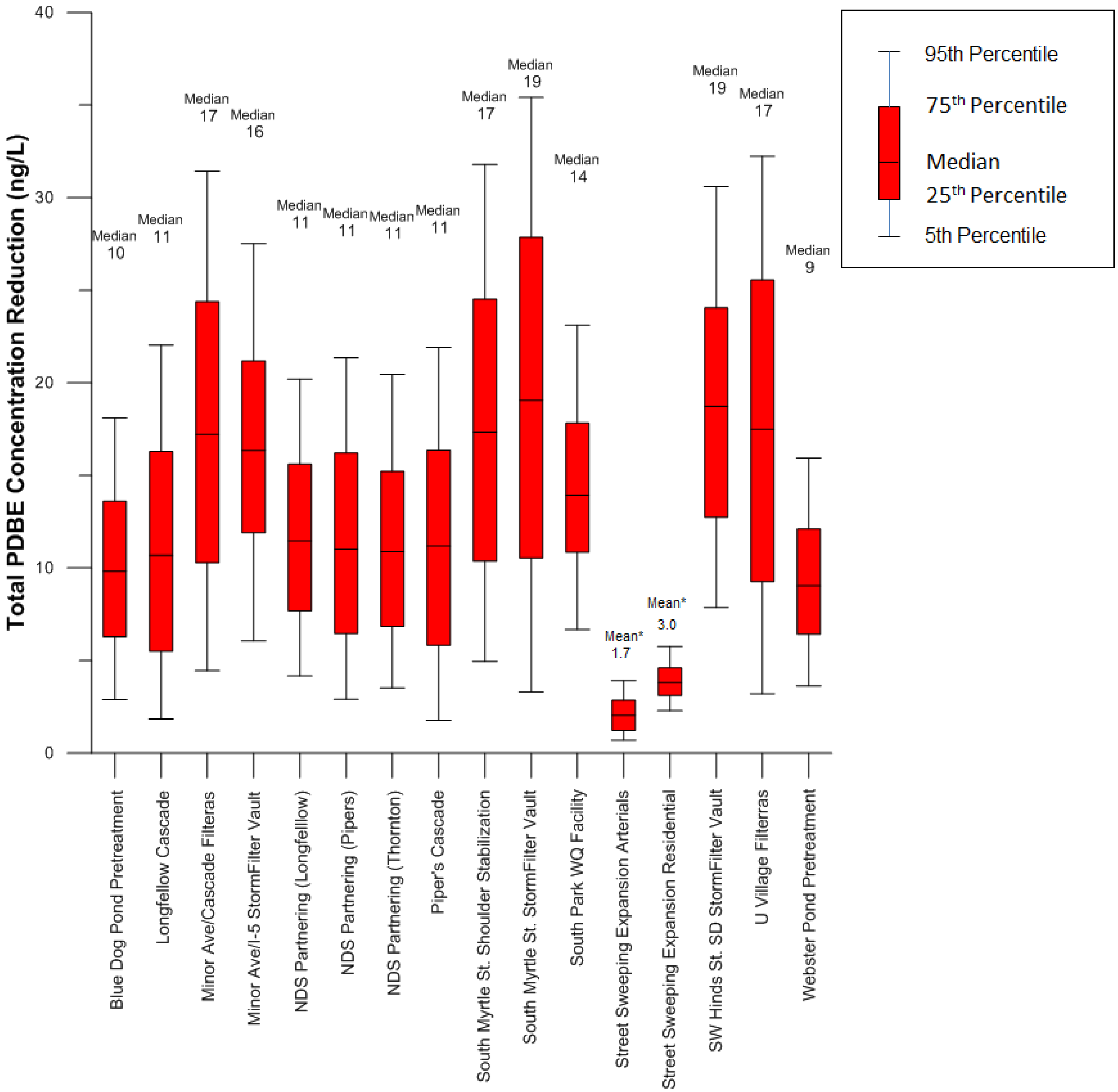

Figure F-3j. Long-term average annual concentration reduction for total PBDEs

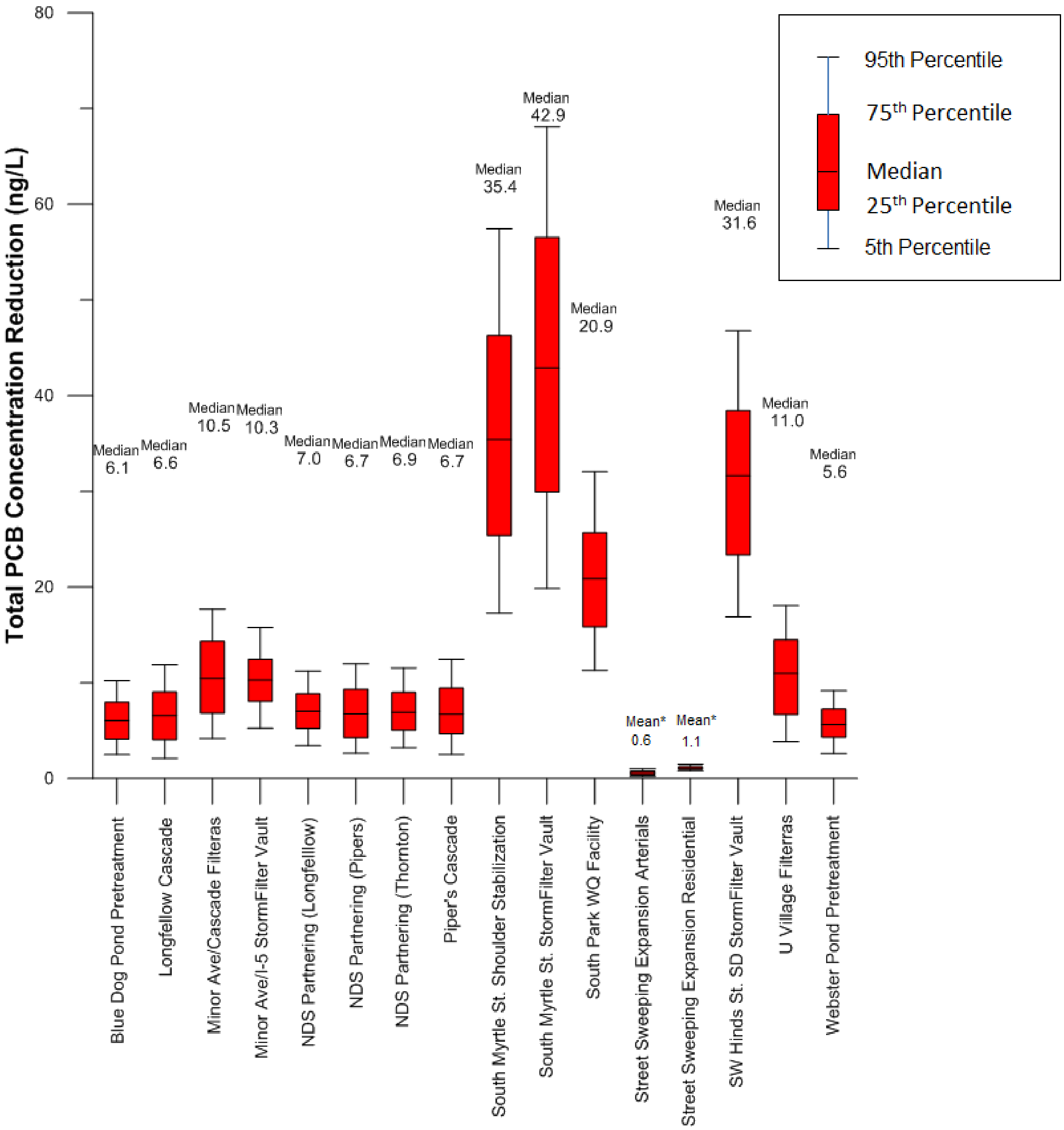

Figure F-3k. Long-term average annual concentration reduction for total PCBs

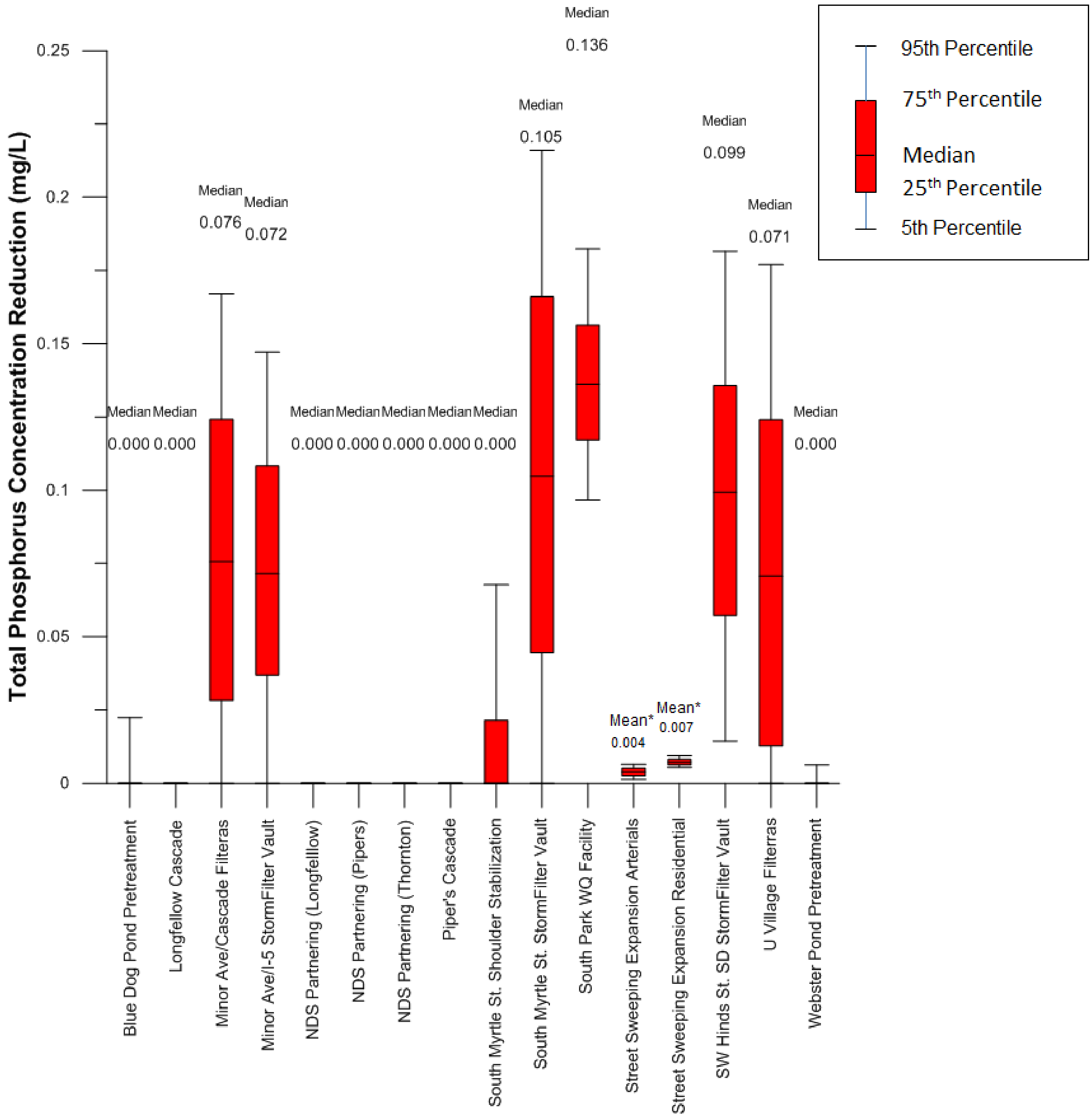

Figure F-3l. Long-term average annual concentration reduction for total phosphorus

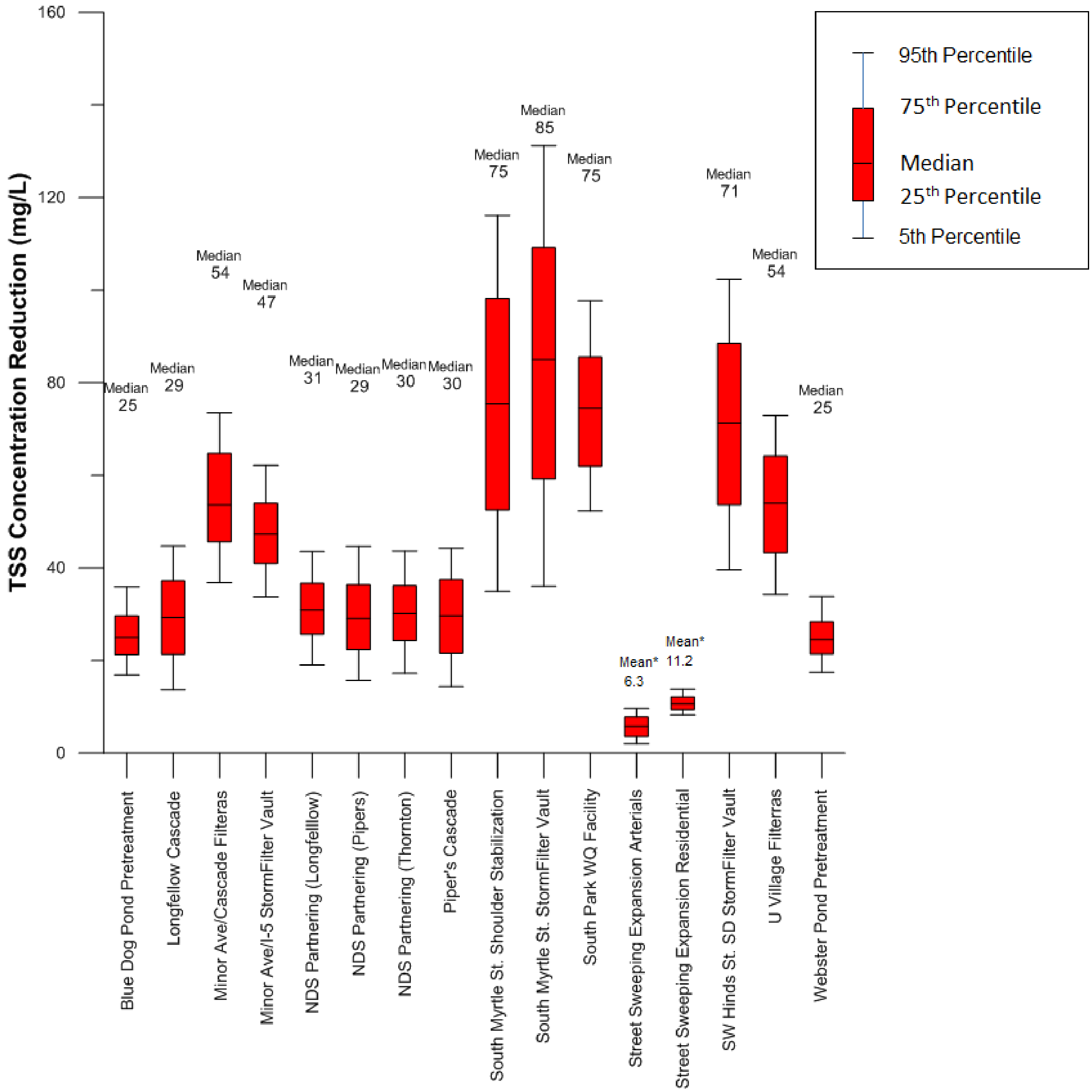

Figure F-3m. Long-term average annual concentration reduction for total phosphorus

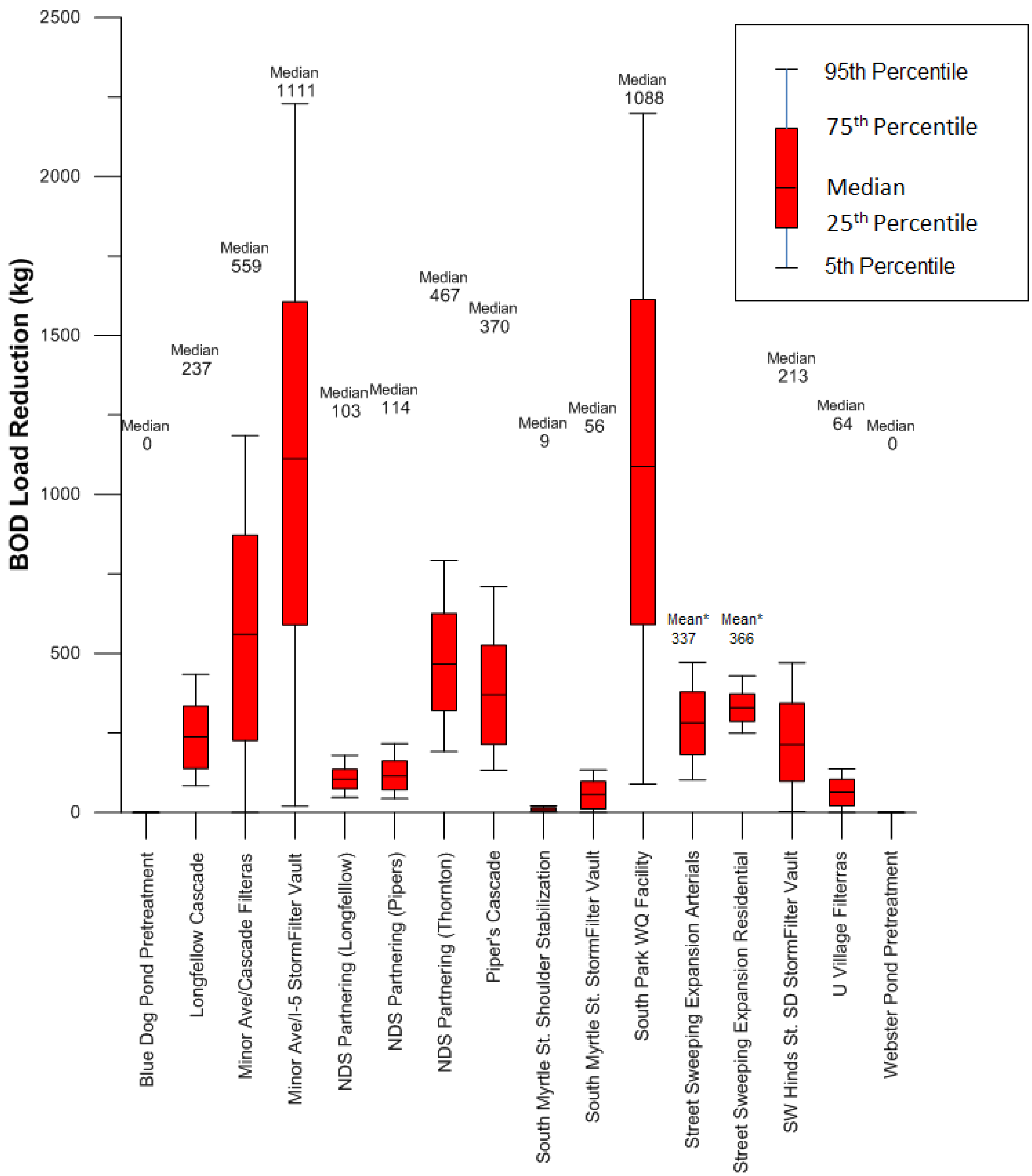

Figure F-3n. Long-term average annual load reduction for BOD_5

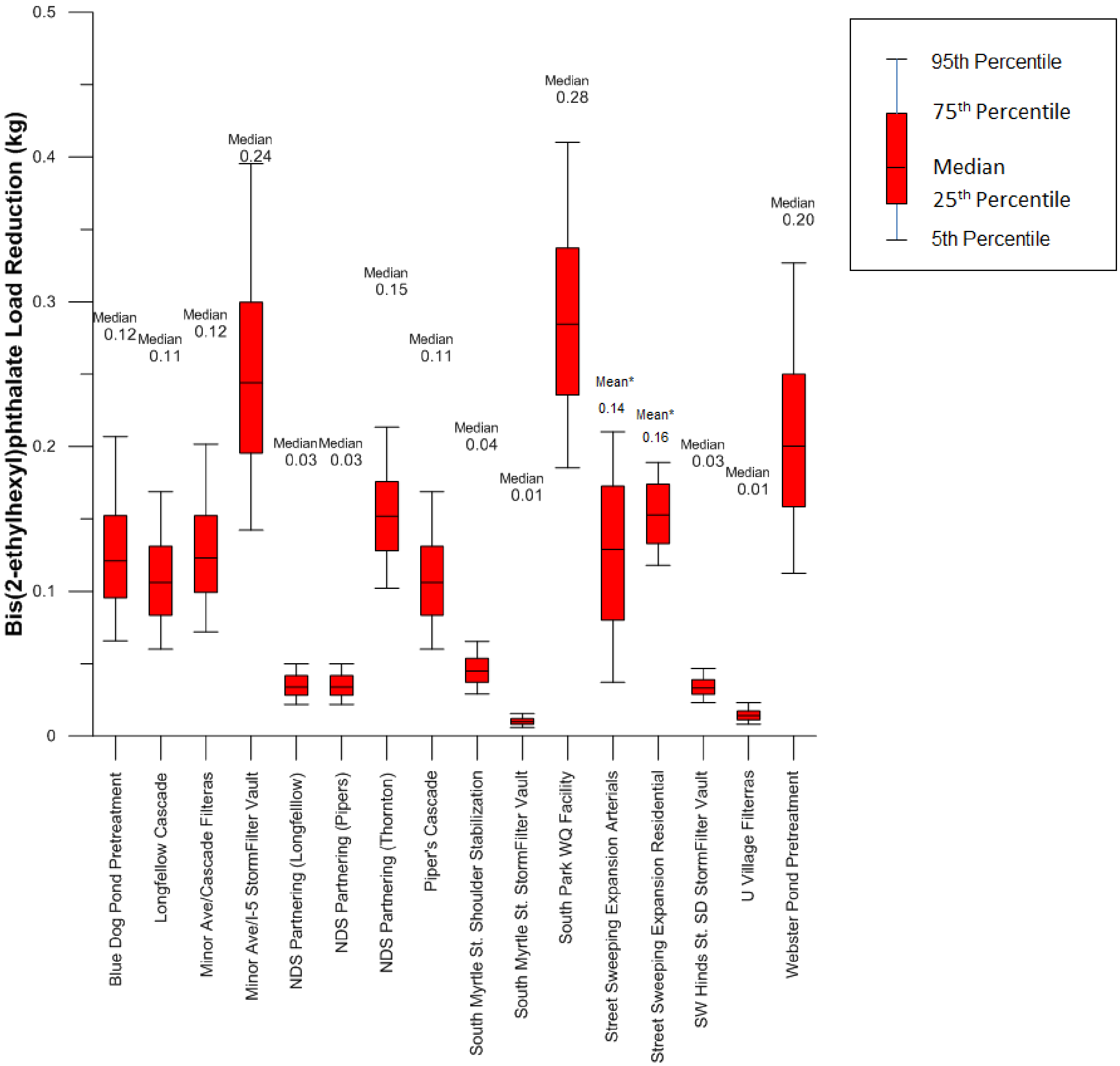

Figure F-3o. Long-term average annual load reduction for bis(2-ethylhexyl)phthalate

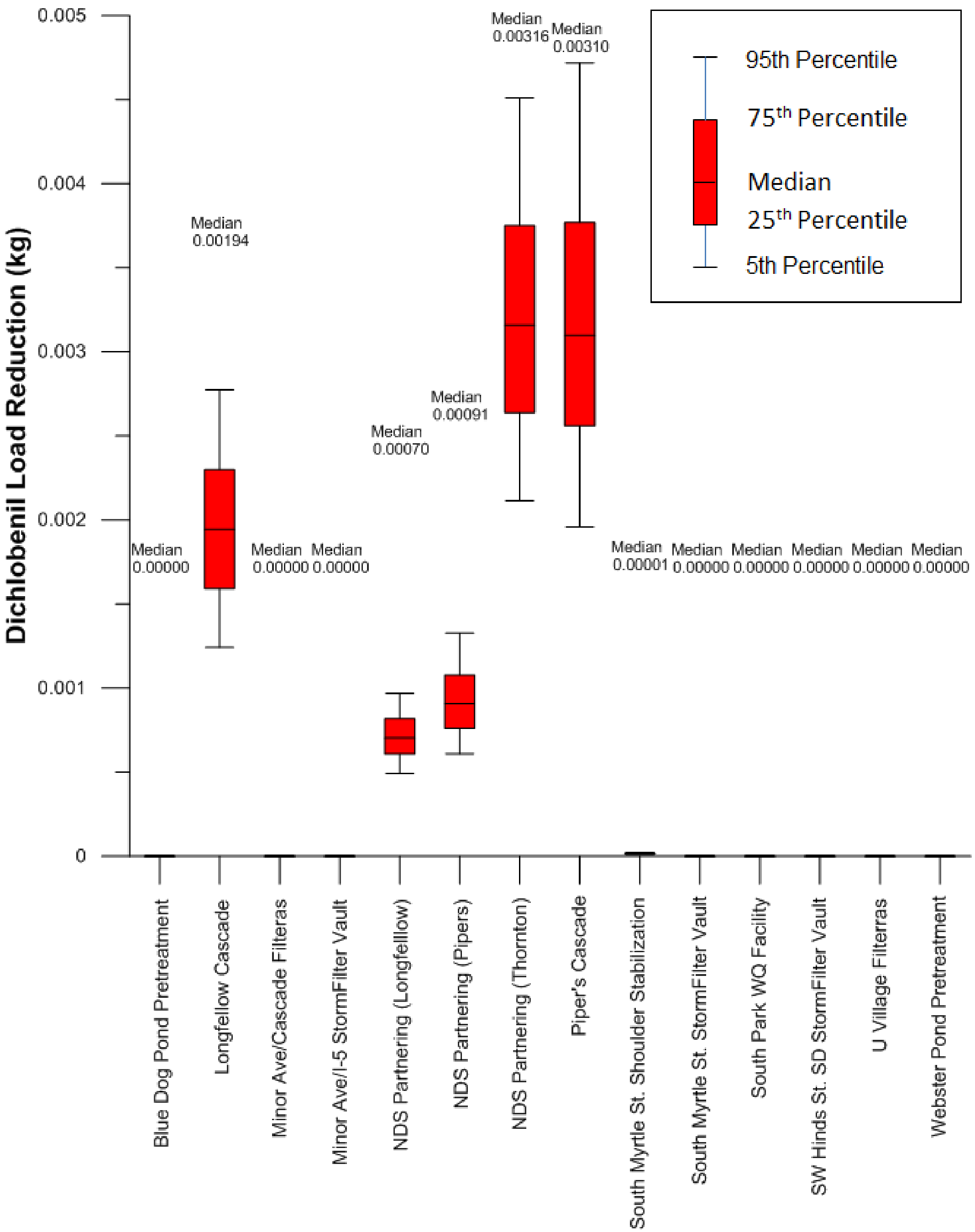

Figure F-3p. Long-term average annual load reduction for dichlobenil

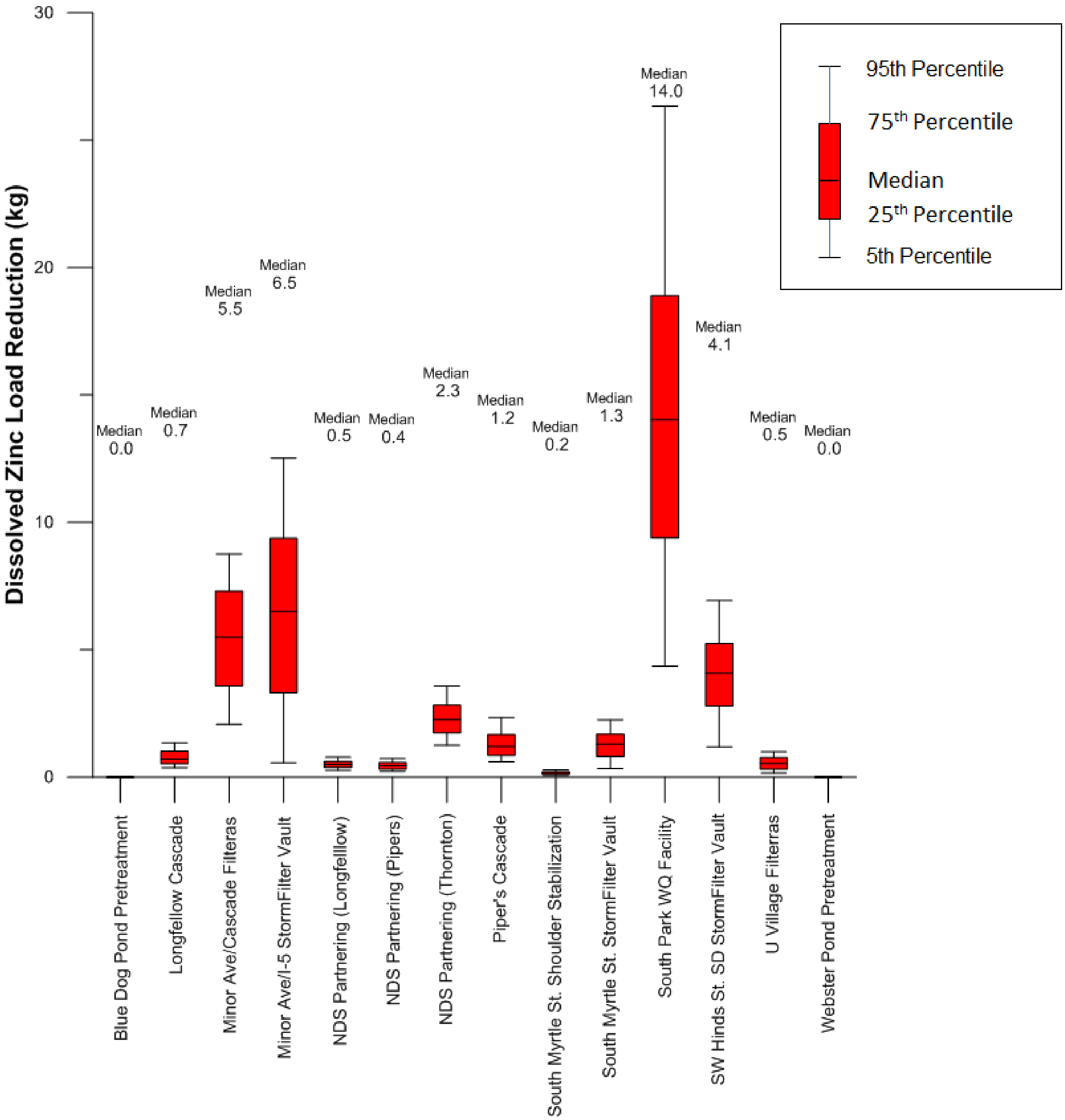

Figure F-3q. Long-term average annual load reduction for dissolved zinc

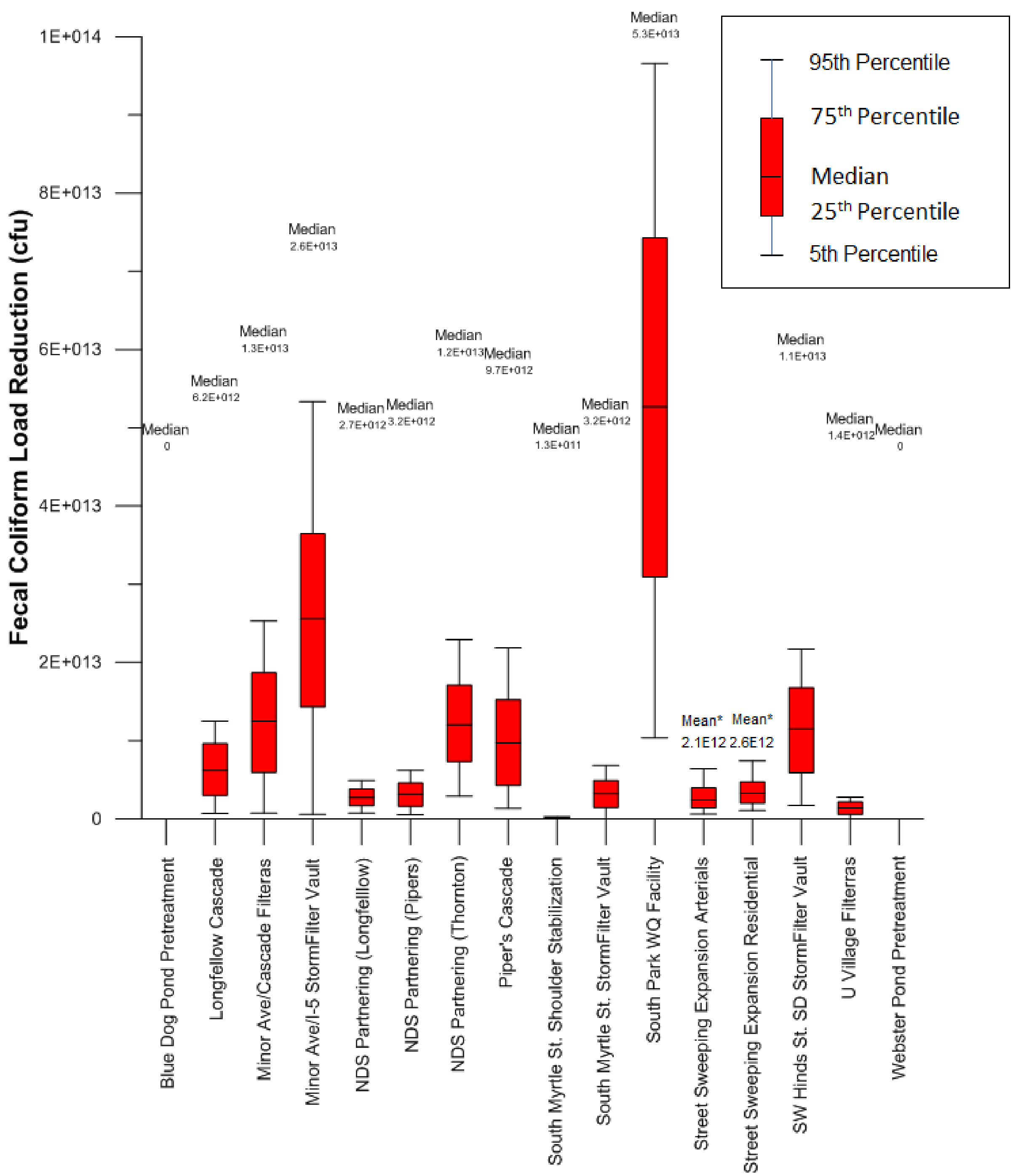

Figure F-3r. Long-term average annual load reduction for fecal coliform bacteria

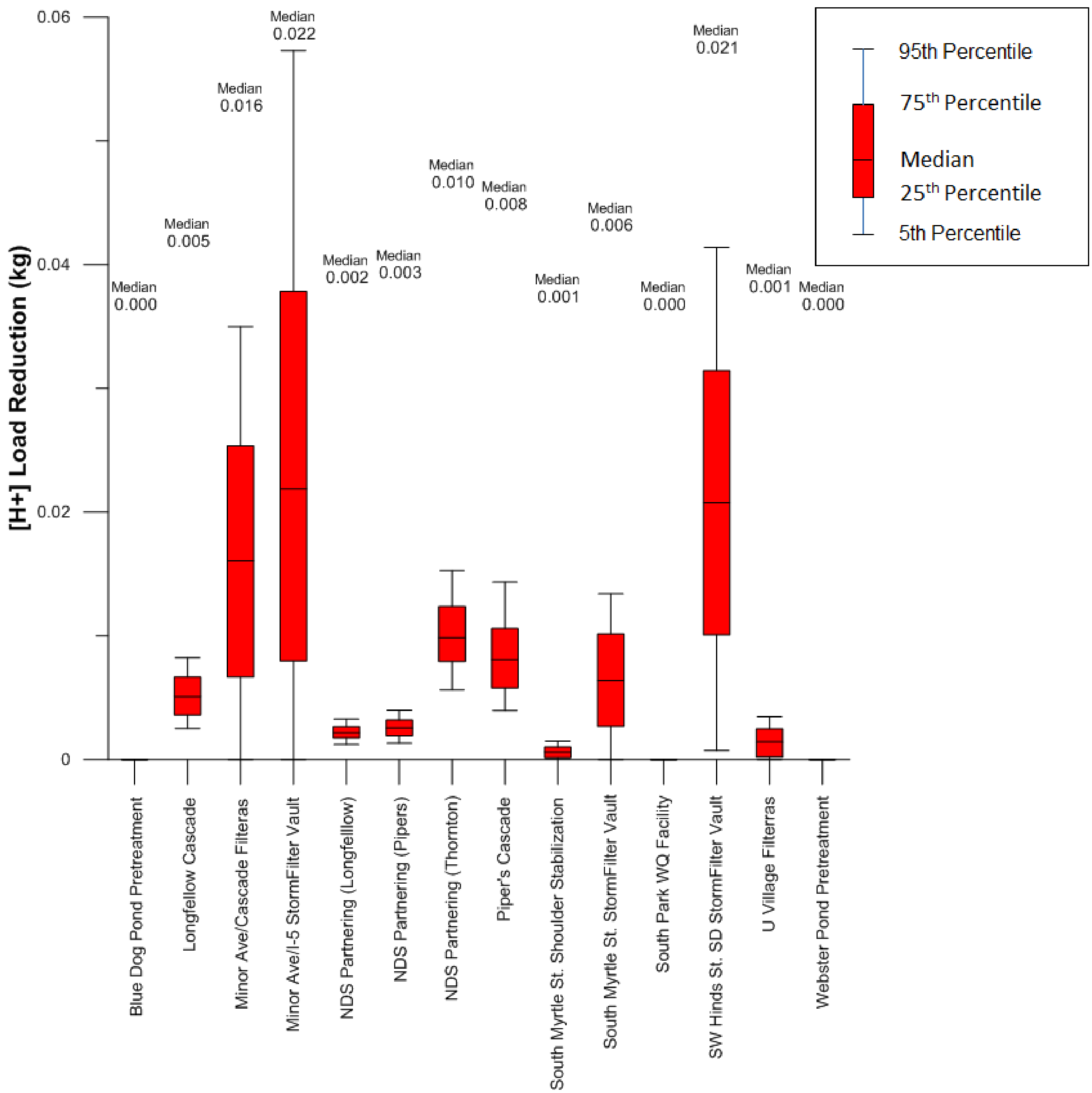

Figure F-3s. Long-term average annual load reduction for [H+]

