Water Quality Assessment and Monitoring Study: Identification and Selection of New Studies to Improve Understanding of Existing Conditions

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King County

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EXECUTIVE SUMMARY

This report documents how data gaps were identified and how studies to fill these gaps were prioritized and selected for implementation as part of King County's Water Quality Assessment and Monitoring Study. The following sections describe the Water Quality Assessment and Monitoring Study and key components and outcomes of the data gap identification and prioritization process.

Water Quality Assessment and Monitoring Study

In 2013, King County initiated the Water Quality Assessment and Monitoring Study to explore ways to optimize water quality improvements in the three waterbodies where the County is planning combined sewer overflow (CSO) control projects: Lake Union/Ship Canal, Elliott Bay, and the Duwamish Estuary. Ordinance 17413, approving the County's 2012 CSO control plan update, calls for completion of the Water Quality Assessment and Monitoring Study to inform the next plan update, which is due to regulators in 2018.

The study set out to do the following:

- Examine baseline water, sediment, and fish and shellfish tissue quality for the waterbodies ("study areas") using data previously collected from a variety of monitoring programs and studies.
- Evaluate data gaps and limitations, and conduct new studies to improve understanding of existing conditions.
- Estimate present-day (2015) and future (2030) loadings of contaminants from major pathways and the effects on contaminant loadings from future planned projects, regulations, projected population, and land use change.

An independent external Scientific and Technical Review Team (STRT) was assembled to review methodology and results.

Identified Data Gaps

In 2014, the following data gaps were identified in the existing data for the study areas:

- Bacteria sources and pathways to the study areas
- Current sediment conditions in Lake Union/Ship Canal
- Tissue chemistry conditions in Lake Union/Ship Canal
- Sources of polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) to King County CSO basins
- Concentrations of contaminants of emerging concern in the study area surface waters
- An effective sewage "tracer" to help quantify the contribution of sewage to pollutant loads or water quality impairments

- Concentrations of metals, organic compounds, PCBs, and flame retardants (PBDEs) in Elliott Bay surface waters
- Concentrations of PBDEs in Duwamish Estuary surface waters

Studies to Fill Selected Data Gaps

The project team, STRT, and King County management scored and ranked new studies to improve understanding of existing conditions based on their ability to meet criteria, such as addressing water quality concerns related to human and aquatic health, providing needed data on ambient conditions, and addressing contaminants contributed by CSOs. In addition, the studies were to be completed within the timeframe and budget of the Water Quality Assessment and Monitoring Study.

Once the studies were scored and ranked, the project team, STRT, and King County management discussed the information in order to select which studies to pursue based on their ability to answer study questions and provide information to the County's CSO Control Program. Management decided to pursue three new studies:

- A bacteria study to better understand the sources and pathways of bacteria in the study areas (collect and analyze new data)
- A literature review to understand if other researchers have identified chemicals that can be used to effectively track sewage in surface waters (sewage tracers)
- A water column survey of a select group of contaminants of emerging concern in the study areas (collect and analyze new data)

A bacteria study ranked highest as a data need in each of the study areas. It scored high as a public health concern and as a water quality impairment. Completion of a bacterial sources and pathway study was determined to be feasible within the timeframe and budget of the Water Quality Assessment and Monitoring Study.

An investigation of potential sewage tracers could identify established tracers, including pharmaceuticals, personal care products, or artificial sweeteners, that could be used to determine if elevated levels of fecal contamination are related to sewage or to other sources or pathways. The presence and concentration of tracers in the study areas could be used to prioritize CSO upgrades and as a baseline for post-construction monitoring of CSO control projects. A literature review was proposed because the resources and time necessary to conduct a field investigation were beyond the scope of the Water Quality Assessment and Monitoring Study.

An evaluation of contaminants of emerging concern in the water column also ranked high in the prioritization process. A growing body of research shows that pharmaceuticals, personal care products, and other consumer chemicals may be a concern for human and environmental health. Additionally, new and enhanced analytical methods that were not available previously are now available to test for these compounds. Information on the presence of these compounds in Lake Union/Ship Canal, Elliott Bay, and the Duwamish

Estuary was important for assessing current water quality conditions. A select group of compounds was targeted for evaluation.

Other Assessment Reports

This report is one of several reports that have been prepared as part of King County's Water Quality Assessment and Monitoring Study. Other reports are as follows:

- Reports describe existing conditions and long-term trends in three study areas—Lake Union/Ship Canal, Elliott Bay, and the Duwamish Estuary.
- Three reports discuss the methodology and results of selected new studies to improve understanding of existing conditions: a study of bacteria in wet and dry weather, a survey of contaminants of emerging concern, and a literature review of potential conservative sewage tracers.
- A loadings report discusses present-day contributions of pollutants from various pathways, including stormwater runoff and CSOs, into the study areas and evaluates water quality impairments.
- A future loadings report assesses the potential of planned actions such as CSO control to improve water quality.
- A final report summarizes these analyses and implications.

King County will use the information from the Water Quality and Assessment Study to inform the next CSO control plan update, including looking for opportunities to improve water quality outcomes, possibly reduce costs of CSO control projects, establish baseline conditions for post-construction monitoring of CSO control projects, and decide whether to pursue an integrated CSO control plan. The information from the assessment can also be used to inform regional efforts to continue to improve water and sediment quality.

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1.0 INTRODUCTION

This report documents how data gaps were identified and prioritized for new research as part of King County's Water Quality Assessment and Monitoring Study. The following sections provide background on the Water Quality Assessment and Monitoring Study and the content of this report.

1.1 Water Quality Assessment and Monitoring Study

King County owns and operates 39 combined sewer overflow (CSO) outfalls in the City of Seattle. The County's 2012 CSO control plan includes nine projects to control 14 uncontrolled CSOs by 2030 to meet the Washington State standard of no more than one overflow per year on a 20-year moving average. The recommended projects involve construction of underground storage tanks, green stormwater infrastructure, and/or wet weather treatment facilities. Four projects are in the Lake Union/Ship Canal area and five in the Duwamish Estuary and Elliott Bay areas.

Ordinance 17413, approving the plan, also calls for completion of a Water Quality Assessment and Monitoring Study to inform the next plan update, which is due to regulators in 2018. In September 2013, the King County Council approved the assessment's scope of work through Motion 13966. The assessment includes a comprehensive scientific and technical analysis of existing water quality of the receiving waters ("study areas") where uncontrolled county CSOs discharge (Elliott Bay, Lake Union/Ship Canal, and the Duwamish Estuary), identification of water quality impairments, trends in water quality, assessment of sources contributing to impairments, and review of ongoing and planned activities to improve water quality. Figure 1-1 shows the study areas. Additional studies were completed within the study timeframe and available budget to address data gaps.

The Water Quality Assessment and Monitoring Study set out to generate information that will help answer the following study questions:

1. What are the existing and projected water quality impairments in receiving waters (waterbodies) where King County CSOs discharge?[1]
2. How do county CSOs contribute to the identified impairments?
3. How do other sources contribute to the identified impairments?
4. What activities are planned through 2030 that could affect water quality in the receiving waters?
5. How can CSO control projects and other planned or potential corrective actions be most effective in addressing the impairments?
6. How do various alternative sequences of CSO control projects integrated with other corrective actions compare in terms of cost, schedule, and effectiveness in addressing impairments?

[1] "Impairments" is defined as water quality-related concerns.

7. What other possible actions, such as coordinating projects with the City of Seattle and altering the design of planned CSO control projects, could make CSO control projects more effective and/or help reduce the costs to WTD and the region of completing all CSO control projects by 2030?