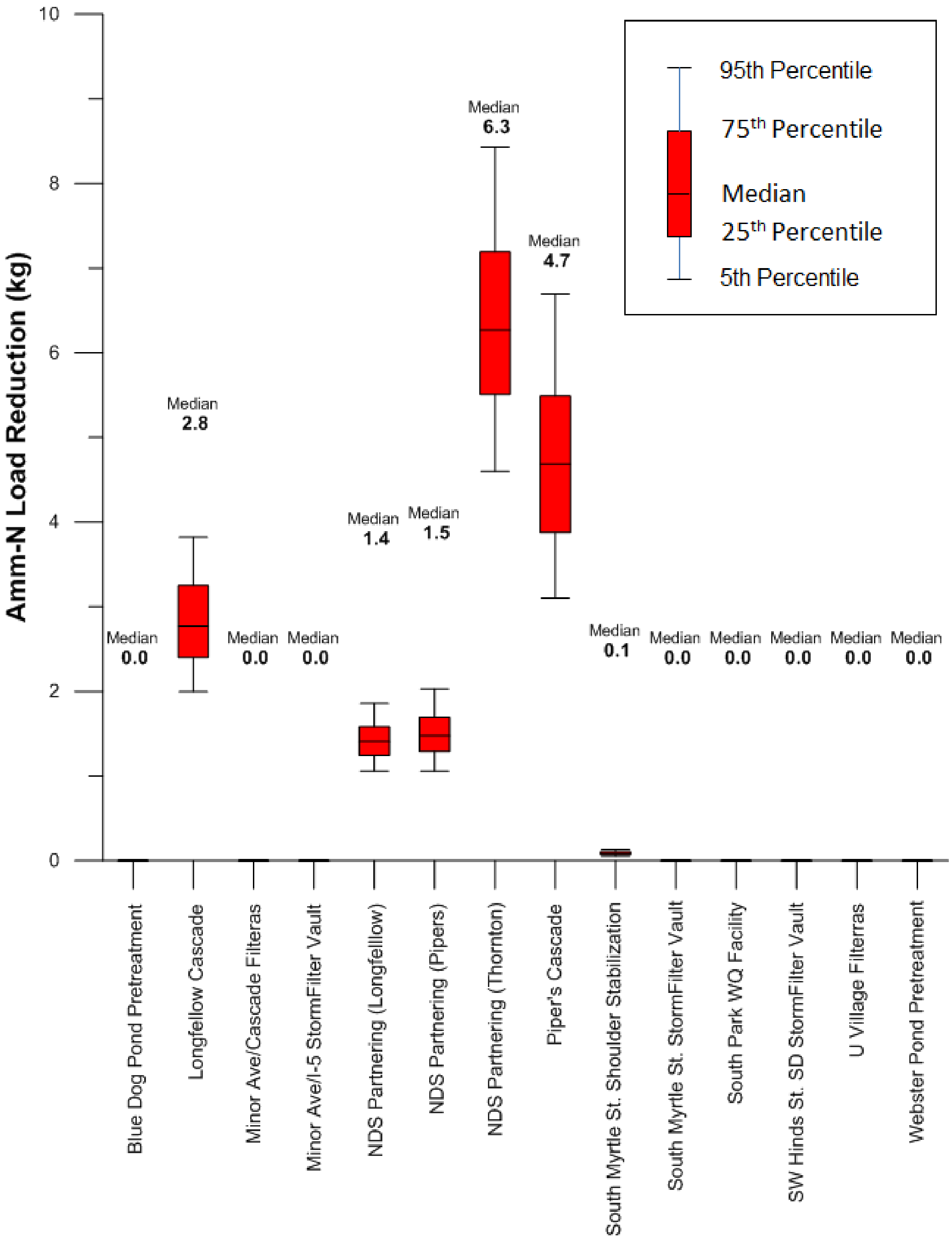

Figure F-3t. Long-term average annual load reduction for ammonia-N

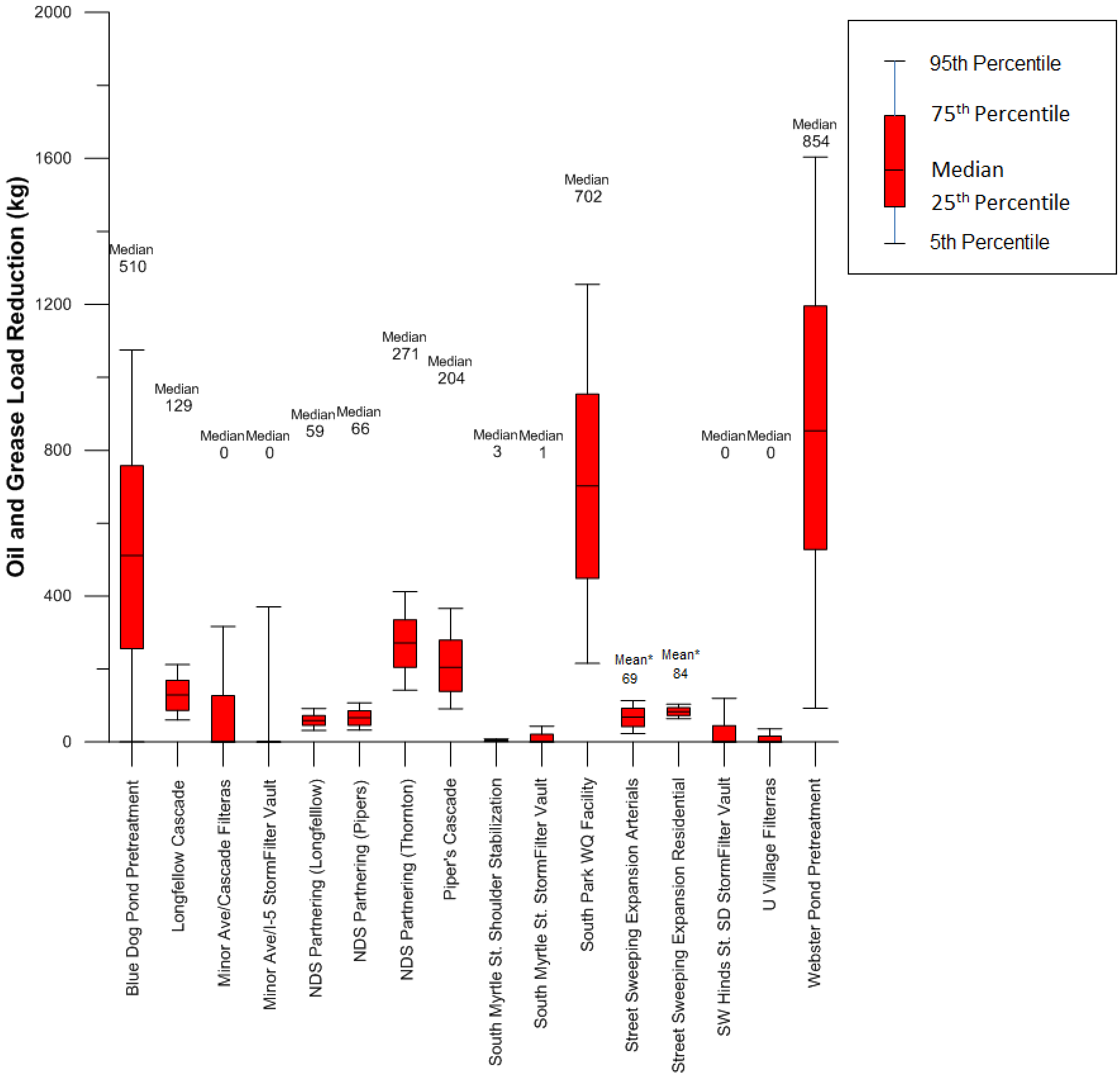

Figure F-3u. Long-term average annual load reduction for oil and grease

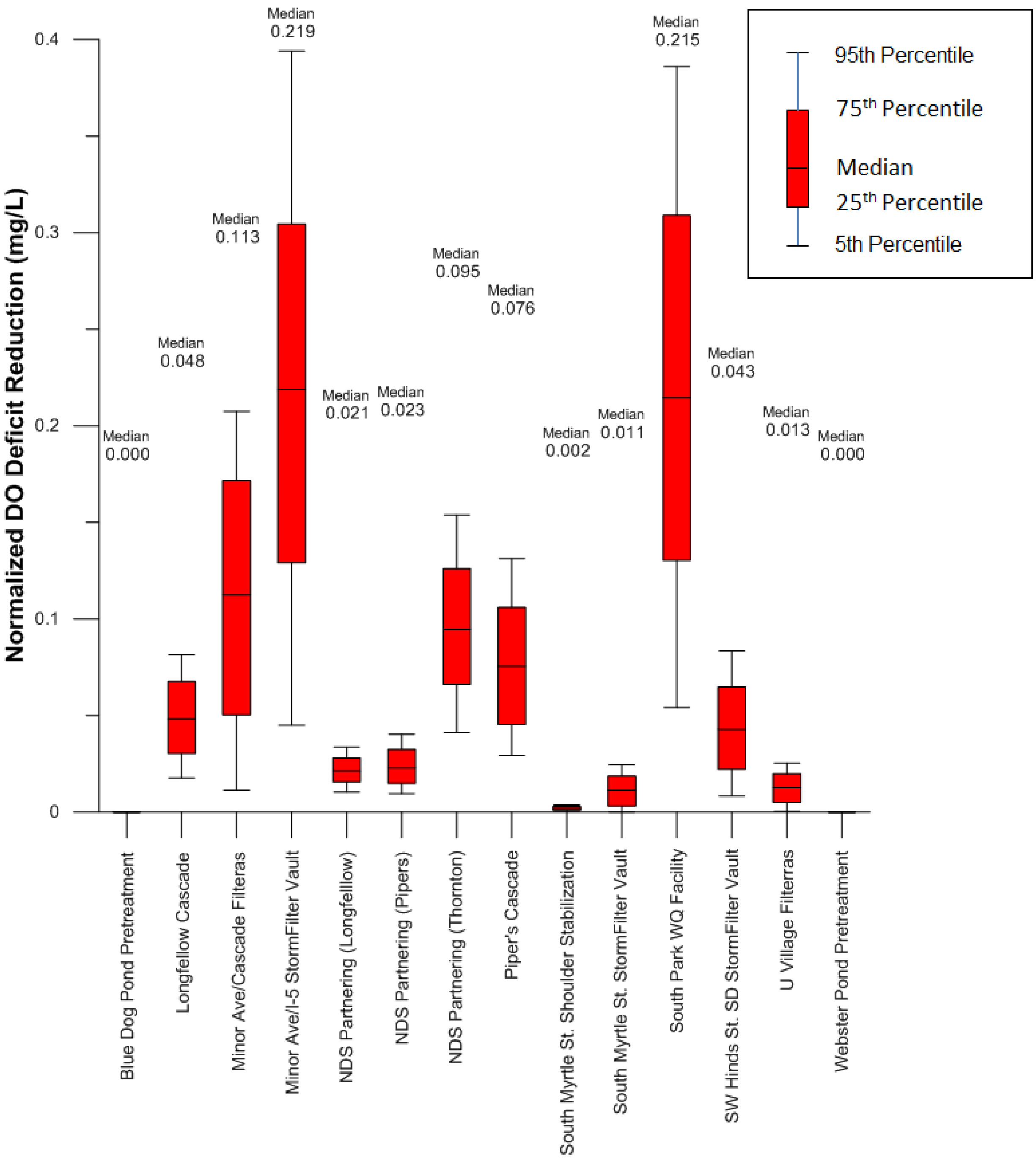

Figure F-3v. Long-term average annual load reduction for normalized DO

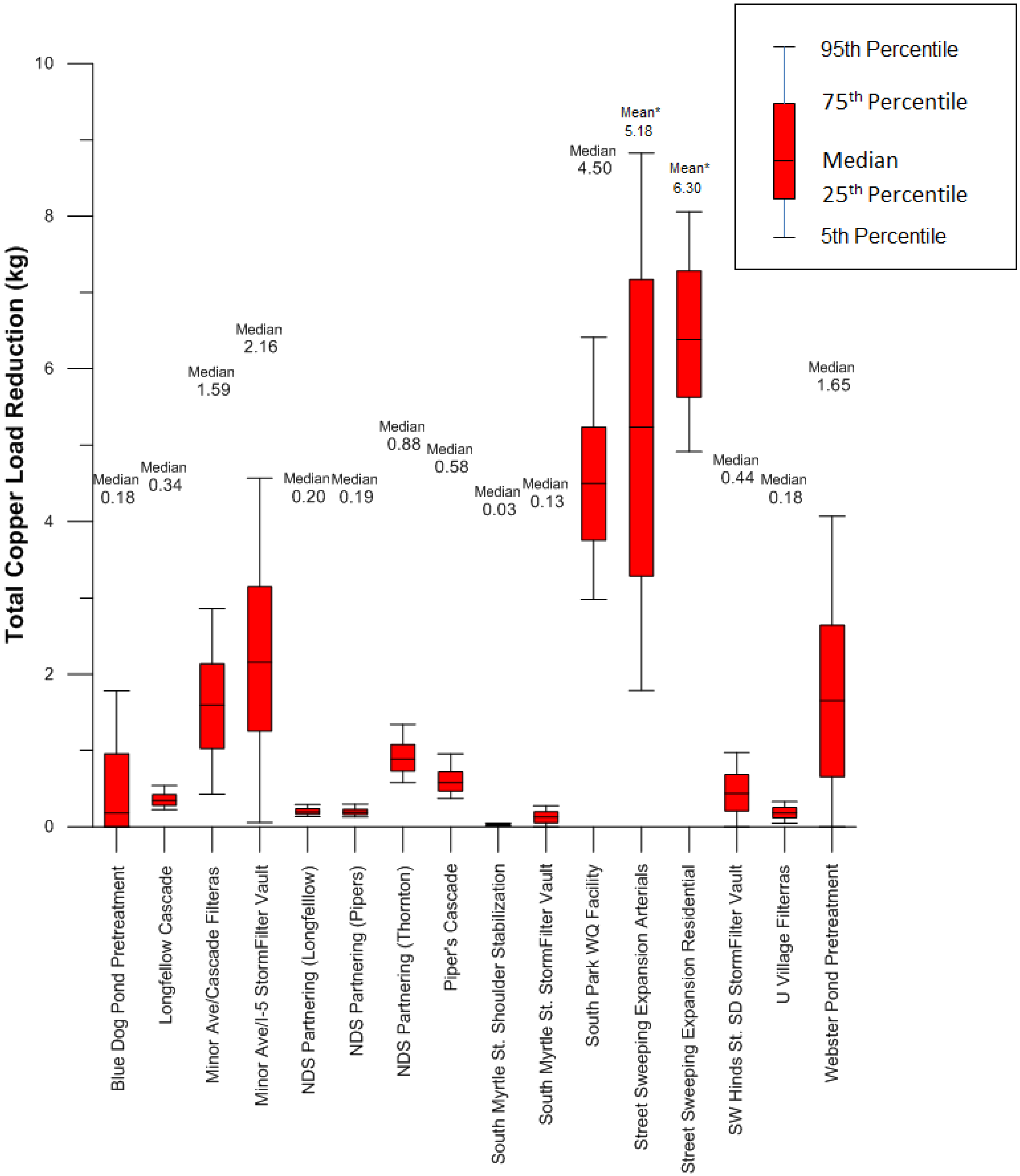

Figure F-3w. Long-term average annual load reduction for total copper

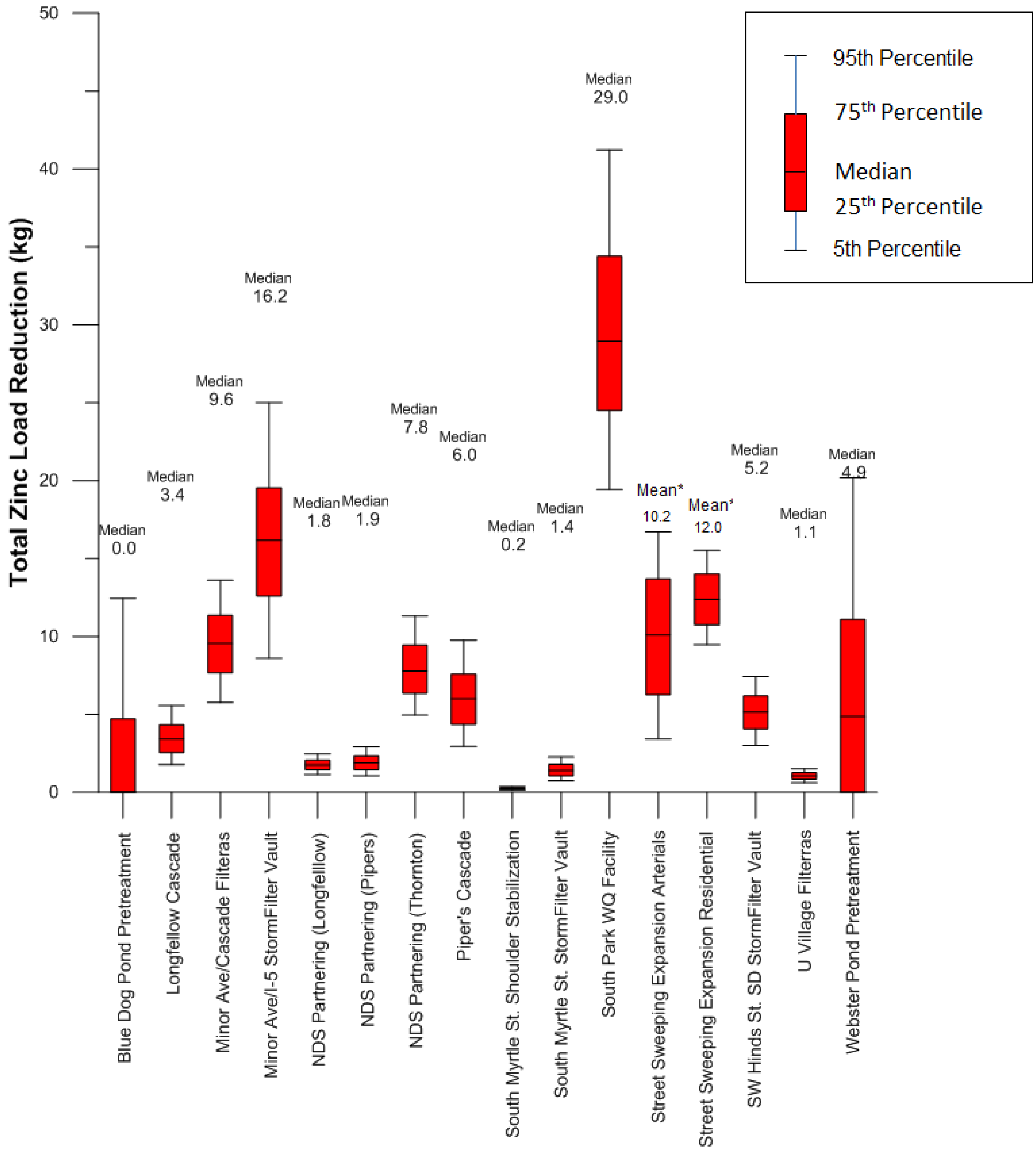

Figure F-3x. Long-term average annual load reduction for total zinc

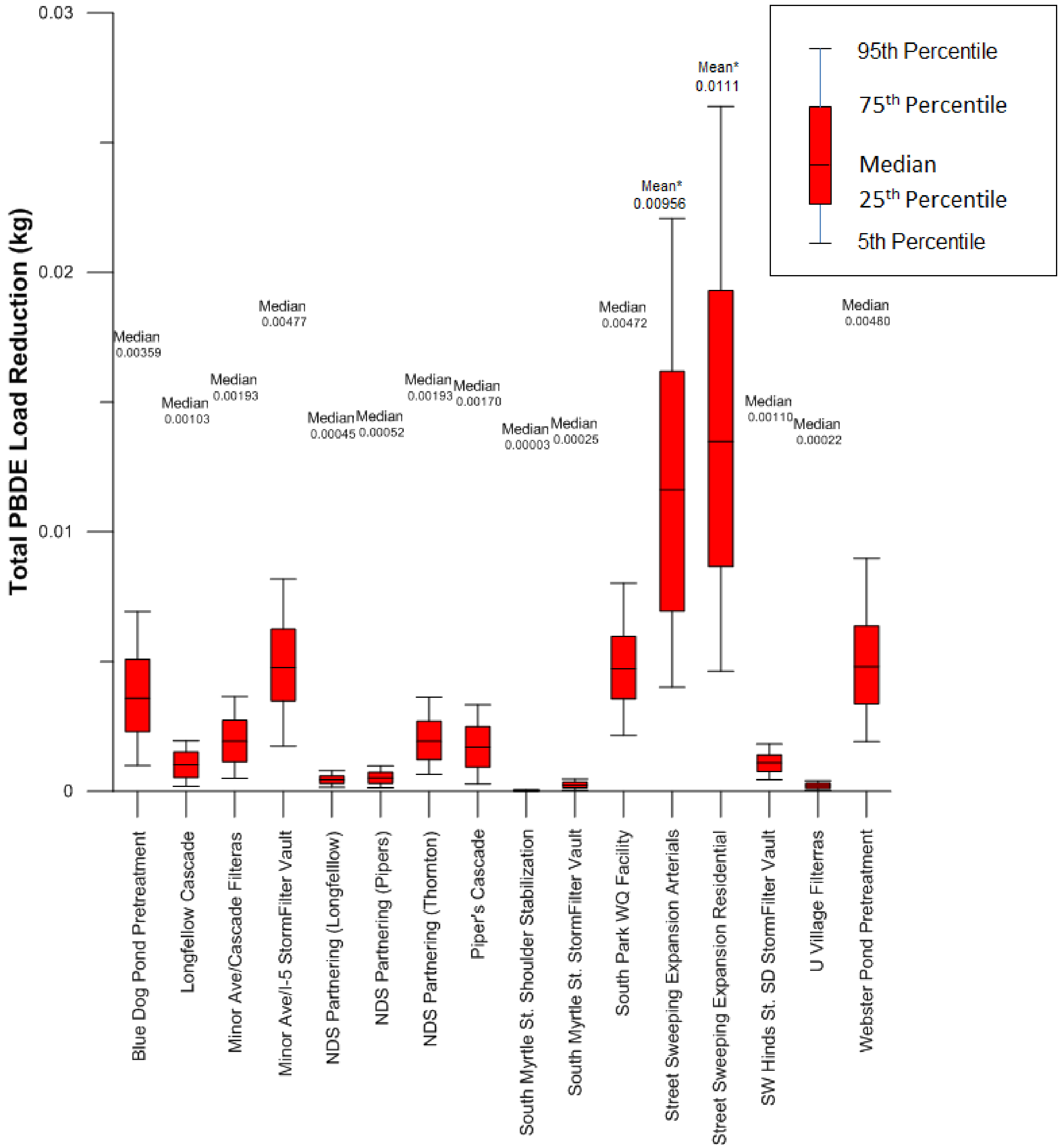

Figure F-3y. Long-term average annual load reduction for total PBDEs

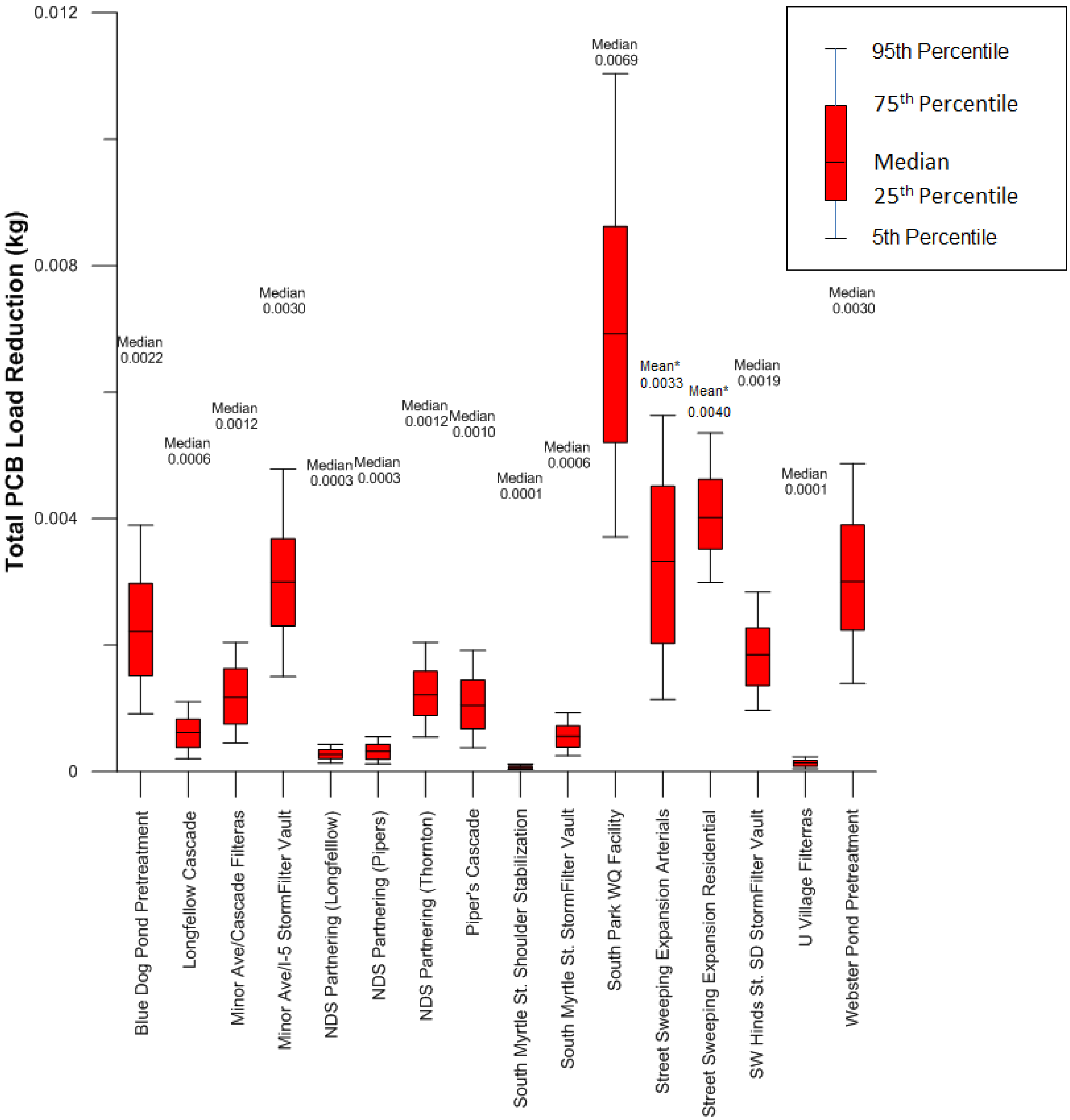

Figure F-3z. Long-term average annual load reduction for total PCBs

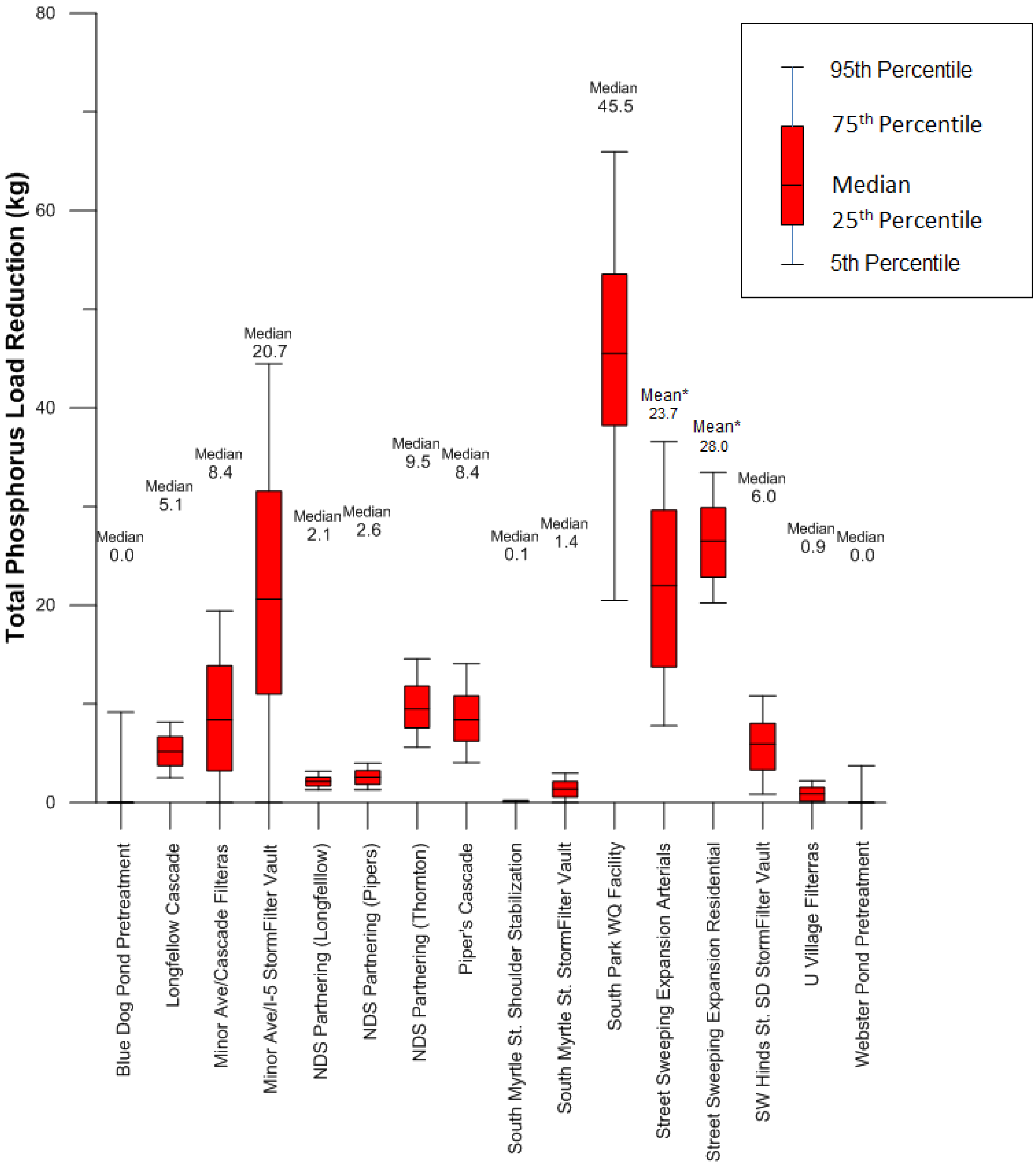

Figure F-3aa. Long-term average annual load reduction for total phosphorus

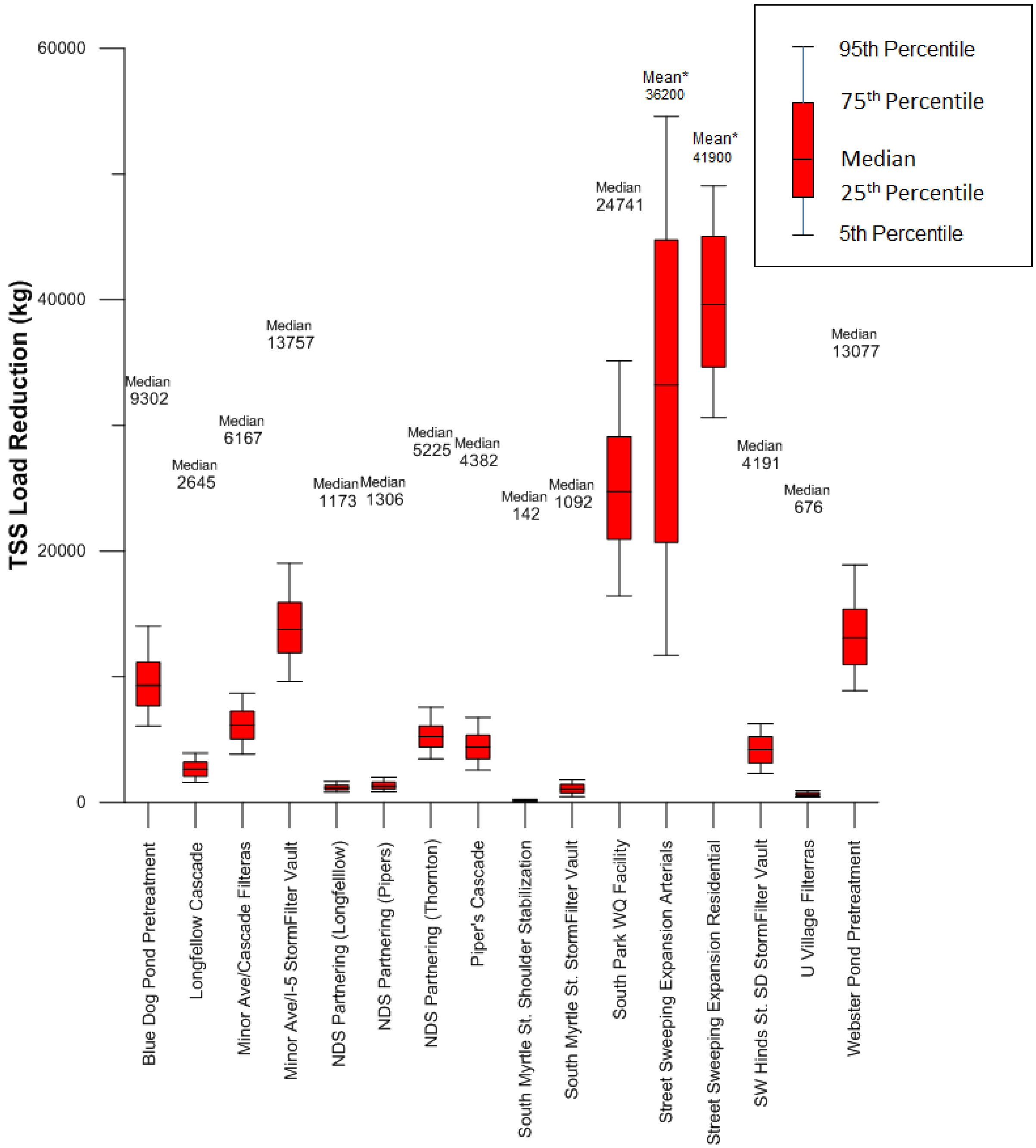

Figure F-3bb. Long-term average annual load reduction for TSS

Appendix G: Pollutant Reduction Estimation Method—Candidate Stormwater Street Sweeping Programs

Seattle Public Utilities

Protecting Seattle's Waterways

Volume 3 – Integrated Plan

Appendix G: POLLUTANT REDUCTION ESTIMATION METHOD—CANDIDATE STORMWATER STREET SWEEPING PROGRAMS

Final

May 29, 2015

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Attachment G-1: Summary of Descriptive Statistics

Attachment G-2: Sample Concentration Box Plots

List of Abbreviations

Term	Definition
°F	degree(s) Fahrenheit
µg	microgram
µm	micrometer
AVL	Automatic Vehicle Location
BMP	best management practice
BOD	biochemical oxygen demand
BTEX	benzene, toulene, ethylbenzene, xylene
BWOF	Bellevue washoff factor
CFU	colony forming unit(s)
COD	chemical oxygen demand
CSO	combined sewer overflow
curb-mile	the total miles swept along the curb during a certain time period, typically on an annual basis
DSL	dry solids load
EPA	U.S. Environmental Protection Agency
Fine PM	fine particulate matter (less than 250 µm diameter particles)
g	gram(s)
IQR	interquartile range
kg	kilogram
KPI	Key Performance Indicator
lane mile	The length of a defined street sweeping route. Typically there are two lane miles for each mile of street length but may be more if the street has a divider.
lb	pound(s)
LIMS	Laboratory Information Management System
MAG	Maricopa Association of Governments
mg	milligram(s)
MG	million gallons
mL	milliliter(s)
mm	millimeter(s)
NPDES	National Pollutant Discharge Elimination System
NSQD	National Stormwater Quality Database
NURP	Nationwide Urban Runoff Program
PCB	polychlorinated biphenyl
PES	primary environmental sample
PM	particulate matter
Program	Street Sweeping for Water Quality Program
PSD	particle size distribution
PV	Present Value
PV$	life-cycle cost
RCOC	Representative Constituent of Concern
SAFL	St. Anthony Falls Laboratory
SPLP	Synthetic Precipitation Leaching Procedure
SVOC	semi-volatile organic compound
swt	short wet tons
SDOT	Seattle Department of Transportation
TS	total solids
TSS	total suspended solids
TKN	total Kjeldahl nitrogen
WOF%	washoff fraction
WOFL	washoff fraction load
WQ	water quality
WSL	wet solids load
WWHM	Western Washington Hydrology Model
yr	year(s)

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CHAPTER 1

Introduction/Overview

This appendix describes the methodology used to estimate washoff particulate-bound pollutant load and concentration reductions for the Integrated Plan candidate stormwater Street Sweeping Expansion Arterials and Street Sweeping Expansion Residential programs. These programs expand on the Street Sweeping for Water Quality Program (Program), a partnership between Seattle Public Utilities and Seattle Department of Transportation (SDOT), which began in February 2011. The objectives of the candidate stormwater street sweeping programs is to cost-effectively reduce the pollutant load running off Seattle's streets and discharging to receiving waters where feasible.

1.1 Candidate Stormwater Street Sweeping Programs

Two candidate stormwater street sweeping programs are included in the Integrated Plan analysis:

- **Street Sweeping Expansion Arterials** augments the current program scope. The target is to sweep 85 percent of curbed arterials during the night by increasing the current sweeping frequency and extending the sweeping season in order to increase the washoff pollutant load removed; i.e., the load picked up by the sweeper that would have washed into the storm drain, from approximately 90,000 to approximately 120,000 kilograms per year (kg/yr). Potentially 25 routes will be swept: 4 on a biweekly basis and 21 on a weekly basis, increasing the annual sweeping from the current amount of 10,000 up to 20,700 curb-miles. A formal parking compliance program is not anticipated.
- **Street Sweeping Expansion Residential** expands into new areas. The target is to sweep 65 percent of curbed local residential streets during the day and reduce the washoff pollutant load by approximately 40,000 kg/yr. Potentially 24 routes would be swept biweekly covering 11,500 curb-miles annually. A phased curb access program will be implemented, beginning with public outreach and, if needed, including parking enforcement (parking enforcement costs are included in the cost estimate).

At full implementation, the current and candidate Street Sweeping Expansion Arterials and Street Sweeping Expansion Residential programs are anticipated to reduce the citywide annual pollutant load discharging to the municipal separate storm sewer system by approximately 5 percent.

1.2 Objective

The objective of this analysis is to characterize the candidate stormwater street sweeping programs pollutant load reductions to: (1) meet the Consent Decree Integrated Plan requirements for pollutant load reduction estimates and (2) for comparison with other Integrated Plan candidate projects from the perspective of the measurable conditions at the outfall. The basis of comparison is a washoff load, the load that would have been washed off the street to the storm drain had it not been picked up by the sweeper.

The characterization includes the following estimates:

- annual pollutant washoff load reduction from selected streets
- average annual washoff concentration reduction from selected streets for relative comparison with candidate projects and literature values

1.3 Selected Approach

The selected approach builds on the methodology implemented in 2007 to support SPU asset management principles, which determine when and where to make investments. The following triple-bottom-line metrics are typically used to compare and contrast candidate water quality projects and programs:

- Environmental benefits are represented by the average annual pollutant load removed (total suspended solids [TSS] per year).
- Economic considerations are represented by the project cost-effectiveness (life-cycle cost [PV$] per kg of TSS removed per year [PV]).
- The social costs and benefits are typically represented qualitatively.

In 2010, an equivalent environmental TSS benefit metric was developed for street sweeping, a source-control best management practice (BMP), to allow comparison with water quality treatment BMPs. SPU assumed that the fine particulate matter (Fine PM), material less than 250-micrometer (µm) diameter, removed by the sweeper represents the particles that would be suspended in stormwater[1]. The Fine PM is approximately 20 percent of the total load removed by sweeping. A similar approach was adopted by the Chesapeake Bay Program Expert Panel in March 2011 (Schueler, 2011).

In October 2013, based on input from the Integrated Plan Expert Panel, a more conservative approach was adopted for this analysis. The selected approach uses a washoff load, the particulate-bound pollutant load that would have been washed off the street to the storm drain had it not been picked up by the sweeper, as a basis for comparing street sweeping water quality benefits with structural stormwater treatment BMPs.

1.4 Key Assumptions

The washoff load, which is approximately 12 percent of the total load removed by sweeping, is estimated by applying the same percent washoff by size fraction and season observed by Pitt (1985) for street dirt washoff rates measured before and after rains in Bellevue, Washington.

Pollutant load and concentration reductions are reported for the washoff particulate-bound fraction only.

- The washoff particulate-bound pollutant load reductions do not consider the seasonal volatile components removed by the sweeper; for example, fall leaf drop and grass clippings. Others (Kalinsky, 2012; Strynchuck, 2000) found that those components have the potential to increase oxygen demand and contribute to nutrient loading.
- The washoff particulate-bound pollutant load reductions do not consider the potential for metals leaching. Synthetic Precipitation Leaching Procedure (SPLP) tests on the sweepings indicate that this is a possibility (see Attachment G-2, Figures G-2g and G-2h).

1 Structural treatment BMPs typically have a range of removal performance and automatic samplers have been reported to be less reliable at capturing particulate matter (PM) greater than 250 µm (Clark et al., 2007).

The washoff particulate-bound pollutant load reduction is estimated based on measured pick-up rates, the particulate-bound pollutant load removed per curb-mile swept.

1.5 Method Overview

The data used to develop the load reduction estimates were collected by SPU to support performance monitoring for the Program. Currently, 24 routes covering 675 lane miles, of which 490 lane miles (73 percent) drain directly to the storm sewer system, are scheduled for sweeping. This includes 16 night routes and 4 day routes that are swept on a biweekly basis and 4 night routes on a weekly basis. There is no formal parking compliance program at this time.

In 2011, pick-up rates, pollutant load reduction per curb-mile swept, were established as Program Key Performance Indicators (KPIs) and for planning metrics. Table 1-1 provides measured average annual pick-up rates by year through 2013.

Table 1-1. Program Average Annual Pick-Up Rates by Year through August 2013 (lb/curb-mile swept)

Pick-up rates	2011	2012	2013
Wet solids load (lb/curb-mile)	230	270	252
Dry solids load (lb/curb-mile)	150	170	160
Fine PM load (lb/curb-mile)	30	38	34
Washoff PM load (lb/curb-mile)	19	22	19

The wet and dry solids loads include the total load removed, regardless of the size fraction. The Fine PM load only includes the material less than 250 µm.

For the purposes of the Integrated Plan, the use of pick-up rates as a planning metric is expanded to include the Representative Constituents of Concern (RCOC).

- The candidate Street Sweeping Expansion Arterials and Street Sweeping Expansion Residential programs estimated that washoff load reductions for each RCOC are the product of the planned curb-miles for the program for a sweeping frequency times the pick-up rate for the program and sweeping frequency for each RCOC.
- The washoff concentration reduction is the quotient of the estimated load reduction for each RCOC divided by the average annual runoff volume.

Figure 1-1 provides an overview of the process for developing the load and concentration reductions.

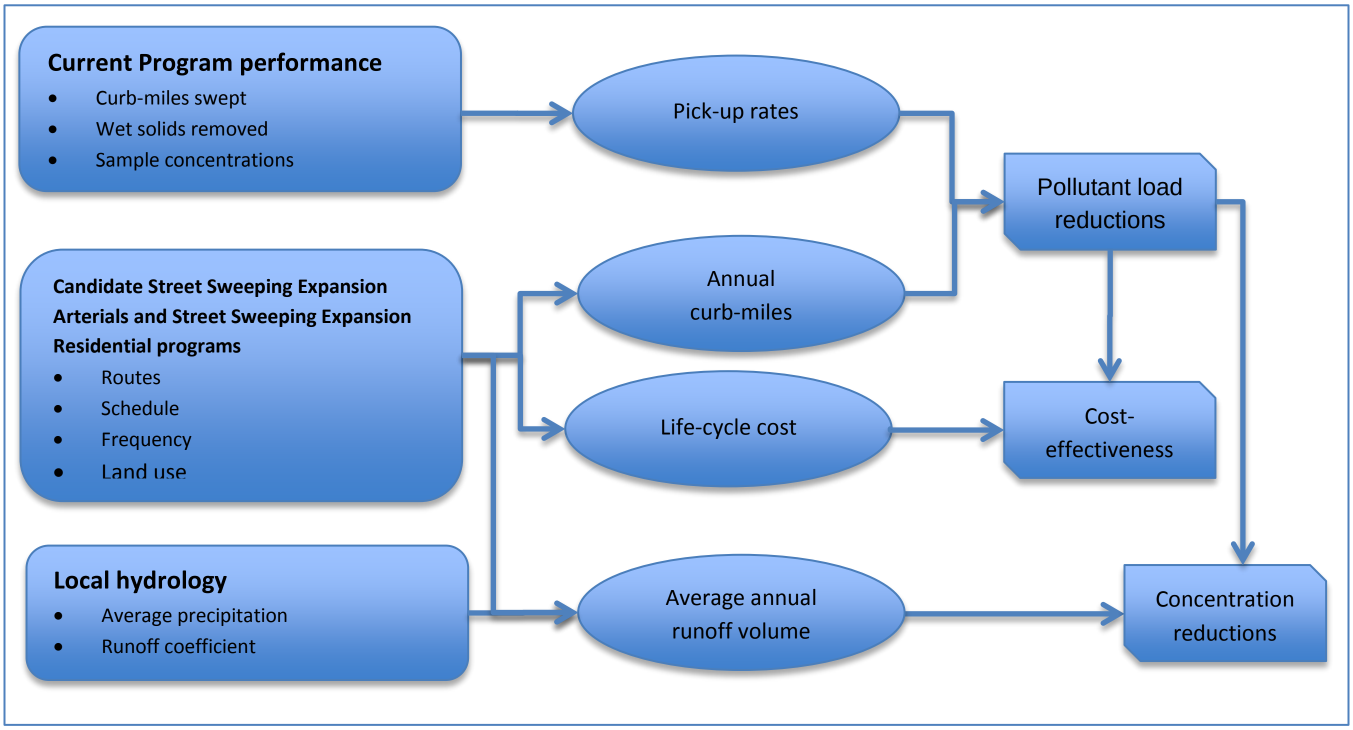

Figure 1-1. Overall process for developing candidate stormwater street sweeping programs performance metrics

1.6 Issues for Further Consideration

During the process of developing pollutant load and concentration reduction estimates for the candidate stormwater street sweeping programs, several areas were identified that may be considered for additional analysis in the future. These include:

- development of a representative dry season fecal coliform pick-up rate
- establishment of the representativeness of particles less than 250 µm in diameter to estimate the concentration of washoff particles
- expansion of the parameter list to include ammonia-N and other organic compounds of interest
- development of a more representative biological oxygen demand (BOD) metric
- development of a relationship to estimate dissolved metals pollutant load and concentration reductions
- development of a method to estimate seasonal volatile solids loadings (e.g., fall leaf drop)
- confirmation that the washoff assumptions are appropriate for the candidate Street Sweeping Expansion Arterials program

1.7 Limitations

The reader should consider the following limitations of the analysis:

- The cost estimate for the candidate Street Sweeping Expansion Arterials program assumes that funding for the portion of the routes draining to the combined sewer system will be provided. This will require an approximate doubling of the SDOT current budget to support the Program.
- The analytical sample results have undergone the process of data review, verification, and validation. The process of quality assessment to ensure that the data meet the quality to support the intended use is ongoing.
- The aggregate nature of the load estimates limits the ability to predict load reductions under different sweeping frequency, land use, road type, and parking compliance conditions.
- The results represent the sweeping practices, sweeping conditions, and rainfall patterns over the course of the period of record.
- The data set is not robust enough to adequately characterize highly variable parameters, such as fecal coliform. Street solids pollutant concentrations are strongly influenced by the particle size and density (ITRC, 2012). In addition, contaminants may bond loosely or tightly to street solids depending on the geochemical makeup of the soil, organic matter content, ambient conditions, and physical and chemical properties of a particular pollutant. Collecting representative samples is challenging.

1.8 Document Organization

This document is organized into three main topics:

- Chapter 2: Data compilation, which describes the data sources, input values, and assumptions used to develop the candidate stormwater street sweeping programs' washoff particulate-bound load and concentration reduction estimates.
- Chapter 3: Methodology, which describes the process to develop the candidate stormwater street sweeping programs' particulate-bound load and concentration reduction estimates.
- Chapter 4: Results, which describes the candidate stormwater street sweeping programs' estimated washoff particulate-bound load and concentration reduction estimates.

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CHAPTER 2

Data Compilation

This chapter describes the data sources, input values, and assumptions used to develop the candidate stormwater street sweeping programs' washoff particulate-bound load and concentration reduction estimates.

2.1 Inputs to Measured Particulate-Bound Pollutant Pick-Up Rate

The two primary inputs needed to estimate measured washoff particulate-bound pollutant pick-up rates include:

- measured program performance metrics: curb-miles swept, and wet load removed
- representative sample concentrations

2.1.1 Program Performance Metrics

Key assumptions supporting development of the pick-up rates include:

- Street sweeping program metrics represent Seattle conditions:
  - street dirt accumulation as a function of land use and street texture
  - washoff as a function of street loads, street texture, and rainfall intensity
  - productivity as a function of sweeper type, street texture, and parking controls and season
- The water quality (WQ) bin wet load recorded by the waste disposal facility truck scale represents the wet load removed from the routes swept and deposited at each location since the last haul date.

From program commencement in February, 2011 through 2013, 37,700 curb-miles, of which 27,030 (72 percent) drain directly to the storm sewer system, have been swept. The current route land use distribution is 29, 15, and 56 percent commercial, industrial, and residential, respectively. Ninety-six percent of the routes are arterials; the remaining 4 percent are local streets; i.e., streets with low traffic volume. Schwarze regenerative air sweepers swept the routes: model A8000 through early 2013 when the fleet was upgraded to model A9000 (Figure 2-1).

The Program performance tracking is based on two data sources:

- **Curb-miles swept**: Approximately 37,700 curb-miles have been swept since the program inception (combined sewer system and storm sewer system). Mileage was manually tracked by sweeper operators from equipment odometer readings until February 2013, at which point an Automatic Vehicle Location (AVL) system went on line. The AVL system reports time and distance sweeping and traveling. The sweeping time and distance is broken down by sweeping of the specified route, sweeping of the portion of the specified route that drains to the storm sewer system, and sweeping of a non-specified route.
- **Wet solids load removed:** Approximately 4,770 short wet tons (swt) of sweepings have been removed since the inception of the Program (combined sewer system and storm sewer system). Sweeper operators empty their hoppers at one of two WQ temporary storage bins: Haller Lake in the north and Charles Street in the south. Bins are emptied periodically, biweekly to bimonthly, and the wet weight removed is recorded from the waste disposal facility truck scale readings.

Table 2-1 summarizes the available performance data and includes the total curb-miles swept and wet solids load removed, of which approximately 72 percent of the mileage is within the storm sewer system.

Table 2-1. Summary of Annual Program Performance and Basis for Estimating Integrated Plan Programs

	2011			2012			2013		
	Annual	Wet season	Dry season	Annual	Wet season	Dry season	Annual	Wet season	Dry season
Annual curb-miles swept	9,848	4,337	5,512	14,710	6,523	8,187	13,116	5,888	7,229
Wet solids load removed (swt)	1,137	545	592	1,978	1,234	744	1,652	716	555

Figure 2-1. Schwarze model A9000 regenerative air sweeper

2.1.2 Program Sample Concentrations

This section includes:

- a brief description of the sample collection process and analysis
- a summary of sample results

2.1.2.1 Sample Collection and Analysis

Key assumptions supporting analysis of the WQ bin sample concentrations include:

- WQ bin samples represent the pollutant concentrations of the load removed by the sweepers sweeping assigned routes and covering recorded curb-miles since the last sample date at that WQ bin, which typically ranges from 1 to 14 days.
- Sample concentrations from the particles less than 250 µm represent the pollutant concentrations in the washoff particles. This may be over-representing some pollutant concentrations that tend to increase with decreasing particle size.

Program street sweeping solids concentration sampling at the temporary storage bin locations began August 19, 2011. On August 24, 2012, a protocol to split the whole sample and analyze both the whole sample and the particles less than 250 µm was implemented (Figure 2-2).

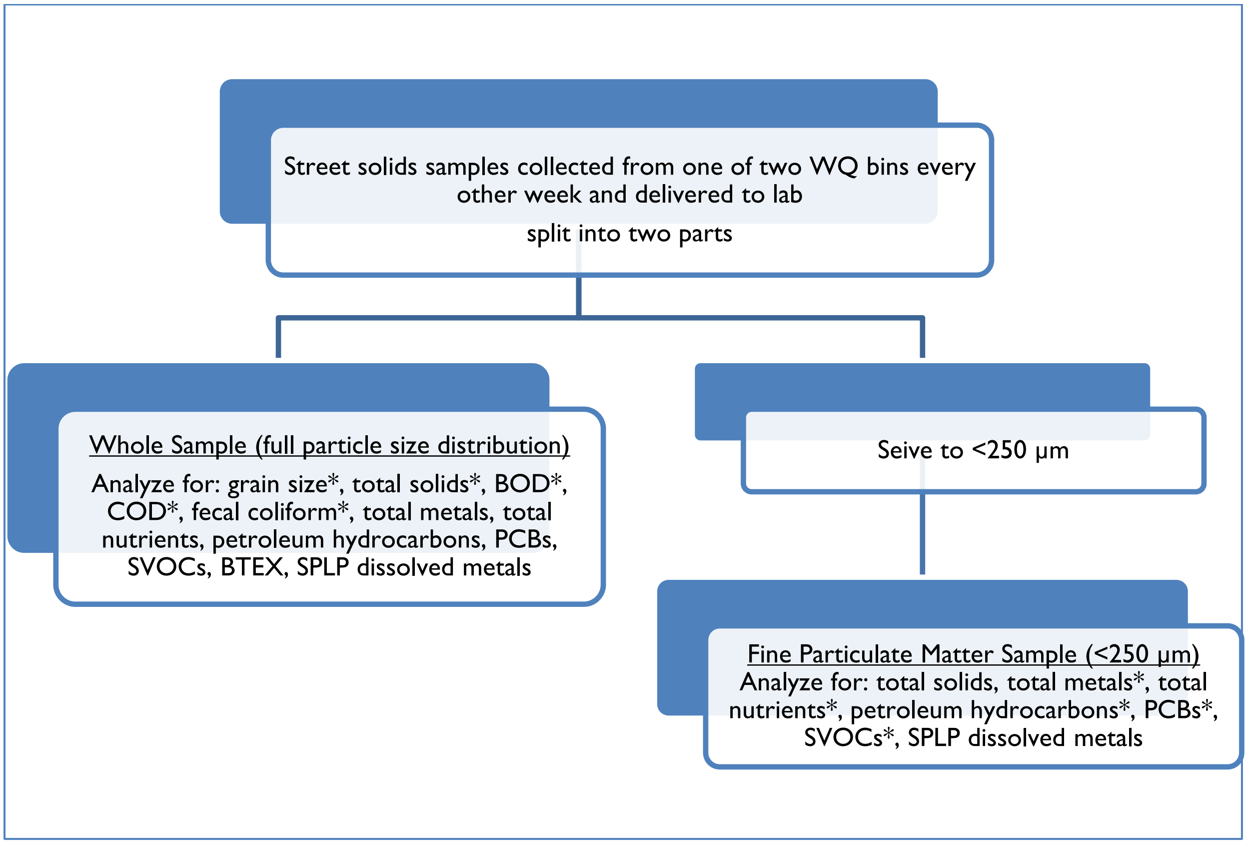

Figure 2-2. Sample processing and analysis summary

Sample results from analytes or analyte groups noted with a * are used in the pollutant reduction analysis.

Samples are collected approximately every other week during program operations from each bin (see Figure 2-3). A decontaminated stainless-steel shovel is used to excavate three to six sub-sampling locations (depending on estimated volume of new material in the bin), each approximately 2 to 2.5 feet deep from the vertical surface of the pile. A sub-sample (approximately one shovelful) is collected from the bottom of each excavation and placed in a large decontaminated stainless-steel bowl.

All sub-samples are homogenized with a decontaminated stainless-steel spoon and synthetic, metal, and/or plastic material is removed. The homogenized material is then placed into sample containers and taken to Analytical Resources, Inc., a local commercial analytical laboratory, to be processed. The laboratory performs analyses on the whole grain size fraction of each sample—with a parallel process of sieving a portion of the material to obtain and analyze the Fine PM (<250 µm grain size fraction). Analytical results are received from the lab, reviewed and verified, loaded to SPU's EQuIS database, a proprietary Laboratory Information Management System (LIMS) application, and then validated by SPU staff.

Figure 2-3. WQ bin sampling at Haller Lake on 10/8/2013

From upper left to lower left; preparing sample locations, homogenizing sub-samples, and final sample jars ready for the laboratory.

Figure 2-4 below shows the Charles Street and Haller Lake WQ bins.

(a) Charles Street WQ bin on 9/24/2013.
Sampling equipment on right side of bin.

(b) Haller Lake WQ bin on 7/31/2013.

Figure 2-4. Temporary WQ sampling bin locations

2.1.2.2 Sample Results

Table 2-2 below summarizes the analyzed RCOCs and the number of samples collected during the period of record. Sample concentration descriptive statistics and box plots are provided in Attachments G-1 and G-2 of this appendix, respectively.

Table 2-2. Summary of Sampling Program Objectives, Parameters, and Sample Sizes

Street sweeping environmental performance indicator	Analytical parameter	Sampling period of record	No. of samples collected
Dry street solids load removed	Solids, total; moisture %	8/5/2011 through 11/18/2013	88
Fine particulate matter and washoff fraction (load reduction)	Grain size	8/19/2011 through 11/18/2013	88
Pollutant load removed within fine particulate fraction (<250 µm)[a]	Biological oxygen demand (BOD_5)[b]	7/23/2012 to 11/4/2013	37
	Bis(2-ethylhexyl)phthalate	8/10/2012 to 11/4/2013	34
	Copper, total	8/10/2012 to 11/4/2013	36
	Fecal coliform[b]	8/19/2012 through 11/4/2013	33
	Motor oil	8/19/2012 through 11/4/2013	33
	Nitrogen, total Kjeldahl	8/10/2012 to 11/4/2013	36
	PCBs	8/10/2012 to 11/4/2013	35
	Phosphorus, total	8/10/2012 to 11/4/2013	36
	Zinc, total	8/10/2012 to 11/4/2013	36

a. Fine PM, material less than 250 µm diameter, represents the particles that would be suspended in stormwater. Structural treatment BMPs typically have a range of removal performance and automatic samplers have been reported to be less reliable at capturing PM greater than 250 µm (Clark et al., 2007).

b. Analysis of BOD_5 and fecal coliform is not practical for the Fine PM fraction; concentrations for the whole sample are assumed to be representative of the material less than 250 µm.

Key assumptions supporting analysis of the WQ bin sample concentrations include:

- General:
  - All pollutant sample concentrations are reported on a dry weight basis.
  - Sample results reported as less than the method reporting limit are assumed to be zero for fecal coliform and aroclors, the only RCOC parameters with non-detects. Fine PM is estimated by subtracting the percent mass retained on a 250 µm screen from 100 percent, thus reducing the influence from non-detect sample results for material finer than 250 µm.
- BOD_5 and COD:
  - WQ bin sample analysis of BOD_5 and chemical oxygen demand (COD) within the Fine PM fraction is not practical given the nature of the sampling approach; concentrations for the whole sample for these parameters are assumed to be representative of the material less than 250 µm. Pitt (2004) reported that the concentration of COD increased with increasing particle sizes, likely a function of increasing amounts of organic material in the larger particle sizes.
  - Samples were analyzed for COD to supplement BOD_5 concentration results. It is assumed that the BOD_5 concentrations under-represent the oxygen demanding load because the analytical test was designed to measure the BOD_5 concentration in wastewater. The ratio of the median COD to BOD_5 concentrations reported in the National Stormwater Quality Database (NSQD, version 1.1), is 6.2 for a sample size of 3,105 and 2,750 for BOD_5 and COD, respectively. The ratio of the street sweeping WQ bin sample concentration medians for COD to BOD_5 is 37 to 1.
- Ammonia:
  - Samples were analyzed for total Kjeldahl nitrogen (TKN) to represent ammonia. The results were not used because a reasonable correlation is not available and it is likely that conversion of TKN is ongoing in the pile between sampling events. Walch et al. (2005) found a range of ammonia to TKN ratios between 0.08 and 0.32, indicating that ammonia concentrations in the pile may potentially range from 150 to 600 milligrams per kilogram (mg/kg).
- Dissolved metals:
  - Samples were analyzed using the SPLP (EP SW-846 Method 1312) to indicate potential dissolved metals concentrations. The results were not used for the Integrated Plan because a meaningful correlation between results and runoff concentrations is not known at this time. This test was designed to simulate material left in situ (in or on top of the ground surface, exposed to rainfall, with an assumption that the rainfall is slightly acidic) and then to determine the mobility of analytes present in liquids, soils, and wastes from the leachate the material would produce. The test is applicable for determining the potential of a contaminated material (left in situ) to impact groundwater or surface water when exposed to normal weathering.
- Fecal coliform:
  - WQ bin sample analysis of fecal coliform within the Fine PM fraction is not practical given the nature of the sampling approach; concentrations for the whole sample for these parameters are assumed to be representative of the material less than 250 µm. Borst et al. (2003) found no correlation between fecal coliform concentrations and mean particle size from one summer storm event. Southern California Coastal Water Research Project (2011) found bacteria preferentially associated with less than 6 µm filter fraction during small storm events (<0.3 inch rain).
- The wet season fecal coliform concentration is assumed to be adequately represented by the samples collected during dry weather sampling. This approach was selected after considering several factors and comparing the results to other stormwater and combined sewer overflow (CSO) projects.
  - The ratio of average dry season (5.6 million colony forming units per gram [CFU/g]) to average wet season (0.63 million CFU/g) fecal coliform concentrations is 8.9, which is greater than the Seattle National Pollutant Discharge Elimination System (NPDES) Stormwater Characterization data ratio of 2.6, average dry season fecal coliform bacteria concentration to average wet season concentration but less than the range reported for the Nationwide Urban Runoff Program (NURP) data (20 dry to 1 wet) (EPA, 2006) (see Figure G-2d).

- Using the wet season concentration to characterize the dry season appears reasonable when compared to fecal coliform bacteria concentrations reported in the literature and estimated concentration reductions for the current program (Table 2-3).

Table 2-3. Comparison of Potential Fecal Coliform Removal Efficiencies for Different Runoff Concentrations and Pick-up Rate Assumptions

Source/ description	Average fecal coliform concentration (CFU/100 mL)	Land use/source
Seattle NPDES Stormwater Characterization	2,791	Residential
	5,046	Commercial
	3,980	Industrial
EPA (2006)	430	Street runoff
Burnhart et al. (1991)	9,627	arterial street M_ArterialST
	5,269	arterial street S_ArterialST
Current Program estimate reduction	1,238	Arterials (reduction estimate based on dry and wet season concentrations)
	108	Arterials (reduction estimated based on wet season concentration representing annual concentration)

Seattle NPDES Stormwater Characterization includes both wet and dry season samples. The Burnhart et al. (1991) samples are during the warmer months.

- The street sweeping fecal coliform bacteria concentrations are highly variable (coefficient of variation 1.53 and 3.0 for Charles Street and Haller Lake WQ bins, respectively).
- Conditions within the WQ temporary storage bins may be conducive to bacteria growth due to adequate moisture, nutrients, and carbon source as well as optimum temperatures, especially in the dry season. At the time of sampling, the sweepings may be from 1 to 14 days old. Pile temperatures ranged from 75 degrees Fahrenheit (°F) to 125°F with averages of 87°F and 96°F at the Haller Lake WQ bin on September 24, 2013, and October 8, 2013, respectively. Pile temperatures ranged from 70°F to 110°F at the Charles Street WQ bin on October 8, 2013, with an average of 87°F (See Figure 2-5). Analytical method SM 9222D stipulates an incubation temperature of 112.1°F for 24 hours.
- Conditions on the street may also be conducive for fecal coliform bacteria growth. Burnhart et al. (1991) found that it was possible for bacteria to increase on the street surface until the next rain, when they would be washed off. The San Bernardino County Flood Control District (2011) will evaluate street sweeping to determine if ongoing programs can be enhanced to further reduce the presence of bacterial indicators on street surfaces. The San Bernardino County Flood Control District assumes that sweeping will eliminate the release of bacteria from biofilms in street gutters for a period of 1 day based on work by Skinner et al. (2010), who found that improved street sweeping practices resulted in an order of magnitude reduction in fecal coliform concentration (14,000 CFU/100 mL to 870 CFU/100 mL) in a 300-foot section of gutter before and after sweeping.

Figure 2-5. Evidence of high temperatures within the Charles Street pile on September 30, 2011

2.1.3 Seasonal Street Dirt Washoff Rates

Seasonal street dirt washoff rates are assumed to represent the particles picked up by the sweeper that would have washed to the storm drain had they not been picked up. Key assumptions supporting development of the seasonal washoff rates include:

- The dry season extends from May through September and the wet season from October through April.
- The washoff load is a function of particle size and is estimated using the observed washoff street dirt load reductions by particle size during tests in Bellevue, Washington (Pitt, 1985) (see Table 2-4).

Table 2-4. Observed Washoff of Street Dirt during Test in Bellevue, Washington (Pitt, 1985)

Size category	Range in size (mm)		Washoff of original load (%)	
	From	To	Dry season	Wet season
Gravel	>2	N/A	0	0
Very coarse sand	1	2	7	6
Coarse sand	0.5	1	8	12
Medium sand	0.25	0.5	15	19
Fine sand	0.125	0.25	20	30
Very fine sand	0.063	0.125	28	49
Silt	<0.063	N/A	39	50

The washoff of original load (%) is referred to as the Bellevue washoff factor (BWOF).

The Bellevue data are based on observations of the difference in approximately 50 pairs of street dirt loading measurements close to the beginnings and ends of rains.

Application of the BWOF to Program data reduces the estimated WQ benefit from 24 and 20 percent of the total load, Fine PM for dry and wet season, respectively, to 11 and 14 percent of the total load, washoff PM for dry and wet season, respectively (see Figure G-2d).

The washoff fraction (WOF%) for each sample, the percentage of particles picked up by the sweeper that would have washed off the street, is estimated by summing the product of the BWOF, for each size category and season and multiplying by the percentage of particles in that size category for all size fractions for the sample.

$$[WOF\%]_{sample} = \sum_{size\ category=1}^{7} [SizeCategory\%]_{sample,s} \times BWOF_{size\ category,s}$$

2.2 Inputs to Estimate Projected Particulate-Bound Pollutant Load and Concentration Estimates

This section describes the input values and assumptions used to estimate particulate-bound pollutant load and concentration estimates from the measured washoff particulate-bound pollutant pick-up rate and includes:

- efficiency and implementation factor adjustments to the measured pick-up rate to develop a projected pick-up rate
- candidate stormwater street sweeping programs' sweeping plan
- candidate stormwater street sweeping programs' average annual runoff volume

2.2.1 Adjustments to Measured Pick-up Rate

Measured particulate-bound pollutant pick-up rates are adjusted to develop projected pick-up rates using efficiency and performance reduction factors.

2.2.1.1 Efficiency Factors

Efficiency factors account for reduced pick-up rates for more frequent sweeping (Street Sweeping Expansion Arterials), or sweeping during different land use and operating conditions (Street Sweeping Expansion Residential):

- **Street Sweeping Expansion Arterials efficiency factor:** A 64 percent efficiency factor is applied to the estimated pick-up rate for arterial weekly sweeping frequency compared to arterial biweekly sweeping frequency based on an assumed street dirt buildup rate of 11 days (e.g., 7 days/11 days is 64 percent). Reported street dirt buildup rates range from 6 to 10 days. San Diego (2013) found that the removal rate (mass per curb-mile swept) was similar for two sweeping frequencies: twice per week and weekly, inferring a buildup rate greater than 7 days. Sorensen (2013) found similar results; sweeping every 3 days provided comparable pick-up rates, inferring a buildup rate greater than 6 days. Maricopa Association of Governments (MAG, 2007), assumed a 9-day buildup rate. SAFL (2013) found a buildup rate of 10 days, and that total solids removed increases with tree canopy at any sweeping frequency. Bannerman (2007) reported annual TSS reduction with a vacuum-assisted sweeper sweeping a commercial strip with light parking density once every week at 16 percent, reducing to 7 percent with sweeping once every 4 weeks. Interpolating to a biweekly sweeping frequency results in approximately a 64 percent reduction from biweekly to weekly sweeping frequency.
- **Street Sweeping Expansion Residential efficiency factor:** A 75 percent efficiency factor applied to the estimated pick-up rate for daytime sweeping of residential streets from nighttime sweeping of arterials accounts for expected reduced pollutant loading rates on low traffic volume residential streets, uncertainty around the effectiveness of curb access controls, and restricted operating conditions (tighter corners, overhanging trees, narrow streets, delivery vehicles, etc.). A relative efficiency factor across all RCOCs does not consider that the pollutant loading by land use is likely to be different. The Seattle Street Sweeping Pilot Study (SPU et al., 2009)

found a median pick-up rate of 21 kg Fine PM per curb-mile for two residential basins with daytime sweeping and parking compliance, higher than the measured pick-up rate of 17 kg Fine PM per curb-mile for arterials. Bannerman (2007) found similar average street dirt accumulation rates for residential and commercial streets but predicts a reduction of approximately 50 percent from light to medium parking density with weekly sweeping for both medium residential and commercial strip land uses with a vacuum-assisted sweeper.

2.2.1.2 Reduction Factors to Account for Potential Future Expansion Implementation Issues

Reduction factors account for uncertainty around implementing an expanded program into the future.

- **Street Sweeping Expansion Arterials implementation reduction factor:** A 25 percent reduction in the estimated pick-up rate is applied to account for reduced flexibility when operating at full capacity. Making up missed routes will become increasingly more difficult once all available routes are scheduled.
- **Street Sweeping Expansion Residential implementation reduction factor:** A 50 percent reduction factor in the estimated pick-up rate is applied to account for potential schedule delays around implementing curb access controls (e.g., signs, parking enforcement, etc.).

2.2.2 Sweeping Plan Scope

The load reduction estimate is the product of the projected pick-up rate and planned curb-miles per year. Table 2-5 below provides the frequency and planned curb-miles for each candidate stormwater street sweeping program.

Table 2-5. Candidate Stormwater Street Sweeping Program (Curb-Miles)

Program	Street type	Routes	Period	Total curb-miles	Biweekly curb-miles	Weekly curb-miles
Street Sweeping Expansion Arterials: augment arterials at night	Arterials	25	Annual	10,600	1,800	8,800
			Wet season	6,500	950	5,550
			Dry season	4,100	840	3,260
Street Sweeping Expansion Residential: expand to local streets during the day	Local streets	24	Annual	11,500	11,500	
			Wet season	6,100	6,100	
			Dry season	5,400	5,400	

2.2.3 Sweeping Plan Runoff Volume

The concentration reduction estimate is the quotient of the projected load reduction by the average annual runoff volume. The average annual runoff volume, V_a, is estimated using the Simple Method (Schueler, 1987). The Simple Method calculates annual runoff as a product of annual runoff volume, and a runoff coefficient (R_v). Runoff volume is calculated as:

$$V_{a,Program} = A_{Program} \times P \times P_j \times R_v$$

where:

$V_{a,Program}$ = Annual runoff volume for the candidate stormwater street sweeping program (Arterials or Residential)
$A_{Program}$ = Runoff surface area for the candidate stormwater street sweeping program (Arterials or Residential)
P = Annual rainfall (37.9 inches)[2]
P_j = Fraction of annual rainfall events that produce runoff (0.9)
R_v = Runoff coefficient, which is equal to $0.05+0.9I_{a.}$ (I_a, impervious fraction, = 1 for road surfaces and sidewalks)

Although structural BMPs are sized to treat up to 91 percent of the average annual runoff volume, for the purposes of this analysis, 100 percent of the average annual runoff volume is used for the Street Sweeping Expansion Arterials and Street Sweeping Expansion Residential programs, a conservative approach resulting in lower pollutant concentration reductions.

It is assumed that 100 percent of sidewalks are connected in the Street Sweeping Expansion Arterials program and 50 percent connectivity for the Street Sweeping Expansion Residential program, which is predominantly neighborhoods with planting strips. Runoff from parking lots and driveways is not included in either of the candidate stormwater street sweeping program assumptions.

Table 2-6 summarizes the key assumptions used to develop the estimated average annual runoff volume that will be affected by each candidate stormwater street sweeping program.

Table 2-6. Estimated Average Annual Runoff Volume from Streets Considered in Each Candidate Stormwater Street Sweeping Program

Parameter	Street sweeping expansion arterials	Street sweeping expansion residential
Street width (average, feet)	41.7	28.3
Street area (acres)	1,422	988
Connected sidewalk area (acres)	314	132
Average annual runoff volume (acre-feet)	4,687	3,025
Average annual runoff volume (MG)	1,527	990

Assumed 100% of Street Sweeping Expansion Arterials program sidewalks are connected and 50% connectivity for the Street Sweeping Expansion Residential program.

2 The City of Seattle Stormwater code (City of Seattle, 2009) specifies use of an "extended precipitation time series" with a 158-year record length for use in designing water quality facilities. An average runoff value of 37.9 inches was extracted from the Western Washington Continuous Simulation Hydrology Model (WWHM2012). See http://www.ecy.wa.gov/programs/wq/stormwater/wwhmtraining/index.html for model description.

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CHAPTER 3

Methodology

This chapter describes the process for developing the candidate stormwater street sweeping programs' particulate-bound pollutant load and concentration reduction estimates and includes four areas:

- developing measured seasonal washoff particulate-bound pollutant load pick-up rates
- developing projected seasonal washoff particulate-bound pollutant load pick-up rates
- developing projected annual washoff particulate-bound pollutant load reductions
- developing projected annual washoff particulate-bound concentration reductions

3.1 Process to Develop Measured Particulate-Bound Pollutant Pick-up Rates

This section describes the process for developing the measured seasonal pick-up rates, which are estimated based on an average monthly swept distance-weighted basis.

Part 1: Develop monthly average sample concentrations and wet loads. A monthly time scale was selected as a common basis for comparison.

Where:

D	=	the swept distance (curb-miles for the period of interest)
[P]	=	pollutant concentration (mass pollutant per mass of Fine PM)
[WSL]	=	the wet solids load (full particle size gradation) (mass)
m	=	the month
e	=	the sample or hauling event
n	=	the number sample or hauling events in the month
l	=	the location
p	=	the pollutant parameter

Step 1.1 Estimate an average monthly swept distance-weighted sample concentration, $[P]_{l,m,p}$, for each location, *l*, month, *m*, and parameter, *p.* Sum the product of the sample concentration, $[P]_{e,l,p}$ for the sample event, *e*, at location, *l*, and parameter, *p* and multiply by the distance swept, $D_{e,l,m}$, since the last sampling event, *e*, at location, *l*, month, *m*, for all sample events in the month, *n.* Then divide by the distance swept in the month. Average monthly swept distance-weighted total solids and the washoff fraction are also estimated using this approach.

$$[P]_{l,m,p} = \frac{\sum_{e=1}^{n}[P]_{e,l,p} \times D_{e,l,m}}{D_{l,m}}$$

Step 1.2 Estimate an average monthly swept distance-weighted wet solids load at each location, $[WSL]_{l,m}$. Sum the product of the wet solids load, $[WSL]_{e,l}$, for the haul event, *e*, at location, *l*, then multiply by the distance swept, $D_{e,l,m}$, since the last haul event, *e*, at location, *l*, for month, *m*, for all haul events in the month, *n*. Then divide by the distance swept in the month.

$$[WSL]_{l,m} = \frac{\sum_{e=1}^{n}[WSL]_{e,l} \times D_{e,l,m}}{D_{l,m}}$$

Part 2: Develop monthly pick-up rates. The average monthly swept distance-weighted concentrations and wet solids loads are then used to estimate average monthly swept distance-weighted pick-up rates. The four-step process is outlined below.

Where:

[DSL] = the dry solids load (full particle size gradation) (mass)
[WOF] = the washoff fraction load (particles that would be washed off the street, see Section 2.1.3) (mass)
PL = the pollutant load contained in the washoff fraction (mass)
PkR = the pick-up rate (load per curb-mile swept)
[TS] = total solids concentration

Step 2.1: Estimate the average monthly swept distance-weighted dry solids load, $[DSL]_{l,m}$, for each location, *l*, by multiplying the average monthly swept distance-weighted wet solids load, *[WSL],* by the average monthly swept distance-weighted total solids concentration, $[TS\%]_{l,m}$, for each location.

$$DSL_{l,m} = WSL_{l,m} x [TS\%]_{l,m}$$

Step 2.2: Estimate the average monthly swept distance-weighted washoff load for the month, $WOL_{m,l}$, for each location*, l,* by multiplying the average monthly swept distance-weighted dry solids load, $DSL_{m,l,}$ by the average monthly swept distance-weighted washoff fraction concentration, $[\% WOF]_{l,m}$, for each location.

$$WOL_{l,m} = DSL_{l,m}\ x\ [\% WOF]_{l,m}$$

Step 2.3: Estimate the average monthly swept distance-weighted dry pollutant load for the month, $PL_{m,l,p}$, for each location and pollutant by multiplying the average monthly swept distance-weighted washoff load, $WOL_{m,l,}$ by the average monthly swept distance-weighted sample concentration, $[P]_{l,m,p}$, for each location and parameter.

$$PL_{l,m,p} = WOL_{l,m}\ x\ [P]_{l,m,p}$$

Step 2.4: Estimate the measured monthly swept distance-weighted pick-up rates for the month, $PkR_{m,l,p}$, for each location and pollutant by dividing the average monthly swept distance-weighted dry pollutant load, $PL_{m,l,p}$, for each location and parameter by the average monthly swept distance, $D_{l,m}$, for each location.

$$PkR_{l,m,p} = \frac{PL_{l,m,p}}{D_{l,m}}$$

Part 3: Develop seasonal measured pick-up rates. The monthly average swept distance-weighted loads and distances are then used to estimate the seasonal pick-up rates.

Step 3.1: Estimate the measured seasonal pick-up rates, $PkR_{s,p,Phase,f}$ for frequency *f*,each season (wet or dry) and pollutant by dividing the sum of the average monthly swept distance-weighted dry pollutant load, $PL_{m,l,p}$, for each location and parameter and month in the season by the average monthly swept distance, $D_{l,m}$, for each location and month in the season.

$$PkR_{s,p,Phase,f} = \frac{\sum_{s=}^{w\ or\ d} PL_{l,m,p}}{\sum_{s=}^{w\ or\ d} D_{l,m}}$$

3.2 Process to Develop Projected Particulate-Bound Pollutant Pick-up Rates

Once the measured average seasonal washoff particulate-bound pollutant pick-up rates are estimated, the projected seasonal pick-up rates, $PkR_{s,p,Program,f}$, are estimated by applying the efficiency and reduction factors established in Section 2.2:

$$PkR_{s,p,Program,f} = PkR_{s,p}\ x\ Efficiency\ factor_{Program,f}\ \ x\ \ Reduction\ factor_{Program}$$

3.3 Process to Develop Particulate-Bound Pollutant Load Reduction Estimates

The annual washoff particulate-bound pollutant load reduction is the sum of the seasonal washoff pollutant load reductions, which are estimated by multiplying the seasonal pick-up rate for the candidate stormwater street sweeping program and sweeping frequency for each RCOC by the candidate stormwater street sweeping program's planned miles for the season and frequency.

$$\Delta WOL_{a,p,Program} = \sum_{s=1}^{2} PkR_{s,p,Program,frequency} \times Planned\ curb\text{-}miles_{s,Program,frequency}$$

Where:

$\Delta WOL_{a,p,Program}$ = annual washoff particulate-bound pollutant load reduction for pollutant, p, and candidate stormwater street sweeping program (Arterials or Residential) (mass)
s = season, either wet or dry
a = annual

3.4 Process to Develop Particulate-Bound Pollutant Concentration Reduction Estimates

The average annual washoff pollutant concentration reduction, $[\Delta P]_{a,p,}$ is the quotient of the annual washoff pollutant load reduction divided by the average annual runoff volume.

$$[\Delta P]_{a,p,Program} = \frac{\Delta WOL_{a,p,Program}}{V_{a,Program}}$$

Where:

$[\Delta P]_{a,p,Program}$ = annual washoff pollutant concentration reduction for pollutant, *p*, and candidate stormwater street sweeping program (Arterials or Residential) (mass/volume)

$V_{a,Program}$ = Annual runoff volume for the candidate stormwater street sweeping program (Arterials or Residential, see Section 2.2.3)

CHAPTER 4

Results

This chapter describes the results for the candidate stormwater street sweeping programs' particulate-bound pollutant load and concentration reduction estimates and includes:

- measured and projected washoff particulate-bound pollutant pick-up rates
- estimated washoff pollutant load reduction for each candidate stormwater street sweeping program
- estimated washoff pollutant load reduction distribution by receiving water
- estimated washoff pollutant concentration reduction

Table 4-1 provides estimated wet and dry season pick-up rates for each of the RCOCs by sweeping frequency and program, Street Sweeping Expansion Arterials or Street Sweeping Expansion Residential.

Table 4-1. Estimated Wet and Dry Season Washoff PM-Bound Pollutant Pick-up Rates for RCOCs for Each Candidate Stormwater Street Sweeping Program

Parameter	Units (dry basis)	Measured August 2011 through November 2013		Street Sweeping Expansion Arterials: biweekly frequency		Street Sweeping Expansion Arterials: weekly frequency		Street Sweeping Expansion Residential: biweekly frequency	
		Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
Washoff PM (TSS equivalent)	kg/curb-mile	12	7.6	8.7	5.7	5.5	3.6	4.3	2.9
BOD_5	kg/curb-mile	0.12	0.048	0.088	0.036	0.056	0.023	0.044	0.018
Bis(2-ethylhexyl)phthalate	gram (g)/curb-mile	0.045	0.029	0.034	0.022	0.021	0.014	0.017	0.011
COD	kg/curb-mile	3.6	1.3	2.7	1.0	1.7	0.6	1.35	0.48
Copper, total	g/curb-mile	1.5	1.4	1.1	1.1	0.72	0.68	0.57	0.53
Fecal coliform	million CFU/curb-mile	590	590	440	440	280	280	221	4088
Motor oil range	g/curb-mile	20	18	15	14	9.7	8.8	7.6	6.9
TKN	g/curb-mile	22	17	17	13	11	8.0	8.4	6.3
PCBs, total	g/curb-mile	0.00095	0.00091	0.00071	0.00068	0.00045	0.00043	0.00035	0.00034
Phosphorus, total	g/curb-mile	7.4	5.4	5.6	4.0	3.5	2.6	2.8	2.0
Zinc, total	g/curb-mile	3.0	2.8	2.2	2.1	1.4	1.3	1.11	1.1

See key assumptions above.

Fecal coliform pick-up rate for dry season assumed to be the wet season rate.

Dry season is from May through September. Wet season is from October through April.

Table 4-2 summarizes the estimated average annual load reduction for each RCOC and each candidate stormwater street sweeping program.

Table 4-2. Estimated Average Annual Washoff Particulate-Bound Load Reduction for Each Candidate Stormwater Street Sweeping Program

RCOC	Units	Street Sweeping Expansion Arterials	Street Sweeping Expansion Residential
Washoff load (TSS equivalent)	kg/year	36,200	42,000
Ammonia-N	NA	No data	No data
Biological oxygen demand (BOD)	kg/year	337	370
Bis(2-ethylhexyl)phthalate	kg/year	0.14	0.16
Chemical oxygen demand (COD)	kg/year	10,000	11,000
Copper, dissolved	NA	Not considered	Not considered
Copper, total	kg/year	5.2	6.3
Dichlobenil	NA	No data	No data
Fecal coliform	trillion CFU/year	2.1	1.8
Oil and grease	kg/year	69	84
TKN	kg/year	72	85
PBDE	NA	No Data	No Data
PCBs[a]	kg/year	0.0033	0.0040
Phosphorus[a]	kg/year	24	28
Zinc, dissolved	NA	Not considered	Not considered
Zinc, total	kg/year	10	12

All washoff pollutant estimate reductions represent the load reduction for particles less that would be washed off the street. Fecal coliform dry season pick-up rate is assumed to equal the wet season pick-up rate. Street Sweeping Expansion Arterials and Street Sweeping Expansion Residential program performance estimates reduced to account for uncertainty (see Section 2.2.1.2)

a. For phosphorus and PCBs, the total values were assessed.

Table 4-3 presents the estimated load reduction distributed by receiving water for potential planned routes.

Table 4-3. Estimated Distribution of Average Annual Load Reduction

Receiving water	Street Sweeping Expansion Arterials	Street Sweeping Expansion Residential
Direct discharge	3%	4%
Duwamish Waterway	30%	14%
Lake Union	13%	13%
Lake Washington	18%	28%
Longfellow Creek	3%	2%
Piper's Creek	1%	2%
Puget Sound Central/Elliott Bay	6%	8%
Puget Sound North	1%	1%
Puget Sound South	9%	12%
Ship Canal/Salmon Bay	7%	12%
Thornton Creek	9%	4%
Total	**100%**	**100%**

At full implementation of the Street Sweeping Expansion Arterials and Street Sweeping Expansion Residential programs, the Program is anticipated to reduce the citywide annual pollutant load discharging to the storm sewer system by 5 percent (Table 4-4).[3]

Table 4-4. Estimated Reduction in Total Runoff Pollutant Load by Candidate Stormwater Street Sweeping Program

Receiving water	Estimated runoff load (TSS kg/year)	Approximate street sweeping load reduction as a percent of estimated citywide load			
		Current	Street Sweeping Expansion Arterials	Street Sweeping Expansion Residential	Total
Duwamish Waterway	930,900	3%	1%	1%	5%
Lake Union/Ship Canal	504,800	3%	1%	2%	7%
Lake Washington	969,600	3%	1%	2%	5%
Puget Sound	653,700	2%	1%	1%	5%
Total	**3,059,000**	**3%**	**1%**	**1%**	**5%**

Estimated runoff load discharging to the storm sewer system is based on land use, source, and coverage.

3 Under current land use and cover assumptions, the street surface area is approximately 12% but contributes approximately 37% of the citywide load. See Seattle Public Utilities (2013) for details.

Table 4-5 summarizes the estimated average annual washoff concentration reduction for each RCOC and candidate stormwater street sweeping program.

Table 4-5. Estimated Average Annual Washoff Particulate-Bound Concentration Reduction for the Current (2013) Program and Each Candidate Stormwater Street Sweeping Program

RCOC	Units	Current	Street Sweeping Expansion Arterials	Street Sweeping Expansion Residential
Washoff fraction (TSS equivalent)	mg/L	17	6	11
Ammonia-N	NA	No data	No data	No data
BOD_5	µg/L	144	58	98
Bis(2-ethylhexyl)phthalate	µg/L	0.066	0.024	0.043
COD	mg/L	4.2	1.8	2.9
Copper, dissolved	NA	Not considered	Not considered	Not considered
Copper, total	µg/L	2.7	0.90	1.7
Dichlobenil	NA	No data	No data	No data
Fecal coliform	CFU/100 mL	108	36	49
Oil and grease	µg/L	35	12	23
TKN	µg/L	35	12	23
PBDEs	NA	No data	No data	No data
PCBs	µg/L	0.0017	0.00056	0.0011
Phosphorus, total	µg/L	11	4.1	7.5
Zinc, dissolved	NA	Not considered	Not considered	Not considered
Zinc, total	µg/L	5.2	1.8	3.3

All pollutant estimate reductions represent the load reduction for particles less than 250 µm diameter that would be suspended in the stormwater column. Fecal coliform dry season pick-up rate is assumed to equal the wet season pick-up rate.

Table 4-6 provides an indication of possible removal efficiencies for each candidate stormwater street sweeping program.

Table 4-6. Estimated Potential Washoff Removal Efficiency for Candidate Stormwater Street Sweeping Programs for Selected Parameters

RCOC	Units	City of Seattle street runoff concentration	Possible current washoff removal efficiency	Candidate Street Sweeping Expansion Arterials program washoff removal efficiency	Candidate Street Sweeping Expansion Residential program washoff removal efficiency
Washoff PM (TSS equivalent)	mg/L	92	18%	7%	12%
Copper, total	µg/L	20	14%	5%	9%
Phosphorus, total	µg/L	173	7%	2%	4%
Zinc, total	µg/L	100	5%	2%	3%

Street Sweeping Expansion Arterials and Street Sweeping Expansion Residential program washoff concentration reductions represent particles that would be washed off the street (see Section 2.1.3).
Fecal coliform dry season pick-up rate is assumed to equal the wet season pick-up rate.
City of Seattle street runoff concentrations are from the NPDES Best Management Practice Study – Catch Basin StormFilters, installed on California Avenue and represent average concentration values.
Combining the possible current and Street Sweeping Expansion Arterials program removal efficiency is indicative of weekly sweeping frequency.

Figure 4-1 presents the schedule of costs and benefits for the Street Sweeping Expansion Arterials and Street Sweeping Expansion Residential programs. Street Sweeping Expansion Arterials is scheduled for implementation in 2016 and Street Sweeping Expansion Residential is scheduled for implementation from 2019 through 2024.

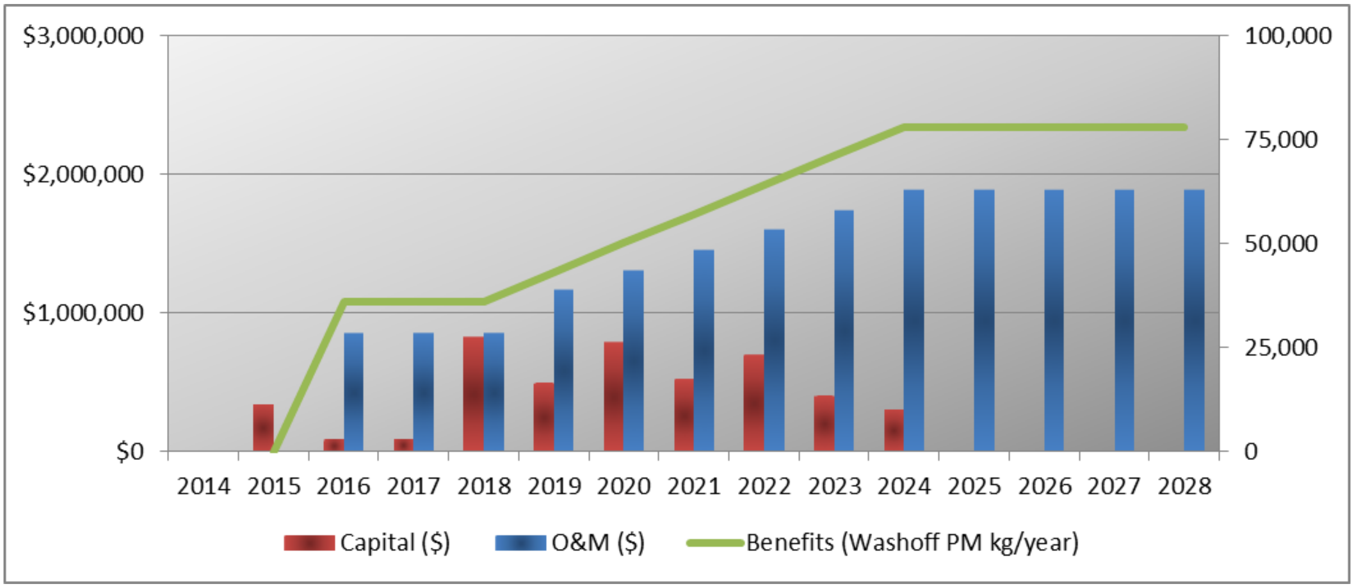

Figure 4-1. Schedule of benefits and costs combined for Street Sweeping Expansion Arterials and Street Sweeping Expansion Residential

Replacement sweeper costs are accrued through the hourly charge rate.

CHAPTER 5

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Attachment G-1: Summary of Descriptive Statistics

Table G-1a. Summary Statistics for BOD_5, COD, Fecal Coliform, and Total Solids Sample Concentrations

	Biological oxygen demand (mg/kg)	Chemical oxygen demand (mg/kg)	Fecal coliform (CFU/g)	Fine particulate matter (%)	Washoff fraction (%)	Solids, total (%)
Sample fraction	PES	PES	PES	PES	PES	PES
Non-detects count	0	0	4	NA	NA	0
Sample count	37	37	35	88	88	69
Mean	6,431	369,981	3,412,613	22	12.6	68
Standard deviation	3,667	486,370	10,286,940	6	2.96	15
Minimum	2,430	79,300	0	10.9	7.68	29.1
Quartile 1	4,040	139,000	1,610	16.8	10.6	64.84
Median	5,220	193,000	382,000	21.45	12.5	72.4
Quartile 3	7,740	250,000	2,145,000	26.525	14.0	77.8
Maximum	17,800	2,220,000	60,300,000	35	22.8	93
Interquartile range (IQR)	3,700	111,000	2,143,390	9.725	3.48	12.96
Outlier count: high	2	8	6	N/A	2	N/A
Outlier count: low	N/A	N/A	N/A	N/A	N/A	7

PES is primary environmental sample, the whole sample including all size fractions.
Outlier count: high is the count of sample results greater than the 75th percentile plus 1.5 times the IQR.
Outlier count: low is the count of sample results less than the 25th percentile minus 1.5 times the IQR.

Table G-1b. Summary Statistics for Organic Sample Concentrations

	Bis(2-ethylhexyl)phthalate (µg/kg)		Oil and grease (mg/kg)		PCBs (µg/kg)	
Sample fraction	PES	<250 µm	PES	<250 µm	PES	<250 µm
Non-detects count	0	0	0	0	7	1
Sample count	57	34	59	33	39	35
Mean	2,178	4,009	2,374	2,398	61	98
Standard deviation	1,478	1,174	1,413	710	84	71
Minimum	540	1,400	870	950	0	0
Quartile 1	1,330	3,300	1,700	2,000	11.5	41.5
Median	2,000	4,050	2,200	2,300	46	89
Quartile 3	2,500	4,800	2,770	2,700	78	134.5
Maximum	9,300	6,800	8,000	3,900	470	330
IQR	1,170	1,500	1,070	700	66.5	93
Outlier count: high	2	N/A	5	3	2	1
Outlier count: low	N/A	N/A	N/A	N/A	N/A	N/A

PES is primary environmental sample, the whole sample including all size fractions.
Outlier count: high is the count of sample results greater than the 75th percentile plus 1.5 times the IQR.
Outlier count: low is the count of sample results less than the 25th percentile minus 1.5 times the IQR.

Table G-1c. Summary Statistics for Nutrient Sample Concentrations

	TKN (mg/kg)		Phosphorus (mg/kg)	
Sample fraction	9	<250 µm	PES	<250 µm
Non-detects count	0	0	0	0
Sample count	59	36	59	36
Mean	2,241	2,053	526	673
Standard deviation	1,234	687	237	236
Minimum	388	1,220	56.6	67.8
Quartile 1	1,390	1,517.5	419	579.25
Median	2,180	1,950	516	690
Quartile 3	2,995	2,377.5	612	790.75
Maximum	6,620	4,390	1,810	1,350
Interquartile range (IQR)	1,605	860	193	211.5
Outlier count: high	1	1	1	1
Outlier count: low	N/A	N/A	2	3

PES is primary environmental sample, the whole sample including all size fractions.
Outlier count: high is the count of sample results greater than the 75th percentile plus 1.5 times the IQR.
Outlier count: low is the count of sample results less than the 25th percentile minus 1.5 times the IQR.

Table G-1d. Summary Statistics for Copper and Zinc Sample Concentrations

	Copper, total (mg/kg)		Copper, dissolved (µg/L)		Zinc, total (mg/kg)		Zinc, dissolved (µg/L)	
Sample fraction	9	<250 µm	PES	<250 µm	PES	<250 µm	PES	<250 µm
Non-detects count	0	0	0	0	0	0	0	0
Sample count	58	36	31	33	59	36	31	33
Mean	81	184	10	23	209	353	37	33
Standard deviation	41	62	4	13	78	110	24	25
Minimum	28.5	86.8	5.2	9.7	90	169	11	8
Quartile 1	55.175	135.5	7.1	12.8	154	270.75	25.2	20
Median	71.1	177	10.3	19.4	190	325	32	27
Quartile 3	91.7	228.75	13	27.3	240.5	430	44.5	39
Maximum	263	321	5.9	14.5	500	590	130	140
IQR	36.525	93.25	5.9	15.45	86.5	159.25	19.3	19
Outlier count: high	4	N/A	N/A	2	3	N/A	2	2
Outlier count: low	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

PES is primary environmental sample, the whole sample including all size fractions.
Dissolved copper and zinc concentrations represent extracts from the Synthetic Precipitation Leaching Procedure (SPLP), not runoff concentrations.
Outlier count: high is the count of sample results greater than the 75th percentile plus 1.5 times the IQR.
Outlier count: low is the count of sample results less than the 25th percentile minus 1.5 times the IQR.

Attachment G-2: Sample Concentration Box Plots

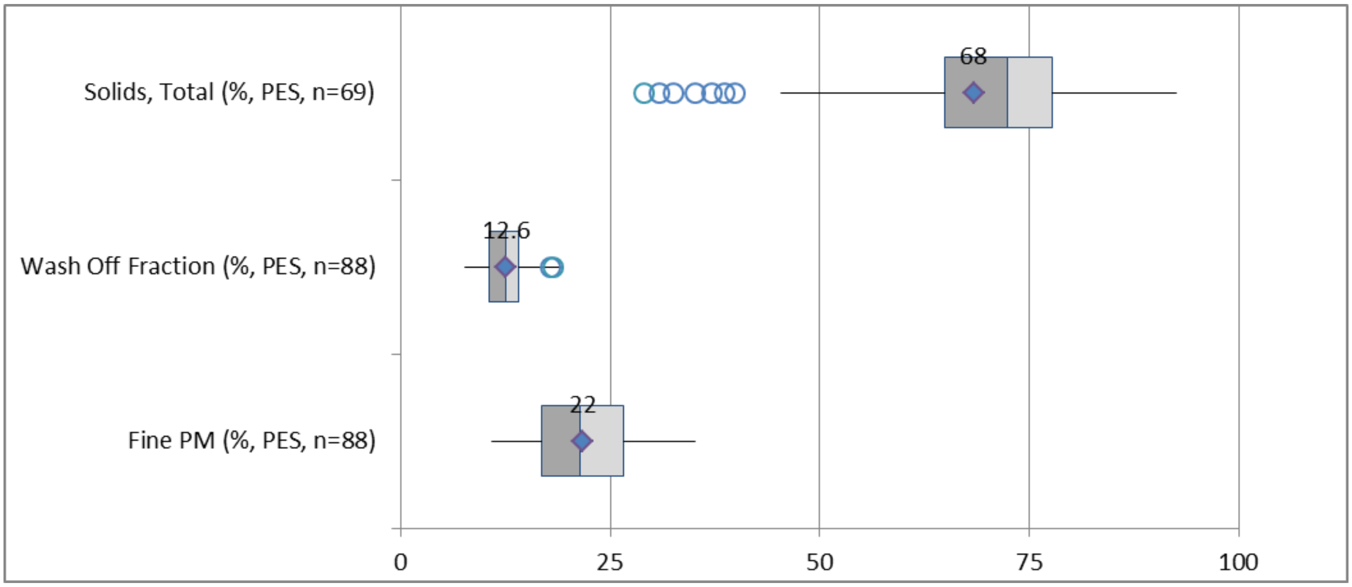

Figure G-2a. Box plot showing percent total solids, washoff fraction, and fine PM (% less than 250 µm) sample concentration distributions

The average values are shown as a diamond, median as a line, and outliers as a circle. The average values are noted on the chart. PES is primary environmental sample (i.e., the whole sample).

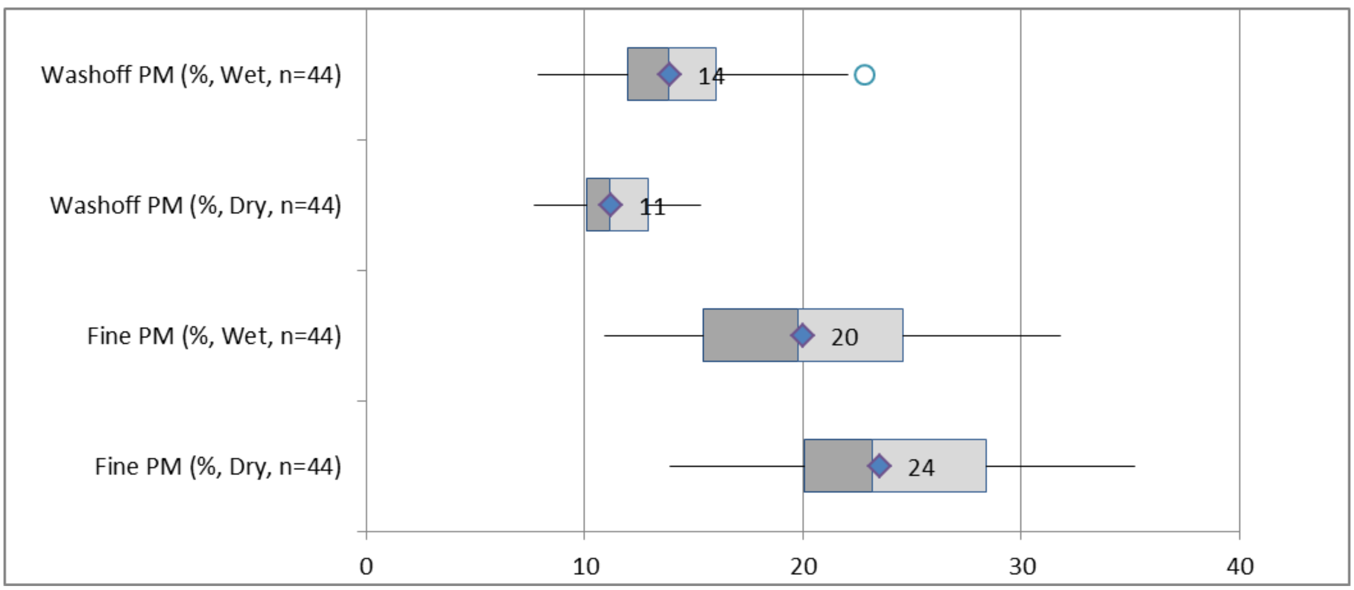

Figure G-2b. Box plot showing washoff fraction and fine PM (% less than 250 µm) sample concentration distributions by season

The average values are shown as a diamond, median as a line, and outliers as a circle. The average values are noted on the chart. PES is primary environmental sample (i.e., the whole sample).

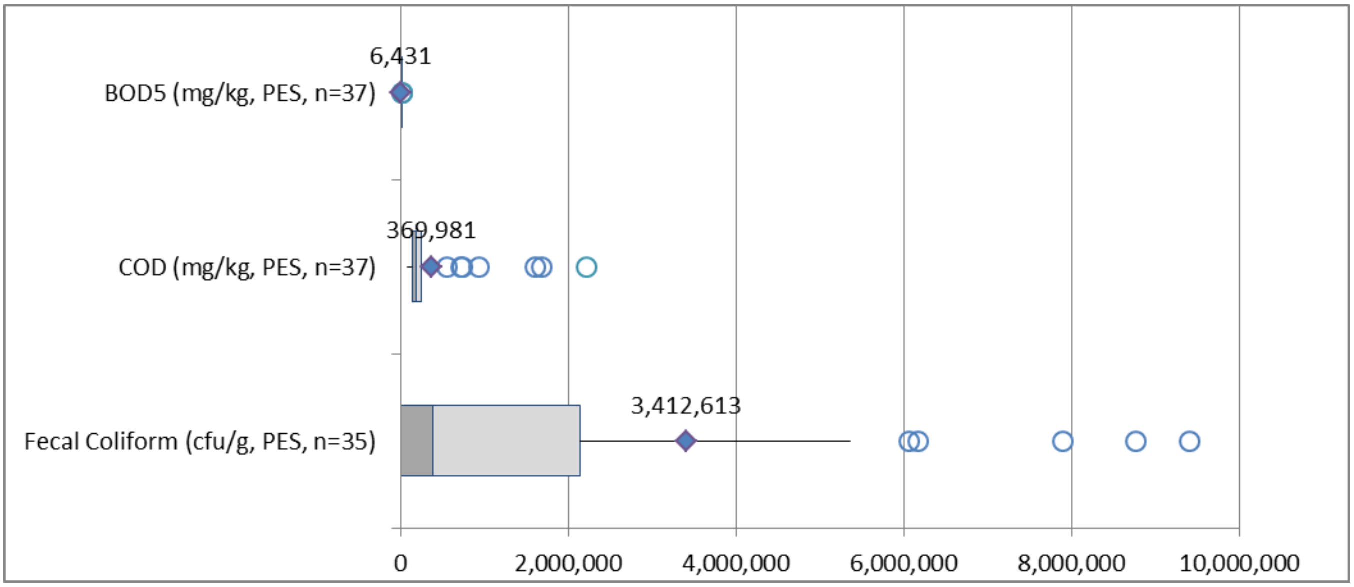

Figure G-2c. Box plot showing BOD$_5$, COD, and fecal coliform sample concentration distributions

The average values are shown as a diamond, median as a line, and outliers as a circle. The average values are noted on the chart. PES is primary environmental sample (i.e., the whole sample).

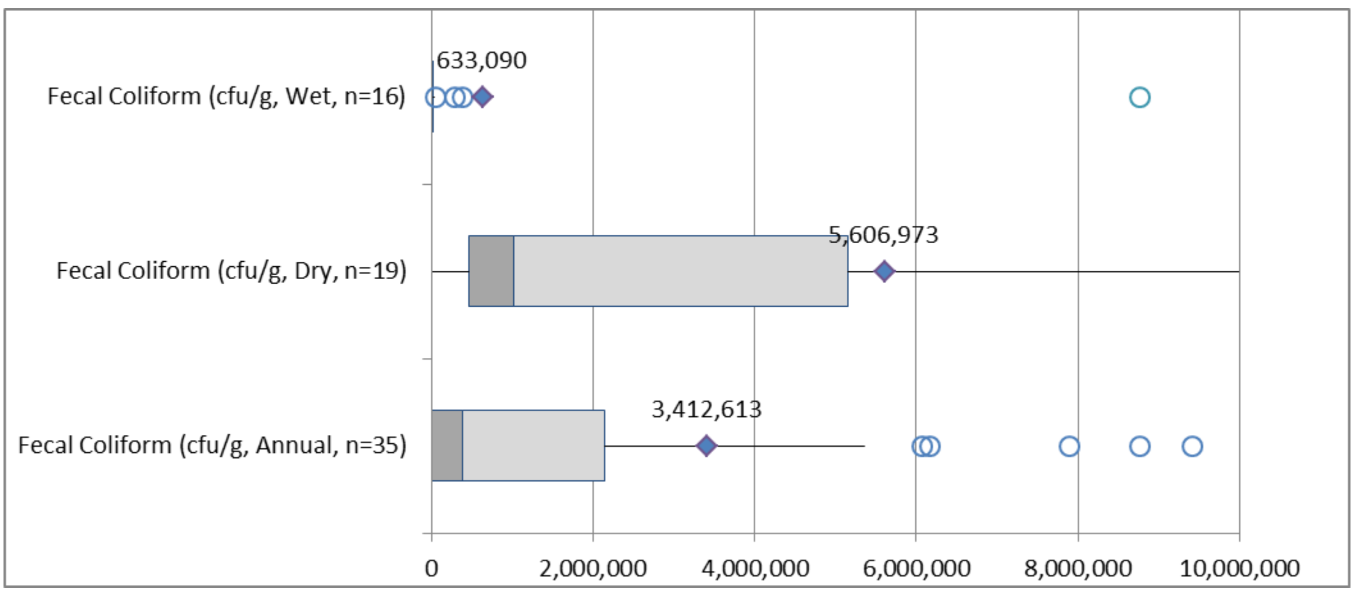

Figure G-2d. Box plot showing fecal coliform sample concentration distributions by season

The average values are shown as a diamond, median as a line, and outliers as a circle. The average values are noted on the chart. PES is primary environmental sample (i.e., the whole sample).

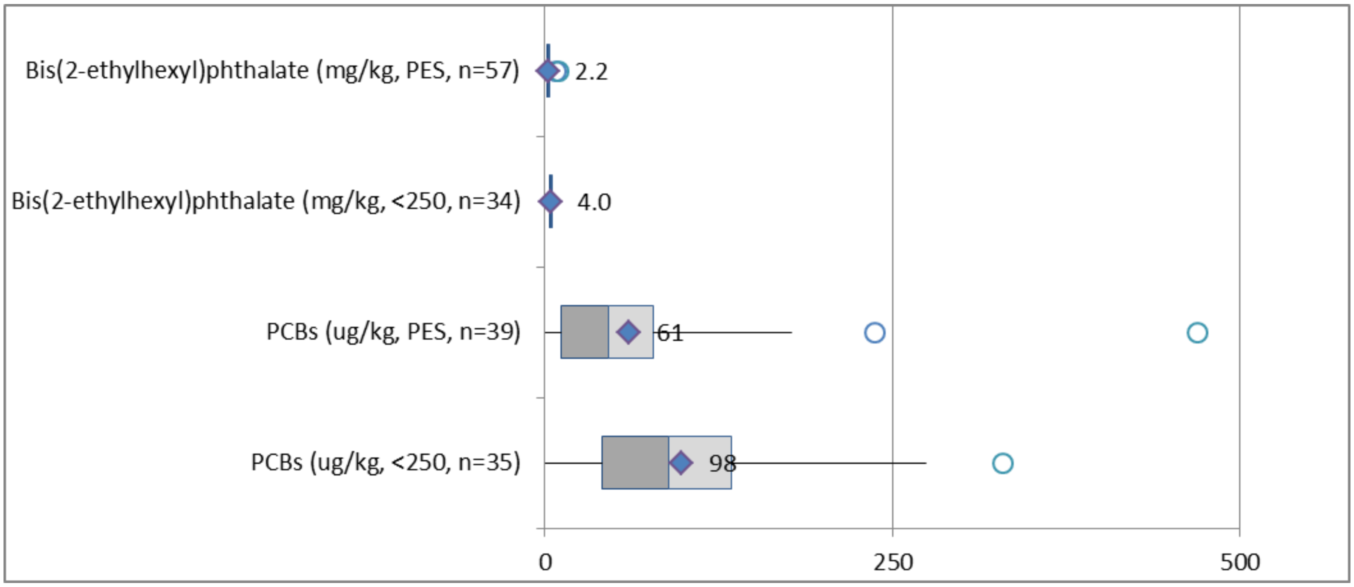

Figure G-2e. Box plot showing organics sample concentration distributions

The average values are shown as a diamond, median as a line, and outliers as a circle. The average values are noted on the chart. PES is primary environmental sample (i.e., the whole sample).

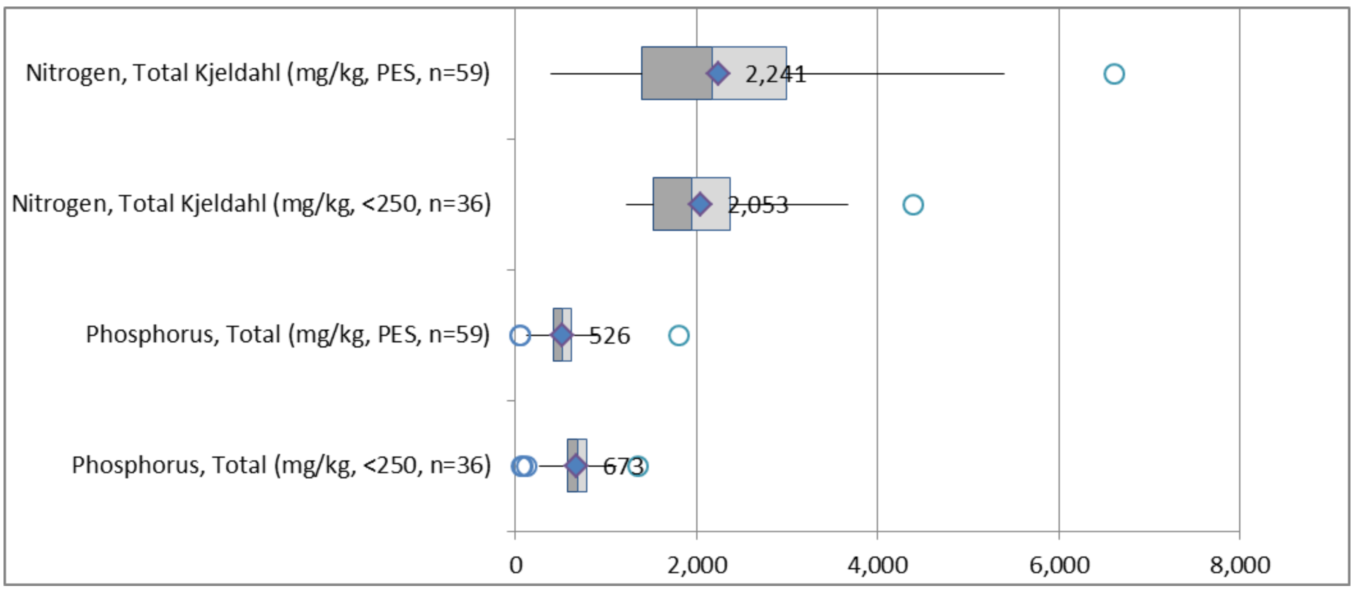

Figure G-2f. Box plot showing nutrient sample concentration distributions

The average values are shown as a diamond, median as a line, and outliers as a circle. The average values are noted on the chart. PES is primary environmental sample (i.e., the whole sample).

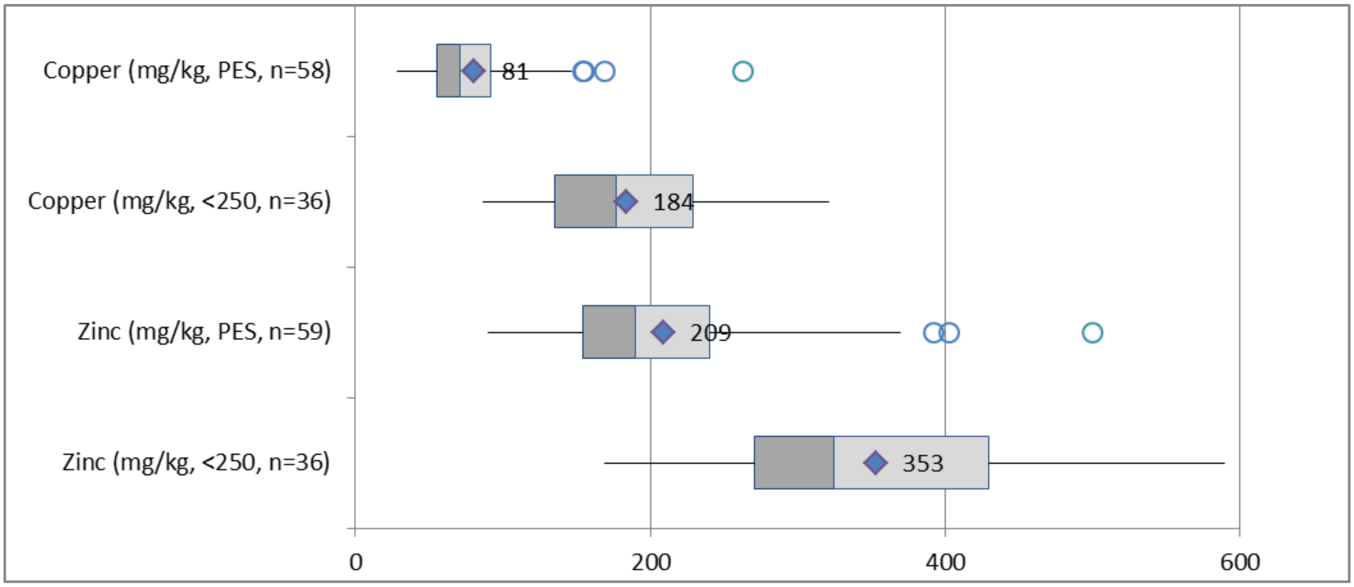

Figure G-2g. Box plot showing total copper and zinc sample concentration distributions

The average values are shown as a diamond, median as a line, and outliers as a circle. The average values are noted on the chart. PES is primary environmental sample (i.e., the whole sample).