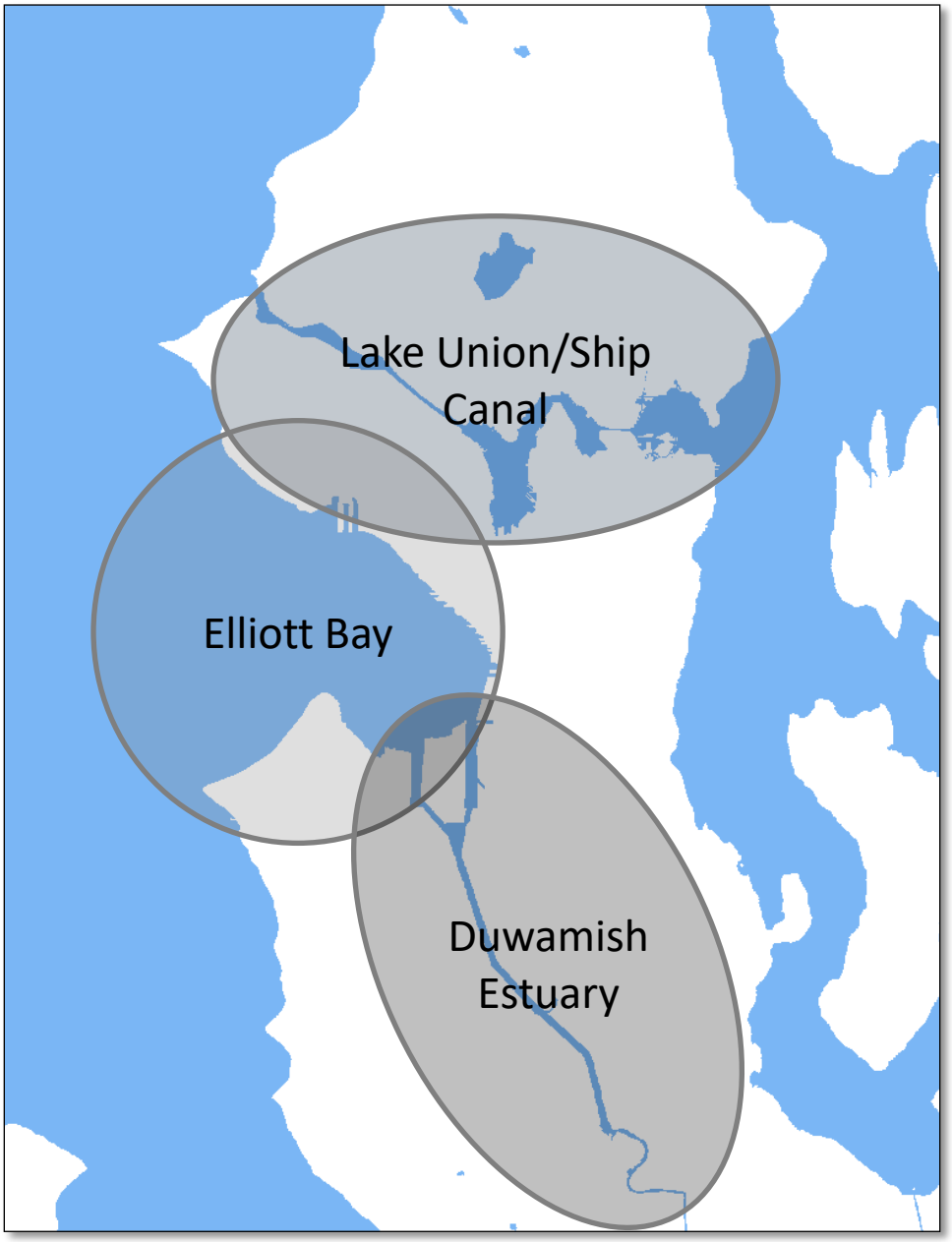

Figure 1-1. Lake Union/Ship Canal, Elliott Bay, and Duwamish Estuary study areas.

The Water Quality Assessment and Monitoring Study addresses Questions 1 through 4. King County will use the information to inform the 2018 CSO control plan update, prioritize and sequence CSO control projects, establish baseline conditions for post-construction monitoring of CSO control projects, and decide whether to pursue an integrated plan based

on U.S. Environmental Protection Agency (EPA) guidelines. Questions 5 through 7 will be addressed during the CSO control program update.

An external Scientific and Technical Review Team (STRT) was assembled to review methodology and results. A synthesis report will incorporate the results of the analyses, data gap studies, and additional assessments. Depending on assessment findings, the King County Council may decide to approve formation of an Executive's Advisory Panel of approximately 10 regional leaders. The panel would develop independent recommendations to the King County Executive on how planned county CSO control projects can best be sequenced and integrated with other projects to maximize water quality gains and minimize costs to ratepayers.

Table 1-1 shows elements of the assessment and their associated study questions, deliverables, and estimated timeframes. Figure 1-2 illustrates the flow of reports and how they will inform the CSO program review process. More information on the assessment is available at http://www.kingcounty.gov/environment/wastewater/CSO/WQstudy.aspx.

Table 1-1. Elements of the Water Quality Assessment and Monitoring Study.

Element	Applicable Study Question	Deliverable	Timeframe
Review and analyze existing scientific and technical data on impairments in Lake Union/Ship Canal, Duwamish Estuary, and Elliott Bay.	1	Area reports: • Elliott Bay • Lake Union/Ship Canal • Duwamish Estuary	2013–2017
Conduct targeted data gathering and monitoring to fill some of the identified gaps in scientific data on water quality in these receiving waters.	1,2,3	Data gaps analysis report[a] Data gap study reports: • Bacteria • Contaminants of emerging concern • Literature review of conservative sewage tracers	2014–2017
Identify and quantify the current (2015) pathways of contaminants into the receiving waters.	2,3	Loadings Report	2015–2017
Identify changes in contaminant loadings between 2015 and 2030, including the potential impact of planned corrective actions on identified impairments in the waterbodies.	1,2,3,4	Future Loadings Report	2015–2017
Summarize scientific and technical data collected and reviewed during the assessment.	1,2,3,4	Synthesis Report	2015–2017

[a] *Identification and Assessment of New Studies to Improve Understanding of Existing Conditions.*