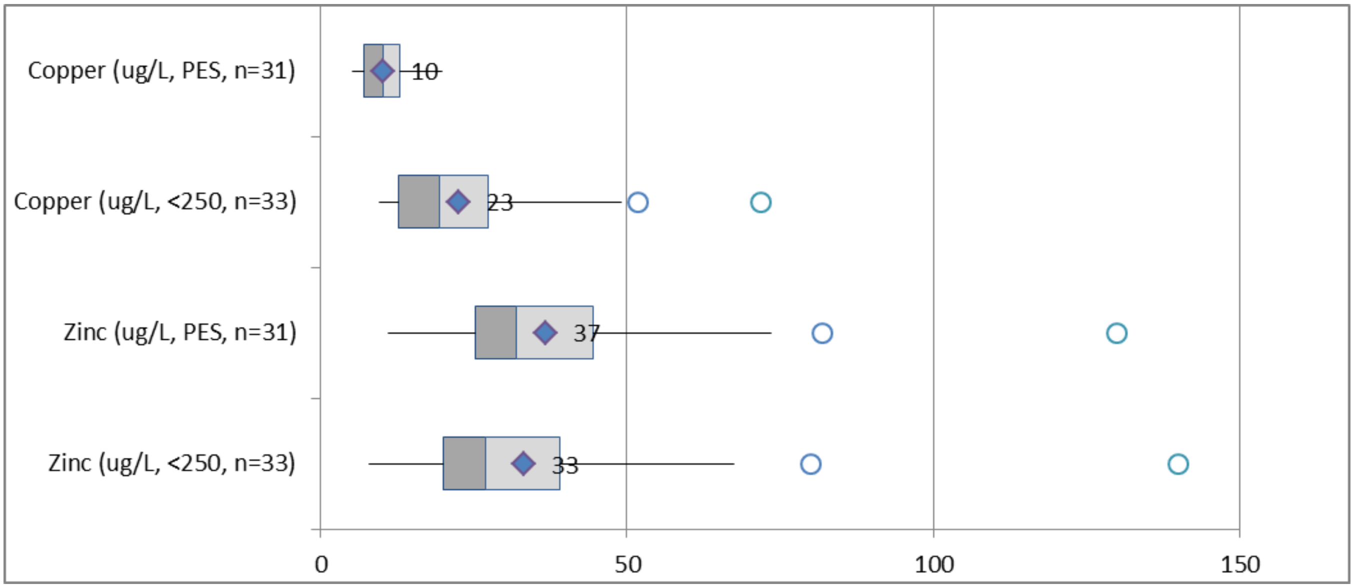

Figure G-2h. Box plot showing dissolved copper and zinc sample concentration distributions

The average values are shown as a diamond, median as a line, and outliers as a circle. The average values are noted on the chart. PES is primary environmental sample (i.e., the whole sample).

Appendix H: Exposure Assessment Methodology and Results

Seattle Public Utilities

Protecting Seattle's Waterways

Volume 3 – Integrated Plan

Appendix H: EXPOSURE ASSESSMENT METHODOLOGY AND RESULTS

Final

May 29, 2015

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List of Abbreviations

Term	Definition
°C	degree(s) Celsius
°F	degree(s) Fahrenheit
AWQC	ambient water quality criterion
BAF	bioaccumulation factor
BOD	biochemical oxygen demand
$CaCO_3$	calcium carbonate
CFU	colony forming unit(s)
cm	centimeter(s)
cm^2	centimeter(s) squared
CSO	combined sewer overflow
CWA	Clean Water Act
d	day(s)
Ecology	Washington State Department of Ecology
EA	Exposure Assessment
EIM	Environmental Information Management
EIV	exposure index value
EPA	U.S. Environmental Protection Agency
hr	hour(s)
kg	kilogram(s)
km	kilometer(s)
L	liter(s)
LA	likelihood of activity
LP	likelihood of presence
LTCP	Long-Term Control Plan
MCLG	maximum contaminant level goal
mg	milligram(s)
mL	milliliter(s)
NH_3	ammonia
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit(s)
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PC	permeability constant
PCB	polychlorinated biphenyl
RAGS	Risk Assessment Guidance for Superfund
RCOC	Representative Constituent of Concern
RD	relative dose
RF	receptor factor
RfD	reference dose
SF	slope factor
TL	trophic factor
TSS	total suspended solids
WQC	water quality criterion
yr	year(s)

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Chapter 1

Introduction

This appendix documents the Exposure Assessment (EA) methodology and results. In particular, this appendix describes the parameters used in the calculation of exposure index values (EIVs) and summarizes the results for the candidate stormwater and Long-Term Control Plan (LTCP) projects proposed for deferral.

Intertox assessed relative hazard reductions and the estimated impact on receiving waters resulting from changes in discharges of Representative Constituents of Concern (RCOCs) associated with each candidate stormwater project or LTCP project proposed for deferral. (EIVs were not calculated for the stormwater street sweeping program as EIVs are based on outfall locations, and runoff from the swept streets would enter many outfalls throughout the city.) The EIV tool is a mathematical model that provides a science-based metric by which the City of Seattle's proposed project outcomes can be compared. The EIV framework is built upon standard principles of risk assessment methodology applied by authoritative bodies worldwide, including the United States' National Academies of Science (EPA, 1996), U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology).

Intertox developed the EIV tool to help address key language in the Consent Decree requirements that:

> … the proposed stormwater control project(s) to be implemented by the City, provided that the proposed stormwater project(s) will result in significant benefits to water quality beyond those that would be achieved by implementation of the approved CSO Control Measures only (pg. 15 of Consent Decree).

And that the Integrated Plan must include:

> …a description of projected reductions in pollutant exposure for humans, ecological receptors, and/or threatened or endangered species through implementation of the proposed stormwater project(s) under the Integrated Plan (Consent Decree Section 20).

The EIV estimates the potential relative (not absolute) impact of each project, using metrics that are consistently and transparently assigned to reflect the estimated potential hazard of each RCOC, the projected relative decrease in discharge loads, and the estimated relative decrease in exposure potential to human and ecological receptor populations. Because estimates of actual concentrations at points of exposure (e.g., in receiving water) to human or ecological receptors that result from decreases in effluent load are not available, the output of the EA reflects an approximate estimate of changes in *relative* exposure, not actual exposure or risk, induced by changes in effluent releases. These estimates are intended to support comparison of the relative benefit of the candidate LTCP or stormwater projects.

Separate EIVs are calculated for human and ecological receptors for each RCOC associated with each project. EIVs are then summed separately for human and ecological receptors for each project. As formulated, a higher EIV indicates that implementing a particular project would have relatively greater impact on reducing hazards in comparison to other projects with lower EIVs.

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Chapter 2

Key Components of the Exposure Assessment

Three separate EIV metrics—two human metrics and one ecological metric— were calculated for each candidate project as follows:

- human: toxics (calculated using chronic toxicity criteria)
- human: fecal coliform (calculated using acute toxicity criteria)
- ecological: toxics and nutrients (calculated using chronic criteria)

The equation used to calculate the EIVs is presented below. EIVs were calculated for the RCOCs listed in the Integrated Plan (see Table 6-1 of the plan). Several RCOCs were not included in EIV calculations because of a lack of human or ecological water quality criteria (WQC) for these compounds. Section 2.2 identifies the RCOCs that were excluded.

2.1 The Exposure Index Value Calculation

For each LTCP and stormwater scenario, the relative significance of changes in exposure to human and ecological receptors was assessed by calculating an EIV, as follows:

$$EIV_{Human\ or\ Eco-RCOC} = \frac{C_{Pre}}{WQC_{Human\ or\ Eco}} \times Relative\ change\ in\ load \times RF_{Human\ or\ Eco}$$

where:

C_{pre} = Concentration in effluent discharged Pre-project (mg/L, or CFU/100 mL for fecal coliform)

WQC = Human or ecological water quality criterion (mg/L, or CFU/100 mL for fecal coliform)

Relative change in load = (Pre-project load – Post-project load for a specific RCOC)/ Total change in load across all projects (LTCP and stormwater) for this RCOC

RF = Receptor factor (unitless)

Overall, the three main terms in the equation can be interpreted as follows:

- C_{pre}/WQC: Reflects the relative human-health risk or ecological hazard associated with discharges prior to implementation of a project (because concentrations are "end-of-pipe" values and not concentrations in receiving water, this term does not reflect "true" hazards, but rather is an index of "relative" hazards). A higher value for this term suggests that implementing the associated project, per unit relative change in load, would have relatively greater impact on reducing hazards.

- *Relative change in load*: This term reflects the relative impact of the project on decreasing the amount (mass) of a given RCOC discharged to the receiving water, compared to other projects (without regard to the potential toxicity or hazard of a unit mass of that RCOC). A higher value for this term suggests that implementing the associated project would have relatively greater impact on reducing the mass of a RCOC discharged.
- *RF*: Reflects the relative potential magnitude of exposure to a given RCOC. A higher value for this term suggests that implementing the associated project, per unit relative change in load, would have relatively greater impact on reducing overall exposures.

2.2 RCOCs Not Included in EIV Calculations

The following RCOCs were not included in EIV calculations:

- **Biochemical oxygen demand (BOD):** BOD is a measure of the amount of oxygen consumed by microorganisms in decomposing organic matter in stream water, and directly affects the amount of dissolved oxygen in rivers and streams (EPA, 2012a). The greater the BOD, the more rapidly oxygen is depleted in a stream, indicating less oxygen available to higher forms of aquatic life. Neither the State of Washington nor EPA has published ambient water quality criteria (AWQCs) for either human or ecological effects for BOD. As such, BOD was not included in the EIV calculations.
- **H+:** EPA has published national AWQC for ecological effects associated with pH, indicating a recommended range between 6.5 and 9 for fresh water and 6.5 and 8.5 for marine water (EPA, 2013). Per the EPA Red Book (EPA, 1996):

  > For open ocean waters where the depth is substantially greater than the euphotic zone, the pH should not be changed more than 0.2 units from the naturally occurring variation or any case outside the range of 6.5 to 8.5. For shallow, highly productive coastal and estuarine areas where naturally occurring pH variations approach the lethal limits of some species, changes in pH should be avoided but in any case should not exceed the limits established for fresh water, i.e., 6.5–9.0.

  The estimated Pre-project concentration of H+ in discharges from the combined sewer overflows (CSOs) and stormwater outfalls ranges from about 2.1×10^{-7} micrograms per liter (µg/L) to 7.1×10^{-7} µg/L, or a pH of about 6.1 to 6.7; however, these estimates do not reflect the pH of receiving waters, and predictions of project impact are based on the change in load of the H+ ion, in kilograms (kg) per season, which cannot be extrapolated to pH estimates. As such, H+ was not included in the EIV calculations.
- **Oil and grease:** While data have demonstrated toxicity of oils to aquatic organisms, the potential toxicity of oil and grease is highly dependent on the specific chemical components of the mixture. For example, the type and concentration of polycyclic aromatic hydrocarbons (PAHs) in the mixture can significantly impact the toxicity (EPA, 1986; EPA, 1996). Because compound-specific data on concentrations and loads for specific components of the oil and grease mixtures released from the CSOs or stormwater outfalls are not available, oil and grease was not included in the EIV calculations.
- **Total suspended solids:** Total suspended solids (TSS) are measured by the weight of the suspended solid material (e.g., silt and clay) per liter of water. No WQCs for TSS were identified. Ecological water quality standards exist for turbidity (which is related to TSS) based on an acceptable increase over background, and hydrodynamic models exist to predict TSS from turbidity; however, these models are complex and water-body-specific. For example, to protect char spawning and rearing, Ecology proposes aquatic life turbidity criteria for fresh water not to exceed 5 nephelometric turbidity units (NTU) over background when the background is 50 NTU or less, or a 10 percent increase in turbidity when the background turbidity is more than 50 NTU (Ecology, 2011a). However, because the influences of TSS discharges on turbidity levels in receiving water could not be estimated in the current assessment, TSS was not included in the EIV calculations.

In conclusion, although these RCOCs were not included in this evaluation, there is not a significant impact on the results and related conclusions reached within this EA.

Chapter 3

Steps in Conducting the Exposure Assessment

To conduct the EA, the following steps were completed:

1. Determine the Pre-project discharge concentration for each candidate stormwater or LTCP project, for each RCOC
2. Identify WQC for each RCOC for human and ecological receptors
3. Determine the change in load for each RCOC assuming implementation of a project at a given discharge location, relative to the predicted total change in load for that RCOC over all projects
4. Develop receptor factors (RFs) for human and ecological receptors that take into account distance from discharge to a potential exposure point, likelihood of exposure via a given pathway at that point, and relative magnitude of the potential reduction in an exposure via a given pathway
5. Calculate human and ecological EIVs for each RCOC for each candidate stormwater and LTCP project scenario
6. Sum EIVs for humans and ecological receptors for each candidate stormwater and LTCP project scenario

The results of the EA were provided to the Integrated Plan team to support the comparison of water quality benefits associated with each project. Since EIVs were not calculated for the street sweeping program, a more qualitative approach was used, to evaluate the potential reductions in exposure from this program, in support of the water quality benefits comparison (see Section 8.2.3 in the Integrated Plan).

Each of these steps in the EA methodology is explained in the sections below.

3.1 Determine the Pre-Project Discharge Concentration for Each RCOC for Each Candidate Stormwater and LTCP Project

For each candidate stormwater or LTCP project, the Pre-project discharge concentrations for RCOCs at the "end-of-pipe" location were provided to Intertox by Integrated Plan team members. (Chapter 6 and Appendices E and F of the Integrated Plan include information on the estimate of the Pre-project discharge locations.)

3.2 Identify Water Quality Criteria

For each of the RCOCs, WQCs were identified that are assumed to be protective of potential health risks for humans and ecological receptors that come in contact with the water. An index of the potential impact of Pre-project discharge concentrations was estimated by dividing the Pre-project RCOC concentration at the discharge point by the WQC.

WQCs for human health effect endpoints are listed in Table 3-1. WQCs for ecological endpoints are listed in Table 3-2. The bases for the criteria are described below.

Table 3-1. Water Quality Criteria for Human Receptors

RCOC	Criterion (mg/L)	Basis	Health impact basis	Source
Bis(2-ethylhexyl) phthalate	0.0012	Assuming ingestion of water and fish consumption	Chronic, cancer (liver cancer in rodents, EPA SF)	EPA AWQC (EPA, 2013)
Copper	1.3	EPA drinking water MCLG	Chronic, non-cancer (gastrointestinal effects in humans, EPA RfD)	EPA AWQC (EPA, 2013)
Dichlobenil	0.44	Assuming ingestion of water and fish consumption	Chronic, non-cancer (decreased body weight in dogs, EPA RfD)	Derived used EPA AWQC equation (EPA, 2000)
Fecal coliform	50 CFU/100 mL 100 CFU/100 mL 200 CFU/100 mL	Extraordinary primary contact (Ship Canal, Portage Bay, Piper's Creek, Thornton Creek) Primary contact (Longfellow Creek) Secondary contact (Duwamish Waterway)	Acute infection	Ecology, 2011a
PBDEs	0.000088	Assuming ingestion of water and fish consumption	Chronic, non-cancer effects (neurobehavioral effects in rats, EPA RfD)	Derived used EPA AWQC equation (EPA, 2000)
PCBs	0.000000064	Assuming ingestion of water and fish consumption	Chronic, cancer (liver cancer in rats, EPA SF)	EPA AWQC (EPA, 2013)
Zinc	7.4	Assuming ingestion of water and fish consumption	Chronic, non-cancer (enzyme activity in humans, EPA RfD)	EPA AWQC (EPA, 2013)

AWQC = ambient water quality criteria.
CFU = colony forming unit(s).
MCLG = maximum contaminant level goal.
PBDE = polybrominated diphenyl ether.
PCB = polychlorinated biphenyl.
RfD = reference dose.
SF = slope factor.

Table 3-2. Water Quality Criteria for Ecological Receptors

RCOC	Chronic criterion, freshwater (mg/L)	Chronic criterion, marine (mg/L)	Basis	Source
Ammonia-N	Location-specific; see discussion below	8.21 (Oct–Jan) 5.52 (Feb–Sep)	Calculated as un-ionized ammonia and converted to total ammonia, as N, assuming salmonids present; see discussion below	Ecology, 2011a
Bis(2-ethylhexyl) phthalate	0.003	0.003	No criteria, based on data suggesting chronic toxicity to aquatic life as low as 3 µg/L	EPA, 1980
Dichlobenil	0.33	0.33	Chronic criteria for fisheries	Ecology, 2013a
Dissolved copper	0.0041 (mesotrophic) 0.011 (streams)	0.0031	For freshwater, based on water-body-specific hardness assumptions using EPA equation; for marine, equal to EPA value; see discussion below	EPA, 2007
Dissolved zinc	0.054 (mesotrophic) 0.14 (streams)	0.081	Based on water-body-specific hardness assumptions using EPA equation; for marine, equal to EPA value; see discussion below	EPA, 2007
PCBs	0.000014	0.00003	Total PCBs	Ecology, 2011b
Phosphorus	0.00875 (lakes) 0.010 (streams)	No value	Total phosphorus, Ecoregion II	EPA, 2002a

PCB = polychlorinated biphenyl.

Because estimated changes in discharge loads are based on annual averages, the water concentrations were divided by WQCs established for chronic exposure, with the exception of the human WQC for fecal coliform, which is based on acute exposures.

3.2.1 Basis for Human Water Quality Criteria

For humans, WQCs for all RCOCs except fecal coliform were based on EPA AWQCs. The AWQCs consider potential cancer risk and non-cancer health effects, bioaccumulation potential in fish, and human exposure through consumption of water and fish.

For some RCOCs, published AWQC values are available (EPA, 2013). Regarding these, EPA states, "Pursuant to Section 304(a)(1) of the Clean Water Act (CWA), EPA is required to publish, and from time to time thereafter revise, criteria for water quality accurately reflecting the latest scientific knowledge on the kind and extent of all identifiable effects on human health which may be expected from the presence of pollutants in any body of water" (EPA, 2000).

For other RCOCs, AWQCs were derived using EPA's *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health* (EPA, 2000), based on EPA toxicity criteria for non-cancer effects (reference doses, RfDs) or cancer effects (cancer slope factors, SFs). Per EPA:

> The 2000 Human Health Methodology is … intended to provide States and authorized Tribes flexibility in establishing water quality standards by providing scientifically valid options for developing their own water

quality criteria that consider local conditions. States and authorized Tribes are strongly encouraged to use this methodology to derive their own AWQC. However, the 2000 Human Health Methodology also defines the default factors EPA intends to use in evaluating and determining consistency of State water quality standards with the requirements of the CWA. The Agency intends to use these default factors to calculate national water quality criteria under 1-2 Section 304(a) of the Act.

For non-cancer effects, the AWQC equation is:

$$AWQC = RfD \times RSC \times \left(\frac{BW}{DI + \sum_{i=2}^{4}(FI_i \times BAF_i)}\right)$$

For cancer effects, the AWQC equation is:

$$AWQC = RSD \times \left(\frac{BW}{DI + \sum_{i=2}^{4}(FI_i \times BAF_i)}\right)$$

where:

$AWQC$ = ambient water quality criterion (mg/L)

RfD = reference dose for non-cancer effects (mg/kg-d)

RSC = risk-specific dose for non-carcinogens

RSD = risk-specific dose for carcinogens based on a linear low-dose extrapolation (mg/kg-d) (equivalent to a target incremental cancer risk of one in 1 million or 10^{-6} /cancer slope factor $(mg/kg\text{-}d)^{-1}$)

BW = human body weight (default = 70 kg for adults)

DI = drinking water intake (default = 2 L/day for adults)

FI_i = fish intake at trophic level (TL) 1 (i = 2, 3, and 4) (default for total intake at TL1= 0.0175 kg/day for general adult population and sport anglers).

BAF_i= bioaccumulation factor at trophic level, lipid normalized (L/kg)

EPA has published human AWQCs for four of the RCOCs, as follows:

- copper: 1.3 mg/L (EPA, 1994; EPA, 2013), based on a drinking water action level (maximum contaminant level goal, or MCLG) of 1.3 mg/L
- zinc: 7.4 mg/L (EPA, 2013), based on an *RfD* of 0.3 mg/kg-d, a relative source contribution of 1, a *BAF* of 47, and a fish intake of 0.0175 kg/d (EPA, 2002b)
- bis(2-ethylhexyl)phthalate: 0.0012 mg/L (EPA, 2013), based on a cancer slope factor (SF) of 0.014 $(mg/kg\text{-}d)^{-1}$, a relative source contribution of 1, a *BAF* of 130, and a fish intake of 0.0175 kg/d (EPA, 2002b)
- PCBs: 0.000000064 mg/L (EPA, 2013), based on a cancer slope factor of 2 $(mg/kg\text{-}d)^{-1}$ (for total PCBs/congeners/isomers), a *BAF* of 31,200, and a fish intake of 0.0175 kg/d (EPA, 2002b)

For the other two RCOCs, AWQCs were derived using the EPA equations (EPA, 2000) to yield the following values:

- PBDEs: 0.000088 mg/L based on a non-cancer *RfD* of 0.0001 mg/kg-d for tetra-BDE (EPA, 2012b), a relative source contribution of 1, a *BAF* of 4,450 (NLM, 2013a), and a fish intake of 0.0175 kg/d
- dichlobenil: 0.44 mg/L based on a non-cancer *RfD* of 0.015 mg/kg-d (EPA, 1998), a relative source contribution of 1, a BAF of 22 (NLM, 2013b), and a fish intake of 0.0175 kg/d

Fecal coliform was evaluated separately from the other RCOCs because the primary health effects of concern are associated with acute exposure. For fecal coliform, the acute WQCs were identified based on the assumed nature of contact[1] as follows (Ecology, 2011b):

- Extraordinary Primary Contact recreation: not to exceed a geometric mean of 50 CFU/100 mL
- Primary Contact recreation: not to exceed a geometric mean of 100 CFU/100 mL
- Secondary Contact recreation: not to exceed a geometric mean of 200 CFU/100 mL

These criteria are based on results of studies of humans exposed to fecal coliform in lakes, including in Lake Michigan and the Ohio River (Ecology, 2002). The Lake Michigan study reported that there were no excess illnesses of any type in swimmers at beaches that had median coliform densities of 91 and 180 per 100 mL over a swimming season, when compared to the number of illnesses in the total study population. A significantly greater illness rate was reported in individuals who swam on the three days when the geometric mean coliform density was 2,300/100 mL when compared to swimmers who swam on the three days when the geometric mean coliform density was 43/100 mL. In addition, data from the Ohio River study indicated that swimmers who swam in water with a median coliform density of 2,300 coliforms per 100 mL had an excess of gastrointestinal illness when compared to an expected rate calculated from the total study population.

3.2.2 Basis for Ecological Water Quality Criteria

Ecological WQCs for RCOCs were identified based on values published by Ecology or EPA. Where different values were available for fresh water and marine waters, freshwater criteria were applied to projects on Longfellow Creek, Piper's Creek, Thornton Creek, Portage Bay, and the Ship Canal, and marine criteria were applied to projects on brackish or saltwater bodies of interest (Duwamish Waterway and Elliott Bay).

The basis for the ecological WQCs was as follows:

- Dissolved copper: 0.0041 mg/L for freshwater mesotrophic (i.e., Portage Bay and Ship Canal) and 0.011 mg/L for freshwater rivers and streams calculated according to the following equation:

  $$\textit{Concentration-freshwater (mg/L)} = (e^{0.8545\,[\ln(H)]\,-\,1.702} * 0.96)/1000$$

  where H = water hardness (mg/L as $CaCO_3$) (EPA, 2007).

  - For Portage Bay and the Ship Canal, a hardness value of 40 mg/L was assumed, based on the average of a single sample collected from Lake Union and three samples collected from Lake Washington (Ecology, 2013b). For Longfellow, Thornton, and Piper's creeks, a hardness value of 120 mg/L was assumed, based on the average of eight samples collected from Longfellow and Piper's creeks (Ecology, 2013b).
  - The marine concentration of 0.0031 mg/L was based on the value for saltwater presented in EPA (2007).

[1] Washington State Department of Ecology designates Recreational Use in the Duwamish River from the mouth to RM 11.0 as being "Secondary Contact," Lake Washington and Ship Canal as "Extraordinary Primary Contact," and all others as "Primary Contact" (Ecology, 2011a).

- Dissolved zinc: 0.054 mg/L for freshwater mesotrophic (i.e., Portage Bay and Ship Canal) and 0.14 mg/L for freshwater rivers and streams, calculated according to the following equation:

$$\textit{Concentration-freshwater (mg/L)} = e^{(0.8473\,[\ln(H)]\,+0.884)} * 0.986$$

  - where: H = water hardness (mg/L as $CaCO_3$) (EPA, 2007). The hardness assumptions applied are the same as those used to calculate the copper criteria.
  - The marine concentration of 0.081 mg/L was based on the value for saltwater presented in EPA (2007).

- Ammonia-N: For freshwater locations where salmonid habitat is an existing or designated use (assumed to be all locations except the Duwamish Waterway, which is assumed to be brackish), location-specific concentrations were calculated for un-ionized ammonia (NH_3) according to the following equation (Ecology, 2011a):

$$Un\text{-}ionized\ ammonia\ \left(\frac{mg}{L}\right) = \frac{0.80}{FT \times FPH \times Ratio}$$

  where:

  FT = based on temperature, equal to 1.4 [if 15 ≤ T ≤ 30] or $10^{0.03(20-T)}$ [if 0 ≤ T ≤ 15]
  FPH = based on pH, equal to 1 [if 8 ≤ pH ≤ 9] or $(1 + 10^{7.4-pH}) \div 1.25$ [if 6.5 ≤ pH ≤ 8.0]
  Ratio = based on pH, equal to 13.5 [if 7.7 ≤ pH ≤ 9] or $(20.25 \times 10^{7.7-pH}) \div (1 + 10^{7.4-pH})$ [if 6.5 ≤ pH ≤ 7.7]

  Because the equation, and estimated concentrations, are affected substantially by pH and temperature values, the calculated concentrations are based on an estimated mean pH and temperature for each water body and season (October–January or February–September), based on data from the Ecology Environmental Information Management (EIM) database (Ecology, 2013b). For marine/brackish locations (e.g., the Duwamish Waterway), an un-ionized ammonia concentration of 0.035 mg/L was used based on the value for marine locations presented by Ecology (2011a). Un-ionized ammonia concentrations were converted to season-specific total ammonia concentrations using the calculations in the Washington State Department of Ecology Spreadsheets for Water Quality-Based Permit Calculations (Ecology, 2010).

  Location-specific Ammonia-N concentrations are summarized in Table 3-3, below.

Table 3-3. Location-Specific Ammonia-N Concentrations

Water body	Season	Assumed, mean pH and temperature	Un-ionized ammonia concentration (mg/L)	Total ammonia concentration (mg/L)
Duwamish Waterway	October–January	7.33, 9.1°C	0.035	8.21
Duwamish Waterway	February–September	7.38, 12.9°C	0.035	5.52
Ship Canal	October–January	7.47, 12.1°C	0.017	2.16
Ship Canal	February–September	7.63, 15.3°C	0.030	2.10
Portage Bay	October–January	7.47, 12.1°C	0.017	2.16
Portage Bay	February–September	7.63, 15.3°C	0.030	2.10
Union Bay/Lake Washington	October–January	7.55, 11.6°C	0.020	2.17
Union Bay/Lake Washington	February–September	7.86, 14.5°C	0.038	1.66
Longfellow Creek	October–January	7.47, 8.7°C	0.013	2.23

Table 3-3. Location-Specific Ammonia-N Concentrations

Water body	Season	Assumed, mean pH and temperature	Un-ionized ammonia concentration (mg/L)	Total ammonia concentration (mg/L)
Longfellow Creek	February–September	7.78, 12.6°C	0.031	1.91
Piper's Creek	October–January	7.72, 9.1°C	0.024	2.16
Piper's Creek	February–September	7.83, 10.7°C	0.028	1.79
Thornton Creek	October–January	7.42, 13.8°C	0.017	2.13
Thornton Creek	February–September	7.74, 9.4°C	0.024	2.09

- phosphorus: 0.00875 mg/L for freshwater mesotrophic (i.e., lakes) and 0.010 mg/L for freshwater streams (EPA, 2002a)
- PCBs: 0.000014 mg/L for fresh water and 0.00003 mg/L for marine (Ecology, 2011b)
- bis(2-ethylhexyl)phthalate: 0.003 mg/L based on data suggesting chronic toxicity to aquatic life at concentrations as low as 3 µg/L (EPA, 1980)
- dichlobenil: 0.33 mg/L (chronic criteria for fisheries; Ecology, 2013a)

3.3 Determine the Relative Change in Load for Each RCOC for Each Project

For each RCOC for each project, the relative change in load was estimated as follows:

$$Relative\ change\ in\ load = \frac{Load_{Post-project} - Load_{Pre-project}}{\sum Change\ in\ load\ for\ all\ projects}$$

This term characterizes the project-specific change in load for a given RCOC relative to the total change in load for that RCOC across all other projects (LTCP and stormwater combined). As such, in the EIV equation, it provides a measure of the decrease in discharge mass that would be implemented by a given project.

3.4 Develop Receptor Factors

For human and ecological receptors, the relative magnitude of potential exposure was evaluated using a receptor factor (*RF*). Separate equations and assumptions were used to calculate *RF*s for humans and ecological receptors, as described below.

3.4.1 Receptor Factors for Humans

For each candidate LTCP or stormwater project and RCOC, an *RF* for human receptors was calculated as a function of three measures: the likelihood of exposure to a receptor at a point via a given exposure pathway, the distance from the discharge point to a human receptor point, and the relative magnitude of reduction in exposure to the receptor via that pathway.

The following scheme was used to calculate RFs for human receptors:

$$RF_H = \frac{LA \times RD}{D}$$

where:

RF_H = Receptor factor for humans (unitless)

LA = Relative likelihood of swimming, wading, recreational boating, fishing, or shellfishing at a given exposure point [scale 1 (low/unlikely) to 5 (high/likely), or 0 if not at all]

RD = Relative dose of RCOC via swimming, wading, recreational boating, fishing, or shellfishing

D = Approximate distance from discharge point to receptor location, in kilometers (maximum 2 km)

The resulting RF_H was adjusted to a normalized *RF* (RF_HN) based on the maximum RF_H identified for any receptor or scenario, such that the range of normalized RF_HN values ranged from 0 to 1.

Values for each of the component factors of the RF_H were assigned as follows.

3.4.2 Identify Locations of and Pathways of Exposure to Human Receptors

The potential for exposure to discharges from a given CSO or stormwater outfall was assessed by characterizing the relative proximity of human receptors to these discharge points. Potential locations of human receptors were determined for each of the receiving water bodies of interest (Longfellow Creek, Piper's Creek, Thornton Creek, Portage Bay, Lake Washington Ship Canal/Lake Union, Duwamish Waterway, and Elliott Bay) as described below.

3.4.2.1 Recreational Users

Human use surveys of Puget Sound, Lake Washington, and Lake Union shorelines have identified how these areas are utilized recreationally by the public (King County, 2002; 2003). Data from these surveys were used in the EA to characterize the relative likelihood and magnitude of human exposure to RCOCs released from outfalls during CSO or stormwater events.

Examples of activities by site location in the Puget Sound survey are summarized in Tables 3-4 and 3-5; numbers of people engaged in recreational activities by specific locations on Lake Union and Lake Washington are not available, but data on activities for the entire lake system are described. Recreational users at Carkeek Park (the location of Piper's Creek and it's outfall into Puget Sound) were observed participating in each activity while users at the two lake locations were interviewed about their activities at Lake Union and Lake Washington (King County, 2002; 2003).

Table 3-4. Percent of People Engaged in Sand/Sediment Activities by Location

Site	Total # surveyed	Sitting on beach	Walking/ running/ hiking	Picnicking/ BBQ	Digging in sand away from water
Carkeek Park	861	28%	40%	6%	7%
Lake Union	125	20%	24%	2%	6%
Lake Washington	2,470	22%	27%	5%	5%

Source: King County (2002, 2003).

Table 3-5. Percent of People Engaged in Water Activities by Location

Site	Total # surveyed	Wading	Swimming	Digging in sand near water	Scuba diving	Surfing	Boating[a]	Jet skiing
Carkeek Park	861	5%	0%	13%	0%	1%	0%	0%
Lake Union	125	1%	1%	1%	0%	0%	18%	0%
Lake Washington	2,470	3%	8%	3%	0%	0%	8%	1%

a. Includes motorboats, sailboats, kayaks, canoes, and rafts.
Source: King County (2002, 2003).

Patterns of human use activities on the Duwamish Waterway and Elliott Bay have also been reviewed, and include swimming and wading, scuba diving, boating, surfing, parasailing, and jet skiing (King County, 1999). However, the number of people engaged in these activities was not assessed.

In all of the water bodies, human use patterns vary depending on seasons and weather conditions. For example, swimming and wading in the Duwamish Waterway and Elliott Bay are expected to be confined to the summer months, if at all, given that average water temperatures are approximately 48 degrees Fahrenheit (°F), with winter water temperatures dropping as low as 39°F and summer water temperatures rising as high as 60°F (King County, 1999). Site visits to Lake Washington and Lake Union were more common during spring and summer than in fall and winter (King County, 2003). In addition, people generally visited these sites more often when the weather was clear or cloudy than when it was raining (King County, 2003). Similar patterns were observed at Carkeek Park (King County, 2002).

3.4.2.2 Anglers/Shellfishers

Human use surveys and fish consumption reports indicate that anglers engage in line fishing (shore/pier and boat) in the Duwamish Waterway, Lake Washington, Lake Union, and Elliott Bay (King County, 1999; 2002; 2003). Interview respondents indicated that they were more likely to fish in Lake Washington than in Lake Union, with an equal number of participants fishing from the shore/pier and boats (King County, 2003). In addition to line fishing, gillnetting was identified as the preferred method of salmon collection by tribal members in the Duwamish Waterway (King County, 1999).

The species of fish collected vary by location (i.e., marine vs. freshwater). Surveys indicate that the majority of fish collected in the Puget Sound and Duwamish Waterway are salmon (King County, 1999; 2002). Sea perch were also commonly collected in Puget Sound. In Lake Washington, the majority of fish collected were perch, followed by salmon and trout (King County, 2003).

Recreational sport fishing is subject to rules set forth by the Washington Department of Fish and Wildlife (Washington State, 2013a). Salmon fishing is seasonally restricted in all areas. The most recent rules for Marine Area 10 (Seattle/Bremerton) allow year-round fishing for trout, mackerel, herring (and related fish), and perch. Seasonal restrictions apply for lingcod and halibut, while fishing for rockfish, Pacific cod, pollack, and hake are closed. Fishing for trout and other game fish (excluding salmon) is open year-round in Lake Washington and Lake Union. Piper's and Longfellow creeks are closed to fishing, while Thornton Creek is open June through August to anglers under 15 years old only. Tribal fishing is subject to different rules than recreational fishing.

Washington State Department of Health fish advisories for Puget Sound recommend no more than one meal per week of Chinook salmon and no more than two meals per month of Blackmouth Chinook, English sole, and other flatfish (Washington State, 2013c). Advisories for the Duwamish Waterway recommend that people do not eat any resident fish, shellfish, or crab (Washington State, 2013a). Lake Washington advisories suggest limiting cutthroat trout and yellow perch to one meal per month (Ecology, 2013a).

Gathering shellfish and other organisms is common in Puget Sound. Clam and oyster beaches in the region of interest include Carkeek Park and Discovery Park. However, these beaches are currently closed as the Washington State Department of Health cautions that shellfish collected from these areas are not fit for human consumption at any time (Washington State, 2013b). Crab fishing is allowed in all of Marine Area 10 during crab fishing season, typically from July to September (Washington State, 2013b).

Several studies have been conducted regarding consumption of fish and shellfish collected from the areas of interest. A human use survey of the Duwamish Waterway and Elliott Bay indicates that less than 50 percent of people ate the seafood they collected from these areas (King County, 1999). Some people release what they catch, others feed their catch to animals, and some use it as bait. Similar results were obtained from surveying people at Golden Gardens (King County, 2002). Approximately 66 percent of anglers surveyed at Lake Washington and Lake Union indicated that they would consume self-caught fish (King County, 2003). All of these reports indicated that anglers often share their catch with family members, including children. Ecology issued a report regarding fish consumption rates, including data for high fish-consuming populations (i.e., tribal, Asian, and Pacific Islander). These data indicate that local tribal populations (Squaxin, Suquamish, and Tulalip) consume 67–96 percent locally caught fish and 62–98 percent locally harvested shellfish (Washington State, 2013c).

3.4.3 Determine Relative Likelihood of Activity for Each Pathway

For each receptor type, the relative likelihood of activity (LA) was estimated for each activity (swimming, wading, recreational boating, fishing, or shellfishing) with values ranging from 5 (most/very likely) to 1 (not at all likely). Estimates were season-specific and were based on human use surveys of Puget Sound, Lake Washington, and Lake Union (King County, 2002; 2003) and recreational sport fishing information from the Washington Department of Fish and Wildlife (Washington State, 2013a), as discussed above, as well as information on the relative proximity of recreational use sites (e.g., boat docks, fishing piers; Seattle Parks and Recreation, 2013a, 2013b) and professional judgment.

These factors were then translated to an assumed estimate of exposure hours per season for each activity, based on descriptive statistics compiled from the King County Human Use Survey (King County, 2003). In brief, “exposure hours per season” for each activity were calculated as follows:

$$Exposure\ hours\ per\ season$$

$$= Mean\ exposure\ duration\ for\ activity\ (Table\ 3\text{-}6)\left(\frac{min}{event}\right)\times\frac{1\ hr}{60\ min}\times$$

$$Assumed\ exposure\ frequency\ for\ LA\ values\ (Table\ 3\text{-}7)\left(\frac{d}{yr}\right)\times\frac{1\ yr}{12\ mths}\times\frac{months}{season}$$

The “warm” or low release season was assumed to be comprised of eight months (February to September) and the “cold” or high release season was assumed to be comprised of four months (October to January).

Table 3-6. Assumed Exposure Duration for Specific Activities

Activity	Exposure duration, “warm” months[a] (minutes per event)	Exposure duration, “cold” months[b] (minutes per event)
Fishing	210[c]	210[c]
Wading	57[d]	19[g]
Kayaking/other recreational boating	168[e]	168[e]
Swimming	95[f]	32[g]
Shellfishing	210[c]	210[c]

a. “Warm” months are assumed to reflect the “low” season for discharges (February–September).

b. “Cold” months are assumed to reflect the “high” season for discharges (October–January). Modeling results from CSO discharges showed that most CSO discharges occur during the “high” season. More specifically, modeling of the candidate LTCP project locations indicates that about 65% of the CSOs occurred during the high season, and the associated overflow volume was about 85% of the total simulated CSO volume from the candidate LTCP project locations.

c. Based on mean value, all locations (Lake Union, Lake Washington, Lake Sammamish) for “fishing” (Table 26 in King County, 2003).

d. Based on mean value, all locations (Lake Union, Lake Washington, Lake Sammamish) for “wading (legs only)” (Table 11 in King County, 2003).

e. Based on mean value, all locations (Lake Union, Lake Washington, Lake Sammamish) for “boating (all types)” (Table 11 in King County, 2003).

f. Based on mean value, all locations (Lake Union, Lake Washington, Lake Sammamish) for “swimming (full body)” (Table 11 in King County, 2003).

g. Event duration for water contact activities (swimming and wading) during cold months was assumed to be one-third that during warm months (professional judgment).

Table 3-7. Assumed Exposure Frequency Corresponding to LA Values

Likelihood of activity value	Exposure frequency, all sites (events/year)[a]
1	2
2	4
3	10
4	16
5	32

a. Extrapolated from “Event frequency (days/year)” statistics for all recreational activities for Lake Union, Lake Washington, and Lake Sammamish, roughly corresponding to the 5th percentile, 25th percentile, 50th percentile, 75th percentile, and 95th percentile of the presented distributions (Table 15 in King County, 2003).

3.4.4 Determine Relative Dose for Each Pathway

For each receptor and activity, the relative dose (*RD*) resulting from exposure to an RCOC, assuming it is present in surface water at the receptor location, was estimated. *RD* was approximated for three exposure pathways via the five human exposure activities, as summarized in Table 3-8.

Table 3-8. Assumed Exposure Pathways for Human Exposure Activities

Exposure pathway	Exposure activity				
	Swimming	Wading	Recreational boating	Fishing	Shellfishing
Incidental ingestion of surface water	✓	✓	✓		✓
Dermal contact with surface water	✓	✓	✓	✓	✓
Ingestion of fish or shellfish				✓	✓

For each pathway, the relative “unit” dose of a specific RCOC was estimated based on data on intake and absorption rates for these pathways, assuming the following:

- a “Unit” concentration in water (e.g., 1 mg/L)
- EPA default contact rates (e.g., incidental water ingestion rates, skin surface area, fish consumption rates) and body weight
- RCOC-specific dermal absorption and fish bioaccumulation factors (*BAF*)
- “Unit” exposure frequency and duration (e.g., 1 hr/d, 1 d/yr)

The exposure equations and assumptions applied were obtained from the following documents:

- EPA Risk Assessment Guidance for Superfund (RAGS) (1989)
- EPA Exposure Factors Handbook (2011)
- EPA Dermal Exposure Assessment (1992)

The equations used to calculate *RD* are presented below. Exposure assumptions are summarized in Tables 3-8 and 3-9.

$$Ingestion\ of\ surface\ water = \frac{C\left(\frac{mg}{L}\,or\,\frac{CFU}{L}\right) \times IR_{s\ or\ w}\left(\frac{mL}{hr}\right) \times CF\left(\frac{L}{mL}\right) \times ET_{s\ or\ w}\left(\frac{hr}{d}\right) \times EF\left(\frac{d}{yr}\right) \times ED(yr)}{BW\ (kg) \times AT(d)}$$

where:

C = Unit concentration of RCOC (1 mg/L or 1 CFU/L)

$IR_{s\ or\ w}$ = Incidental ingestion rate of surface water while swimming or wading (mL/hr; see Table 3-9)

CF = Conversion factor (0.001 L/mL)

$ET_{s\ or\ w}$ = Exposure time during swimming or wading (hr/d; see Table 3-9)

EF = Exposure frequency (Unit value, 1 d/yr)

ED = Exposure duration (yrs; see Table 3-9)

BW = Body weight (kg; see Table 3-9)

AT = Averaging time (d; see Table 3-9)

$$Dermal\ exposure\ to\ surface\ water =$$

$$\frac{C\left(\frac{mg}{L}\,or\,\frac{CFU}{L}\right) \times CF\left(\frac{L}{mL}\right) \times PC\left(\frac{cm}{hr}\right) \times SA_{s,w,f,or\ sf}\ (cm2) \times ET_{s,w,f,or\ sf}\left(\frac{hr}{d}\right) \times EF\left(\frac{d}{yr}\right) \times ED(yr)}{BW \times AT(d)}$$

where:

C = Unit concentration of RCOC (1 mg/L or 1 CFU/L)

CF = Conversion factor (0.001 L/mL)

PC = Permeability constant (cm/hr; RCOC-specific: see Table 3-10)

$SA_{s,\ w,\ f\ or\ sf}$ = Surface area of exposed skin during swimming, wading, fishing, or shellfishing (cm^2; see Table 3-9)

$ET_{s,\ w,\ f,\ or\ sf}$ = Exposure time to surface water during swimming, wading, fishing, or shellfishing (hr/d; see Table 3-9)

EF = Exposure frequency (Unit value, 1 d/yr)

ED = Exposure duration (yrs; see Table 3-9)

BW = Body weight (kg; see Table 3-9)

AT = Averaging time (d; see Table 3-9)

$$Ingestion\ of\ fish\ or\ shellfish = \frac{C\left(\frac{mg}{L}\,or\,\frac{CFU}{L}\right) \times BAF\left(\frac{mg/kg}{mg/L}\right) \times IR_F\left(\frac{kg}{d}\right) \times EF\left(\frac{d}{yr}\right) \times ED(yr)}{BW \times AT(d)}$$

where:

C = Unit concentration of RCOC (1 mg/L or 1 CFU/L)

BAF = Fish bioaccumulation factor ((mg/kg)/(mg/L); RCOC-specific: see Table 3-10)

IR_F = Ingestion rate of fish or shellfish (kg/d; see Table 3-9)

EF = Exposure frequency (Unit value, 1 d/yr)

ED = Exposure duration (yrs; see Table 3-9)

BW = Body weight (kg; see Table 3-9)

AT = Averaging time (d; see Table 3-9)

Table 3-9. Exposure Assumptions for Calculating Relative Dose

Parameter	Description	Value	Basis	Source
IR_s (mL/hr)	Incidental ingestion rate of surface water while swimming	16 mL/hr (adult) 37 mL/hr (child)	Average volume ingested while swimming in an outdoor pool, based on measurement of cyanuric acid in urine	(Dufour et al., 2006)
IR_w (mL/hr)	Incidental ingestion rate of surface water while wading	8 mL/hr (adult) 18.5 mL/hr (child)	Assumed to be one-half that for swimming	(Dufour et al., 2006)
ET_s (hr/d)	Exposure time while swimming	1 hr/d (adult) 0.85 hr/d (child)	King County Human Use Survey: mean event duration for swimming for an adult age 18–59 = 98 minutes vs. 84 minutes for child age 6–12	(King County, 2003)
ET_w (hr/d)	Exposure time while wading	1 hr/d (adult) 0.58 hr/d (child)	King County Human Use Survey: mean event duration for wading for an adult age 18–59 = 62 minutes vs. 36 minutes for child age 6–12	(King County, 2003)
ET_f (hr/d)	Exposure time to surface water while fishing	1 hr/d (adult) * 0.2 0.78 hr/d (child) * 0.2	King County Human Use Survey: mean event duration for fishing for an adult age 18–59 = 214 minutes vs. 167 minutes for child age 6–12; ET to surface water assumed to be 20% of time spent fishing (professional judgment)	(King County, 2003); professional judgment
ET_sf (hr/d)	Exposure time to surface water while shellfishing	Assumed to be same as wading	Assumed to be same as wading	Assumed to be same as wading

Table 3-9. Exposure Assumptions for Calculating Relative Dose

Parameter	Description	Value	Basis	Source
SA_s (cm^2)	Surface area of exposed skin while swimming	18,000 cm^2 (adult) 6,600 cm^2 (child)	Recommended default for full body exposure (50th percentile values)	(EPA, 2004)
SA_w (cm^2)	Surface area of exposed skin while wading	6,000 cm^2 (adult) 2,200 cm^2 (child)	Assumed to be one-third of value for full body exposure (approximately equal to forearms, hands, lower legs, and feet)	(EPA, 2004); professional judgment)
SA_sf (cm^2)	Surface area of exposed skin while shellfishing	Assumed to be same as wading	Assumed to be same as wading	Assumed to be same as wading
SAf (cm^2)	Surface area of exposed skin while fishing	2,250 cm^2 (adult) 825 cm^2 (child)	Assumed to be one-eighth of value for full body exposure (approximately equal to forearms and hands)	(EPA, 2004); professional judgment
IR_F(kg/d)	Ingestion rate of fish or shellfish	0.010, 0.042 (mean, 95th percentile adult) 0.7 X adult (child), shellfish was assumed to be 50% of fish	King County Human Use Survey, recreational self-caught freshwater fish consumption rates from Lake Washington and Lake Sammamish; no specific consumption data for shellfish but assumed to be 50% of fish based on relative catch rate and weight of fish and shellfish reported in Puget Sound Human Use Survey	(King County, 2002; 2003); professional judgment
ED (yr)	Exposure duration	9 yr (adult) 6 yr (child)	Recommended default for Central Tendency scenarios: Water contact	(EPA, 2004)
BW (kg)	Body weight	70 kg (adult) 22 kg (child)	Recommended default for adult; Mean of means of recommended values for body weight for child age 2–<7 years	(EPA, 1989) (adult); (EPA, 2008) (child)
AT (d)	Averaging time	3,285 d (adult) 2,190 d (child)	Equal to exposure duration, such that *RD* reflects an annual average daily intake rate	EPA, 1989 and professional judgment

Table 3-10. RCOC-Specific Assumptions for Calculating Relative Dose (*RD*)

RCOC	PC (cm/hr) [permeability constant for skin]	Source	*BAF* (mg/kg)/(mg/L) [bioaccumulation factor]	Source
Copper	0.001	EPA, 2004	36	EPA, 2002b
Zinc	0.0006	EPA, 2004	47	EPA, 2002b
PCBs	0.43	EPA, 2004	31,200	EPA, 2002b
PBDEs	0.03	EPA, 2004	4,450	NLM, 2013a
Bis(2-ethylhexyl) phthalate	0.025	EPA, 2004	130	EPA, 2002b
Dichlobenil	0.012	EPA, 2004 (based on data for dieldrin as surrogate)	22	NLM, 2013b

Table 3-10. RCOC-Specific Assumptions for Calculating Relative Dose (*RD*)

RCOC	PC (cm/hr) [permeability constant for skin]	Source	*BAF* (mg/kg)/(mg/L) [bioaccumulation factor]	Source
Fecal coliform	NA		NA	

NA = not available.

3.4.5 Determine Distance from Discharge Point to the Receptor Location

For each receptor type, the minimum distance from the discharge point to the receptor location was assigned a value equal to its approximate distance in kilometers (km), up to a maximum of 2 km (potential receptors beyond 2 km will not be considered).

3.4.6 Receptor Factors for Ecological Receptors

Ecological *RFs* were developed based on the presence and sensitivity of egg/breeding, juvenile, and adult life stages for eight fish species (bull trout, Chinook salmon, chum salmon, Coho salmon, cutthroat trout, pink salmon, sockeye salmon, and steelhead) in each of the water bodies of interest. These species represent important fish in Seattle both ecologically and as a human food source. Some of these species represent, in some locations, endangered or threatened species. Consideration of life stages reflects the differential sensitivities of different life stages. The fish species selected, and life stages included, in the *RFs* provide a representative range of presence and sensitivity of receptors in the receiving water bodies.

The source and basis of assumptions applied for each of these parameters are discussed below.

RFs for ecological receptors were calculated using the following equation:

$$RF_E = \sum_{species} (LP_{egg} \times S_{egg}) + \left(LP_{juv} \times S_{juv}\right) + (LP_{adult} \times S_{adult})$$

where:

RF_E = Ecological receptor factor

LP = Likelihood of presence for a given life-stage, for each species and location

S = Relative sensitivity of life-stage

3.4.7 Determine Likelihood of Presence of Species and Life-Stage

Assumptions regarding species and life-stage presence were based on data compiled by SeaRun and Ridolfi. Values were assumed to range from 1 (rarely present) to 5 (frequently present), or 0 if not present at all, as follows:

- 0: not present at all
- 1: if present during 1 month during a given season (“high” or “low”)
- 3: if present during 2–3 months during a given season (“high” or “low”)
- 5: if present during >3 months during a given season (“high” or “low”)

The *LP* values assumed for each water body, season, species, and life stage are summarized in Table 3-11. Data to support these assumptions are presented in the attachment to this appendix.

Table 3-11. Assumed Likelihood of Presence (*LP*) of Fish Species and Life Stages, by Water Body and Season[a]

Receiving water body[b]	Species	Low season (Feb–Sep)			High season (Oct–Jan)		
		Egg/breeding	Juvenile	Adult	Egg/breeding	Juvenile	Adult
Duwamish Waterway	Chinook salmon	0	5	5	0	1	3
Duwamish Waterway	Steelhead	0	5	5	0	0	3
Duwamish Waterway	Bull trout	0	0	5	0	0	0
Duwamish Waterway	Cutthroat trout	0	3	1	0	3	0
Duwamish Waterway	Coho salmon	0	3	5	0	0	1
Duwamish Waterway	Sockeye salmon	0	3	3	0	0	3
Duwamish Waterway	Chum salmon	0	5	3	0	0	3
Duwamish Waterway	Pink salmon	0	3	3	0	0	3
Portage Bay	Chinook salmon	0	3	3	0	0	1
Portage Bay	Steelhead	0	1	5	0	0	3
Portage Bay	Bull trout	0	0	3	0	0	0
Portage Bay	Cutthroat trout	0	0	3	0	0	3
Portage Bay	Coho salmon	0	3	3	0	0	3
Portage Bay	Sockeye salmon	0	3	5	0	0	3
Portage Bay	Chum salmon	0	0	0	0	0	0
Portage Bay	Pink salmon	0	0	0	0	0	0
Ship Canal	Chinook salmon	0	5	3	0	0	1
Ship Canal	Steelhead	0	3	5	0	0	3
Ship Canal	Bull trout	0	0	3	0	0	0
Ship Canal	Cutthroat trout	0	0	3	0	0	3
Ship Canal	Coho salmon	0	3	3	0	0	3
Ship Canal	Sockeye salmon	0	5	5	0	0	5
Ship Canal	Chum salmon	0	0	0	0	0	0
Ship Canal	Pink salmon	0	0	0	0	0	0
Longfellow Creek	Chinook salmon	0	0	3	0	0	3
Longfellow Creek	Steelhead	0	3	0	0	3	0
Longfellow Creek	Bull trout	0	0	0	0	0	0
Longfellow Creek	Cutthroat trout	3	1	0	3	3	0
Longfellow Creek	Coho salmon	0	1	3	0	3	3

Table 3-11. Assumed Likelihood of Presence (*LP*) of Fish Species and Life Stages, by Water Body and Season[a]

Receiving water body[b]	Species	Low season (Feb–Sep)			High season (Oct–Jan)		
		Egg/breeding	Juvenile	Adult	Egg/breeding	Juvenile	Adult
Longfellow Creek	Sockeye salmon	0	0	0	0	0	0
Longfellow Creek	Chum salmon	0	0	0	0	0	0
Longfellow Creek	Pink salmon	0	0	0	0	0	0
Union Bay/Lake Washington	Chinook salmon	0	5	3	0	1	1
Union Bay/Lake Washington	Steelhead	0	3	5	0	0	0
Union Bay/Lake Washington	Bull trout	0	0	1	0	0	0
Union Bay/Lake Washington	Cutthroat trout	0	3	5	0	3	3
Union Bay/Lake Washington	Coho salmon	0	5	1	0	0	3
Union Bay/Lake Washington	Sockeye salmon	3	5	5	3	1	5
Union Bay/Lake Washington	Chum salmon	0	0	0	0	0	0
Union Bay/Lake Washington	Pink salmon	0	0	0	0	0	0
Thornton Creek	Chinook salmon	3	1	3	3	0	3
Thornton Creek	Steelhead	0	3	3	0	3	0
Thornton Creek	Bull trout	0	0	0	0	0	0
Thornton Creek	Cutthroat trout	3	3	3	3	0	3
Thornton Creek	Coho salmon	3	3	3	3	1	3
Thornton Creek	Sockeye salmon	0	0	3	0	0	3
Thornton Creek	Chum salmon	0	0	0	0	0	0
Thornton Creek	Pink salmon	0	0	0	0	0	0
Piper’s Creek	Chinook salmon	0	1	0	0	0	0
Piper’s Creek	Steelhead	3	3	0	3	3	0
Piper’s Creek	Bull trout	0	0	0	0	0	0
Piper’s Creek	Cutthroat trout	3	5	0	3	3	0
Piper’s Creek	Coho salmon	0	0	3	0	1	3
Piper’s Creek	Sockeye salmon	0	0	0	0	0	0
Piper’s Creek	Chum salmon	0	3	3	0	3	3
Piper’s Creek	Pink salmon	0	0	0	0	0	0

a. *0 = not likely, 1 = minimal, 3 = moderate, 5 = high. Based on data presented in the attachment to this appendix document.*

b. *Candidate LTCP or stormwater projects corresponding to water bodies are as follows:* ***Duwamish Waterway:*** *CSO Outfall 99, CSO Outfall 107, CSO Outfall 111, South Park WQ Facility, SW Hinds SD StormFilter Vault, South Myrtle St. Shoulder Stabilization, South Myrtle St. StormFilter Vault.* ***Longfellow Creek:*** *NDS Partnering, Longfellow Bioretention;* ***Piper’s Creek:*** *NDS Partnering, Piper’s Cascades;* ***Portage Bay:*** *CSO Outfall 138;* ***Ship Canal:*** *CSO Outfall 139, CSO Outfall 140;* ***Thornton Creek:*** *NDS Partnering.*

3.4.8 Determine Relative Sensitivity of Life-Stage

With regard to the relative sensitivity of life stages, the ranking was assumed to be as follows: egg/breeding > juvenile > adult (Hutchinson et al., 1998.; Mayer and Ellersieck, 1986). Specifically, the following factors were assumed:

- egg/breeding: most sensitive = 1
- juvenile: half as sensitive as embryotic stage = 0.5
- adult: order of magnitude less sensitive than embryotic stage = 0.1

Normalized RF_Es were then calculated by dividing the RF_E for each project and season by the maximum RF_E for all projects/seasons, such that RF_Es fell within the range 0 to 1.

3.5 Calculate Exposure Index Values

For each scenario, RCOC-specific EIVs were calculated by dividing the Pre-project concentration by the appropriate water criterion and multiplying by the relative change in load and the *RF*. The calculation yields a unitless value.

3.6 Calculate Sums of EIVs

For each candidate LTCP and stormwater project, RCOC- and season-specific EIVs were summed for humans and ecological receptors separately. For humans, separate EIVs were computed for toxics (which were evaluated using chronic WQCs) and fecal coliform (which were evaluated using acute WQCs). At each location, annual EIVs were then calculated by algebraically summing the EIVs for each season as follows:

$$Annual\ EIV = \frac{(EIV_{Oct-Jan} \times 4\ months) + (EIV_{Feb-Sep} \times 8\ months)}{12\ months}$$

The estimated EIVs are summarized in Tables 3-12 through 3-14 and Figures 3-1 through 3-4.

Because project EIVs are relative and a consistent method was used for developing the inputs to the EIV calculations, a sensitivity analysis was not deemed necessary.

Table 3-12. Human EIVs for Toxics by Project Outfall, Annual

Project	Receiving water body	Sum of [(Cpre/WQC-human) × (relative change in load)]	Average RF_H	Human EIV
CSO Outfall 99	Duwamish Waterway	1.6	0.20	0.39
CSO Outfall 107	Duwamish Waterway	48.4	0.20	13.2
CSO Outfall 111	Duwamish Waterway	0.42	0.27	0.16
CSO Outfall 138	Portage Bay	0.93	0.27	0.13
CSO Outfall 139	Ship Canal	0.056	0.22	0.0061
CSO Outfall 140	Ship Canal	0.55	0.27	0.080
Longfellow Cascades	Longfellow Creek	12.2	0.07	0.27
NDS Partnering: Thornton Creek	Thornton Creek	24.5	0.17	3.8
NDS Partnering: Piper's Creek	Piper's Creek	6.3	0.13	0.89
NDS Partnering: Longfellow Creek	Longfellow Creek	5.4	0.07	0.12
Piper's Cascades	Piper's Creek	20.0	0.18	3.8
South Myrtle St. Shoulder Stabilization	Duwamish Waterway	4.6	0.25	1.6
South Park WQ Facility	Duwamish Waterway	308.7	0.26	116.6
Street Sweeping Expansion Arterials	Multiple	Not calculated		
Street Sweeping Expansion Residential	Multiple	Not calculated		
SW Hinds SD StormFilter Vault	Duwamish Waterway	99.2	0.26	36.2
South Myrtle St. StormFilter Vault	Duwamish Waterway	39.5	0.25	13.7
U Village Filterras	Union Bay/Lake Washington	2.6	0.71	2.0

Table 3-13. Human EIVs for Fecal Coliform by Project Outfall, Annual

Project	Receiving water body	[(Cpre/WQC-human) × (relative change in load)]	RF_H	Human EIV
CSO Outfall 99	Duwamish Waterway	2.4	0.12	0.18
CSO Outfall 107	Duwamish Waterway	17.0	0.11	1.3
CSO Outfall 111	Duwamish Waterway	0.15	0.14	0.019
CSO Outfall 138	Portage Bay	6.0	0.41	2.0
CSO Outfall 139	Ship Canal	0.36	0.34	0.093
CSO Outfall 140	Ship Canal	3.6	0.43	1.4
Longfellow Cascades	Longfellow Creek	8.5	0.12	1.1
NDS Partnering: Thornton Creek	Thornton Creek	37.8	0.18	7.0
NDS Partnering: Piper's Creek	Piper's Creek	9.6	0.12	1.2
NDS Partnering: Longfellow Creek	Longfellow Creek	4.1	0.12	0.52
Piper's Cascades	Piper's Creek	30.9	0.17	5.3
South Myrtle St. Shoulder Stabilization	Duwamish Waterway	0.19	0.13	0.024
South Myrtle St. StormFilter Vault	Duwamish Waterway	5.2	0.13	0.67
South Park WQ Facility	Duwamish Waterway	62.4	0.13	8.3
Street Sweeping Expansion Arterials	Multiple	Not calculated		
Street Sweeping Expansion Residential	Multiple	Not calculated		
SW Hinds SD StormFilter Vault	Duwamish Waterway	14.5	0.13	1.9
U Village Filterras	Union Bay/Lake Washington	4.7	0.68	3.2

Table 3-14. Ecological EIVs by Project Outfall, Annual

Project	Receiving water body	Sum of [(Cpre/WQC-Eco) × (relative change in load)]	RF_E	Eco EIV
CSO Outfall 99	Duwamish Waterway	0.010	0.74	0.0057
CSO Outfall 107	Duwamish Waterway	0.54	0.74	0.35
CSO Outfall 111	Duwamish Waterway	0.0051	0.74	0.0038
CSO Outfall 138	Portage Bay	0.15	0.32	0.039
CSO Outfall 139	Ship Canal	0.0090	0.44	0.0031
CSO Outfall 140	Ship Canal	0.089	0.44	0.035
Longfellow Cascades	Longfellow Creek	1.5	0.41	0.61
NDS Partnering: Thornton Creek	Thornton Creek	2.8	0.87	2.5
NDS Partnering: Piper's Creek	Piper's Creek	0.72	0.74	0.54
NDS Partnering: Longfellow Creek	Longfellow Creek	0.60	0.41	0.24
Piper's Cascades	Piper's Creek	2.4	0.74	1.8
South Myrtle St. Shoulder Stabilization	Duwamish Waterway	0.026	0.74	0.019
South Myrtle St. StormFilter Vault	Duwamish Waterway	0.19	0.74	0.14
South Park WQ Facility	Duwamish Waterway	2.6	0.74	1.9
Street Sweeping Expansion Arterials	Multiple	Not calculated		
Street Sweeping Expansion Residential	Multiple	Not calculated		
SW Hinds SD StormFilter Vault	Duwamish Waterway	0.49	0.74	0.36
U Village Filterras	Union Bay/Lake Washington	0.41	0.76	0.32

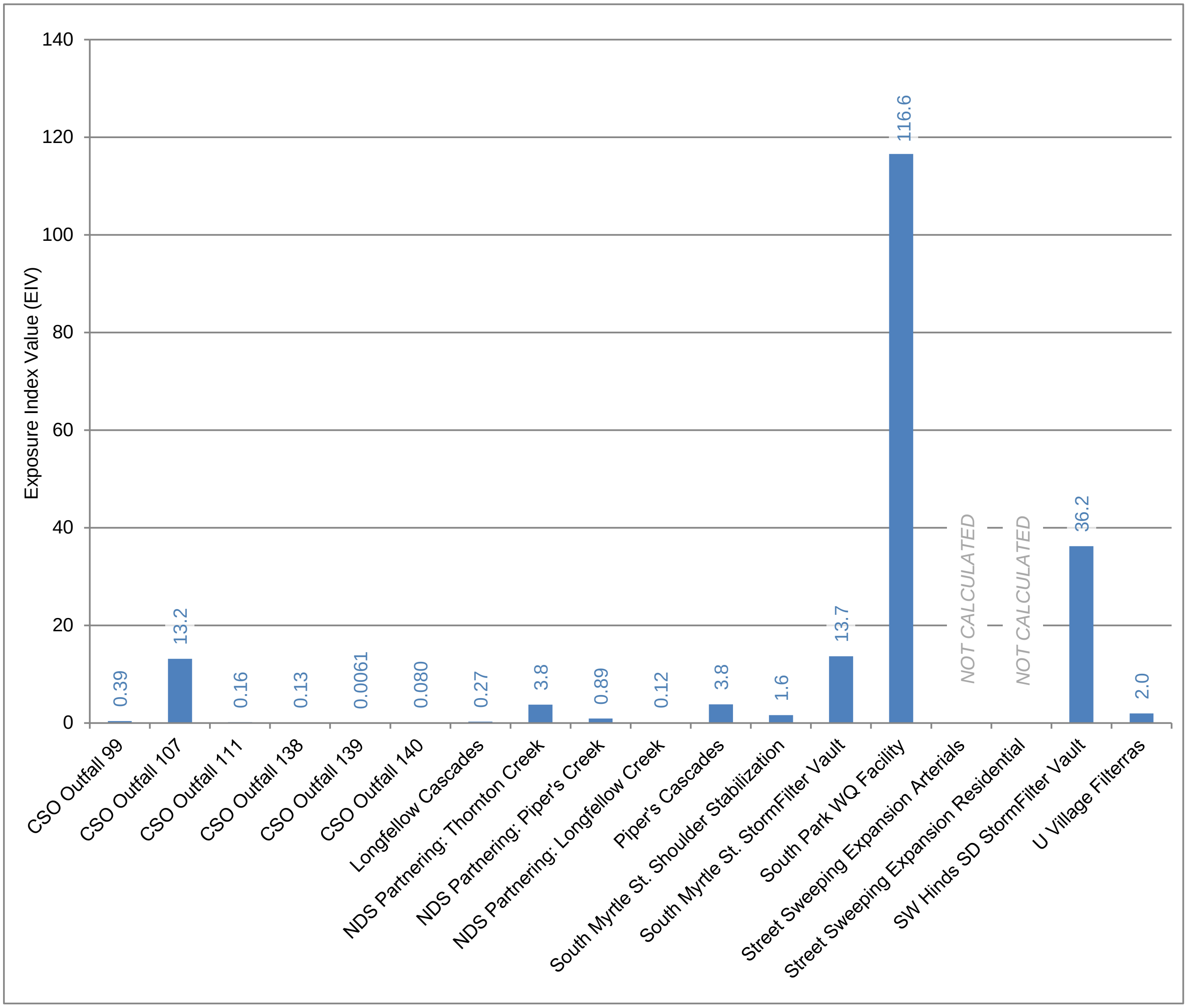


Figure 3-1. EIVs for human toxics

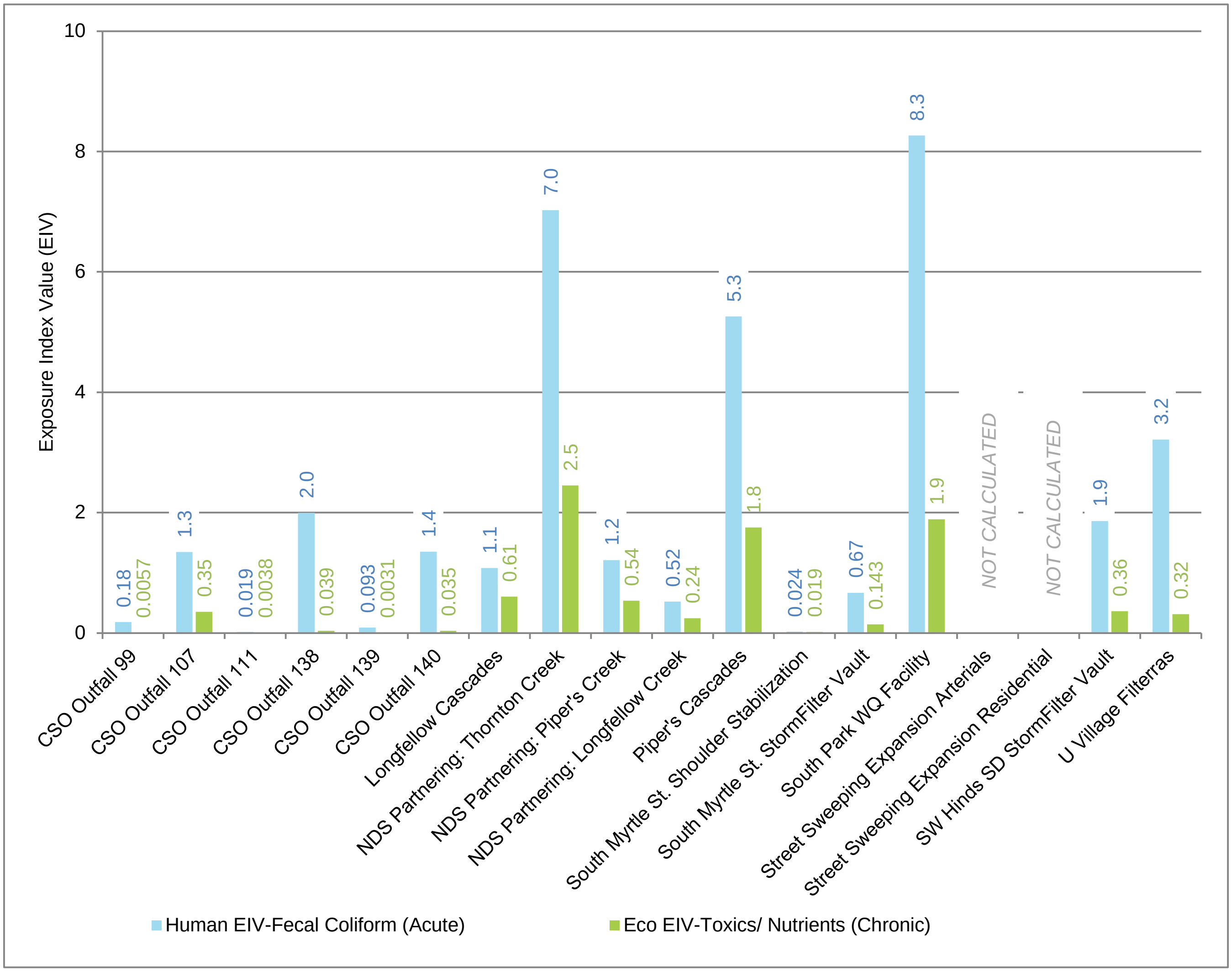


Figure 3-2. EIVs for human fecal coliform and ecological toxics and nutrients

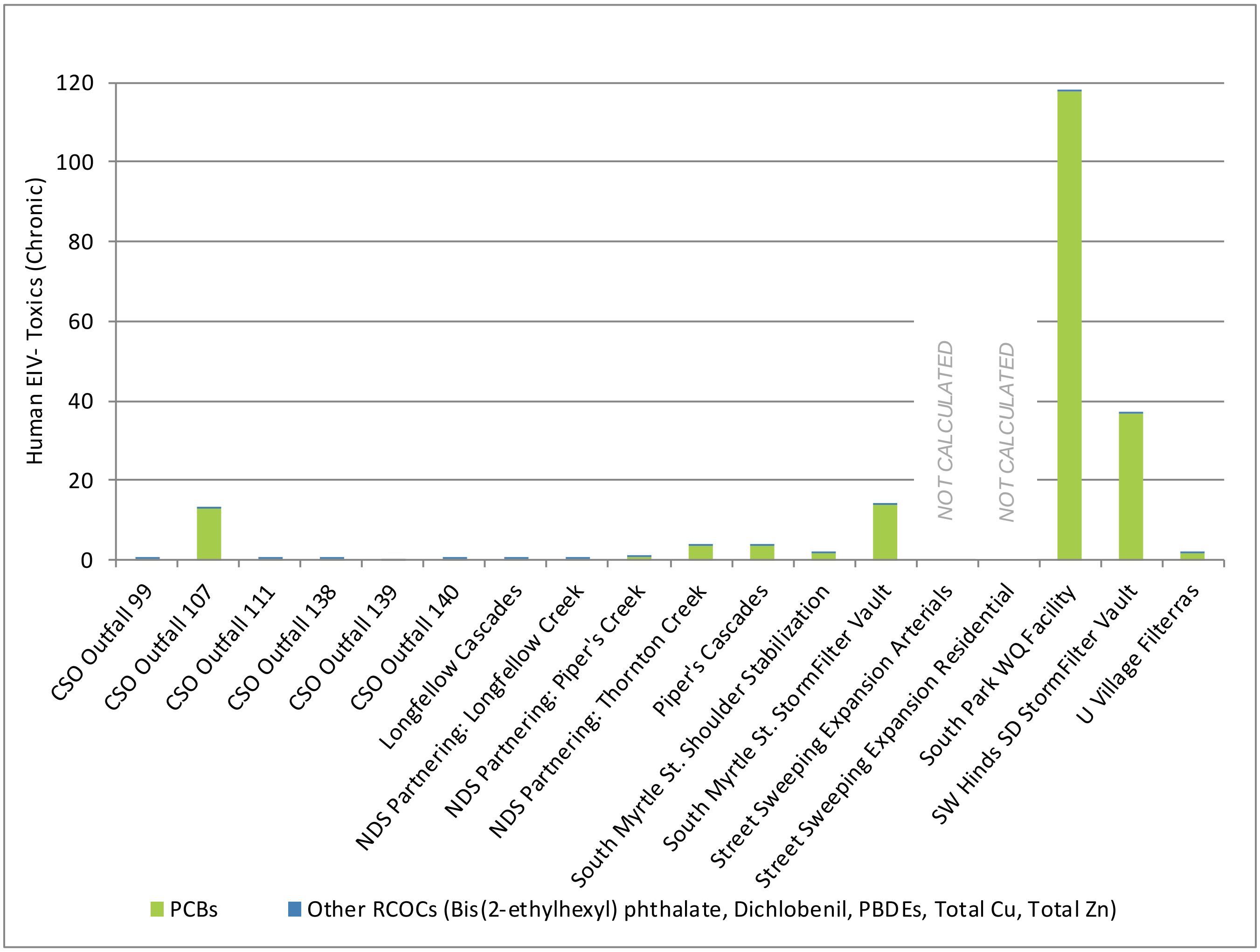
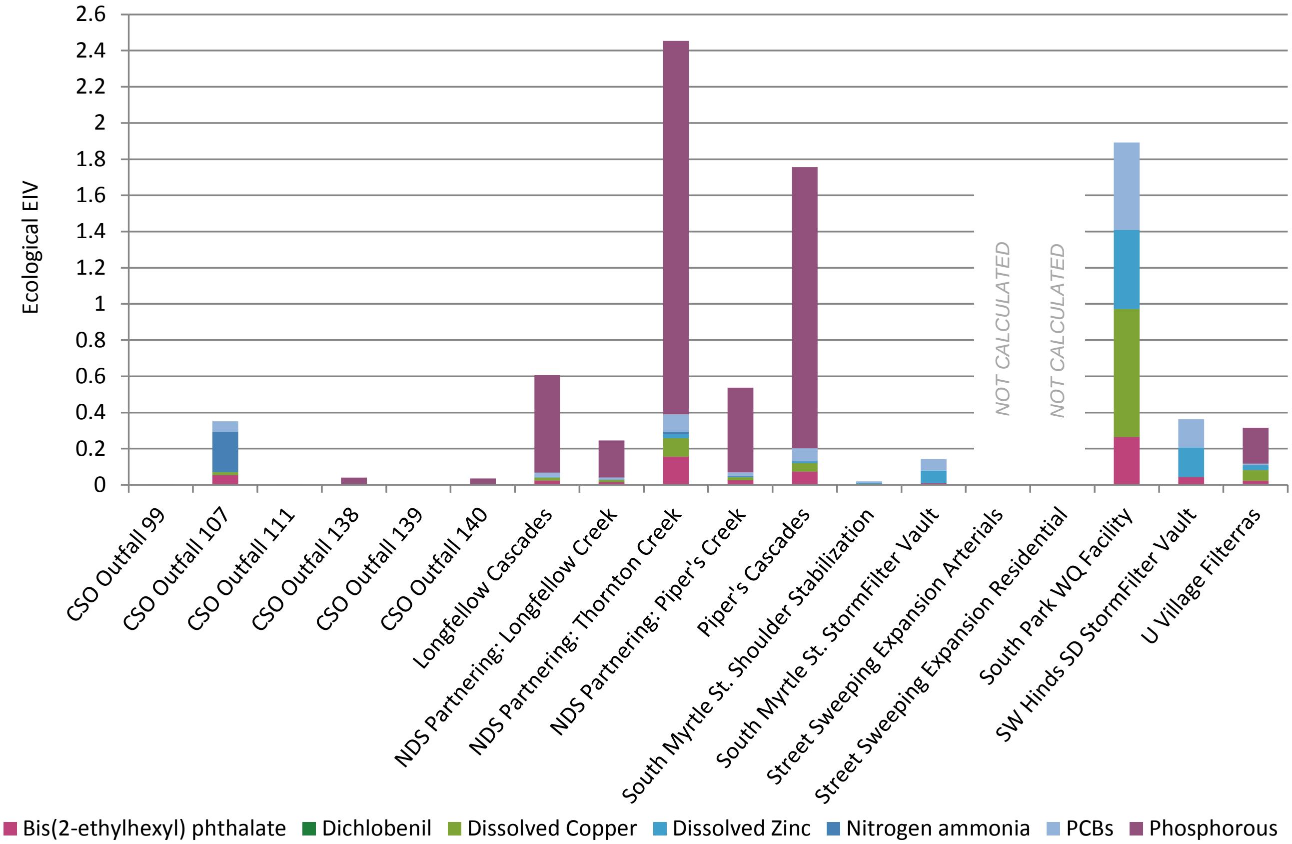


Figure 3-3. Relative contribution of specific RCOCs to human-toxics EIVs



NOTE: Projects discharging to saltwater/brackish water are: CSO Outfall 99, CSO Outfall 107, CSO Outfall 111, South Myrtle St. Shoulder Stabilization, South Myrtle St. StormFilter Vault, South Park WQ Facility, SW Hinds SD StormFilter Vault

Figure 3-4. Relative contribution of specific RCOCs to ecological EIVs

Chapter 4

Conclusions

The Exposure Assessment (EA) was conducted to assess relative hazard reductions and the estimated impact on receiving waters resulting from changes in discharges of Representative Constituents of Concern (RCOCs) associated with each candidate stormwater or LTCP project. The EA tool is a mathematical model that provides a science-based metric by which the City of Seattle's proposed project outcomes can be compared, and is based on standard risk assessment methodologies.

The EA tool's output is termed the exposure index value, or EIV. Separate EIVs were calculated for human and ecological receptors for each RCOC associated with each project. EIVs were then summed separately for human and ecological receptors for each project. As formulated, a higher EIV indicates that implementing a particular project would have relatively greater impact on reducing hazards in comparison to other projects with lower EIVs.

Because estimates of actual concentrations at points of exposure (e.g., in receiving water) to human or ecological receptors that result from decreases in effluent load are not available, the output of the EA reflects an approximate estimate of changes in *relative* exposure, not actual exposure or risk, induced by changes in effluent releases. These estimates allow for a comparison of the relative benefit of the candidate LTCP or stormwater projects.

Based on this analysis, the following observations were noted:

- PCBs are the main drivers of estimated human EIVs for toxics. Specifically, PCBs contribute at least 92 percent to each EIV estimate. The next-most significant contributor is bis(2-ethylhexyl)phthalate, which contributes up to 8 percent of the EIV estimates.
- At freshwater locations, phosphorus is the main contributor to estimated ecological EIVs. At these locations, phosphorus contributes from 63 to 90 percent of the estimated EIV. Other RCOCs also contribute significantly at these locations, at levels that vary by location, specifically bis(2-ethylhexyl)phthalate, dissolved copper, dissolved zinc, nitrogen ammonia, and PCBs.
- At saltwater/brackish locations (i.e., on the Duwamish Waterway), bis(2-ethylhexyl)phthalate, dissolved copper, dissolved zinc, nitrogen ammonia, and PCBs contribute to ecological EIVs.
- The highest overall ranked project, based on the estimated human-toxics EIV, is the stormwater project associated with the South Park WQ Facility on the Duwamish Waterway (EIV_H =116.6). The highest-ranked candidate LTCP project is CSO Outfall 107, also on the Duwamish Waterway (EIV_H = 13.2).
- The highest overall ranked project based on the estimated fecal coliform EIV for humans is also the stormwater project associated with the South Park WQ Facility on the Duwamish Waterway (EIV_{FC} =8.3). The highest-ranked candidate LTCP project is CSO Outfall 138 on Portage Bay (EIV_{FC} = 2.0).
- The highest overall ranked project based on the estimated ecological EIV is the stormwater project associated with NDS Partnering on Thornton Creek (EIV_E = 2.5). The highest-ranked candidate LTCP project is CSO Outfall 107 on the Duwamish Waterway (EIV_E = 0.35).

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Chapter 5

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Attachment H-1: Fish Species Presence Matrix

Sheet 7: Fish Species Presence Matrix (Source: SeaRun Consulting)

NOTE: Juvenile salmonids are dependent on the shoreline/shore near outfalls. Adults are independent/deep water: outfalls may not present exposure risk.

NOTE: Juvenile column refers to fish spawned in-system, not migratory. Adult column includes large juveniles that are suspected migrants

NOTE: Underline/bold indicates primary migration months

NOTE: Numbers in parentheses refer to comments and references, not data values

ABBREVIATIONS: * = not ESA species; x = presumed present, no specific data; NP=Not Present; AR = AR's KC data

Species Considered	Present in: Fresh	Marine	Elliott Bay Egg/Breeding	Juvenile	Reference	Adult	Ref.
Chinook salmon	yes	yes	NP	D,J, F, M, A, **M, J,** J, A, S	(4, 13 = M-S, 8 = M-A)	D,J,F or All mos.	(8a)
Steelhead	yes	yes	NP	F,M,A,M	(8a)	D,J,F(8a), M,J,J,A,N (22)	(8a, 22)
Bull trout	yes	yes	NP	NP	(20, 8)	x, Apr (9a)	(22, 19, 9a)
Cutthroat trout*	yes	yes	NP	A,M,J,J,A,S	(20, 25)	All mos.	
Coho salmon*	yes	yes	NP	**J**,J,A	(17, (8)	All mos.	
Sockeye salmon*	yes	yes	NP	NP in nearshore	(8)	J,J,A	
Chum salmon*	yes	yes	NP	**A,M,J**,J,A, S, O	(17, 8)	x	(8)
Pink salmon*	yes	yes	NP	x	(8)	J,A,S,O	(8)
3 Rockfish Spp.	no	yes	?	x SPRING-SUMMER	*(22)*	x	(22)
Marbled Murrelet	yes	yes	NP	x	(22)	x	(22)
Killer Whale	no	yes	NP	A,S,O,N,D,J,F,M,A	(22)	A,S,O,N,D,J,F,M,A	(22)
Steller sea lion	can be	yes	NP	x	(22)	x	(22)
Humpback Whale	no	yes	NP	M,J,J,S	(22)	M,J,J,S	(22)
Spp. Not Considered							
Eulachon	yes	yes	NP	NP		x	(22)
Green sturgeon	yes	yes	NP	NP			
Pacific Herring*	no	yes	NP	NP			
Smelt*	no	yes	NP	NP	(22)	x	
Sandlance*	no	yes	NP	NP	(22)		

* = not ESA species Notes to references listed here

(8a) yearlings+subadults

(9a) subadult caught in beach seine 1998

Sheet 7: Fish Species Presence Matrix (Source: SeaRun Consulting)

Species Considered	Duwamish River Egg/Breeding	Juvenile	Ref.	Adult	Ref
Chinook salmon	NP	J, F, **M**, A, **M, J,** J, A, S	(4, 13, 8)	J,J,**A**,S,O,N	(13)
Steelhead	NP	F, M, A, M, J	(14, 8)	N,D,J,F,M,A (20),M,J.J(8a)	(20, 8a, (11a)
Bull trout	NP (24)	NP	(20, 8, 24)	A,M,A,S, visitors	(19, 20, 22, 24)
Cutthroat trout*	NP	x	(8)	A	(8a)
Coho salmon*	NP	A,M,J	(8)	J,F,M,A,M	(8a)
Sockeye salmon*	NP	M,A (few)	(8)	x	(8)
Chum salmon*	NP	F**,M.A.M**.J.J	(8)	x	(8)
Pink salmon*	NP	M,A (few)	(8)	x	(8)
3 Rockfish Spp.	NP	NP		NP	
Marbled Murrelet	NP	NP		NP	
Killer Whale	NP	NP		NP	
Steller sea lion	NP	NP	(20)	NP	
Humpback Whale			(20)		
Spp. Not Considered					
Eulachon	NP	NP			
Green sturgeon	NP	NP			
Pacific Herring*	NP	NP			
Smelt*	NP	NP			
Sandlance*	NP	NP			

* = not ESA species

(14) hatchery releases into Green River, 9-day residence time

(11a) N,D,J,F,M,A,M is Green R. instream & spawning per WDFW 2002 data.

Sheet 7: Fish Species Presence Matrix (Source: SeaRun Consulting)

Species Considered	Shilshole Bay (either L WA or Elliott Bay origin) Juvenile	Ref	Lake Union/Ship Canal Egg/Breeding	Juvenile	Ref	Adult	Ref
Chinook salmon	**M,J**,J,**A**,S,O	(17, 21a,e; 6)	NP	M**, J, J, A**	(6)	J,J,A,S,O	(15,18b)
Steelhead	A,M	(18)	NP	A,M	(18)	N,D,J,F,M,A,M,J	(18)
Bull trout	M, J	(19, 22, 24c)	NP	NP		M,J,J, strays	(7, 22, 24b)
Cutthroat trout*	A,M,J,J,A,S	(25, 21d, h)	NP	?		x LATE WIN-EARLY SPRING	
Coho salmon*	**M,J**,J,A, S?, O?	(17, 18, 21b,f)	NP	M,J, J	(16)	A,S,O,N	(18)
Sockeye salmon*	June	(17)	NP	A,M,J,J	(16, 18)	M,**J,J,A**,S,O (18), N,D,J,F	(18), missing re
Chum salmon*	**M,J**,J,A,S,O--Elliott Bay	(17, 21c,g)	NP	NP	(18)	NP	
Pink salmon*			NP	NP		NP	
3 Rockfish Spp.			NP	NP		NP	
Marbled Murrelet			NP				
Killer Whale			NP				
Steller sea lion			NP				
Humpback Whale							
Spp. Not Considered							
Eulachon			NP				
Green sturgeon							
Pacific Herring*	J,J,**A**	(17)	NP				
Smelt*			NP				
Sandlance*	M,J	(17)	NP				

* = not ESA species

(18) LWSC pass time average 2 d Chin, 4 d sockeye, >1 wk coho; LWA pass time 2.9 d Chin, 85 d sockeye

(16) June, July along shore & littoral zone

(21a) Carkeek Park M,J,J,A,S in 2001; May-Oct 2002
(21b) Carkeek Park J,A only in 2001, May-Aug 2002
(21c) Carkeek Park May only in 2001 & 2002
(21d) Carkeek Park J,J,A,S in 2001; M,J 2002
(21e) Golden Gardens May-Aug 2001; Jun-O 2002
(21f) Golden Gardens J,J 2001; May-Aug 2002
(21g) Golden Gardens May-Jun 2002 (no data 2.
(21h) Golden Gardens May-S 2002 (no data 2001)
(24c) Shilshole Bay in May
(6) Chinook:moved through Portage Bay in fewer than 24 hours;
spent one day to two weeks in Lake Union; moved through the Fremont Cut in fewer than 24 hours; and,
spent hours to a week or more in Salmon Bay and near the locks

(15) hold at Locks for weeks, move thru Canal in 1 day
(18b) Chin ave. 1 d in LWSC, sockeye ave. 4 d in LWSC
(24b) in fish ladder May, June

Sheet 7: Fish Species Presence Matrix (Source: SeaRun Consulting)

Species Considered	Lake Washington Egg/Breeding	Juvenile	Ref	Adult	Ref
Chinook salmon	NP	J,F,M,**A,M,J,J**,A	(16)	J,A,S,O	(7a,18c)
Steelhead	NP	A,M ,J	(18)	**M,A,M**,J	(18)
Bull trout	NP	NP (only subadult strays)	(24a)	N,D,J,F,M,A,M,A strays	(11a, 7, 19, 22, 24a)
Cutthroat trout*	NP	X		LATE WIN-EARLY SPRING	
Coho salmon*	NP	A**,M**, J,J	(18)	S,O,N	(18)
Sockeye salmon*	x	J,**F,M,A**,M, J + all year	(16, 18)	All year	(18d)
Chum salmon*	NP	NP	(18)	NP-strays	(7)
Pink salmon*	NP	NP		NP-strays	(7)
3 Rockfish Spp.	NP	NP		NP	
Marbled Murrelet	NP	possibly present	(26)	possibly present	(26)
Killer Whale	NP				
Steller sea lion	NP				
Humpback Whale					
Spp. Not Considered					
Eulachon	NP				
Green sturgeon	?				
Pacific Herring*	NP				
Smelt*	NP				
Sandlance*	NP				

* = not ESA species

(24a) March, May (1985) fish were subadults >300 mm FL
(26) presence based on use of coastal lakes and predation on sockeye and other salmonids
(18c) Chin 2-5 d before entering rivers
(7a) Adult Chin spend 2.9 d in L. WA
(18d) spend 85 d below thermocline
(11a) LW winter stlhd migration Nov-May includes instream spawning Mar-May.
Data from WDFW et al. (2002)
(23) one 24" female steelhead carcass in Thornton Creek in 2004.

Sheet 7: Fish Species Presence Matrix (Source: SeaRun Consulting)

Species Considered	Thornton Creek Egg/Breeding	Ref	Juvenile	Ref	Adult	Ref	Pipers Creek Egg/Breeding	Ref	Juvenile	Ref	Adult	Ref
Chinook salmon	x	(1a)	**by June**	(1b, 2)	X	(7, 22)	NP		Jul '99=6 (22), NP (1, 2)	(1,2, 22)	NP	(7b, 2)
Steelhead	NP		x	(1b, 3)	F,M	(22, 23)	x	(1c)	summer	(1d, 7, 23)		
Bull trout	NP		NP		NP		NP		NP		NP	
Cutthroat trout*	x		F, **Sept**	(2, 3 ,5, 7)	X	(7)	x		summer, Aug., S,O, winter, F,M	(2, 3, 5)		
Coho salmon*	x		F, Aug, O	(2, 3)	x	(7, 22)	?		Oct	(2, 3)	x	(7, 22)
Sockeye salmon*					x	(7)	NP					
Chum salmon*	NP		NP		NP	(7)	?		x	(7)	x	(7c)
Pink salmon*	NP		NP		NP	(7)	NP					
3 Rockfish Spp.	NP		NP		NP		NP		NP		NP	
Marbled Murrelet	NP											
Killer Whale	NP											
Steller sea lion	NP											
Humpback Whale												
Spp. Not Considered												
Eulachon	--						--					
Green sturgeon	--						--					
Pacific Herring*	--						--					
Smelt*	--						--					
Sandlance*	--						--					

* = not ESA species

(1a) 19 redds counted 2000-2005, 1 in 2006

(1b) no juv caught J, A, S, M, A 2005-2011

(3) RBT observed 2005-6

(5) summer and winter surveys

(1c) 3-4 possible redds 2001-2006

(1d) 1 juv 2006

(2) No PS Chin redds or smolts 2001-6

(7b) 1 Chin adult in 1998

(7c) Minter Cr Hatch fingerling releases

(12) McCarthy implied pre-spawner mort 2007 poster

Sheet 7: Fish Species Presence Matrix (Source: SeaRun Consulting)

Species Considered	Longfellow Creek Egg/Breeding	Juvenile	Ref	Adult	Ref
Chinook salmon				x	(22)
Steelhead		x	(3)		
Bull trout	NP	NP			
Cutthroat trout*	x	Aug	(2, 3, 6)		
Coho salmon*		Aug	(2, 3)	x	(12, 22)
Sockeye salmon*					
Chum salmon*					
Pink salmon*					
3 Rockfish Spp.	NP	NP		NP	
Marbled Murrelet					
Killer Whale					
Steller sea lion					
Humpback Whale					
<u>Spp. Not Considered</u>					
Eulachon					
Green sturgeon					
Pacific Herring*					
Smelt*					
Sandlance*					

* = not ESA species

(6) summer only

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Appendix I: Development of Integrated Plan

Seattle Public Utilities | Protecting Seattle's Waterways

Volume 3 – Integrated Plan

Appendix I: DEVELOPMENT OF INTEGRATED PLAN

Final
May 29, 2015

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List of Abbreviations

Term	Definition
m	micron/micrometer
BMP	best management practice
BOD	biochemical oxygen demand
CESF	chitosan-enhanced sand filtration
CSO	combined sewer overflow
EIV	exposure index value
ESA	Endangered Species Act
GAC	granular activated carbon
I/I	infiltration and inflow
LTCP	Long-Term Control Plan
MAUT	Multi-Attribute Utility Theory
MODA	Multiple Objective Decision Analysis
NDS	Natural Drainage Systems
O&M	operations and maintenance
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
PS	pump station
RCOC	Representative Constituent of Concern
R/D	research and development
ROW	right-of-way
TAPE	Technology Assessment Protocol – Ecology
SDOT	Seattle Department of Transportation
SMARTS	Simple Multi-Attribute Rating Technique with Swings
TSS	total suspended solids
WTD	(King County) Wastewater Treatment Division
WWTF	wastewater treatment facility

Summary

The Consent Decree allows the City of Seattle (City) the opportunity to prepare an Integrated Plan as an alternative to the Long-Term Control Plan (LTCP). According to Section V.B. paragraph 20 of the Consent Decree, the Integrated Plan must propose water quality improvement project(s) "that will result in significant benefits to water quality beyond those that would be achieved by implementation of the approved CSO [combined sewer overflow] Control Measures only." The Consent Decree requires that the City describe the benefits of the proposed projects in terms of reductions in pollutant loads and exposure to human and ecological receptors.

The City developed its Integrated Plan based on these Consent Decree requirements. The City first compared the water quality benefits of the candidate stormwater projects with the water quality benefits of the candidate LTCP projects. This allowed the City the opportunity to identify any stormwater projects that might not contribute significant benefits to water quality over and above the projected benefits of the deferred LTCP projects. The City also evaluated the candidate stormwater projects based on other factors, such as level of treatment (pretreatment, basic, or enhanced) and proximity to other planned stormwater quality projects. Based on these evaluations, the City decided to retain 10 of the candidate stormwater projects for further evaluation.

The City then scored and ranked the candidate stormwater projects using Multiple Objective Decision Analysis (MODA). In keeping with the Consent Decree, MODA gave primary consideration to the expected water quality benefits of each project. MODA also considered criteria relevant to other City priorities and values. MODA helped the City compare the stormwater projects with regard to their overall benefits.

Based on the water quality comparisons and MODA, the City selected a suite of stormwater projects for implementation by 2025 and LTCP projects for deferral until 2028–30.

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CHAPTER 1

Comparison of Candidate LTCP and Stormwater Projects

The City of Seattle (City) selected candidate stormwater projects that would take advantage of opportunities in key drainage basins and receiving water bodies. In contrast, the City identified relatively small Long-Term Control Plan (LTCP) projects as potential candidates for deferral. The intent was to identify candidate stormwater projects that would provide significant water quality benefits as compared to the deferred LTCP projects.

1.1 Pollutant Load Reduction

The City compared the projected pollutant load reductions for the candidate stormwater projects with the projected load reductions for the candidate LTCP projects. As shown in Table 1-1, for all Representative Constituents of Concern (RCOCs) except ammonia-N, the highest-ranked candidate projects are all stormwater projects. CSO Outfall 107, the largest candidate LTCP project, would provide the largest ammonia-N load reduction of the candidate projects. Figure 1-1 compares the estimated RCOC load reductions for each candidate stormwater project with the estimated load reductions for CSO Outfall 107. As shown in the figure, most of the stormwater projects provide greater load reduction for most RCOCs because they would treat or reduce larger volumes than the candidate LTCP projects (see Figure 1-2).

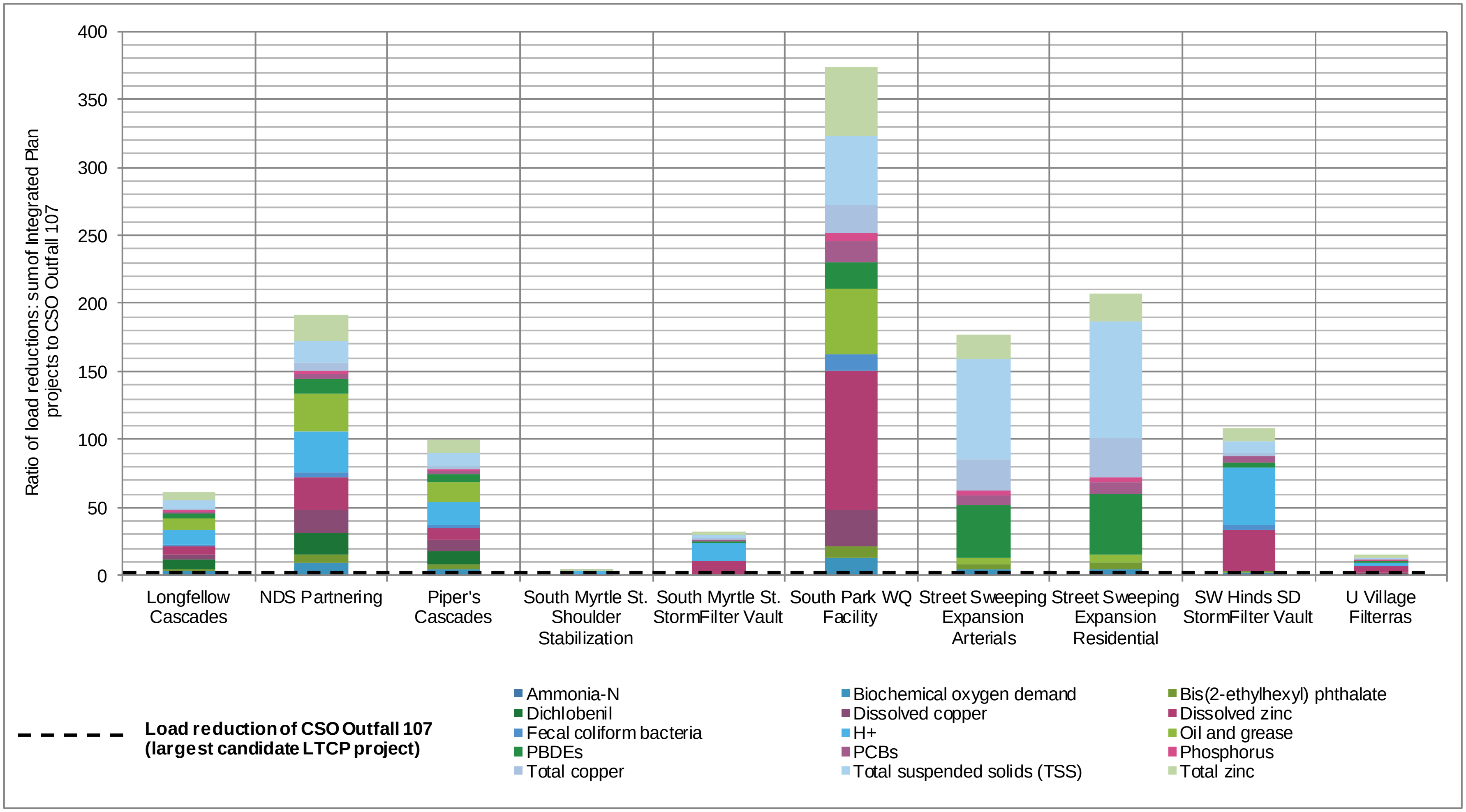

Figure 1-1.Comparison of candidate stormwater projects to largest candidate LTCP project load reductions

Table 1-1. Average Pollutant Load Reductions for Candidate LTCP and Stormwater Projects

Candidate project	Volume treated/ reduced	Ammonia-N	BOD	Bis(2-ethylhexyl) phthalate	Dichlobenil	Dissolved copper	Dissolved zinc	Fecal coliform	H+	Oil and grease	PBDEs	PCBs	Phosphorus	Total copper	Total suspended solids	Total zinc
	MG/yr	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (billion CFU/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)	Reduction (kg/yr)
CSO Outfall 99	0.17	0.78	12	0.0015	0.000070	0.0032	0.012	651	0.000073	2.2	0.000038	0.000032	0.37	0.0084	20	0.026
CSO Outfall 107	1.1	19	82	0.035	0.00029	0.027	0.14	4,346	0.00049	15	0.00025	0.00046	6.6	0.22	494	0.57
CSO Outfall 111	0.0086	0.15	0.64	0.00027	0.000003	0.00021	0.0011	34	0.0000038	0.11	0.0000020	0.0000036	0.05	0.0017	4	0.0044
CSO Outfall 138	0.091	0.43	6.8	0.00081	0.000041	0.0018	0.0067	360	0.000040	1.2	0.000021	0.000018	0.21	0.0046	11	0.015
CSO Outfall 139	0.0057	0.027	0.42	0.00005	0.000003	0.00011	0.00042	22	0.0000025	0.075	0.0000013	0.0000011	0.013	0.00029	0.69	0.0009
CSO Outfall 140	0.051	0.24	3.8	0.00045	0.000023	0.0010	0.0038	201	0.000023	0.67	0.000012	0.000010	0.12	0.0026	6	0.0081
Longfellow Cascades	5.0	2.8	237	0.063	0.0019	0.12	0.71	6,212	0.00510	129	0.0010	0.00062	5.1	0.34	2,645	3.4
NDS Partnering	35	9.2	684	0.22	0.0048	0.46	3.2	17,910	0.015	396	0.0029	0.0018	14	1.3	7,704	11
Piper's Cascades	8.3	4.7	370	0.11	0.0031	0.22	1.2	9,734	0.0081	204	0.0017	0.0010	8.4	0.58	4,382	6
South Myrtle St. Shoulder Stabilization.	0.10	0.086	8.7	0.0021	0.000015	0.0024	0.16	125	0.00062	3.4	0.000033	0.000069	0.09	0.027	142	0.24
South Myrtle St. StormFilter	3.1	0.0	56	0.0098	0.0	0.0	1.29	3,232	0.0064	1.3	0.00025	0.00056	1.4	0.13	1,092	1.4
South Park WQ Facility	74	0.0	1,088	0.29	0.0	0.71	14	52,700	0.0	702	0.0047	0.0069	46	4.5	24,741	29
Street Sweeping Expansion Arterials	1527	N/A	337	0.14	N/A	N/A	N/A	2,100	N/A	69	0.0096	0.0033	24	5.2	36,200	10
Street Sweeping Expansion Residential	986	N/A	366	0.16	N/A	N/A	N/A	2,560	N/A	84	0.011	0.0040	28	6.3	41,900	12
SW Hinds SD/ StormFilter	14	0.0	213	0.045	0.0	0.0	4.1	11,496	0.021	0.0	0.0011	0.0019	6.0	0.44	4,191	5
U Village/Filterras	3.0	0.0	64	0.014	0.0	0.043	0.54	1,395	0.0014	0.0	0.00022	0.00014	0.87	0.18	676	1

The top-performing stormwater projects treat or reduce much larger volumes than the candidate LTCP projects (Figure 1-2). Four of the six candidate LTCP projects have volume reductions that are one to two orders of magnitude smaller than CSO Outfall 107. Most of the candidate stormwater projects, therefore, would provide considerably greater load reductions for most RCOCs when compared to the four smallest candidate LTCP projects. Moreover, the larger candidate stormwater projects treat or reduce much larger volumes than the candidate LTCP projects from February through September, when human exposure is more likely.

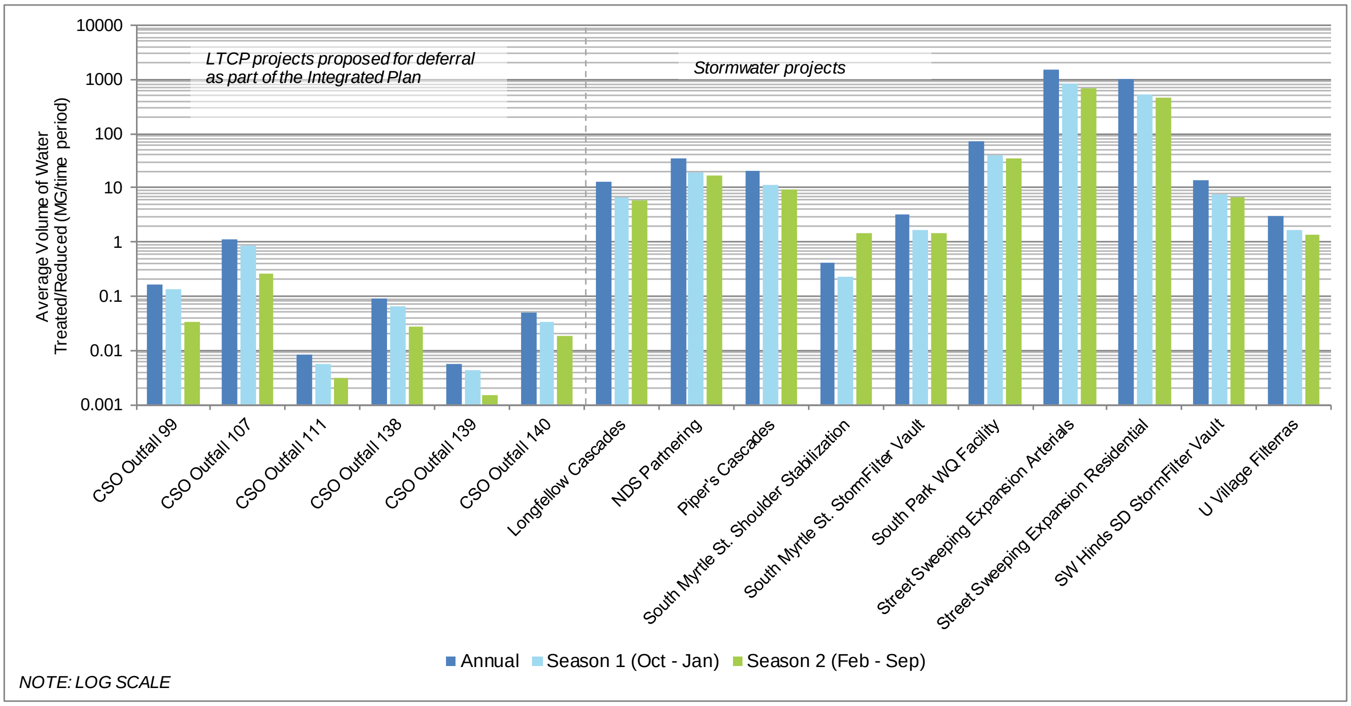

Figure 1-2. Average volume of water treated or reduced from the candidate LTCP and stormwater projects

Figure 1-3 through Figure 1-17 compare the estimated pollutant load reductions for each of the RCOCs.