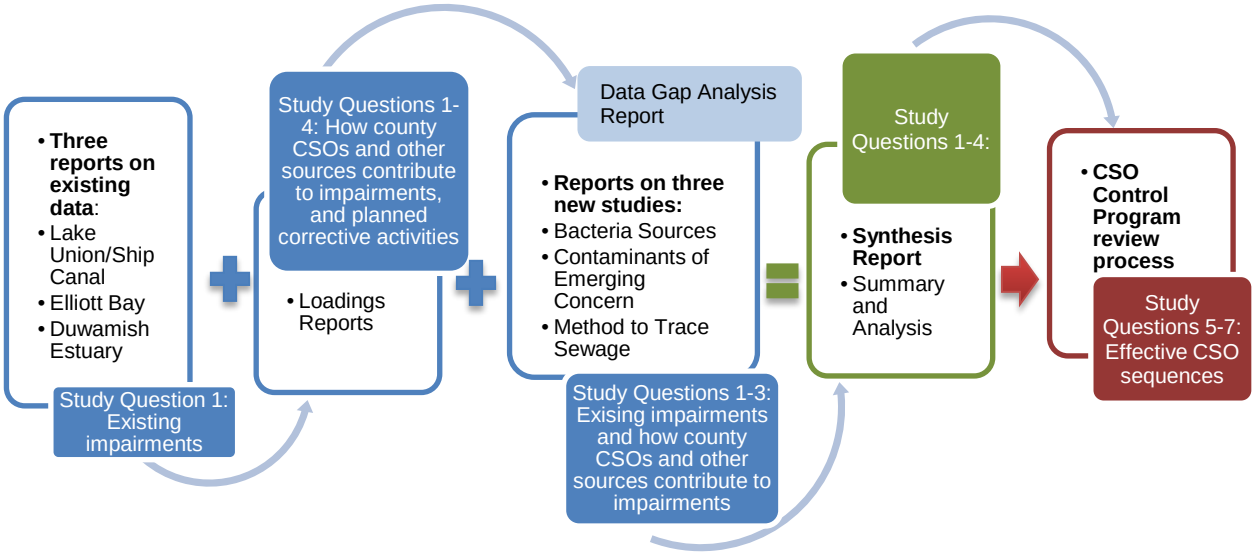

Figure 1-2. Reports and study questions answered as part of the Water Quality Assessment and Monitoring Study.

1.2 Content of This Report

A key component of the Water Quality Assessment and Monitoring Study was to complete water quality characterizations of the study areas using data previously collected from a variety of monitoring programs and studies. The characterizations included assessment of current water, sediment, and fish and shellfish tissue quality and other indicators of ecological health; evaluation of long-term trends in conditions over time; comparison to Washington State water and sediment quality standards to help identify impairments; and estimation of loadings to these waterbodies from contaminant pathways and expected future loadings following planned water quality improvement actions.

Early in the Water Quality Assessment and Monitoring Study, a number of gaps were identified in the existing data for each study area. These data gaps were prioritized using a variety of criteria based on the importance of the missing information for answering the study questions. The results of this ranking were used to assist county managers in selecting projects to fill some of the identified gaps. This report documents existing data limitations and gaps and the prioritization process used to fill some of these gaps.[2]

[2] The title of this report is abbreviated as "data gaps analysis report" in Table 1-1, Figure 1-2, and places in the text.

2.0 IDENTIFICATION OF DATA GAPS

Over the years King County and other agencies have collected a substantial amount of environmental data on water quality, sediment chemistry, benthic invertebrate communities, and fish and shellfish tissue chemistry in the study areas. These data were evaluated and summarized as part of the Water Quality Assessment and Monitoring Study to describe current conditions, identify long-term trends, and compare values with Washington State water and sediment quality standards (King County, 2017a, 2017b, 2017c). Water column data included physical parameters (temperature, dissolved oxygen, salinity/conductivity, pH, total suspended solids, and turbidity), chlorophyll *a*, nutrients, fecal coliform bacteria, metals, and a number of organic compounds. Data on metals and organic compounds in sediments, benthic invertebrate communities, and fish and shellfish tissue were also analyzed.

Existing data were assembled from a variety of sources. A thorough literature review was conducted through King County's Technical Document and Research Center. Additionally, local agencies were consulted including the Washington State Department of Ecology (Ecology), the U.S. Army Corps of Engineers (USACE), and the City of Seattle. Data were queried from King County's Laboratory Information Management System (LIMS) database, where monitoring data from the County's lakes, stream, and marine monitoring programs are stored, and from Ecology's Environment Information Management system (EIM). Data were also compiled from other monitoring programs led by agencies such as USACE and the U.S. Geological Survey and from a number of published studies.