Total PCBs. The exposure assessment found that polychlorinated biphenyls (PCBs) were the major driver for the human-chronic exposure index values (EIVs) at all locations, and contributed to the ecological EIVs at several locations. Figure 1-3 indicates that most of the candidate stormwater projects would provide more PCB removal, on an average annual basis, than the largest of the candidate LTCP projects (CSO Outfall 107).

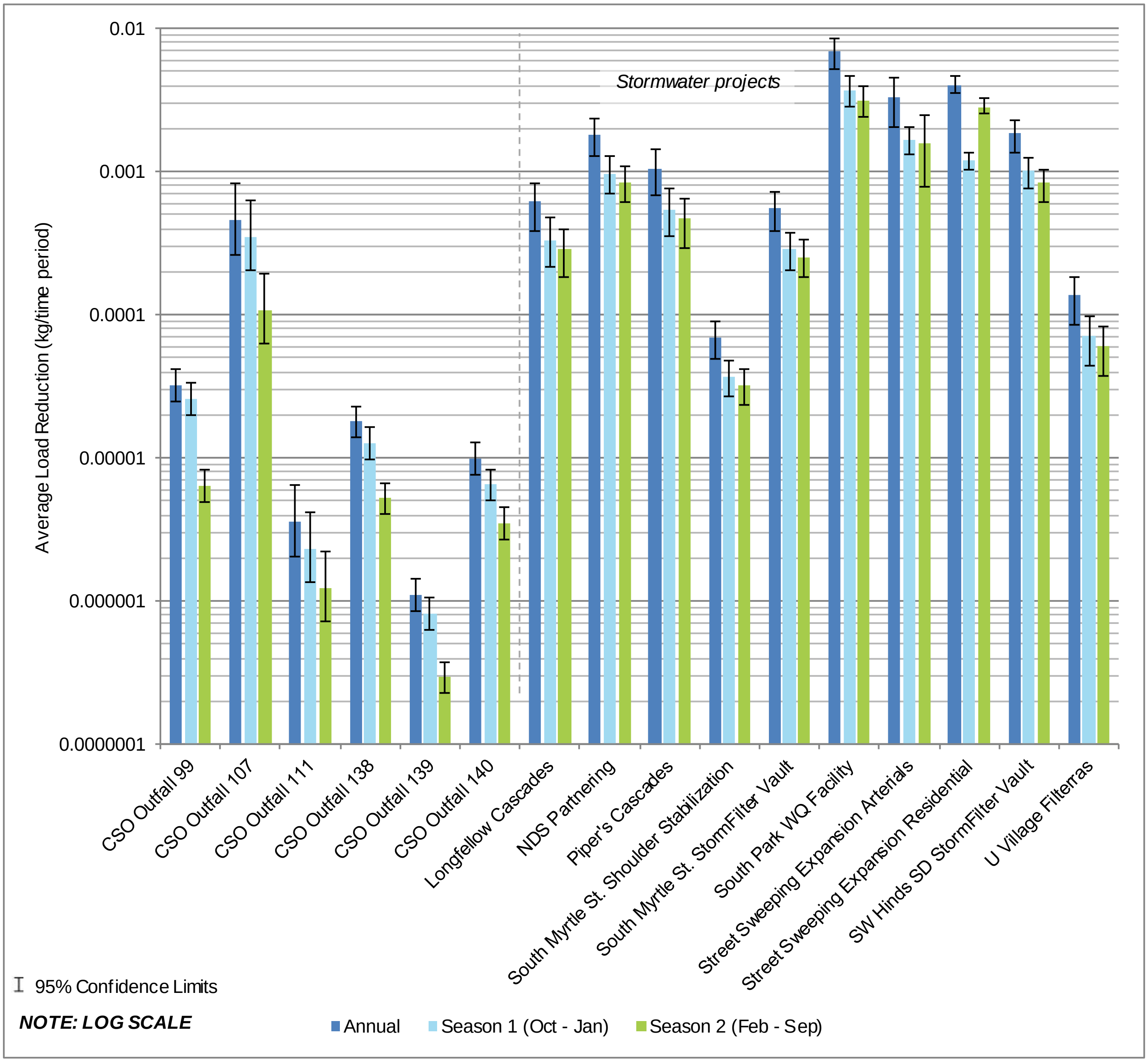

Figure 1-3. Average PCB load reduction from the candidate LTCP and stormwater projects

Note: Exposure assessment found that PCBs were the most important RCOC for human exposure over the long term.

Fecal Coliform Bacteria. Fecal coliform was identified as a key driver for human-acute EIVs. Figure 1-4 shows that half of the candidate stormwater projects would provide more fecal coliform reduction than the best candidate LTCP project (CSO Outfall 107). These five stormwater projects treat much larger discharge volumes than any of the candidate LTCP projects.

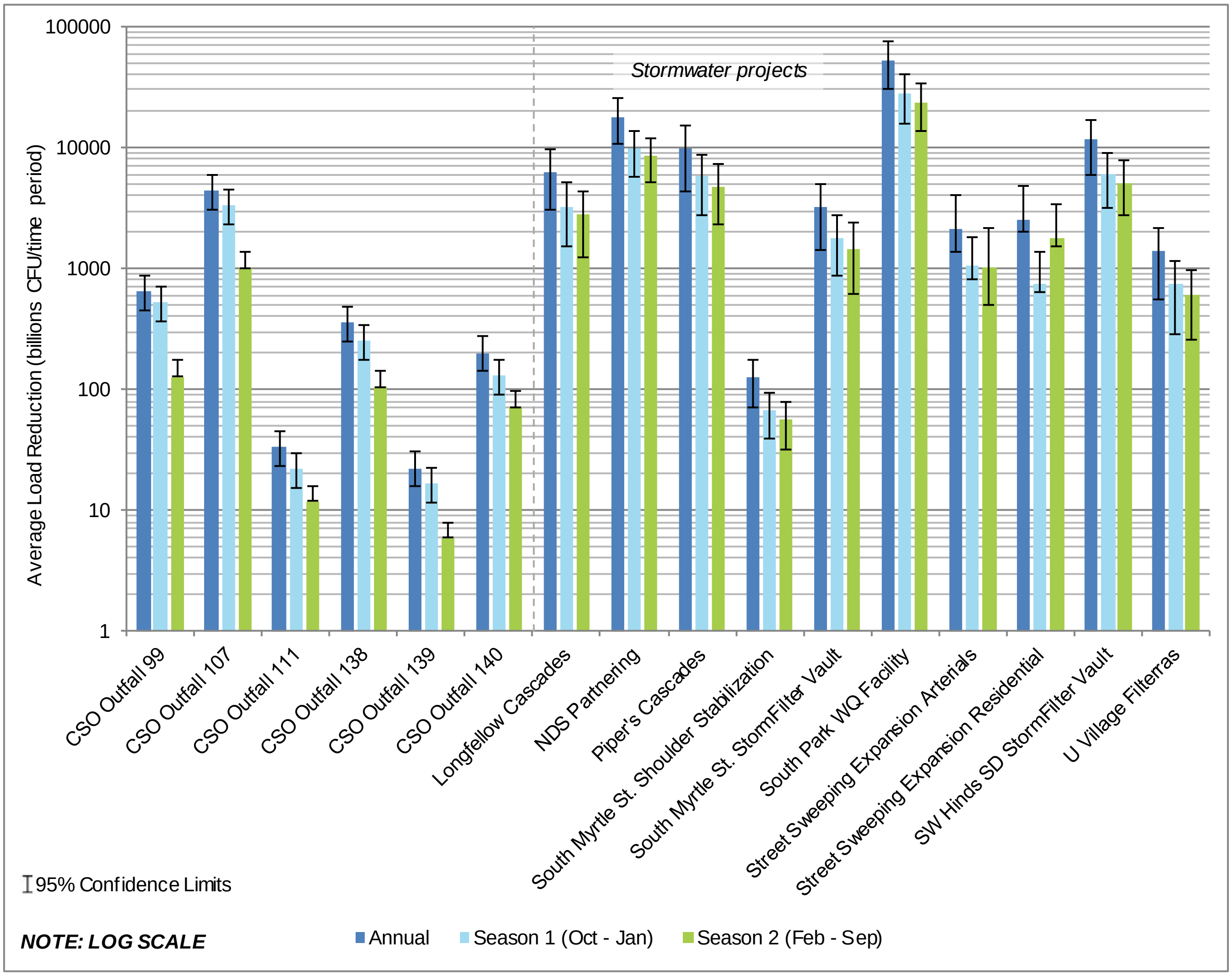

Figure 1-4. Average fecal coliform load reduction from the candidate LTCP and stormwater projects

Dissolved Zinc. The exposure assessment identified dissolved zinc as a driver for ecological EIVs at several locations. Figure 1-5 shows that most of the candidate stormwater projects would provide more dissolved zinc reduction than the best candidate LTCP project (CSO Outfall 107).

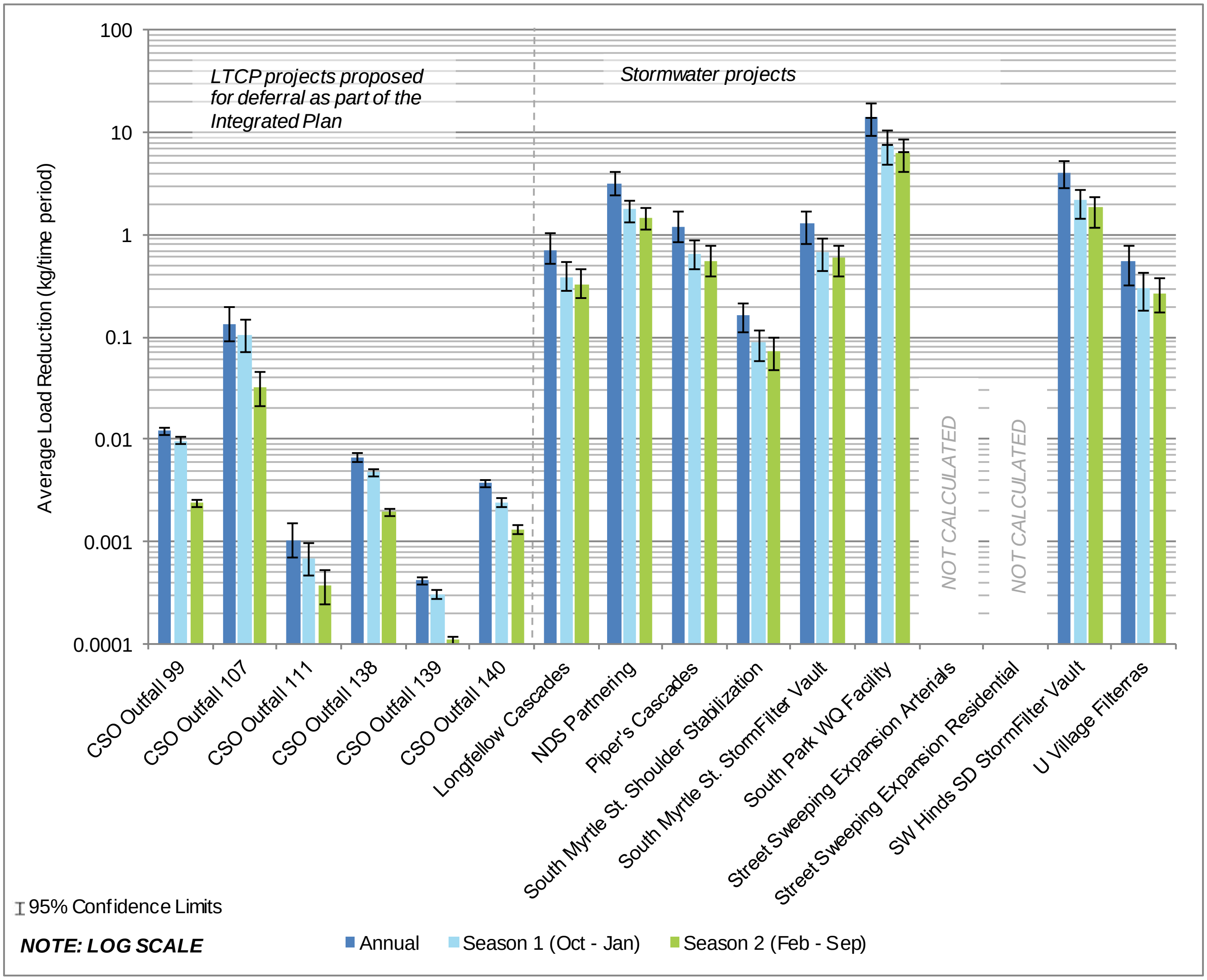

Figure 1-5. Average dissolved zinc load reduction from the LTCP and stormwater projects

Phosphorus. The exposure assessment found that total phosphorus was a major driver for the ecological EIVs at freshwater discharge locations. The candidate stormwater projects that discharge to freshwater bodies (NDS Partnering, Piper's Cascades, Longfellow Cascades, U Village Filterras, portions of the street sweeping) would provide more average annual phosphorus reduction than the LTCP projects that discharge to freshwater bodies (CSO Outfalls 138, 139, 140). See Figure 1-6 for the estimated phosphorus load reductions for the candidate LTCP and stormwater projects.

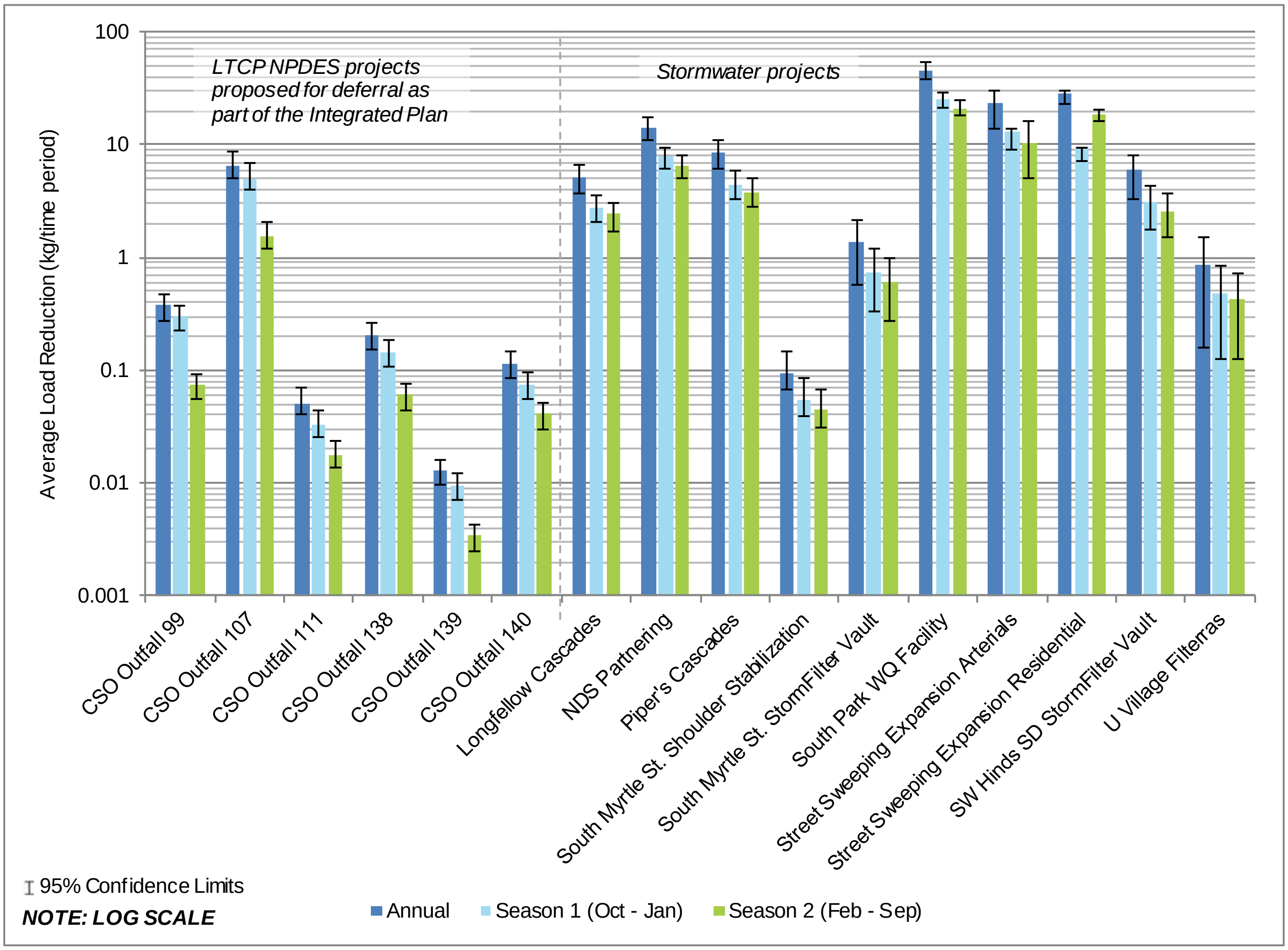

Figure 1-6. Average phosphorus load reduction from the candidate LTCP and stormwater projects

Ammonia-N. The exposure assessment indicated that ammonia contributed to the ecological EIVs at several discharge locations. The pollutant loads modeling assumed that only the stormwater projects that provide volume reduction would reduce ammonia-N loads. As shown in Figure 1-7, four of the candidate stormwater projects are expected to provide appreciable ammonia reoval.

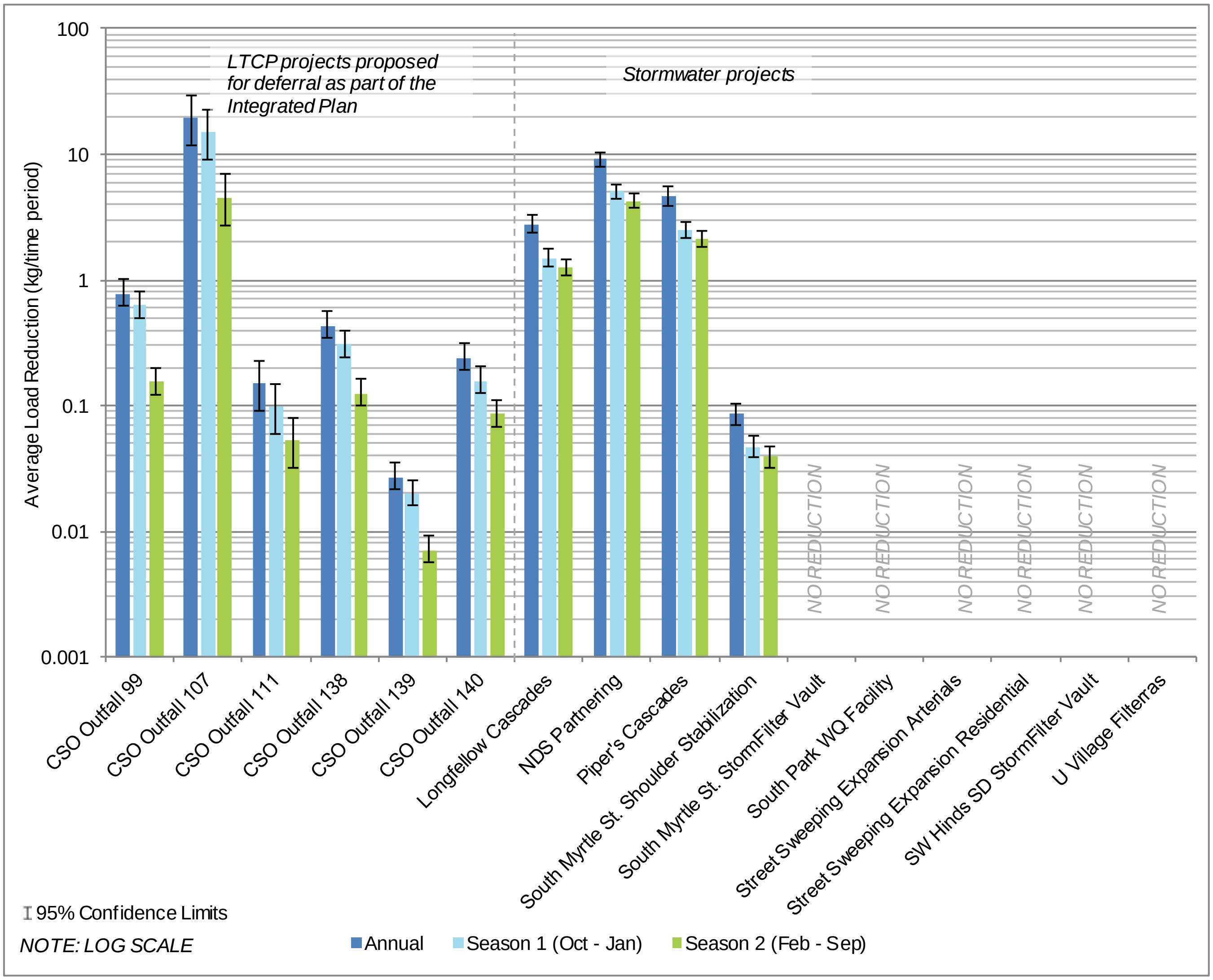

Figure 1-7. Average ammonia-N load reduction from the candidate LTCP and stormwater projects

Dissolved Copper. The exposure assessment found that dissolved copper contributed to the ecological EIVs at some locations. Figure 1-8 compares the load reduction results for dissolved copper. Five of the candidate stormwater projects have higher estimated dissolved copper removal than the largest candidate LTCP project (CSO Outfall 107), while four of the candidate stormwater projects are expected to provide little or no dissolved copper removal.

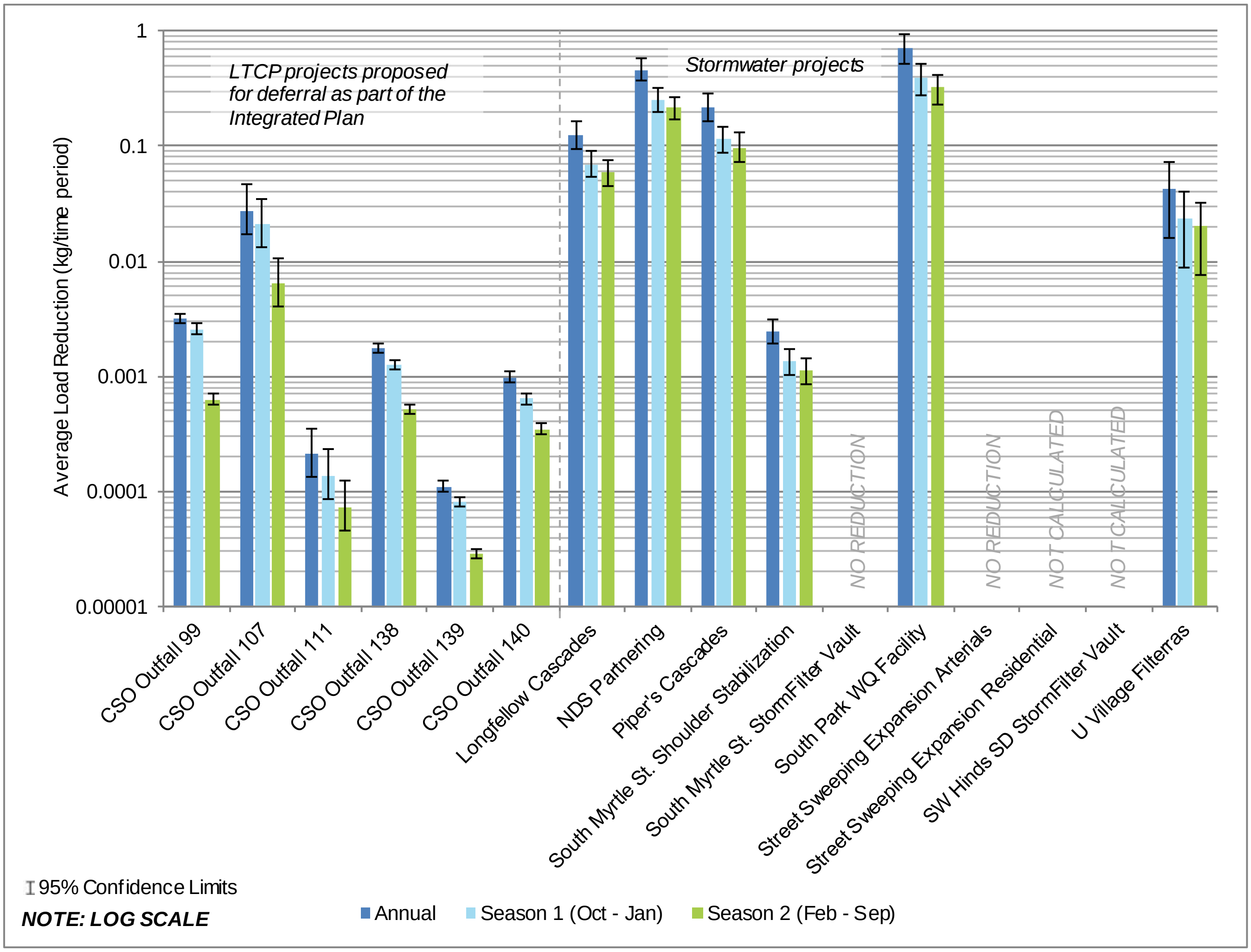

Figure 1-8. Average dissolved copper load reduction from the candidate LTCP and stormwater projects

Biochemical Oxygen Demand. Figure 1-9 compares the candidate stormwater and LTCP projects based on biochemical oxygen demand (BOD) reduction. Most of the stormwater projects have higher estimated annual BOD load reductions than the largest of the candidate LTCP projects for deferral (CSO Outfall 107).

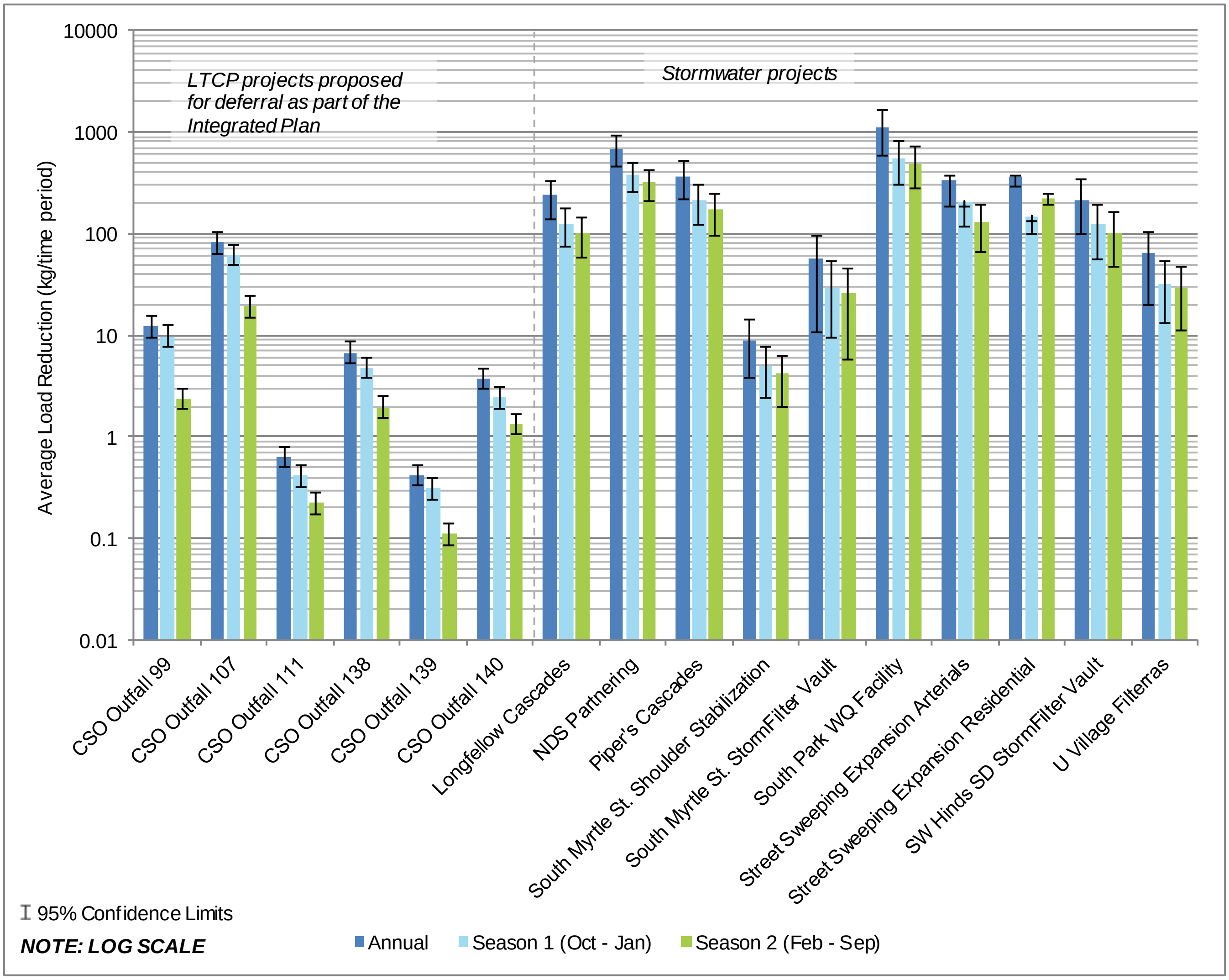

Figure 1-9. Average BOD load reduction from the candidate LTCP and stormwater projects

Bis(2-ethylheyl)phthalate. The exposure assessment found that bis(2-ethylheyl)phthalate contributed to the human and ecological EIVs at several locations. Figure 1-10 presents the loads modeling results for bis(2-ethylheyl)phthalate. Seven of the candidate stormwater projects have higher estimated bis(2-ethylheyl)phthalate annual load reductions than the largest candidate LTCP project (CSO Outfall 107).

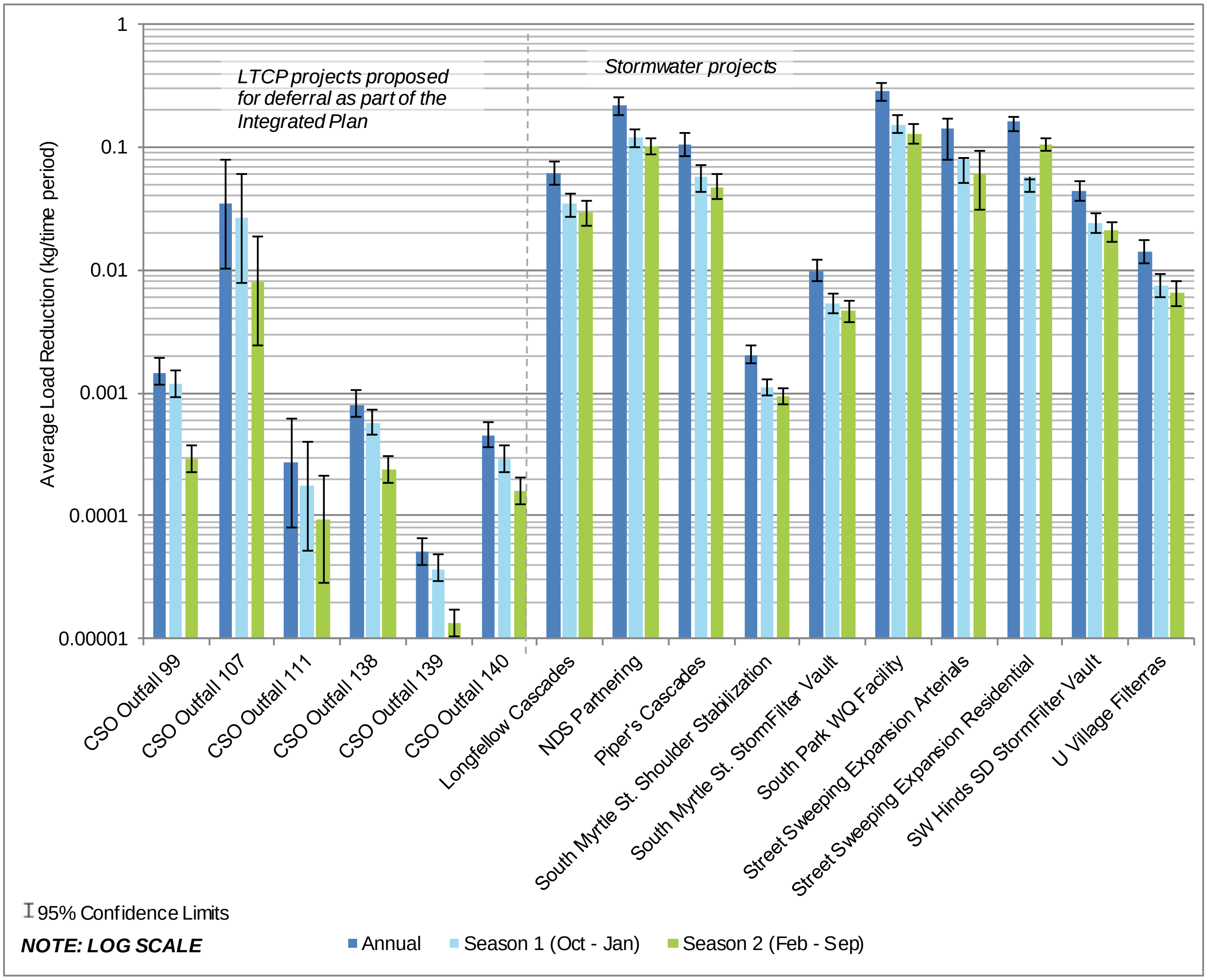

Figure 1-10. Average bis(2-ethylhexyl)phthalate load reduction from the candidate LTCP and stormwater projects

Dichlobenil. Figure 1-11 shows the loads modeling results for dichlobenil. The City assumed that dichlobenil would be removed only by the four candidate stormwater projects that include infiltration: Longfellow Cascades, Natural Drainage Systems (NDS) Partnering, Piper's Cascades, and South Myrtle St. Shoulder Stabilization. Three of these projects would provide larger load reduction than the largest LTCP project (CSO Outfall 107).

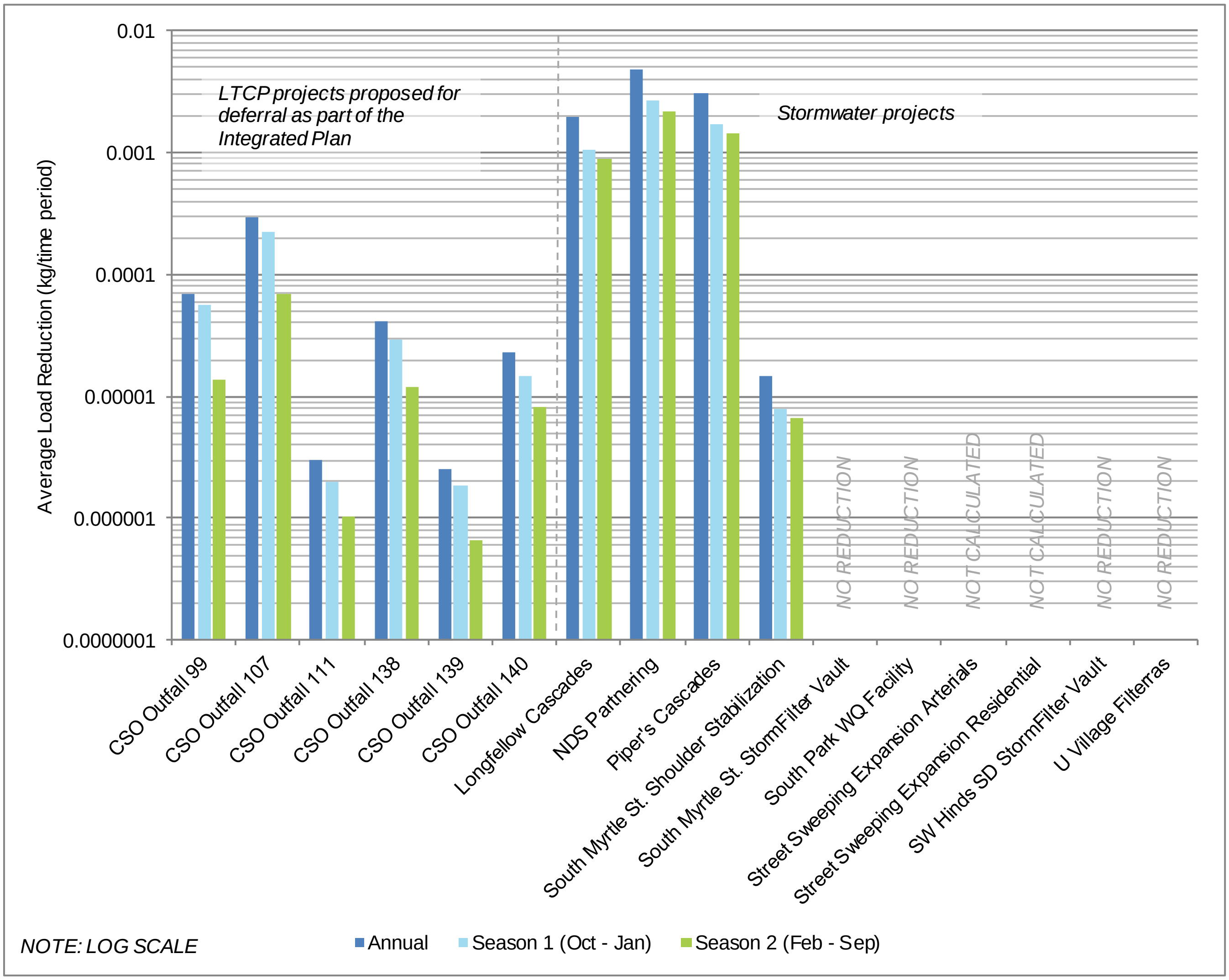

Figure 1-11. Average dichlobenil load reduction from the LTCP and stormwater projects

Note that due to insufficient data, UCL and LCL values were unable to be calculated for dichlobenil.

H+. Figure 1-12 indicates that seven of the candidate stormwater projects would provide greater reductions in H+ annual loads compared to the largest LTCP project (CSO Outfall 107).

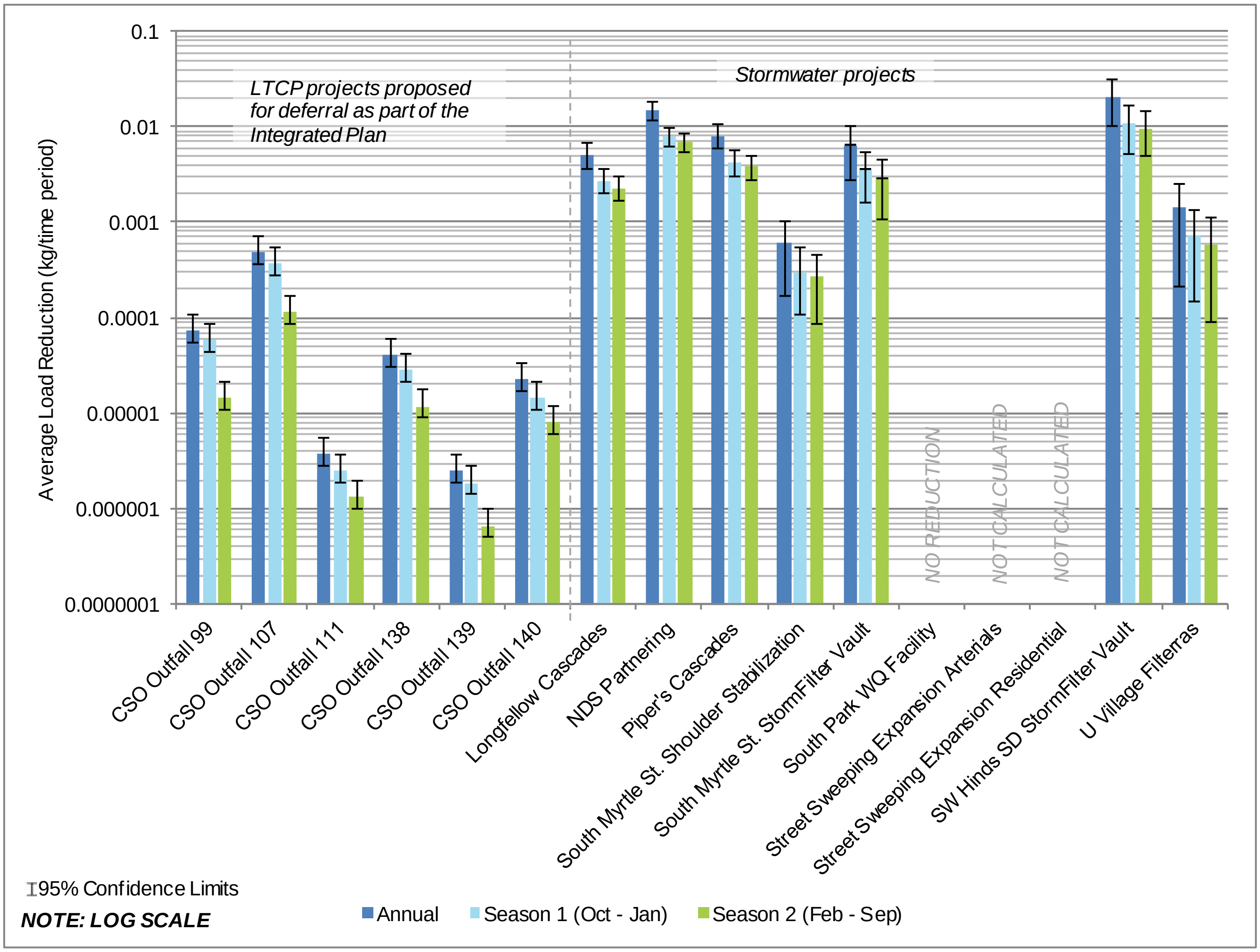

Figure 1-12. Average H+ load reduction from the LTCP and stormwater projects

Oil and Grease. Figure 1-13 compares the estimated oil and grease load reductions for the candidate LTCP and stormwater projects. Six of the candidate stormwater projects would provide more annual loads reduction in oil and grease than the largest candidate LTCP project (CSO Outfall 107).

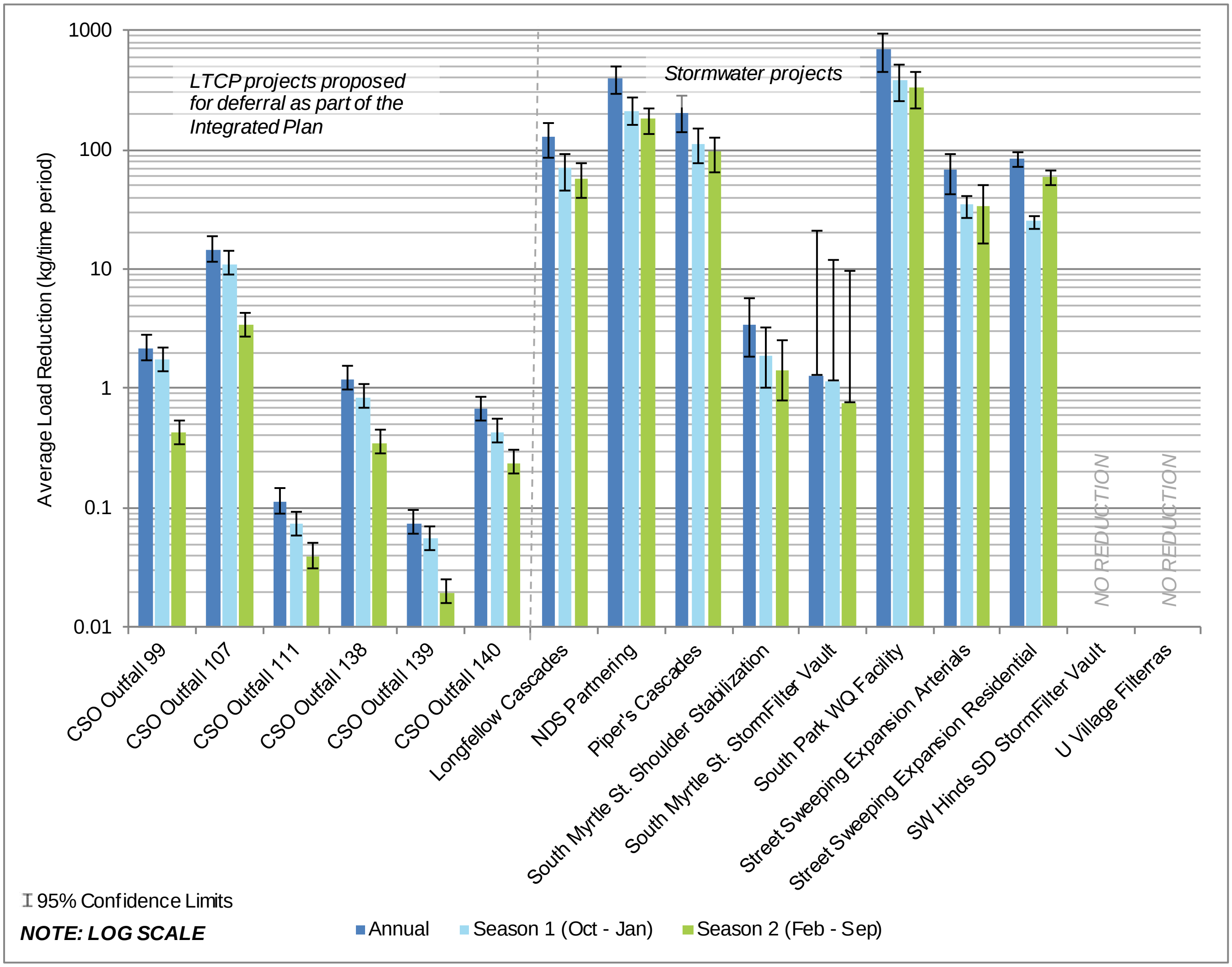

Figure 1-13. Average oil and grease load reduction from the candidate LTCP and stormwater projects

PBDEs. Figure 1-14 presents the load reduction estimates for polybrominated diphenyl ethers (PBDEs). Seven of the candidate stormwater projects have higher PBDE load reductions than the largest candidate LTCP project (CSO Outfall 107).

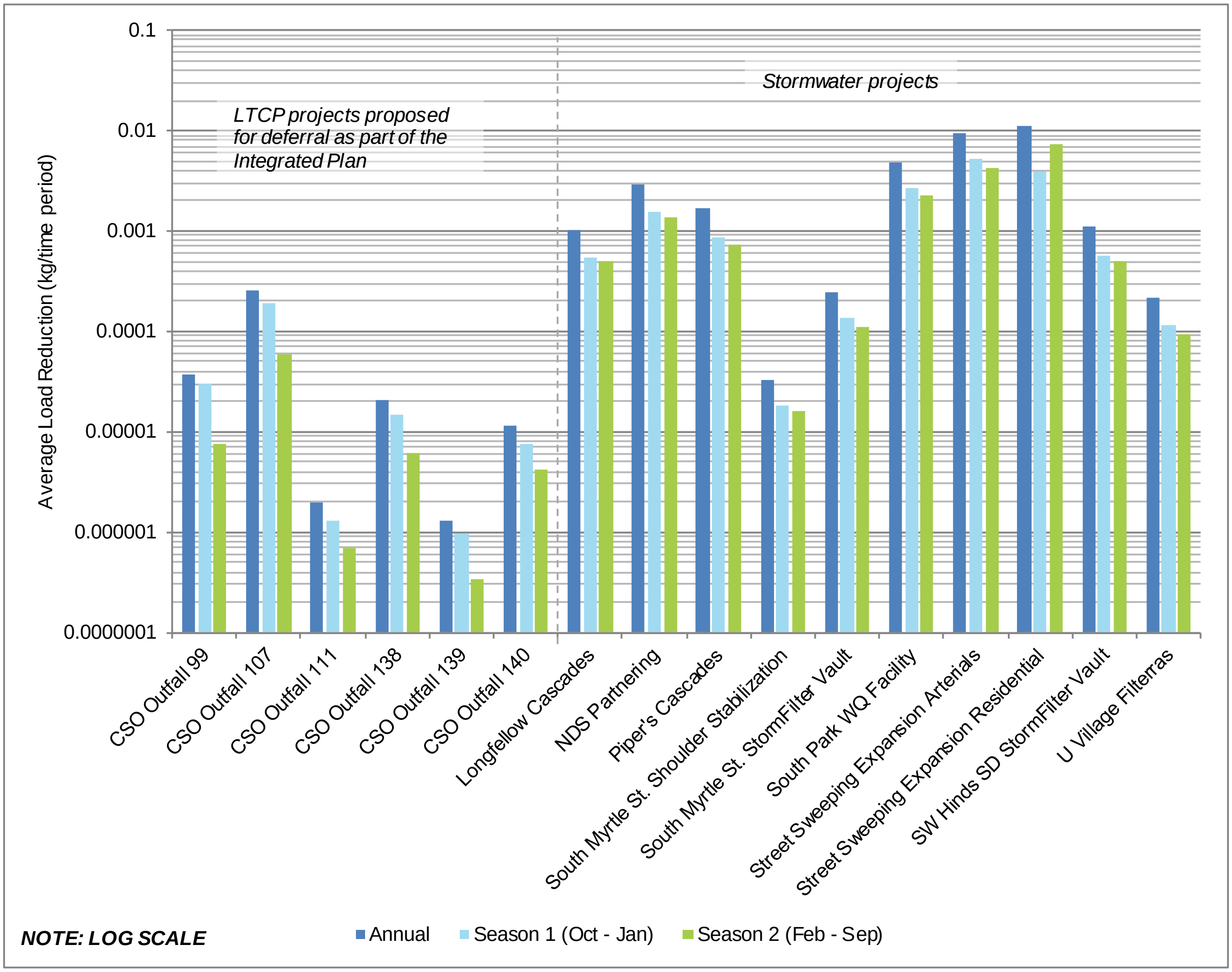

Figure 1-14. Average PBDE load reduction from the candidate LTCP and stormwater projects

Note that due to insufficient data, UCL and LCL values were unable to be calculated for PBDEs.

Total Copper. As shown in Figure 1-15, seven of the candidate stormwater projects would provide more total copper removal than the largest of the candidate LTCP projects (CSO Outfall 107).

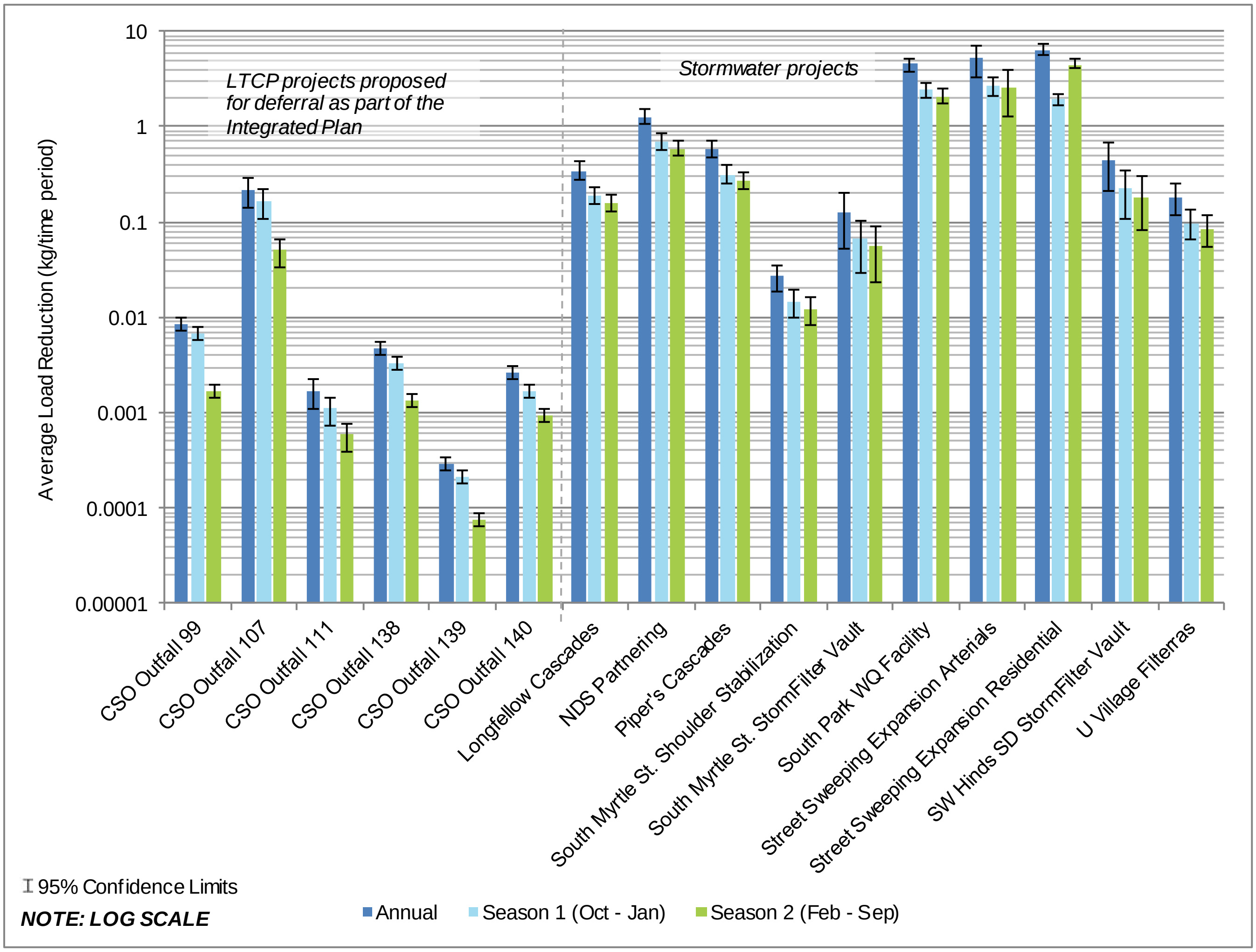

Figure 1-15. Average total copper load reduction from the candidate LTCP and stormwater projects

Total Suspended Solids. Figure 1-16 presents the total suspended solids (TSS) loads modeling results for the candidate LTCP and stormwater projects. Eight of the candidate stormwater projects have higher estimated TSS annual load reductions than the largest candidate LTCP project (CSO Outfall 107).

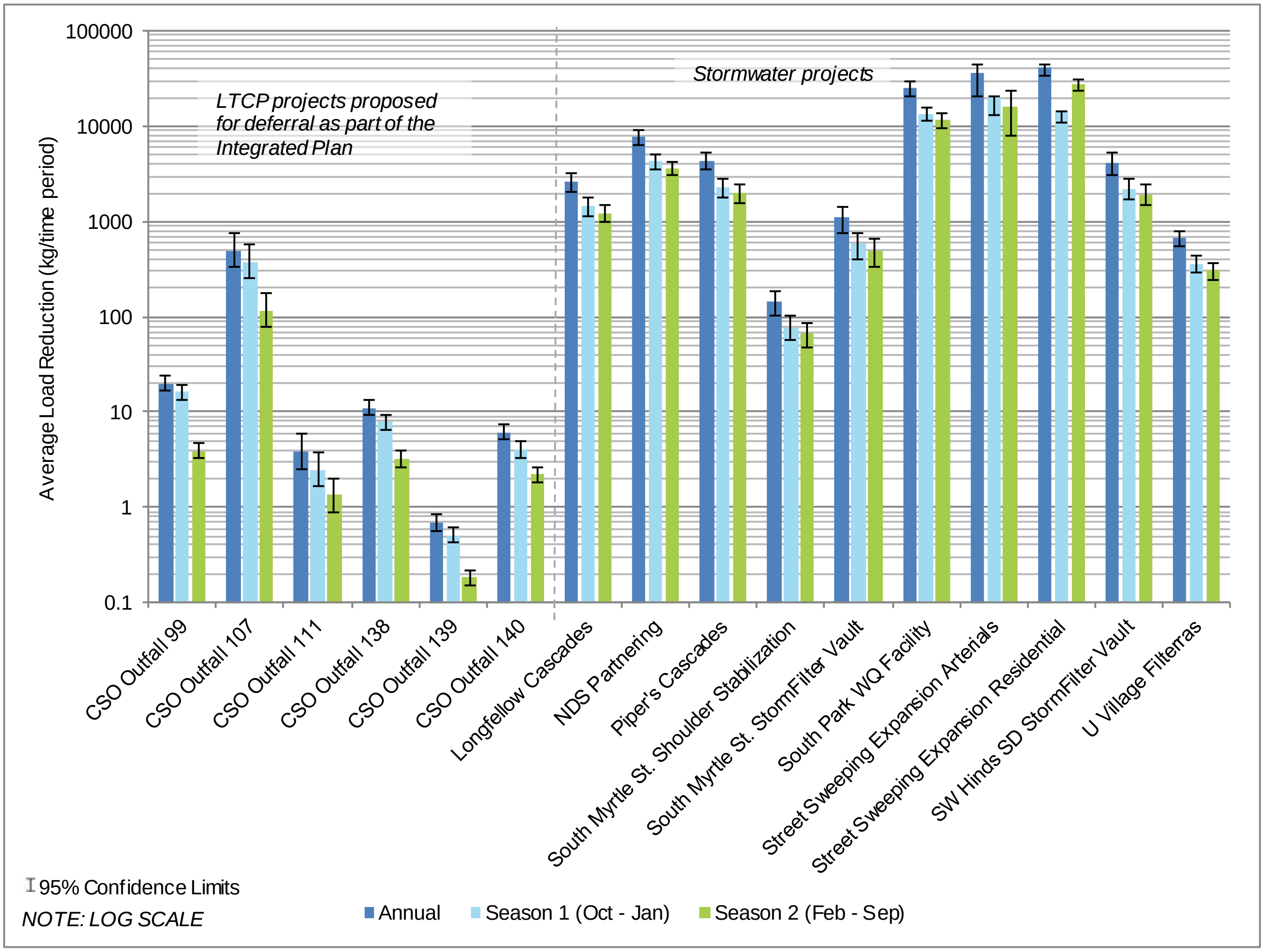

Figure 1-16. Average TSS load reduction from the candidate LTCP and stormwater projects

Total Zinc. Figure 1-17 compares the load reduction estimates for zinc. Nine of the candidate stormwater projects would provide more total zinc removal than the largest of the candidate LTCP projects (CSO Outfall 107).

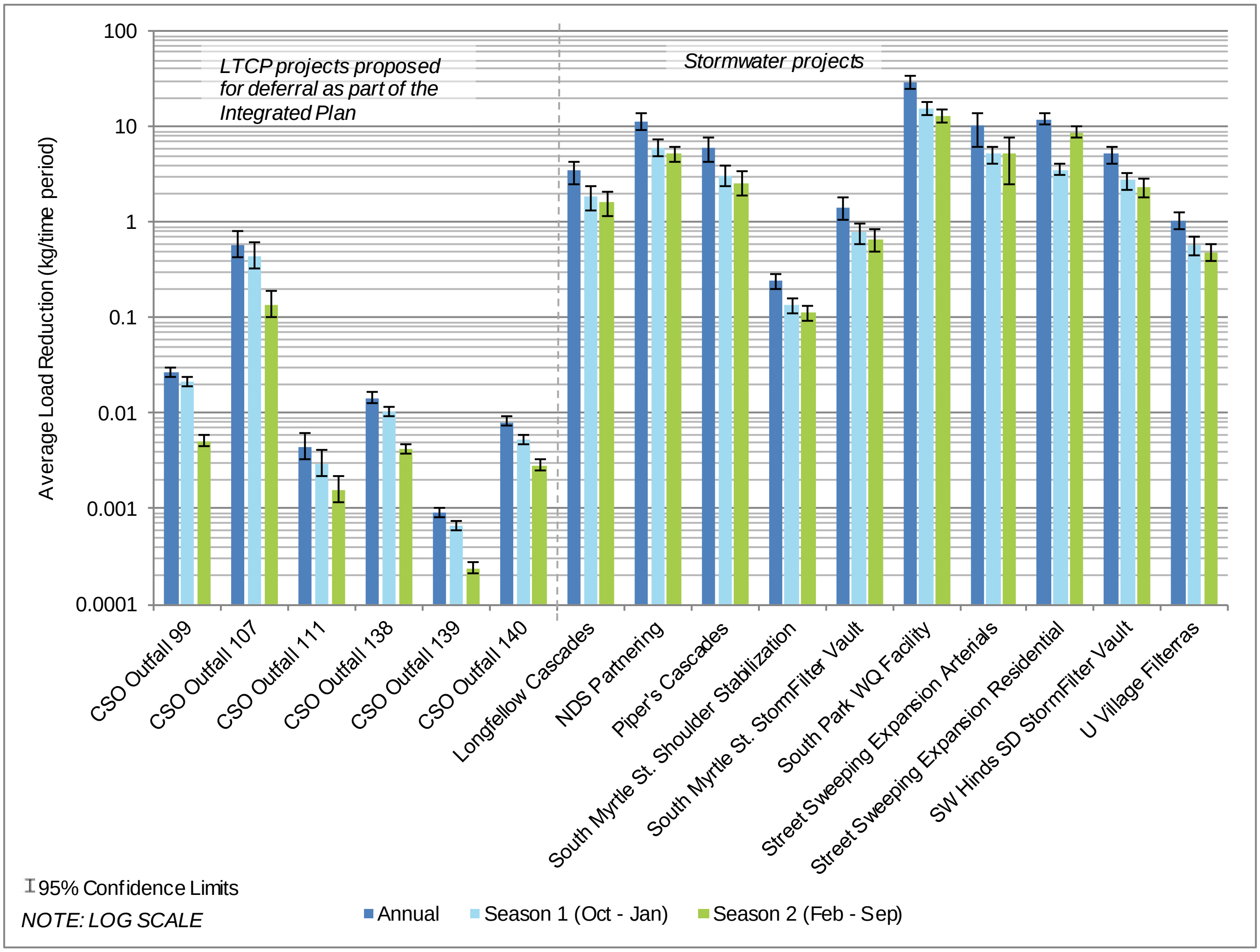

Figure 1-17. Average total zinc load reduction from the candidate LTCP and stormwater projects

1.2 Relative Exposure Reductions for Candidate Projects

The City used the pollutant loads reduction results, together with information on local receiving water bodies, to estimate the potential relative reductions in exposure of human and ecological receptors associated with the candidate LTCP and stormwater projects. Human and ecological EIVs were calculated for the candidate LTCP and structural stormwater projects to estimate the relative exposure reductions. The City used the EIVs to compare the candidate projects and select the projects to include in the Integrated Plan.

EIVs were not calculated for the candidate street sweeping programs because the EIV receptor factors are based on the outfall location, and runoff from the swept streets would affect more than 100 outfalls throughout the city. Section 1.3 explains the approach used to evaluate the potential reductions in exposure that would result from the candidate street sweeping programs.

Table 1-2 lists the EIVs for the candidate stormwater and LTCP projects. The highest (best) EIVs were associated with candidate stormwater projects. The South Park WQ Facility project had the highest EIVs for human receptors while the NDS Partnering project had the highest EIV for ecological receptors among all of the candidate stormwater and LTCP projects. Of the LTCP projects only, CSO Outfall 107 had the highest human-chronic (toxics) and ecological EIVs, and CSO Outfall 138 had the highest fecal coliform EIV.

Figure 1-18 compares the EIVs for the candidate stormwater projects to the highest EIVs for the candidate CSO projects (CSO Outfall 107 and CSO Outfall 138). As shown in the figure, the human and ecological EIVs for the South Park WQ Facility are many times higher than the highest EIVs for the candidate CSO projects. The ecological EIVs for the NDS Partnering and Piper's Cascades projects were several times higher than the ecological EIVs for the highest candidate CSO project (CSO Outfall 107).

PCBs were by far the most important driver for human-toxics EIVs, and contributed to ecological EIVs at some locations. Phosphorus was the main contributor to ecological EIVs at freshwater locations. Dissolved zinc, dissolved copper, bis(2-ethylheyl)phthalate, and ammonia-N also contributed to the ecological EIVs at some locations.

Appendix H of the Integrated Plan provides a detailed description of the EIV methods and results.

Table 1-2. Comparison of EIVs for Candidate LTCP and Stormwater Projects, by Project

Candidate project	Receiving water body	Human				Ecological	
		Toxics		Fecal coliform		Toxics/nutrients	
		EIV	Rank	EIV	Rank	EIV	Rank
CSO Outfall 99	West Waterway of the Duwamish River	0.39	10	0.18	13	0.0057	14
CSO Outfall 107	East Waterway of the Duwamish River	13	4	1.3	8	0.35	7
CSO Outfall 111	Duwamish River	0.16	12	0.019	16	0.0038	15
CSO Outfall 138	Portage Bay	0.13	13	2.0	5	0.039	11
CSO Outfall 139	Portage Bay	0.0061	16	0.093	14	0.0031	16
CSO Outfall 140	Portage Bay	0.080	15	1.4	7	0.035	12
Longfellow Cascades	Longfellow Creek	0.27	11	1.1	10	0.61	4
NDS Partnering: Thornton Creek	Thornton Creek	3.8	6	7.0	2	2.5	1
NDS Partnering: Piper's Creek	Piper's Creek	0.89	9	1.2	9	0.54	5
NDS Partnering: Longfellow Creek	Longfellow Creek	0.12	14	0.52	12	0.24	9
Piper's Cascades	Piper's Creek	3.8	5	5.3	3	1.8	3
South Myrtle St. Shoulder Stabilization	Lower Duwamish Waterway	1.6	8	0.024	15	0.019	13
South Myrtle St. StormFilter Vault	Lower Duwamish Waterway	14	3	0.67	11	0.14	10
South Park WQ Facility	Lower Duwamish Waterway	117	1	8.3	1	1.9	2
Street Sweeping Expansion Arterials	Multiple	N/A[a]					
Street Sweeping Expansion Residential	Multiple	N/A[a]					
SW Hinds SD StormFilter Vault	Lower Duwamish Waterway	36.2	2	1.9	6	0.36	6
U Village Filterras	Lake Washington Ship Canal/Lake Union	2.0	7	3.2	4	0.32	8

a. *EIVs were not calculated for street sweeping because the receptor factors are based on the outfall location, and runoff from the swept streets would enter many outfalls throughout the city.*

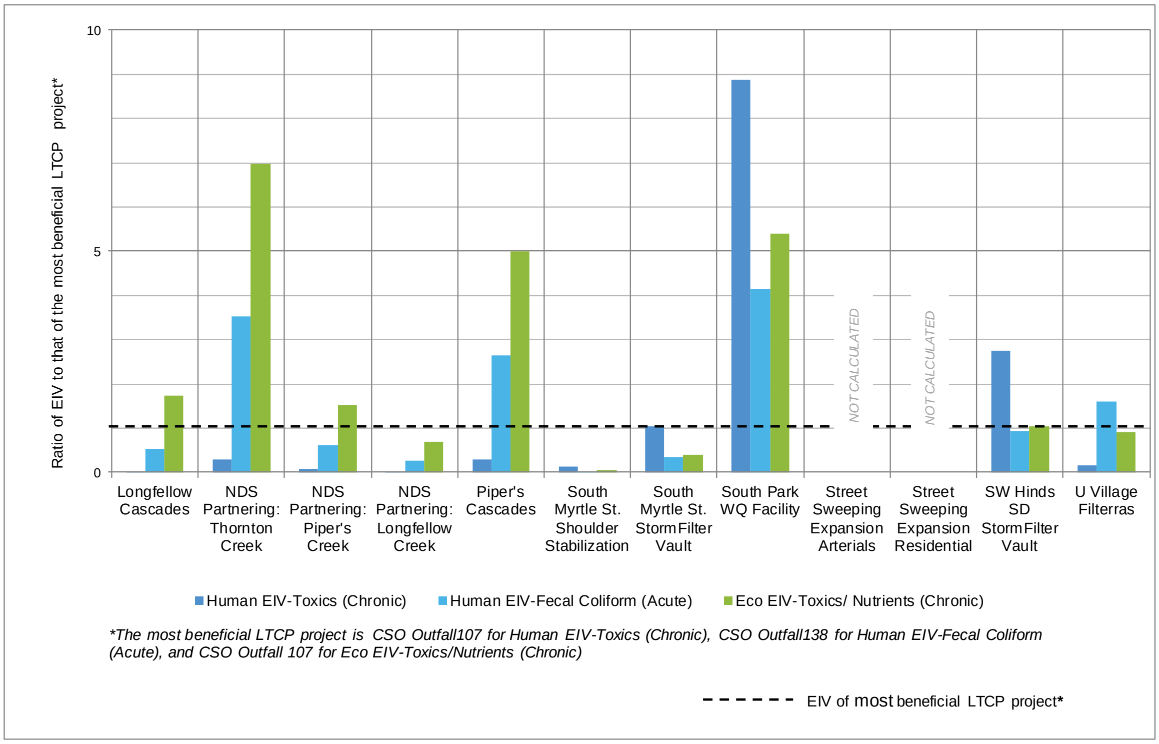

Figure 1-18. Ratio of candidate stormwater project EIVs to most beneficial LTCP project EIVs

EIVs were not calculated for the candidate street sweeping programs because the EIV receptor factors are based on the outfall location, and runoff from the swept streets would affect more than 100 outfalls throughout the city.

1.3 Relative Exposure Reductions for Candidate Street Sweeping Programs

EIVs were not calculated for the candidate street sweeping programs because the EIV receptor factors are based on the outfall location, and runoff from the swept streets would affect numerous outfalls and water bodies throughout the city. Therefore, a more qualitative approach was used to evaluate the potential reductions in exposure that would result from the candidate street sweeping programs.

Table 1-1 above and Figures 1-3 and 1-6 show that the candidate street sweeping programs would provide much larger reductions in PCBs and phosphorus than the candidate LTCP projects. PCBs were found to be the key driver for human-toxics EIVs at all locations. Phosphorus was the key driver for ecological EIVs at freshwater locations, while PCBs were an important contributor to ecological EIVs at several saltwater/brackish locations. These results suggest that the candidate sweeping programs would provide substantial reductions in human exposure to toxics and ecological exposure to nutrients and toxics as compared to the candidate LTCP projects.

The pollutant loads modeling results indicate that neither of the candidate street sweeping programs would provide as much fecal coliform load reduction as CSO Outfall 107. However, both sweeping programs would provide more fecal coliform load reduction than any of the other candidate LTCP projects. The loads modeling results also indicate that the candidate sweeping programs would provide appreciable reductions in human exposure to fecal coliform. Moreover, the loads reductions from sweeping would benefit water bodies throughout the city.

CHAPTER 2

Multiple Objective Decision Analysis

The City used MODA to compare the candidate stormwater projects and programs for potential inclusion in the Integrated Plan. This section summarizes the MODA methods and results.

2.1 Methodology Overview

The City often uses MODA to help make decisions regarding projects or programs. For the Integrated Plan, the City used MODA to compare candidate stormwater projects based on their expected water quality benefits as well as other criteria important to the community.

MODA is a generalized term often used for a suite of analytical techniques referred to in the literature as Multi-Attribute Utility Theory (MAUT) (Keeney et al., 1976). MAUT is derived from the basic von Neumann-Morgenstern axioms of preference (Von Neumann and Morgenstern, 1947) and thus upon a utility function, which allows the comparison of risky outcomes through the computation of expected utility. The specific form of MAUT used in the Integrated Plan is a simplified form called the Simple Multi-Attribute Rating Technique with Swings (SMARTS) (Edwards and Barron, 1994).

The MODA methodology for the Integrated Plan involved the following steps:

1. Establish evaluation criteria
2. Develop measurement scales and assign draft scores
3. Establish relative value weights
4. Normalize scores and calculate results
5. Perform sensitivity analysis

These steps are described below.

2.2 Establish Evaluation Criteria

The Integrated Plan team developed evaluation criteria during a series of workshops facilitated by the same MODA specialists who supported the LTCP decision-making process. Through these workshops the team developed criteria that represent the City values and objectives relevant to making decisions about the Integrated Plan. The criteria are:

1. Performance risk
2. Flexibility
3. Relationship with other agencies (tribes, King County)
4. Water quality
5. Other positive environmental outcomes
6. Construction impacts (short-term)
7. Community impacts (long-term)
8. Environmental/social justice
9. Ease of operations and maintenance (O&M) and safety

For each criterion, a number of questions were developed, to be answered, as a means to evaluate how well each candidate project met the criteria. Table 2-1 lists the criteria and questions and provides a comparison to the MODA criteria used for the candidate LTCP projects. The responses to the criteria questions, considered in the evaluation of each of the candidate stormwater projects, are provided in Table 2-2 through 2-13.

Table 2-1. Comparison of Evaluation Criteria from Integrated Plan and Long-Term Control Plan

Integrated plan		LTCP		Major differences in evaluation criteria
Criterion	**Questions**	**Criteria**	**Questions**	
1. Performance Risk	How flexible does the system perform in response to varying flow and pollutant characteristics above and below the design point?	1. Technical Complexity and Performance Risk	Does implementation require complex coverall system controls? How many individual CSO facilities are needed to implement control strategy? How do King County Boundary Conditions impact City CSO facility operations?	Integrated Plan focuses on performance of the system; LTCP criteria focuses on complexity of controls, number of CSO facilities, and King County impact on operations.
2. Flexibility	What are the intervention opportunities to address under-performance, changes in rainfall patterns, and/or increases in temperature and drought situations?	2. Flexibility	Can the alternative meet changing control criteria and flow conditions?	None.
3. Relationship with Other Agencies	To what extent does the alternative enhance long-term relationships with Puget Sound area tribes and King County WTD?	5. King County Concurrence on Joint Projects	Does King County agree to implement a Joint King County/City Project(s) by September 1, 2013, and confirm in writing?	Integrated Plan considers relationship with King County and tribes; LTCP only focuses on relationship with King Co.
4. Water Quality	Based on the Pre-project concentration for each RCOC and water quality criteria for the receiving water body, how does the load reduction for the project compare to the load reduction for the largest candidate CSO project for deferral LTCP project (CSO Outfall 107)?	None.	None.	Integrated Plan has water quality as an independent criteria; LTCP does not.

Table 2-1. Comparison of Evaluation Criteria from Integrated Plan and Long-Term Control Plan

Integrated plan		LTCP		Major differences in evaluation criteria
Criterion	**Questions**	**Criteria**	**Questions**	
5. Other Positive Environmental Outcomes	Does the project help meet the City's Green Goal by reducing stream flow rates, and/or does the project add green space and habitat? Does the project or program have an impact on carbon dioxide emissions (climate pollution)?	9. Environmental	Will the construction impact wetlands, streams, shorelines, habitats, and/or endangered species?	Integrated Plan focuses on City's green goals; LTCP criteria are broader in scope.
6. Construction Impacts (short-term)	What level of disruption will occur during project construction?	6. Construction Impacts (Short-Term)	What level of disruption will occur? Are the cumulative construction impacts significant?	None.
7. Community Impacts (longer-term)	Does the project support (visual) connection to water system? Does the project support citizen stewardship of project/facility? Does it support formal education? What lasting impact will the project and its O&M activities have on the neighborhood, either positive (culturally relevant, sidewalks, water access, bike paths, traffic calming, visual appeal), or negative (odor, noise, visual)?	7. Community Impacts (Long-Term)	Can the facility be designed to be compatible with the community, and how will O&M activities impact the community?	Integrated Plan specifically includes supporting educational opportunities; LTCP does not.
8. Environmental/ Social Justice	Who and where? Will location of project address the historical inequity (e.g., address problems that were historically "underreported")? Does it protects a current use by socioeconomic class (e.g., fishing in Duwamish/Green Lake)? Will project siting affect an already heavily impacted area (e.g., South Park has transfer station)?	8. Environmental/ Social Justice	What are the project's overflow and operation impacts and benefits? Does the project result in unequal impacts and benefits to historically underserved communities and low-income populations during construction or operation of the facility?	None.

Table 2-1. Comparison of Evaluation Criteria from Integrated Plan and Long-Term Control Plan

Integrated plan		LTCP		Major differences in evaluation criteria
Criterion	**Questions**	**Criteria**	**Questions**	
9. Ease of O&M and Safety	Beyond any cost implications, what are the implications for City staff to operate the system assuming adequate resources are available? Beyond any cost implications, what are the implications for City staff to maintain the system assuming adequate resources are available? Assuming safety and security are addressed appropriately during design, what safety concerns remain?	10. Ease of O&M and Safety	What level of staffing is required for operation and shutdown (how often is the facility used, how long is the facility in use, how many operators are required, what level of operator experience is required, what are travel times)? What are peak staff required? Does the facility have access requirements in the ROW or require confined space entry? Are traffic control procedures required? Does access require a street use permit or lane closure?	None.
None.	None.	3. Constructability	Are construction risks associated with the alternative significant? What are the expected permitting/regulatory/ land use compliance complexities and how difficult is it expected to be to obtain permits and approvals?	Not specifically addressed in Integrated Plan criterion.
None	None	4. Consent Decree Compliance Schedule	Does the alternative meet the City's Consent Decree Construction Completion Milestone Date of Dec 31, 2025?	Not specifically addressed in Integrated Plan criterion.

Table 2-2. Evaluation Criteria for Street Sweeping Expansion Residential	
Evaluation criteria	**Project evaluation information**
1. Performance Risk	1. Removal rates based on less than 1 year of monitoring data from one source, but representative of Seattle area. 2. Seattle-specific pollutant removal rates available for almost all RCOCs. 3. Limited research documenting the correlation between pollutant removal and reduction in stormwater concentrations. Significant experience exists related to the treatment mechanism and maintenance needs. 4. Does not address some pollutants; single removal mechanism.
2. Flexibility	Technology is fixed and cannot be adapted to changing water quality standards.
3. Relationship with Other Agencies	Results in reduction of pollutants in stormwater from streets tributary to combined and partially separated sewers. Targets residential areas that carry less pollutants than industrial areas. Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. While the Duwamish Waterway, Lake Washington, Lake Union, and Puget Sound are high-priority water bodies, the project does not appear to provide much benefit to salmon recovery because it will not reduce flow or enhance or provide habitat. However, it will help eliminate contaminants in stormwater over a large area, which is a component of salmon recovery that is important to area tribes.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	Project will not manage flow. The project does not provide terrestrial habitat.
6. Construction Impacts (short-term)	No construction impacts.
7. Community Impacts (longer-term)	Not clear that project addresses current concern of particular neighborhood(s) but improves upon amenities used in a variety of neighborhoods; during sweeping high visibility around the city during day; outreach re: parking/moving cars provides education opportunity but may not be particularly culturally relevant; operation requires staff on site regularly but only when sweeper is active on particular residential street; traffic and noise could require mitigation; cleaner streets visible; longer-term benefits less visible.
8. Environmental/Social Justice	Improves water quality of waterways in underserved communities and contributes to efforts to protect current use. Daytime sweeping could be disruptive and affect public transportation, traffic, and parking for residents and businesses. Sweeping is loud and dusty.
9. Ease of O&M and Safety	Rating criteria not really applicable to stormwater. Does require operator, so more like active treatment than passive treatment, but sweeping done by SDOT crews. Assumed sweeper trucks require frequent maintenance. Work in ROW. Sweeper dust impacts pedestrians.

Table 2-3. Evaluation Criteria for Street Sweeping Expansion Arterials

Evaluation criteria	Project evaluation information
1. Performance Risk	1. Removal rates based on less than 1 year of monitoring data from one source, but representative of Seattle area. 2. Seattle-specific pollutant removal rates available for almost all RCOCs. 3. Limited research documenting the correlation between pollutant removal and reduction in stormwater concentrations. Significant experience exists related to the treatment mechanism and maintenance needs. 4. Does not address some pollutants; single removal mechanism.
2. Flexibility	Technology is fixed and cannot be adapted to changing water quality standards.
3. Relationship with Other Agencies	Results in reduction of pollutants in stormwater tributary to combined and partially separated areas. Targets industrial areas that are the most polluted categories. Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. While the Duwamish Waterway, Lake Washington, Lake Union, and Puget Sound are high-priority water bodies, it does not appear that the project will provide much benefit to salmon recovery because it will not reduce flow or enhance or provide habitat. However, it will help eliminate contaminants in stormwater over a large area, which is a component of salmon recovery that is important to area tribes.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	Project will not manage flow. The project does not provide terrestrial habitat.
6. Construction Impacts (short-term)	No construction impacts.
7. Community Impacts (longer-term)	May be less visible because sweeping occurs during night; may require less mitigation than the Street Sweeping Expansion Residential project because it occurs on the arterials; not clear that project addresses current concern of particular neighborhood(s) but improves upon amenities used in a variety of neighborhoods; outreach re: parking/moving cars provides education opportunity but may not be particularly culturally relevant; operation requires staff on site regularly but only when sweeper is active on particular arterial street; traffic and noise could require mitigation; cleaner streets visible; longer-term benefits less visible.
8. Environmental/Social Justice	Improves water quality of waterways in underserved communities and contributes to efforts to protect current use. Nighttime sweeping could minimize impact disruption on traffic. But will impact parking and/or create noise that could potentially be disruptive to residents in the area.
9. Ease of O&M and Safety	Rating criteria not really applicable to stormwater. Does require operator, so more like active treatment than passive treatment, but sweeping done by SDOT crews. Assumed sweeper trucks require frequent maintenance. Work in ROW. Sweeper dust impacts pedestrians.

Table 2-4. Evaluation Criteria for South Park WQ Facility

Evaluation criteria	Project evaluation information
1. Performance Risk	1. Removal rates available for some RCOCs from full-scale chitosan-enhanced sand filtration (CESF) at NBF; representative of Seattle area; consistent performance is expected with CESF. Where data not available, filled with fairly conservative assumptions. 2. Over half the RCOCs have data drawn from other sources, such as the International BMP database or professional judgment. 3. Removal mechanism well understood and documented. 4. Commitments to active maintenance protocol are implied in selecting a CESF; appears to address wide range of pollutants.
2. Flexibility	Coagulant type, dosing can be adjusted. Could add GAC to improve performance but that would increase costs substantially. Not affected by changes in rainfall, drought, temperature, etc. Can add additional treatment technology onto facility if needed.
3. Relationship with Other Agencies	• Project addresses localized flooding in an area of both separate sewers and partially separated sewers and treatment of stormwater prior to discharge to the Duwamish Waterway. Benefits to King County are reduction in potential inflow as a result of better flood protection and removal of pollutants from the Duwamish Waterway, a high-priority water body for King County. • Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. The Duwamish Waterway is a high-priority water body. Although it does not appear that the project will provide much benefit to salmon recovery because it will not reduce flow or enhance or provide habitat, it will treat contaminants in stormwater, which is a component of salmon recovery that is important to area tribes, particularly in the Lower Duwamish Waterway because it provides important rearing and osmoregulation habitat for salmonids.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	Project will not manage flow. Project includes landscaping/native vegetation along shoreline.
6. Construction Impacts (short-term)	Most work will be outside ROW. Small amount along S Riverside Drive and 7th Avenue S road end. But >6 months and lots of truck traffic.
7. Community Impacts (longer-term)	Minimal staff visits facility; provides lasting benefits to users of the Duwamish Waterway; partially visible but no public access to facility; facility located in commercial/industrial areas; no particular education opportunity.
8. Environmental/Social Justice	Above ground. Improves water quality in an underserved community and contributes to efforts to protect current use by the community. Located in heavily impacted area. Concerns with impact on traffic and disruption to businesses, residents, and commuters in nearby neighborhoods. Construction will be during daylight hours and is expected to be long and loud.
9. Ease of O&M and Safety	• Assume operations contracted out and remote operation likely (e.g., CESF). • Assume frequent maintenance for solids handling. • All work outside of ROW in secure/industrial location.

Table 2-5. Evaluation Criteria for NDS Partnering

Evaluation criteria	Project evaluation information
1. Performance Risk	1. International BMP database effluent concentration was used based on the results of at least three studies, each with at least three data points. 2. International BMP database data available for approximately 2/3 of RCOCs, supplemented with unit process/chemical properties understanding for remaining. 3. Non-proprietary vegetated system; performance and maintenance needed of individual designs are a function of design decisions and media properties; performance and maintenance understood to a somewhat lesser degree than proprietary systems. 4. Addresses wide range of RCOCs via various treatment mechanisms and volume reduction. Well-designed vegetated system can be self-sustaining between maintenance cycles.
2. Flexibility	Changes in rainfall, drought, and temperature could stress plants and require more frequent weeding and/or plant replacement. Changing filter media in existing facilities would require excavation and replanting. Could add downstream treatment (e.g., media filter, pond) if suitable sites and sufficient funds are available. Can adapt by changing media in bioretention.
3. Relationship with Other Agencies	• The installation of bioswales will attenuate peak flows as well as remove pollutants. The benefit to King County will be a function of the actual location of the installed swales. King County is supportive of the use of bioretention swales. • Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. The projects will provide benefit to salmon recovery because they will reduce flow, which will enhance or provide habitat in mainstem water bodies to these tributaries. The swales will also provide terrestrial habitat and additional pervious areas along developed and paved streets. Piper's Creek, Thornton Creek, and Longfellow Creek are not high-priority water bodies for ESA-listed species but they are tributaries flowing into high-priority water bodies.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	Project will reduce flow over a fairly large area and provide terrestrial habitat.
6. Construction Impacts (short-term)	Same for all NDS Partnering projects. Impacts ROW in high-density residential area; however, short construction period.
7. Community Impacts (longer-term)	High visibility in a variety of neighborhoods right in front of homes and businesses; opportunity for education that is culturally relevant; notable positive lasting benefits for residents.
8. Environmental/Social Justice	Dependent on feasibility of project site. Impacts/benefits on historically underserved communities vary depending on which neighborhood is selected. Sites of high community acceptance may not be communities with high percentages of underserved populations.
9. Ease of O&M and Safety	• Totally passive, no operational requirements. • The City typically maintains vegetation four times per year. • Used same rank for all NDS Partnering projects. Project in ROW, accessible to public.

Table 2-6. Evaluation Criteria for SW Hinds SD StormFilter Vault

Evaluation criteria	Project evaluation information
1. Performance Risk	1. International BMP database effluent concentration was used based on the results of at least three studies, each with at least three data points. 2. International BMP database data available for approximately 2/3 of RCOCs, supplemented with unit process/chemical properties understanding for remaining. 3. Proprietary filter device, method of removal well understood and documented. 4. Known performance.
2. Flexibility	Could increase maintenance frequency to reduce clogging/bypass. Manufacturer is not conducting research and development (R/D) on new media for filters so flexibility is limited.
3. Relationship with Other Agencies	• The project will not impact flows to King County. It will reduce pollutant discharged to 190 acres tributary to the Duwamish Waterway, a high-priority water body for the King County. • Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. While the Duwamish Waterway is a high-priority water body, it does not appear that the project will provide much benefit to salmon recovery because it will not reduce flow or enhance or provide habitat.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	Project will not manage flow. The project does not provide terrestrial habitat.
6. Construction Impacts (short-term)	Vault in a parking lot in an industrial area. Only one business impacted.
7. Community Impacts (longer-term)	Below ground: limited visibility; some opportunities for educational signage; regular maintenance on site required in area where people shop and live; long-term benefit but may not address particular neighborhood concerns.
8. Environmental/Social Justice	Below ground. Impact on traffic and parking and disruption to residents and businesses are short-term. Project provides benefits to historically underserved communities.
9. Ease of O&M and Safety	• Totally passive, no operational requirements. • Maintenance requirements uncertain. The City has found these can clog frequently. Manufacturer typically underestimates maintenance needs. • All work outside of ROW in secure location. Confined space requirements.

Table 2-7. Evaluation Criteria for South Myrtle St. Shoulder Stabilization

Evaluation criteria	Project evaluation information
1. Performance Risk	1. International BMP database effluent concentration was used based on the results of at least three studies, each with at least three data points. 2. International BMP database data available for approximately 2/3 of RCOCs, supplemented with unit process/chemical properties understanding for remaining. 3. Non-proprietary vegetated system; performance and maintenance needed of individual designs are a function of design decisions and media properties; performance and maintenance understood to a somewhat lesser degree than proprietary systems. 4. Provides less diverse treatment mechanisms than bioretention; does not treat some constituents; Well-designed vegetated system can be self-sustaining between maintenance cycles.
2. Flexibility	Cannot be modified easily. Not affected by changes in rainfall, drought, temperature, etc.
3. Relationship with Other Agencies	• The project will not impact flows and loadings to King County. It will reduce pollutants discharged to the Duwamish Waterway, a high-priority water body for the King County. • Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. The project will provide benefit to salmon recovery because it will reduce flow, which will enhance or provide habitat in a high-priority mainstem water body. The swale will also provide terrestrial habitat and additional pervious area along developed and paved streets. However, this is a small area of treatment compared to the larger area of the Duwamish Waterway.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	While the project will reduce flow, the Duwamish Waterway is not a flow-impacted water body. The terrestrial habitat that will be provided is a small footprint. Treats a small amount of flow.
6. Construction Impacts (short-term)	Impacts ROW in an industrial area; however, short construction period.
7. Community Impacts (longer-term)	Visible but located on dead-end street in area where people visiting or seeking it out is low; minimal staff will be present infrequently; project alleviates current concern and will have notable positive lasting benefit.
8. Environmental/Social Justice	Project site is in an isolated area. Minimal impact to residents. Project provides benefits to historically underserved communities.
9. Ease of O&M and Safety	• Totally passive, no operational requirements. • Biofiltration swale pretty straightforward maintenance. The larger question is, will the City actually maintain? • Swale in ROW, but physical barrier between road and swale. Industrial location. Not much public use.

Table 2-8. Evaluation Criteria for Piper's Cascades

Evaluation criteria	Project evaluation information
1. Performance Risk	1. International BMP database effluent concentration was used based on the results of at least three studies, each with at least three data points. 2. International BMP database data available for approximately 2/3 of RCOCs, supplemented with unit process/chemical properties understanding for remaining. 3. Non-proprietary vegetated system; performance and maintenance needed of individual designs are a function of design decisions and media properties; performance and maintenance understood to a somewhat lesser degree than proprietary systems. 4. Addresses wide range of RCOCs via various treatment mechanisms and volume reduction. Well-designed vegetated system can be self-sustaining between maintenance cycles.
2. Flexibility	Changes in rainfall, drought, and temperature could stress plants and require more frequent weeding and/or plant replacement. Changing filter media would require excavation and replanting. Could add downstream treatment (e.g., media filter, pond) if suitable sites and sufficient funds are available. Can adapt by changing media in bioretention.
3. Relationship with Other Agencies	• The project is a nominally separated area with high levels of infiltration and inflow (I/I) that are discharged to King County's Carkeek Park pump station (PS) and wastewater treatment facility (WWTF). Project could potentially modify groundwater flow and coincident rates of I/I. • Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. The project will provide benefit to salmon recovery because it will reduce flow, which will enhance or provide habitat in mainstem water bodies to these tributaries. The swales will also provide terrestrial habitat and additional pervious areas along developed and paved streets. Piper's Creek is not a high-priority water body for ESA-listed species, but it is a tributary to a high-priority water body.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	Project will reduce flow over a large area and provide terrestrial habitat.
6. Construction Impacts (short-term)	Impacts ROW in high-density residential area; however, short construction period.
7. Community Impacts (longer-term)	High visibility; high opportunity for education that is culturally relevant; high visibility in a variety of neighborhoods right in front of homes and businesses; notable positive lasting benefits for residents.
8. Environmental/Social Justice	Dependent on feasibility of project site. Impacts/benefits on historically underserved communities vary depending on which neighborhood is selected. Smaller percentage of people from underserved communities residing in project site.
9. Ease of O&M and Safety	• Totally passive, no operational requirements. • The City typically maintains vegetation four times per year. • Project in ROW, accessible to public.

Table 2-9. Evaluation Criteria for Longfellow Cascades

Evaluation criteria	Project evaluation information
1. Performance Risk	1. International BMP database effluent concentration was used based on the results of at least three studies, each with at least three data points. 2. International BMP database data available for approximately 2/3 of RCOCs, supplemented with unit process/chemical properties understanding for remaining. 3. Non-proprietary vegetated system; performance and maintenance needed of individual designs are a function of design decisions and media properties; performance and maintenance understood to a somewhat lesser degree than proprietary systems. 4. Addresses wide range of RCOCs via various treatment mechanisms and volume reduction. Well-designed vegetated system can be self-sustaining between maintenance cycles.
2. Flexibility	Changes in rainfall, drought, and temperature could stress plants and require more frequent weeding and/or plant replacement. Changing filter media would require excavation and replanting. Could add downstream treatment (e.g., media filter, pond) if suitable sites and sufficient funds are available. Can adapt by changing media in bioretention.
3. Relationship with Other Agencies	• The project is located in a combined/partially separated area. The facility will reduce peak flows and reduces pollutants. • Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. The project will provide benefit to salmon recovery because it will reduce flow, which will enhance or provide habitat in mainstem water bodies to these tributaries. The swales will also provide terrestrial habitat and additional pervious areas along developed and paved streets. Longfellow Creek is not a high-priority water body for ESA-listed species, but it is a tributary to a high-priority water body.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	Project will reduce flow and provide terrestrial habitat. However, the project footprint is fairly small.
6. Construction Impacts (short-term)	Impacts ROW in high-density residential area; however, short construction period.
7. Community Impacts (longer-term)	High visibility; high opportunity for education that is culturally relevant; high visibility in a variety of neighborhoods right in front of homes and businesses; notable positive lasting benefits for residents.
8. Environmental/Social Justice	Dependent on feasibility of project site. Impacts/benefits on historically underserved communities vary depending on which neighborhood is selected. Sites of high community acceptance may not be communities with high percentages of underserved populations.
9. Ease of O&M and Safety	• Totally passive, no operational requirements. • The City typically maintains vegetation four times per year. • Project in ROW, accessible to public.

Table 2-10. Evaluation Criteria for South Myrtle St. StormFilter Vault

Evaluation criteria	Project evaluation information
1. Performance Risk	1. International BMP database effluent concentration was used based on the results of at least three studies, each with at least three data points. 2. International BMP database data available for approximately 2/3 of RCOCs, supplemented with unit process/chemical properties understanding for remaining. 3. Proprietary filter device, method of removal well understood and documented. 4. Known performance.
2. Flexibility	Could increase maintenance frequency to reduce clogging/bypass. Manufacturer is not conducting R/D on new media for filters so flexibility is limited.
3. Relationship with Other Agencies	• This provides treatment to a small industrial area prior to discharge to the Duwamish Waterway, a King County high-priority water body. • Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. While the Duwamish Waterway is a high-priority water body, it does not appear that the project will provide much benefit to salmon recovery because it will not reduce flow or enhance or provide habitat.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	Project will not manage flow. The project does not provide terrestrial habitat.
6. Construction Impacts (short-term)	Vault on cul-de-sac in industrial area. Only one business impacted.
7. Community Impacts (longer-term)	Below ground: limited visibility; some opportunities for educational signage; regular maintenance on site required in area where people shop and live; long-term benefit but may not address particular neighborhood concerns.
8. Environmental/Social Justice	Below ground. Impact on traffic and parking and disruption to residents and businesses are short-term. Project provides benefits to historically underserved communities.
9. Ease of O&M and Safety	• Totally passive, no operational requirements. • Maintenance requirements uncertain. The City has found these can clog frequently. Manufacturer typically underestimates maintenance needs. • All work outside of ROW in secure location. Confined space requirements.

Table 2-11. Evaluation Criteria for U Village Filterras

Evaluation criteria	Project evaluation information
1. Performance Risk	1. International BMP database effluent concentration was used based on the results of at least three studies, each with at least three data points. 2. International BMP database data available for approximately 2/3 of RCOCs, supplemented with unit process/chemical properties understanding for remaining. 3. Proprietary filter device, method of removal well understood and documented. 4. Known performance.
2. Flexibility	Changes in rainfall, drought, and temperature could stress plants. Could increase mulch maintenance frequency to reduce clogging/bypass. However, changing media in existing facilitates would require excavation and replanting.
3. Relationship with Other Agencies	• Project targets treatment of roadway runoff in a partially separated area with eventual discharge to Portage Bay. • Project will not create additional risks to the tribes' salmon recovery plans and natural resource protection goals. While Lake Union is a high-priority water body, it does not appear that the project will provide much benefit to salmon recovery because it will not reduce flow or enhance or provide habitat.
4. Water Quality	Water quality score was calculated using the relevant water quality criteria.
5. Other Positive Environmental Outcomes	Project will not manage flow. However, the project provides a small amount of terrestrial habitat.
6. Construction Impacts (short-term)	Impacts ROW of a high-traffic arterial with a bus route; however, short construction period.
7. Community Impacts (longer-term)	Highly visible; provides education opportunity; minimal staff will be present infrequently; notable positive lasting benefit for residents; improves upon existing neighborhood conditions.
8. Environmental/Social Justice	Treatment facility is below ground. Selected site will be dependent on feasibility of project site. Impact on traffic and parking and disruption to residents and businesses are short-term. Project provides benefits to populations who are historically underserved.
9. Ease of O&M and Safety	• Totally passive, no operational requirements. • All work in ROW in secure location.

2.3 Develop Measurement Scales and Assign Draft Scores

A measurement scale describes the extent to which a project meets each evaluation criterion. The Integrated Plan team developed measurement scales of 1 to 5 for each criterion (except water quality). The worst potential outcome was given a score of 1 and the best possible outcome was given a score of 5. For the water quality criterion, the score was calculated based on the Pre-project concentration, Post-project load reductions, and applicable water quality criteria. The measurement scales and scoring for each of the nine criteria are described below.

Criterion 1. Performance Risk

Description. How flexible is the project in terms of responding to varying flow and pollutant characteristics above and below the project location?

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
• High confidence: Monitoring data available to document system performance (e.g., Technology Assessment Protocol – Ecology [TAPE] or other comparable program) for most Consent Decree parameters under varying flow and quality conditions • Project performance can be easily measured (e.g., inlet/outlet monitoring) • Treatment mechanisms and maintenance needs are well understood and documented	• Medium confidence: Monitoring data available (e.g., TAPE or other comparable program) for typical stormwater pollutants (conventionals and metals) under varying flow and quality conditions • Technology has been tested and used in other stormwater or other wet weather applications • Treatment mechanisms and maintenance needs well understood	• Low confidence: Minimal or conflicting data available on technology performance • Technology has been tested, but not widely used in stormwater or other wet weather applications • Treatment mechanisms and maintenance needs understood, but not well documented • Project performance not easily measured (e.g., disperse systems)

Criterion 2. Flexibility

Description. What are the intervention opportunities to address under-performance, changes in rainfall patterns, and/or increases in temperature and drought situations?

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
Can be easily modified to meet potential future regulatory requirements or changes in CSO/stormwater quality with low capital expenditure	Can be modified to meet potential future regulatory requirements or changes in CSO/stormwater quality with additional treatment train and/or modifications to filter media	Cannot be modified, requires rebuild to meet future regulatory requirements or changes in CSO/stormwater quality

Criterion 3. Relationship with Other Agencies

Description. To what extent does the project enhance long-term relationships with Puget Sound area tribes and King County Water Treatment Division (WTD)? The score for this criterion was the average of the scores given for the two sub-criteria that follow.

Relationship with the Tribes

Description. Enhances long-term relationships with Puget Sound area tribes.

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
Supports and enhances Puget Sound area tribes' salmon recovery plans and natural resource protection goals	Does not create additional risks to Puget Sound area tribes' salmon recovery plans and natural resource protection goals	Creates additional risks to Puget Sound area tribes' salmon recovery plans and natural resource protection goals

Relationship with King County

Description. Enhances long-term relationship with King County WTD.

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
Reduces hydraulic and/or pollutant loading to WTD system; does not require special operation of WTD facilities: reduces risk on achieving permit compliance	No change on loading to WTD; no additional risks on WTD facility performance or permit compliance	Increases hydraulic and/or pollutant loading to WTD system; requires additional operational commitment from WTD; has potential to impact permit compliance

Criterion 4. Water Quality

Description. To what extent does the candidate project contribute water quality benefits beyond those that would be achieved by the deferred LTCP projects? The project score for this criterion was determined in the following manner.

For each RCOC, a weight was calculated as the ratio of the Pre-project concentration to the water quality criteria:

$$Weight_{RCOC} = \frac{Pre\text{-}project\ concentration_{RCOC}}{Water\ quality\ criteria_{RCOC}}$$

The water quality criterion used was either marine or fresh water, based on the receiving water body of the project. PCBs has two criteria: ecological and human health. The PCBs criterion used to calculate the weight was based on human health because it is more conservative (i.e. lower).

Next, the load reduction for each RCOC was normalized to the largest candidate LTCP project (CSO Outfall 107):

$$Normalized\ load\ reduction_{RCOC} = \frac{Load\ reduction\ project_{RCOC}}{Load\ reduction\ \mathrm{CSO\ Outfall\ 107}_{RCOC}}$$

For each RCOC, the weight was multiplied by the normalized load reduction, and then summed to provide the project water quality score.

$$Water\ quality\ score_{project} = \sum (weight * normalized\ load\ reduction)_{RCOC}$$

Criterion 5. Other Positive Environmental Features

Description. Does the project help meet the City's Green Goal by reducing stream flow rates, and/or does the project add green space and habitat?

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
• Project reduces flow/volume to a flow-impacted water body • Project provides substantive terrestrial habitat	• Project reduces flow/volume to a flow-impacted water body • Project does not provide terrestrial habitat	• Project will not manage flow • Project does not provide terrestrial habitat

Criterion 6. Construction Impacts (Short-Term)

Description. What level of disruption will occur during project construction?

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
Construction impacts will be relatively minor compared to other major City infrastructure projects. Impacts are generally consistent with the following: • Project is located in lightly populated area and will affect a small number of businesses/residents (1–5) • Project is located far from residents and no asthma or health impacts are likely • Project will have low neighborhood intensity • Project is located on a low traffic street • Construction activities involve minor excavation and disruption to streets and adjacent properties • Construction will last less than 3 months	Construction impacts will be similar to other major City infrastructure projects. Impacts are generally consistent with the following: • Project is located in lightly populated area and will affect a small number of businesses/residents (6–15) • Some actions are necessary to mitigate the potential for asthma or health impacts • Project will have moderate neighborhood intensity • Project is located on an arterial, but not a major transportation corridor • Construction activities involve significant excavation and disruption to streets and adjacent properties • Construction will last 3–6 months	Construction impacts will be similar to many other major City infrastructure projects. Impacts are generally consistent with the following: • Project is located in a densely populated area and will affect more than 15 businesses/residents (>15) • The potential for asthma or health impacts cannot be mitigated completely • Project will have high neighborhood intensity • Project is located on an arterial that serves as a major transportation corridor • Heavy construction activities will occur such as heavy excavation, heavy equipment use, pile driving, and disruption to streets and adjacent properties • Construction will last more than 6 months

Criterion 7. Community Impacts (Longer-Term)

Description. What lasting impact will the project and its O&M activities have on the neighborhood, either positive (culturally relevant, sidewalks, water access, bike paths, traffic calming, visual appeal), or negative (odor, noise, visual). Note: This is not meant to include construction impacts. This project supports (visual) connection to a water system, citizen stewardship of a project or facility, and/or formal education.