This chapter summarizes existing data for various parameters in each study area and identifies data limitations and gaps for each parameter. Using best professional judgement, a distinction was made between data that would be needed to answer study questions (a data gap) and data that would be useful but not imperative to answer study questions (a data limitation). For water column data, the most recent five years of data were typically used to describe current conditions. Occasionally, data were used that were a few years older (for example, water column data for organic compounds) and were noted as a data limitation. To evaluate potential impacts to human health or aquatic life in the study areas, data were compared to Washington State water quality criteria (WQC).

Table 2-1 lists the identified data limitations and gaps, followed by a discussion of existing data for each parameter. Water column data from the Green River were included in the assessment of existing conditions because extensive data were available and the Green River directly impacts the Duwamish Estuary. Consequently, Green River water column data were also considered in this data gap assessment.

Table 2-1. Data limitations and gaps.

Parameter	Lake Union/Ship Canal	Duwamish Estuary	Elliott Bay
Temperature, dissolved oxygen, pH, salinity/conductivity	Adequate, with some limitations	Adequate, with some limitations	Adequate, with some limitations
Total suspended solids, turbidity, Secchi transparency	Adequate, with some TSS and turbidity limitations	Adequate, with some TSS and turbidity limitations	Adequate, with some TSS and turbidity limitations
Alkalinity	Adequate, with some limitations	Adequate, with some limitations	Adequate, with some limitations
Nutrients	Adequate	Adequate	Adequate
Chlorophyll *a*	Adequate	Adequate	Adequate
Bacteria	Adequate, but data gap on sources and pathways	Adequate, but data gap on sources and pathways	Adequate, but data gap on sources and pathways
Metals	Water column data limitations; data limitation for trend analysis	Water column data limitations; data limitation for trend analysis	Water column data gap; data limitation for trend and criteria analyses
Organic compounds	Water column data limitations; data limitation for trend analysis	Water column data limitations; data limitation for trend analysis	Water column data gap; data limitation for trend and criteria analyses
Sediment chemistry	Data gap for recent data; data limitation for trend analysis	Data limitation for trend analysis	Data limitation for trend analysis
Benthic invertebrates	Data limitation for characterization and trend analysis	Data limitation for characterization and trend analysis	Data limitation for characterization and trend analysis
Tissue chemistry	Data gap	Adequate	Data gap
CSO quality	Adequate for CSO characterization but no CEC data; data gap for PCB/PDBE sources to combined system	Adequate for CSO characterization but no CEC data	Adequate for CSO characterization but no CEC data; data gap for PCB/PDBE sources to combined system
Stormwater quality	Adequate for most parameters; data gap for CECs and PBDEs; data limitation for PCB congeners	Adequate for most parameters; data gap for CECs, PBDEs; data limitation for PCB congeners	Adequate for most parameters; data gap for CECs and PBDEs; data limitation for PCB congeners

CEC = contaminant of emerging concern; PBDE = polybrominated diphenyl ether; PCB = polychlorinated biphenyl; TSS = total suspended solids.

2.1 Physical Parameters

Data on physical water quality parameters have been collected routinely in the study areas starting in the late 1970s to early 1980s and continuing through the present. Over time, stations have been added or lost based on budget needs or program goals.

Temperature, Dissolved Oxygen, pH, and Salinity/Conductivity

Temperature, dissolved oxygen (DO), pH, and salinity/conductivity measurements have been collected in the field by King County, Ecology, and USACE. Data available for the study area are as follows:

- **Lake Union/Ship Canal.** King County has collected temperature, DO, pH, and conductivity data monthly from the late 1970s to the present at three stations. Other stations in Lake Union/Ship Canal have been monitored sporadically and are not currently included in the monitoring program. USACE has collected 15-minute interval data for temperature, conductivity, and salinity from five locations in the Lake Washington Ship Canal beginning in 2000 (USACE, 2004).
- **Elliott Bay.** King County has collected monthly temperature and salinity data from Elliott Bay at six nearshore and three offshore sites. The data record begins in the early 1970s for three of the nearshore sites; data records for the remaining sites vary. pH data have not been collected as part of the County's marine ambient monitoring program. Ecology collected temperature, salinity, and DO data at one offshore site in Elliott Bay. No DO data have been collected from nearshore sites in Elliott Bay. Beginning in 2008, temperature, DO, and salinity data have been collected at 1-, 10-, and 15-minute intervals at a moored data collection installation at the Seattle Aquarium. In general, pH data in Elliott Bay were considered to be unreliable and not precise enough to adequately track changes over time.
- **Green-Duwamish system.** Monthly temperature, DO, pH, and conductivity data are available from 17 locations. Measurements were collected by King County at 15 locations and by Ecology at two locations. Measurements at some sites have been collected consistently since the 1970s; others have been monitored sporadically. Temperature data could not be compared to WQC in the Green-Duwamish system because of temporal limitations. Temperature data have typically been collected monthly; however, more frequent data collection is necessary to calculate the 7-day average of the daily maximum temperature required for comparison to WQC (such as the USACE data in Lake Union/Ship Canal and the moored station data from the Seattle Aquarium in Elliott Bay).

Aside from the pH and temperature limitations noted above, data availability was adequate to assess water quality for these parameters and compare values to WQC.

Total Suspended Solids, Turbidity, and Secchi Transparency

Total suspended solids (TSS) and turbidity have been monitored as part of King County and Ecology long-term monitoring programs at various locations in the study areas. Available data are as follows:

- **Lake Union/Ship Canal.** Turbidity has been monitored sporadically in Lake Union/Ship Canal with various method changes over time. Turbidity data were no longer collected after 2008, making trend analysis results uncertain. Data limitations were also identified in the TSS record. Secchi transparency measurements were consistently collected in Lake Union starting in the mid-1980s.

- **Elliott Bay.** TSS has been monitored in Elliott Bay since 1997. Turbidity has been measured at the Seattle Aquarium mooring station beginning in 2008.
- **Green-Duwamish system.** TSS and turbidity have been monitored at various locations since the mid-1970s.

While there were TSS and turbidity data limitations, data availability was adequate to assess water quality, including comparisons to WQC, in the study areas and was not considered a data gap for this study.

Alkalinity

Alkalinity has been monitored in two of the study areas as part of King County's monitoring program beginning in the 1980s. Alkalinity has not been measured in Elliott Bay because this parameter is not typically measured in marine environments. Available data are as follows:

- **Lake Union/Ship Canal.** Alkalinity was monitored quarterly at one site in the southwest main basin of Lake Union from the mid-1980s through 2008; since 2008, it has been monitored on a monthly basis. While alkalinity data have been collected from other locations, efforts have been sporadic.
- **Green-Duwamish system.** Alkalinity has been monitored at four locations in the Green River beginning in 1997; monitoring at two of these sites was discontinued in 2008. Alkalinity has not been monitored in the Duwamish Estuary.

While some alkalinity data limitations exist, data availability was adequate to assess water quality in the study areas and was not considered a data gap for this study. There are no WQC for alkalinity.

2.2 Nutrients

Nutrients have been monitored as part of King County and Ecology long-term monitoring programs. Monitoring includes analysis of ammonia, nitrate + nitrite, total nitrogen, orthophosphate, total phosphorus, and silica. Available data are as follows:

- **Lake Union/Ship Canal.** Orthophosphate, total phosphorus, nitrate + nitrite, ammonia, and silica were monitored monthly at three stations in Lake Union/Ship Canal starting in the 1970s. Total nitrogen analyses began in 1993. Two additional stations were monitored monthly starting in the 1970s until 2008. Other stations have been monitored for short-term projects.
- **Elliott Bay.** Nutrients have been monitored in Elliott Bay at six nearshore and four offshore stations since 1997 to the present, depending on location. Analyses of orthophosphate replaced total phosphorus in 2010.
- **Green-Duwamish system.** Currently, nutrients are monitored monthly at one site in the East Waterway, one site in the West Waterway, two sites in the Lower Duwamish Waterway, and two sites in the mainstem Green River. For a variety of reasons, no sites in the East and West waterways have been continuously monitored; sites have been discontinued or moved to other locations. Long-term

data are available starting in the early 1970s for one site in the Lower Duwamish Waterway, one site in the Duwamish River, and two sites in the Green River.

Nutrient data availability was adequate to assess water quality in the study areas and was not considered a data gap for this study. Data were adequate for WQC comparisons.

2.3 Chlorophyll *a*

Available data for chlorophyll *a* are as follows:

- **Lake Union/Ship Canal.** Chlorophyll *a* has been monitored monthly at three stations in Lake Union/Ship Canal from the mid-1980s through the present. Two additional stations were monitored monthly from the mid-1980s through 2008. Several other stations were monitored sporadically during various timeframes.
- **Elliott Bay.** Chlorophyll *a* has been monitored monthly at three offshore stations in Elliott Bay from the mid-1990s through the present. Fifteen-minute interval data for Chlorophyll *a* are available from the Seattle Aquarium mooring station starting in 2008.
- **Green-Duwamish system.** Chlorophyll *a* is not good indicator of productivity in rivers and streams and, thus, has not been monitored in the Duwamish Estuary as part of King County's monitoring program.

Chlorophyll *a* data availability was adequate to assess water quality in the study areas and was not considered a data gap for this study. There are no WQC for chlorophyll *a*.