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
• Facility is compatible with and culturally relevant to the surrounding community and minimal staff will be present infrequently • Completed project or ongoing program alleviates a current concern of residents or will have a notable positive lasting benefit for residents and/or visitors to the site • Project is visible and provides a strong opportunity for education that is culturally relevant	• Facility and grounds can be designed to screen facility, and minimal staff visits are necessary • Traffic, odor, and noise from the facility would require mitigation to be acceptable to the community • Project does not alleviate a current concern but improves upon existing neighborhood conditions • Project is visible and may provide some opportunity for education, but it will not be achieved readily and/or the opportunity may not be particularly culturally relevant	• Facility will impact the community negatively and there would be staff on site regularly • Traffic odor and noise from the facility would require significant mitigation to be acceptable to the community • No significant improvement to amenities desired by the neighborhood • Project is hidden from view and provides no particular opportunity for education

Criterion 8. Environmental/Social Justice

Description. Who and where? Will the location of the project address the historical inequity (e.g., address problems that were historically “underreported”)? Will the project protect a current use by a socioeconomic class (e.g., fishing in Duwamish/Green Lake)? Will facility siting affect an already heavily impacted area (e.g., South Park has a transfer station)?

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
• Alternative provides substantial culturally relevant benefits to historically underrepresented and low-income populations • Project will not add to ongoing negative effects to an area already heavily impacted	• Alternative provides some culturally relevant benefits to historically underrepresented and low-income populations • Project has the potential to provide some ongoing negative effects to an area already heavily impacted, but those effects can be mitigated effectively	• Alternative provides no culturally relevant benefits to historically underrepresented and low-income populations • Project likely to provide some ongoing negative effects that cannot be mitigated effectively to an area already heavily impacted

Criterion 9. Ease of O&M and Safety

The score for this criterion was the average of the scores given for the three sub-criteria that follow (operations, maintenance, and safety).

Operations (9a)

Description. Beyond any cost implications, what are the implications for City staff to operate the system assuming that adequate resources are available?

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
• Passive system, no crew required to operate	• Active treatment/operations, can be remotely operated, onsite operator(s) not required • Vendor service contract available for operation • City crews can be trained easily	• Active treatment/operations, onsite operator(s) required • No vendor service available • City crews need specialized training or certifications

Maintenance (9b)

Description. Beyond any cost implications, what are the implications for City staff to maintain the system assuming that adequate resources are available?

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
• Maintenance requirements/frequency well established and consistent with City standard practices (e.g., one–two times per year) • Quarterly inspections • Requires no special skills, knowledge, or equipment for City crews to maintain	• Maintenance requirements/frequency not well established, but on the order of requiring maintenance two–four times per year • Monthly inspections • Requires special equipment	• Requires maintenance more than two times per year • Requires special equipment, skills, training, or licensing and/or heavy lifting or intense physical labor • Requires inspections more frequent than monthly • Large underground structure requiring regular structural inspections (e.g., every 5 years)

Safety to City Staff and Public (9c)

Description. Assuming that safety and security are addressed appropriately during design, what safety concerns remain?

Measurement Scale. Constructed scale, 5 is best outcome; 1 is worst outcome.

Best = 5	Medium = 3	Worst = 1
Project would result in few safety concerns that would need to be mitigated. At least two of the following exist: • Outside ROW or does not require traffic control/flagging to access • No confined-space entry to operate or maintain • Little potential for inadvertent contact by public	Project would result in some safety concerns that would need to be mitigated. One or more of the following exists: • Facility located in ROW and traffic control/flagging needed, but no police support • Confined-space entry may be required, but not for routine maintenance • Few public safety areas in relatively low use area or; can be designed to minimize risk (e.g., short ponding duration to minimize mosquito concerns; vegetation selected to minimize public access, e.g., NW 110th Cascades system)	Project would result in many safety concerns that would need to be mitigated. Two or more of the following exists: • Facility located in ROW and traffic control/flagger/police support required • Confined-space entry required for routine operations • Some public safety concerns: Project located in high-use area (e.g., residential neighborhood) or attractive nuisance concerns (e.g., biofiltration swale/biological removal cells that encourage access) and community has expressed concerns about safety (e.g., drowning hazard from stormwater ponding)

2.4 Assign Draft Scores

The Integrated Plan team assigned scores using the 1–5 measurement scale for each criterion except water quality. Scores for each criterion were assigned based on each team member's knowledge of the project. For water quality, a measurement scale was not used to develop the score. The score was determined based on the Pre-project concentration of each RCOC, the water quality criterion for that RCOC, and the project load reduction.

The scoring process did not always result in one project with a score of 1 and one with a score of 5 because some criteria did not vary appreciably among the projects. Many projects have scores clustered around the midpoint of the range (i.e., scores of 3). Table 2-12 shows the MODA scores for the candidate stormwater projects.

Table 2-12. MODA Scores for Integrated Plan Alternative Projects

Evaluation criteria	Street Sweeping Residential[a]	Street Sweeping Arterials[a]	South Park WQ Facility	NDS Partnering	SW Hinds St. SD StormFilter Vault	South Myrtle St. Shoulder Stabilization	Piper's Cascades	Longfellow Cascades	South Myrtle St. StormFilter Vault	U Village Filterras
1. Performance Risk	3.5	3.5	4.0	4.0	4.0	3.5	4.0	4.0	4.0	4.0
2. Flexibility	3.0	3.0	3.5	3.5	2.0	1.0	3.5	3.5	2.0	2.0
3. Relationship with Other Agencies	4.0	4.5	4.5	4.5	3.0	4.0	4.0	4.0	3.5	3.0
4. Water Quality	17,135	20,800	28,687	4,307	9,093	343	2,410	1,458	3,527	372
5. Other Positive Environmental Outcomes	1.0	1.0	1.5	5.0	1.0	3.0	5.0	4.5	1.0	1.5
6. Construction Impacts (Short-Term)	5.0	5.0	3.0	3.0	4.0	4.0	3.0	3.0	4.0	4.0
7. Community Impacts (Long-Term)	2.0	2.0	2.0	5.0	2.5	2.5	5.0	5.0	2.5	4.5
8. Environmental/Social Justice	2.5	3.0	3.0	3.0	3.5	3.5	3.0	3.5	3.5	3.5
9. Ease of O&M and Safety	3.5	3.5	3.0	3.5	3.0	4.5	3.5	3.5	3.0	4.5

a. *The street sweeping technology used to reduce the stormwater pollutant load was developed to address air quality, specifically the reduction of fine fugitive dust from roadways. The street sweeping for water quality program sweepers are PM10-certified, meaning that they are capable of collecting and holding particulate matter sized less than 10 µm. The South Coast Air Quality Management District, a leader in the nation's efforts to reduce air pollution emissions, developed the certification process. When operating as designed, there will be no visible dust. See http://www.aqmd.gov/rules/siprules/sr1186.pdf for additional information.*

2.5 Establish Relative Weights

Relative value weights are subjective expressions of the relative value of each criterion within the context of the decision being made. This leads to the concept of swing weighting (as described in SMARTS), in which a trained facilitator helps groups consider the relative importance of each criterion and the extent to which each criterion varies among projects when establishing weights.

Weights were determined at an Integrated Plan team meeting where a trained facilitator led City senior managers using a modified Delphi process in which managers provided weights, the weights were shown to the group, and the differences were discussed. Weights were assigned based on the relative importance of the criterion and the extent to which the scores for the criterion varied among the candidate projects. The discussion resulted in a consensus set of weights that were used in the evaluation. Table 2-13 presents the consensus weights used for the MODA evaluation of the candidate stormwater projects. The water quality criterion was given the greatest weight.

Table 2-13. Criteria Weights

Evaluation criterion	Relative value weight	Percent of total
1. Performance risk	18	10%
2. Flexibility	12	7%
3. Relationship with other agencies	4	2%
4. Water quality	100	54%
5. Other positive environmental outcomes	8	4%
6. Construction impacts (short-term)	8	4%
7. Community impacts (longer-term)	8	4%
8. Environmental/social justice	8	4%
9. Ease of O&M and safety	18	10%

2.6 MODA Results

All scores were normalized to a 0–1 scale using linear transformation. The normalized scores were multiplied by the relative value weight for each criterion, then multiplied by 100 (a scalar for presentation), and summed over all criteria, resulting in a total value score for each project. As typically conducted at the City, cost was not a weighted parameter. The City and its advisor’s experience with weighting has demonstrated that technical staff are typically not comfortable (or skilled) at making explicit tradeoffs between cost and non-monetary criteria. Cost is addressed by comparing non-monetary value against cost in a value-cost tradeoff analysis.

The results of the analysis for the evaluated projects are summarized in Table 2-14, which shows the total score for each project and the project rank. The results of the analysis are also shown on Figure 2-1 as a stacked bar chart where each bar represents the contribution to the score from each criterion. As shown, the South Park WQ Facility provides the highest overall non-monetary value. Water quality and performance risk impacts contributed the most value to the South Park WQ Facility project. The two street sweeping projects provided the next-highest overall value. Their overall value score was also dominated by its performance on the water quality criterion.

Table 2-14. MODA Results

Candidate project/program	Total score	Rank
South Park WQ Facility	79	1
Street Sweeping Expansion Arterials	64	2
Street Sweeping Expansion Residential	57	3
NDS Partnering	41	4
SW Hinds SD StormFilter Vault	40	5
Piper’s Cascades	37	6
Longfellow Cascades	35	7
U Village Filterras	30	8
South Myrtle St. StormFilter Vault	30	9
South Myrtle St. Shoulder Stabilization	27	10

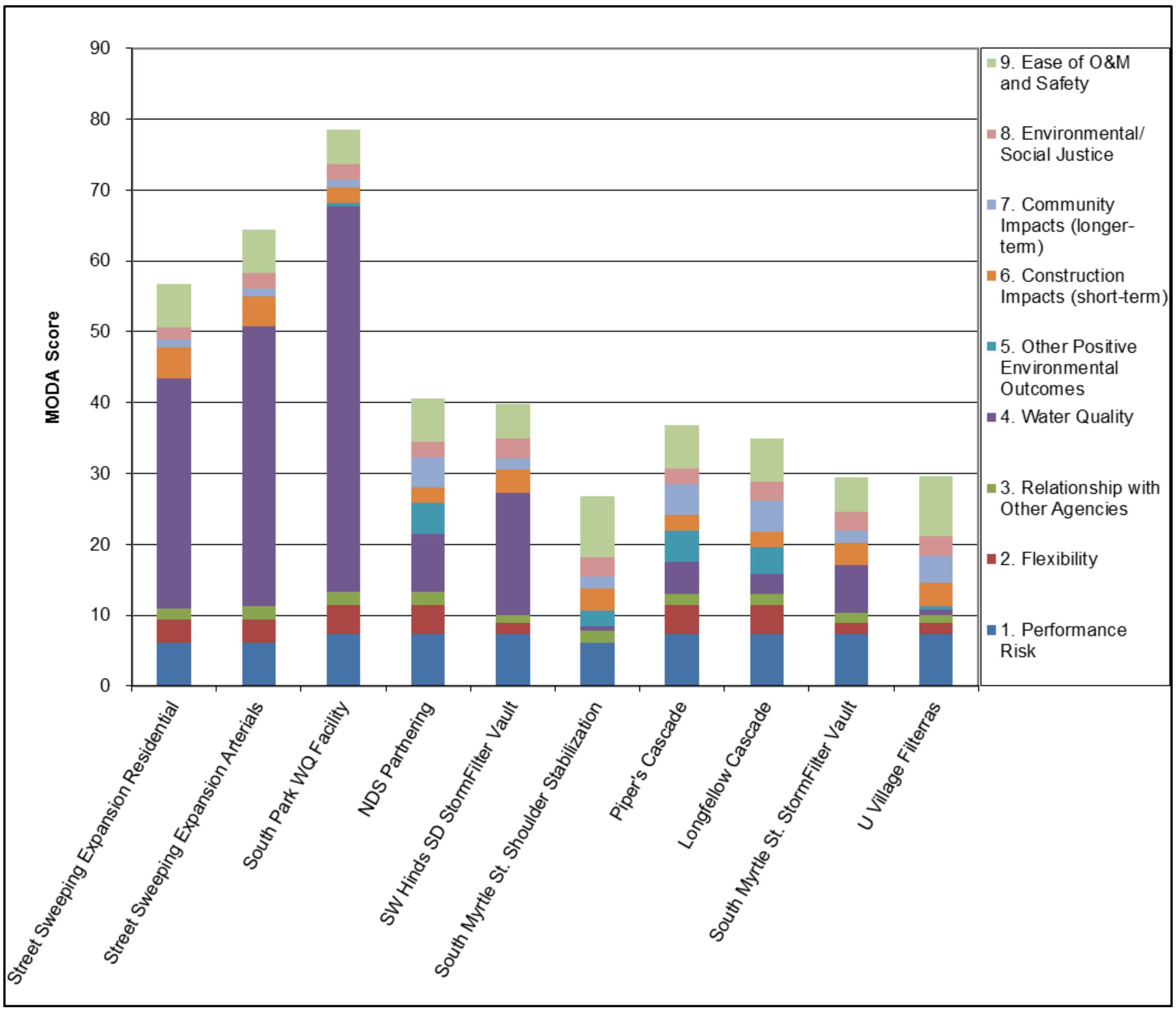

Figure 2-1. MODA results

2.7 Sensitivity Analysis

A sensitivity analysis was conducted to provide additional insight for decision making. The sensitivity analysis involved varying the criteria weights, recalculating the project score, and comparing the results. The City reviewed the results of the sensitivity analysis and decided that the MODA scores did not need to be adjusted.

CHAPTER 3

References

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Appendix J: Stormwater Project Fact Sheets

Seattle Public Utilities

Protecting Seattle's Waterways

Volume 3 – Integrated Plan

Appendix J: STORMWATER PROJECT FACT SHEETS

Final

May 29, 2015

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NDS Partnering

Project name	NDS Partnering
Project type	Green stormwater infrastructure (GSI): bioretention with routing to infiltration
Objective	Reduce geomorphically significant flows and loads of polychlorinated biphenyls (PCBs), metals, bacteria, and other pollutants to Longfellow, Piper's and Thornton creeks
Description	The Natural Drainage Systems (NDS) Partnering project entails using bioretention (i.e., engineered rain gardens), the most commonly used GSI management practice, within various basins that drain to Longfellow, Piper's and Thornton creeks. This project would entail modifications to 4 miles of rights-of-way to manage flow and provide water quality treatment for polluted urban runoff. Projects would be designed to infiltrate into native soil where appropriate. Where complete reliance on infiltration is technically infeasible, systems would be augmented with underdrains. The "partnering" aspect of the program relates to how the project sites will be selected. NDS Partnering project sites comprise only 4 percent of the potentially feasible residential streets within the watersheds, allowing significant flexibility in project site selection. The site selection approach will involve information exchange with neighborhood groups and other public agencies about the program, and selection of project sites based on input from these groups.
Location	The project is located in three areas of the city: the Longfellow Creek drainage basin in West Seattle, the Piper's Creek drainage basin in northwest Seattle, and the Thornton Creek drainage basin in northeast Seattle. See Figures J-1 through J-3 for project locations and receiving water bodies.
Tributary area	City rights-of-way within Longfellow, Piper's and Thornton creeks have a combined impervious area of more than 1,200 acres within the fully separated portions of their watersheds. Adjacent parcels also direct runoff to these rights-of-way. In total, runoff from more than 2,200 acres of currently unmanaged impervious surfaces is directed from rights-of-way to Longfellow, Piper's and Thornton creeks. GSI approaches within these rights-of-way have the potential to manage polluted runoff from more than 1,100 acres.

Watershed	Available impervious area for GSI, acres	Tributary area to NDS Partnering GSI	
		Impervious, acres	Total (impervious and pervious), acres
Longfellow Creek	150	6.5	557
Piper's Creek	215	7.5	160
Thornton Creek	745	30	2,703
Total	**1,110**	**44**	**3,420**

Project name	NDS Partnering
Basis of design/assumptions	*Site Characteristics* GIS data were used to exclude potentially unsuitable areas within each watershed, identified based on the following criteria: • Areas already mitigated by previous GSI projects • Street slope >7% • Low infiltration potential: areas where infiltration likely not feasible due to high groundwater or shallow bedrock • Steep slopes, steep slope buffer, or known landslide potential • Known contaminated soils The remaining areas of each watershed were identified as potentially feasible for bioretention. Most blocks deemed potentially feasible for bioretention are in areas with informal drainage systems (i.e., lacking curbs and gutters). *Site Constraints* Due to the large number of potential NDS project sites, sites were not visited as part of the Integrated Plan development. Site constraints have not been identified. *Basis of Design* Bioretention will be sized to capture 80% of the average annual runoff volume generated from the tributary area. It was assumed that 50% of the runoff volume captured by the NDS Partnering facilities will infiltrate into native soil beneath the facilities while the remainder will be collected in underdrains. The underdrains will collect the portion of the treated stormwater that does not infiltrate and convey it to a City stormwater conveyance system or underground injection control (UIC) structure. *Project Elements* One of two types of template blocks will be constructed at each project site: dispersed block and full right-of-way reconstruction. A dispersed block template includes minor conveyance upgrades along the block, one sidewalk, and installation of a bioretention system. • Bioretention system sizing: Capture 80% average annual volume • Average sizing factor: 4% • Assumed street length: 600 linear feet • Impervious area to be managed: 39,000 square feet • Bioretention bottom area: 1,560 square feet • Conveyance improvements: 350 linear feet • Sidewalk: Constructed on one side of the street • Project streets constructed with this template: 27 • Project streets needing underdrains: 13.5 • Underground Injection Controls (UIC): None A right-of-way reconstruction template includes conveyance upgrades along a full block, one sidewalk, and installation of a bioretention system. • Bioretention system sizing: Capture 80% average annual volume • Average sizing factor: 2.6% • Assumed street length: 600 linear feet • Impervious area to be managed: 101,400 square feet (2.6 upstream blocks) • Bioretention bottom area: 2,640 square feet • Conveyance improvements: 600 linear feet • Sidewalk: Constructed on one side of the street • Project streets constructed with this template: 6 • Project streets needing underdrains: 3 • UICs: 6 • UIC depth: 60 to 90 feet

Project name	NDS Partnering
Recommended predesign refinements	Prior to design, the following should be completed: • Identify blocks that are potentially feasible for bioretention • Perform community outreach to encourage residents to nominate blocks as candidates for NDS and determine community goals (mobility, traffic calming, and beautification) • Prioritize project locations based on stormwater goals, including ability to manage flow from upstream blocks and space available for bioretention cells (including identification of right-of-way area and setback requirements) • Develop concept design block, based on community engagement and technical considerations, including geotechnical analysis (i.e., infiltration testing, depth to groundwater and hydraulic restrictive layer, evaluation of adjacent slopes and structures)
Average volume of water treated or reduced	35 million gallons per year; -NDS Partnering-Longfellow Creek: 5.4 MG/yr -NDS Partnering-Piper's Creek: 6.2 MG/yr -NDS Partnering-Thornton Creek: 23.9 MG/yr

Loads reduction

Longfellow Creek Annual Loads Reduction			
RCOC	**Lower confidence limits**	**Mean**	**Upper confidence limits**
PCBs (kg/yr)	0.00020	0.00027	0.00035
Fecal coliform (billion CFU/yr)	1,686	2,715	3,833
Phosphorus (kg/yr)	1.7	2.1	2.6
Total copper (kg/yr)	0.16	0.20	0.24
Total zinc (kg/yr)	1.4	1.7	2.0
TSS (kg/yr)	1,017	1,173	1,352

Piper's Creek Annual Loads Reduction			
RCOC	**Lower confidence limits**	**Mean**	**Upper confidence limits**
PCBs (kg/yr)	0.00020	0.00032	0.00043
Fecal coliform (billion CFU/yr)	1,625	3,159	4,580
Phosphorus (kg/yr)	1.9	2.6	3.2
Total copper (kg/yr)	0.16	0.19	0.23
Total zinc (kg/yr)	1.4	1.9	2.3
TSS (kg/yr)	1,080	1,306	1,602

Thornton Creek Annual Loads Reduction			
RCOC	**Lower confidence limits**	**Mean**	**Upper confidence limits**
PCBs (kg/yr)	0.00089	0.00121	0.00159
Fecal coliform (billion CFU/yr)	7,338	12,037	17,064
Phosphorus (kg/yr)	7.6	9.5	11.8
Total copper (kg/yr)	0.73	0.88	1.08
Total zinc (kg/yr)	6.4	7.8	9.5
TSS (kg/yr)	4,382	5,225	6,085

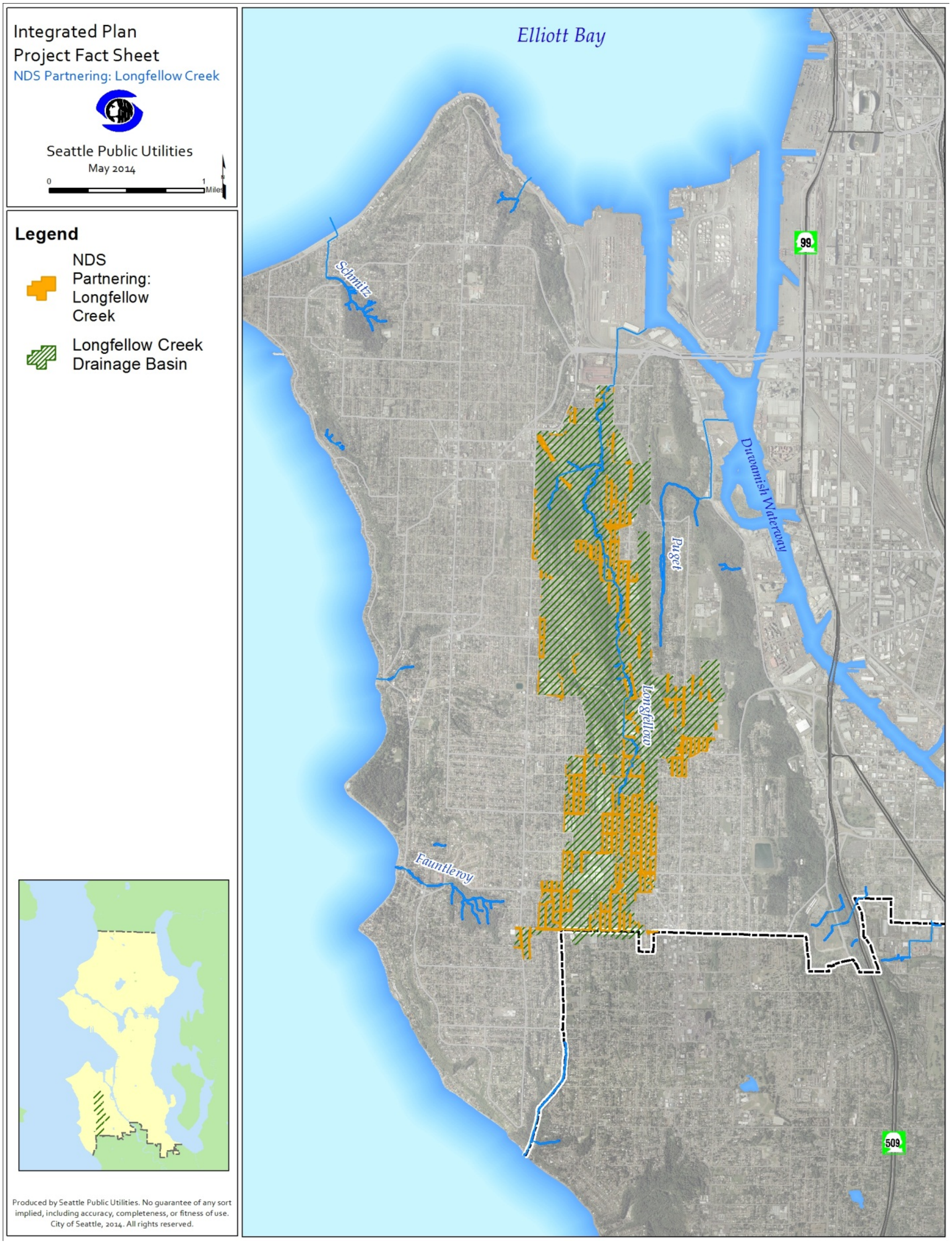

Figure J-1. Project location: NDS Partnering Longfellow Creek

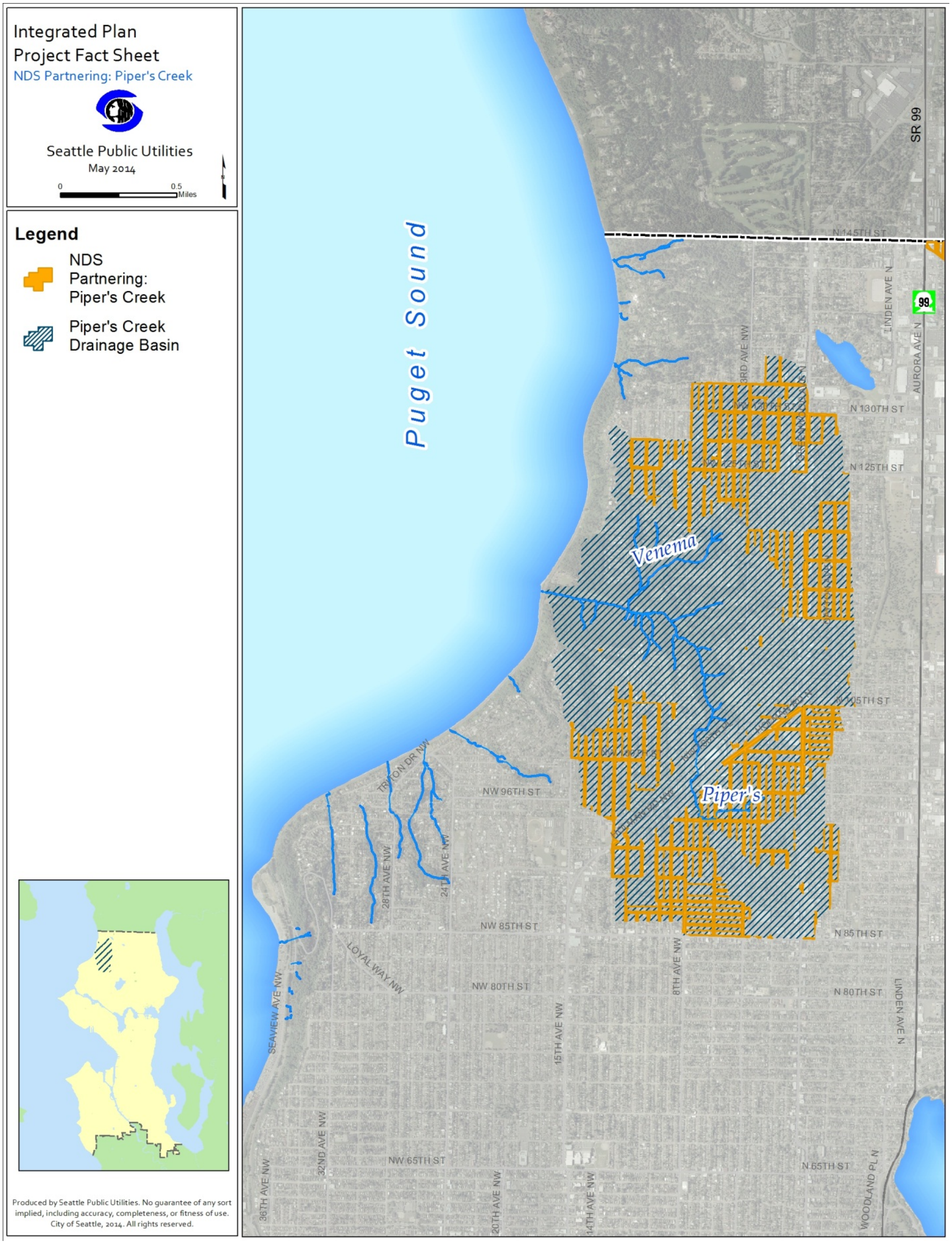

Figure J-2. Project location: NDS Partnering Piper's Creek

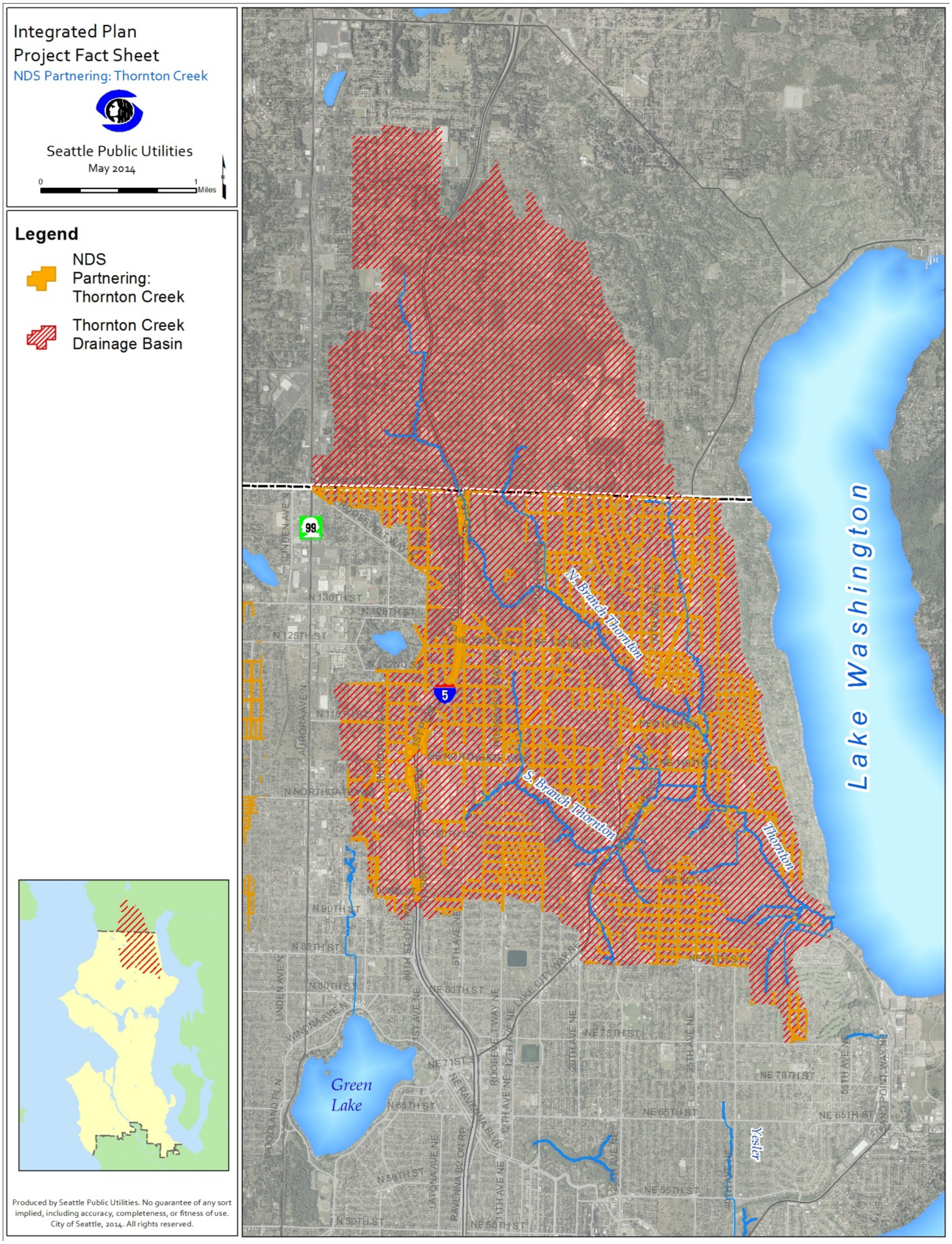

Figure J-3. Project location: NDS Partnering Thornton Creek

Project name	NDS Partnering

Project Cost Estimate

Unit Cost Escalation to Today	
Description	**ENR CCI Index**
Estimate Unit Cost Index ENR CCI (Seattle), Sept 2011	9056.6
Current ENR CCI Index (Seattle), November 2012	9423.77
Unit Cost Adjustment	1.041
Market Conditions % (Set by SPU Finance office)[1]	0.0%
Current Seattle WA Sales Tax rate[2]	0.0%

Agency	Total Costs	Pipe/Horz Conveyance	Green Stormwater Infrastructure
	$ 11,110,500	$ -	$ 11,110,500
Subtotal	**$ 11,110,500**	**$ -**	**$ 11,110,500**
Retrofit Costs	$ -	$ -	$ -
Other Misc Mitigation Items	$ -	$ -	$ -
Street Use Permit	$ 111,105	$ -	$ 111,105
Permit Fees	$ 111,105	$ -	$ 111,105
Construction Line Item Pricing (Sept 2011 Dollars)	$ 11,332,710	$ -	$ 11,332,710
Construction Line Item Pricing (See above for ENR Index Date	$ 11,792,000	$ -	$ 11,792,000
Adjustment for Market Conditions[1]	$ -	$ -	$ -
Construction Bid Amount	**$ 11,792,000**	**$ -**	**$ 11,792,000**
Sales Tax[2]	$ -	$ -	$ -
Construction Contract Amount	**$ 11,792,000**	**$ -**	**$ 11,792,000**
Crew Construction Cost	$ 2,240,480	$ -	$ 2,240,480
Miscellaneous Hard Costs	$ 589,600	$ -	$ 589,600
Hard Cost Total	**$ 14,622,080**	**$ -**	**$ 14,622,080**
Soft Cost %[3]		49%	49%
Soft Cost Amount	$ 7,165,000	$ -	$ 7,165,000
Property Cost (Per SPU Real Estate)	$ -	$ -	$ -
Base Cost	**$ 21,787,080**	**$ -**	**$ 21,787,080**
Construction Contingency %[4]		40%	25%
Construction Contingency Amount	$ 5,447,000	$ -	$ 5,447,000
Management Reserve %[5]		25%	15%
Management Reserve Amount	$ 3,268,000	$ -	$ 3,268,000
Allowance for Indeterminates %		25%	0%
Allowance for Indeterminates Amount	$ -	$ -	$ -
Total Project Costs, 2012 Dollars[6]	**$ 30,500,000**	**$ -**	**$ 30,500,000**

Present Values Costs in 2014 Dollars	
Capital	$ 24,500,000
O&M	$ 2,800,000
Total Project Costs[11]	**$ 27,200,000**

Notes:
[1] SPU Finance office to provide market condition adjustment
[2] WA State Dept of Revenue 3 Qtr 2011 Seattle Tax Rate of 9.5% is excluded for GSI
[3] Soft Cost % for large drainage or wastewater projects (TCP>$5M) is 49% per SPU guidelines.
[4] Contingency for SPU Initiation ranges from 25% to 40% of Base Cost.
[5] Management Reserve for SPU Initiation ranges from 10% to 25% of Base Cost.
[6] Total Project Dollar values are rounded to the nearest $10,000.
[7] Street use permit is 1% of Subtotal (line 20)
[8] Permit Fees is 5% of Subtotal (line 20)
[9] Construction Crew Cost is 19% of the Construction Contract Amount
[10] Misc Hard Cost (survey, geotech) is 5% of the Construction Contract Amount
[11] Present value costs in 2014 dollars over 100 years at 3%

South Park WQ Expansion

Project name	South Park WQ Facility
Project type	Basic, Active Treatment (e.g., chitosan-enhanced sand filtration [CESF])
Objective	Reduce loads of polychlorinated biphenyls (PCBs), metals, bacteria, and other pollutants to the Duwamish Waterway.
Description	The South Park Water Quality (WQ) Facility would entail an end-of-pipe treatment system (e.g., regional) using a CESF system that would be installed in the 7th Avenue S drainage system. The treatment facility would be co-located with a new stormwater pump station that the City of Seattle (City) plans to build in order to reduce flooding in the 7th Avenue S drainage system. This project would take advantage of the opportunity to integrate water quality treatment with flood control.
Location	The project is located in south Seattle, adjacent to the Duwamish Waterway. See Figure J-4 for project location and receiving water body.
Tributary area	The current South Park drainage area is approximately 238 acres, about 145 acres (61 percent) of which is impervious. In the future, the drainage area could be expanded to encompass up to 278 acres and the impervious area could increase to approximately 219 acres (79 percent) due to new development and conversion of existing residential areas to high-density residential or industrial uses.
Basis of design/assumptions	*Site Characteristics* This project is located in the 7th Avenue S storm drainage basin, in a predominantly commercial/industrial area. *Site Constraints* The treatment system sizing is limited due to the land available for the facility *Basis of Design* • Average annual runoff: 89 MG/yr • BMP capture efficiency (% of average annual runoff treated): 83% (74 MG/yr treated) *Project Elements* Basic CESF system components include: • chemical storage/feed • sedimentation/flocculation basin • sand filters • solids handling facility • supervisory control and data acquisition (SCADA) equipment
Recommended predesign refinements	Prior to design, the following should be completed: • land acquisition • refine tributary area to the facility • collect flow monitoring data to calibrate flow model • characterize baseflow • use calibrated model and baseflow estimates to confirm/refine facility sizing

Project name	South Park WQ Facility
Average volume of water treated or reduced	74 million gallons per year
Loads reduction	

Annual Loads Reduction

RCOC	Lower confidence limits	Mean	Upper confidence limits
Total zinc (kg/yr)	24.5	29.0	34.4
Total copper (kg/yr)	3.8	4.5	5.2
Fecal coliform (billion CFU/yr)	31,000	52,700	74,200
PCBs (kg/yr)	0.0052	0.0069	0.0086
Phosphorus (kg/yr)	38.3	45.5	53.5
TSS (kg/yr)	20,935	24,741	29,086

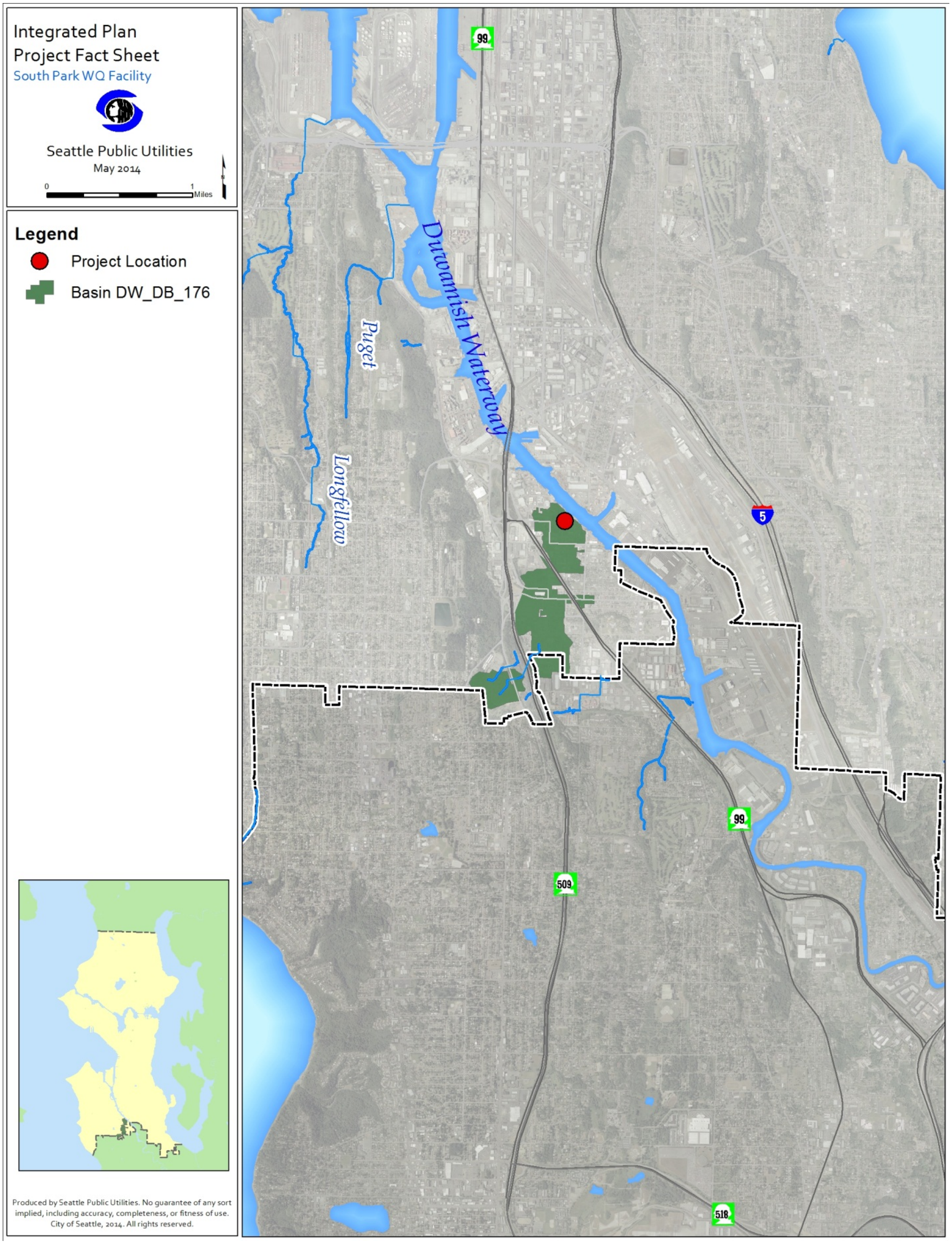

Figure J-4. Project location: South Park Water Quality Facility

Project name	South Park WQ Facility

Project Cost Estimate

Unit Cost Escalation to Today		
Description	**ENR CCI Index**	
Estimate Unit Cost Index ENR CCI (Seattle), Sept 2011	9056.6	
Current ENR CCI Index (Seattle), November 2012	9423.77	
Unit Cost Adjustment	1.041	
Market Conditions % (Set by SPU Finance office)[1]	0.0%	
Current Seattle WA Sales Tax rate[2]	9.5%	

Agency	Total Costs	South Park Water Quality Facility Basic Active Treatment
	$ -	$ -
Subtotal	$ -	**$ -**
Retrofit Costs	$ -	$ -
Other Misc Mitigation Items	$ -	$ -
Street Use Permit[6]	$ -	$ -
Permit Fees[7]	$ -	$ -
Construction Line Item Pricing (Sept 2011 Dollars)	$ -	$ -
Construction Line Item Pricing (See above for ENR Index Date)	$ -	$ -
Adjustment for Market Conditions[1]	$ -	$ -
Construction Bid Amount	$ -	**$ -**
Sales Tax[2]	$ -	$ -
Construction Contract Amount	**$ 8,636,373**	**$8,636,373**
Construction Crew Cost	$ 1,640,911	$ 1,640,911
Miscellaneous Hard Costs	$ 431,819	$ 431,819
Hard Cost Total	**$ 10,709,103**	**$ 10,709,103**
Soft Cost %[3]	49%	49%
Soft Cost Amount	$ 5,247,000	$ 5,247,000
Property Cost (Per SPU Real Estate)	$ -	$ -
Base Cost	**$ 15,956,103**	**$ 15,956,103**

Project name	South Park WQ Facility

Project Cost Estimate (continued)

Allowance for Indeterminates %[10]	25%	25%
Allowance for Indeterminates Amount	$ 3,989,000	$ 3,989,000
Construction Contingency %[4]	40%	40%
Construction Contingency Amount	$ 6,382,000	$ 6,382,000
Management Reserve %[5]	25%	25%
Management Reserve Amount	$ 3,989,000	$ 3,989,000
Total Project Costs, 2012 Dollars	**$ 30,320,000**	**$ 30,320,000**
Present Values Costs in 2014 Dollars		
Capital	$ 24,300,000	
O&M	$ 10,500,000	
Total Project Costs[11]	**$ 34,800,000**	
Notes:		
[1] SPU Finance office to provide market condition adjustment		
[2] WA State Dept of Revenue 3 Qtr 2011 Seattle Tax Rate of 9.5%		
[3] Soft Cost is 49% per SPU guidelines.		
[4] Management Reserve for SPU Options Analysis ranges from 10% to 25% of Base Cost.		
[5] Total Project Dollar values are rounded to the nearest $10,000.		
[6] Street use permit is 1% of Subtotal.		
[7] Permit Fees is 1% of Subtotal.		
[8] Construction Crew Cost is 19% of the Construction Contract Amount		
[9] Misc Hard Cost (survey, geotech) is 5% of the Construction Contract Amount		
[10] Allowance for Indeterminates is 25% of Base Cost.		
[11] Present value costs in 2014 dollars over 100 years at 3%		

Note: Cost estimate is based on a pump station design flow rate of 11 cubic feet per second.

References

Seattle Public Utilities. 2014. South Park Hydraulic Modeling Report. September 2014.

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Street Sweeping Expansion Arterials

Project name	Street Sweeping Expansion Arterials
Program type	Street sweeping, weekly, evening arterial sweeping
Objective	Reduce loads of polychlorinated biphenyls (PCBs), metals, bacteria, and other particulate-bound pollutants to multiple receiving water bodies.
Description	The Street Sweeping Expansion Arterials program would be done in addition to the current Street Sweeping for Water Quality Program, a partnership between Seattle Public Utilities and Seattle Department of Transportation. The existing program would be expanded by increasing the: • route coverage from 83 percent to approximately 85 percent of curbed arterials, for a total of 25 routes • sweeping frequency from biweekly to weekly, for some routes (21 routes will be swept on a weekly basis, and 4 routes will be swept on a biweekly basis) • sweeping season from 40 to 48 weeks per year
Location	The program affects arterials throughout the city. See Figure J-5 for program location and receiving water bodies.
Tributary area	1,736 acres (10,600 annual curb-miles), including streets and adjacent sidewalks

<table>
<tr><th>Project name</th><th>Street Sweeping Expansion Arterials</th></tr>
<tr><td>Basis of design/assumptions</td><td>
Site Characteristics
The streets that will be swept are arterials, citywide.

Site Constraints
There are no known site constraints.

Basis of Design
The program was developed based on the Street Sweeping for Water Quality Program, which began February 2011.

Average street width: 41.7 feet
Street area: 1,422 acres
Sidewalks: 314 acres, 100% connected to roads
Effective area or area draining to municipal separate storm sewer system: 1,736 acres
Average annual runoff: 4,687 acre-feet/year
Washoff load: 12 percent of total load removed
Washoff pollutant load removed: 36,200 kg/yr
Street sweeping pick-up rates were estimated based on:

sample results from the sweepings temporarily stored in the stockpiles located in the designated bins
productivity metrics (curb-miles swept within and without the storm sewer system)
disposal facility scale readings
efficiency factor of 64 percent, to account for reduced pickup rates for more frequent sweeping
reduction factor of 25 percent, to account for reduced flexibility when operating at full capacity

Project Elements

One new regenerative sweeper
One additional street sweeping route, for a total of 25 routes
Sweeping frequency of biweekly (4 routes) and weekly (21 routes)
Sweeping season from 40 to 48 weeks per year for all routes

</td></tr>
<tr><td>Recommended predesign refinements</td><td>Route optimization</td></tr>
</table>

Project name	Street Sweeping Expansion Arterials
Average volume of water treated or reduced	1,527 million gallons per year (based on estimated runoff from swept streets)
Loads reduction	(see Annual Loads Reduction table below)
Loads reduction by receiving water body	(see Receiving Water Body table below)

Annual Loads Reduction

RCOC	Lower confidence limits	Mean	Upper confidence limits
PCBs (kg/yr)	0.0020	0.0033	0.0045
Fecal coliform (billion CFU/yr)	1,380	2,100	3,970
Phosphorus (kg/yr)	13.7	23.7	29.6
Total copper (kg/yr)	3.3	5.2	7.2
Total zinc (kg/yr)	6.3	10.2	13.7
TSS equivalent (kg/yr)	20,700	36,200	44,700

N/A = not available

Receiving Water Body	Distribution of Load Reduction
Direct discharge	3%
Lower Duwamish Waterway	30%
Lake Washington Ship Canal/Lake Union	20%
Lake Washington	18%
Longfellow Creek	3%
Piper's Creek	1%
Elliott Bay	6%
Puget Sound	10%
Thornton Creek	9%

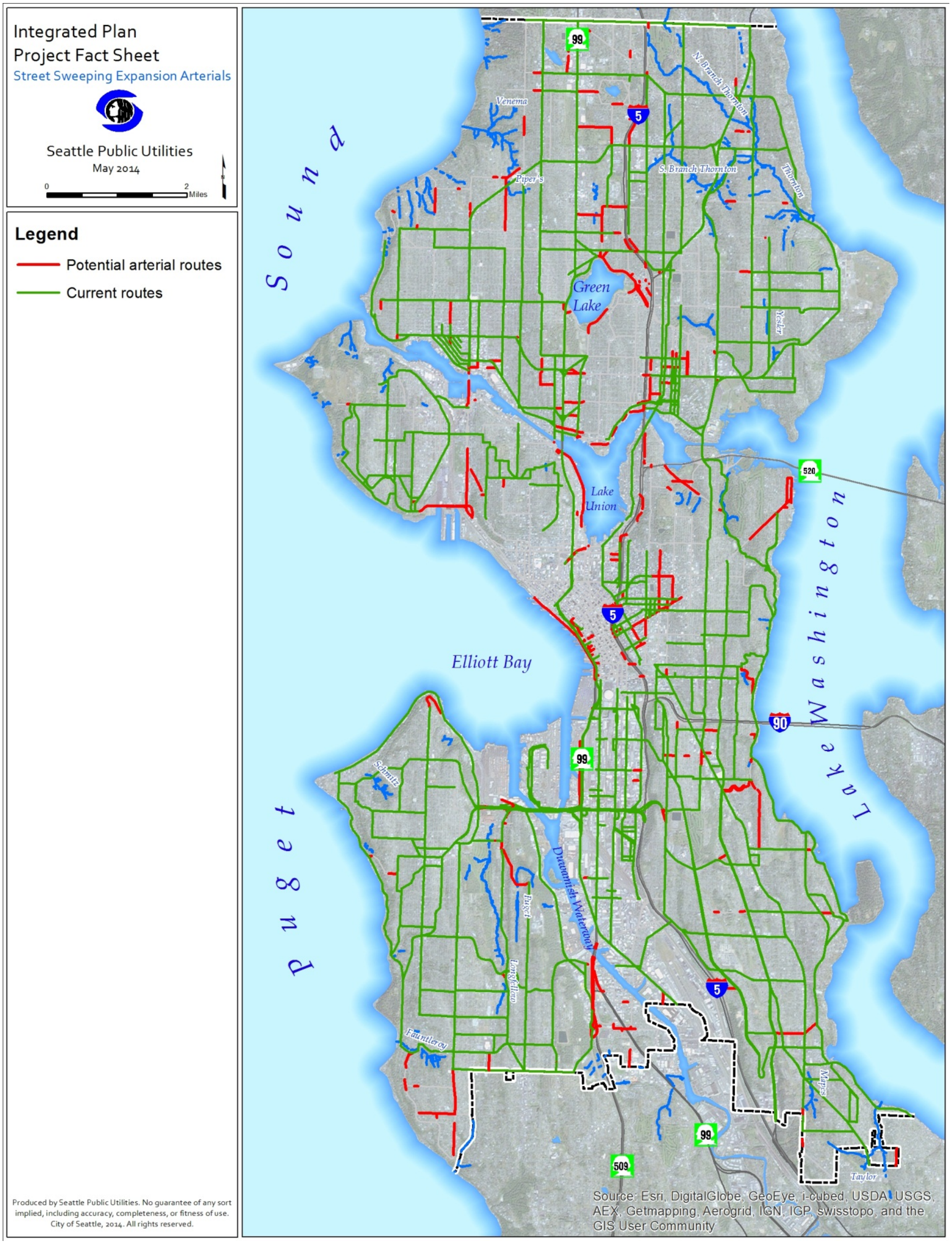

Figure J-5. Project location: Street Sweeping Expansion Arterials

Project name	Street Sweeping Expansion Arterials

Project Cost Estimate

Item	Costs
New sweepers	$ 300,000
Design	$ 25,000
Commissioning	$ 10,000
Post-Construction Monitoring	$ 270,000
Total	$ 605,000
Annual Operations and Maintenance	
Sweeping and disposal costs	$ 748,645
Program overhead	$ 86,250
Total	$ 834,895