2.4 Bacteria

King County and Ecology have collected bacteria data monthly at several stations in each of the study areas. Available data are as follows:

- **Lake Union/Ship Canal.** Fecal coliform bacteria data have been collected at three stations in Lake Union from the late 1970s or early 1980s until the present. Other stations in Lake Union have been monitored, but data collection has been inconsistent. *E. coli* data were collected in addition to fecal coliform data starting in the 1990s until 2008, when analysis of *E. coli* was discontinued.
- **Elliott Bay.** Bacteria are monitored monthly in Elliott Bay at six nearshore and four offshore sites, including one offshore site monitored by Ecology. The sample record is variable but extends back to the 1970s at some sites.
- **Green-Duwamish system.** Bacteria are monitored monthly at one station in the East Waterway, one station in the West Waterway, one station in the Lower Duwamish Waterway, and two stations in the mainstem Green River, which includes a station from Ecology's monitoring program. Long-term data are available starting in the early 1970s for one site in the Lower Duwamish Waterway, one site in the Duwamish River, and two sites in the Green River.

Bacteria data were sufficient in all three study areas to assess trends and compare values to WQC. However, the data did not provide information on sources or pathways of bacteria to

the study areas. Such information would aid in determining measures to control the sources and pathways contributing to bacteria WQC exceedances in the study areas.

2.5 Metals

Measurement of water column metals in the study areas is not part of the King County and Ecology routine monitoring programs. King County has periodically collected metals data in the areas either monthly or quarterly for one- or two-year periods. Available data are as follows:

- **Lake Union/Ship Canal.** King County monitored metals quarterly at four locations in Lake Union/Ship Canal in 2000–2002 and 2006–2008. Metals analyzed included dissolved and total arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc. Because collection of metals data from Lake Union/Ship Canal has been sporadic, it was not possible to evaluate long-term trends.
- **Elliott Bay.** King County has periodically collected metals data from Elliott Bay at two offshore and two nearshore sites. One offshore site was sampled monthly at three depths from April 1999 through June 2000; the other offshore site was sampled four times from three depths in July and December 2011 and 2012. At the two nearshore sites, metals were monitored at a single depth just below the surface in August 1999, 2001, and 2002.
- **Green-Duwamish system.** Metals data are available for 14 sites in the Green-Duwamish system. Samples were collected between 2000 and 2013.

Water column metals data was considered a data gap for Elliott Bay and a data limitation for the other study areas. Long-term trend analysis was not possible because of the sporadic collection of water column metals data in the study areas, and water quality characterization was limited in most cases by the amount and age of data. In Elliott Bay, the spatial distribution of sample sites was determined to be poor along the Seattle waterfront. Data in Lake Union/Ship Canal and the Duwamish Estuary were sufficient to compare with applicable WQC.

2.6 Organic Compounds

Measurement of organic compounds in the water column is not part of the King County and Ecology ambient monitoring programs. King County and other agencies have conducted periodic monitoring of semivolatile, chlorinated pesticides, polychlorinated bipheynyl (PCB) Aroclors, and polycyclic aromatic hydrocarbon (PAH) compounds. Other organic compounds, such as PCB congeners, endocrine disrupting compounds (EDCs), and polybrominated diphenyl ethers (PBDEs) have been monitored as part of special studies. Available data are as follows:

- **Lake Union/Ship Canal.** King County monitored organic compounds quarterly at three sites in Lake Union/Ship Canal between 2000 and 2004 and at six additional sites in 2000. This effort included sampling and analysis of a select number of EDCs. The County collected PCB and PDBE congener data at two ambient locations in 2013 (King County, 2013).

- **Elliott Bay.** King County collected the following data on organic compounds in Elliott Bay:
    - From April 1999 to April 2000, monthly organic chemical data at three depths (5, 50, 130 m) at a site near the South Wastewater Treatment Plant outfall.
    - From March 2003 through January 2004, quarterly organic chemical data at one site at three depths (1, 50, and 75 m) in central Elliott Bay and at another site at one depth (1 m) from the Seattle waterfront. This effort included sampling and analysis of a select number of EDCs.
    - In 2004, PCB congener data from central Elliott Bay (four samples at one site at 15-m depth) (King County, 2006).
- **Green-Duwamish system.** In 2001–2012, King County collected 60 samples for organic chemical analysis, including a select number of EDCs, at six sites in the Green-Duwamish system. Samples were collected from one site in the Lower Duwamish Waterway, one site in the Duwamish River, and four sites in the Green River. In 2008–2009, a total of 59 samples were collected in the East Waterway as part of the East Waterway supplemental remedial investigation; these samples were analyzed for total and dissolved metals, PCB congeners, PAHs and other semivolatile organic compounds, tributyltin, and physical parameters (Windward and Anchor QEA, 2014).

Ambient water column organics data was considered a data gap for Elliott Bay and a data limitation for the other study areas. Periodic data collection in the study areas precluded long-term trend analysis, and characterization of organic compounds in the water column was limited by the number of samples collected, the number of detections for each parameter, and detection limits above WQC. The age of the data and method blank contamination were issues for some parameters.

Thousands of organic compounds likely present in the environment are manufactured and used in consumer products. Sampling efforts do not currently test for many of these compounds. The STRT identified additional high priority chemical data gaps:

- No data are available for pharmaceutical compounds, personal care products, or other contaminants of emerging concern in the water column in any of the study areas.
- Contaminants of emerging concern and other compounds may also serve as a chemical marker or "tracer" of sewage if the compounds are found only in sewage and are persistent after discharge. If a chemical that is being monitored could be used to trace the fate and transport of sewage as it flows through the study area, then researchers could better understand the sources and pathways of water quality concerns in the study areas.

2.7 Sediment Chemistry

Sediment chemistry data were compiled from a number of studies conducted in the study areas. The data were typically collected for a specific purpose, such as contaminant

delineation or site characterization, and not with the overall goal of characterizing sediment conditions in the waterbodies where CSOs discharge. Combining the data from different studies, however, does provide an understanding of the spatial distribution of contaminants in the study areas.

Sediment data compiled are as follows:

- **Lake Union/Ship Canal.** From 1977 through 2004, Ecology, EPA, King County, USACE, and others have collected sediment data for a number of parameters including particle size distribution, total organic carbon (TOC), metals, PAHs, PCBs, pesticides, and phthalates (Tomlinson et al., 1977; Cubbage, 1992; Metro, 1993; Herrera and Brown & Caldwell 1994; Serdar et al., 2000; King County, 2004). No recent data are available to characterize current sediment conditions in Lake Union/Ship Canal. The lack of a consistent data record precluded an assessment of trends as well.
- **Elliott Bay.** King County, Port of Seattle, Ecology, and others have conducted a number of sediment studies in Elliott Bay. A search of King County's LIMS database and Ecology's EIM database found data collected from 283 sites since 1990. Samples were analyzed for metals, organic compounds (PAHs, PCBs, pesticides, phthalates), particle size distribution, TOC, and other parameters. The sporadic collection of the dataset precluded an assessment of trends.
- **Green-Duwamish system.** Sediment quality data for the Duwamish Estuary were available from a number of investigations and studies conducted between 1991 and 2013:
    - In the Lower Duwamish Waterway, 76 sediment sampling events occurred between 1991 and 2009 as part of the remedial investigation conducted by the Lower Duwamish Waterway Group in response to the listing of the Lower Duwamish Waterway as a Superfund site (AECOM, 2012).
    - The East Waterway sediment data, obtained from the supplemental remedial investigation, were compiled from 17 sampling events between 1995 and 2009 (Windward and Anchor QEA, 2014).
    - Sediment data for the sediment cleanup area in the West Waterway were obtained from the Lockheed West Seattle remedial investigation and feasibility study (Tetra Tech, 2012).
    - King County conducted sediment quality studies between 1995 and 2013 near some CSO outfall discharge locations in the Duwamish Estuary. (King County, 1998; King County unpublished data, 2013).

The lack of recent sediment data in Lake Union/Ship Canal was considered a data gap; the lack of routinely collected sediment data in all three study areas was considered a limitation because trends could not be assessed.

2.8 Benthic Invertebrates

Collection of benthic invertebrate community data in the study areas is not part of King County's routine monitoring program. However, limited benthic invertebrate data have been collected sporadically in the study areas for site-specific projects:

- **Lake Union/Ship Canal.** Fourteen benthic samples were collected in 2001 from the main basin of Lake Union, Portage Bay, the east and west arms of Lake Union, and Salmon Bay (King County, 2004).
- **Elliott Bay.** King County collected benthic community samples in 2010 near the Denny Way CSO. Ecology collects benthic invertebrate data from several locations in Elliott Bay as part of two routine monitoring programs: the regional sediment monitoring program collects samples from six sites in Central Puget Sound (about every 10 years) and the more targeted Urban Waters Initiative collects samples from a larger number of sites (about every 6 years). The most recent sampling events in Elliott Bay occurred in 2008–2009 and 2013.
- **Green-Duwamish system.** Benthic invertebrate community data were collected in the Duwamish Estuary at the Duwamish-Diagonal storm drain/CSO outfall (five stations) and at Kellogg Island (five stations) in 1998. A sediment cleanup was completed at the Duwamish-Diagonal storm drain/CSO, and benthic data collected there no longer represents current conditions. Data collected at Kellogg Island is over 15 years old and also may not represent current conditions.

Benthic invertebrate data were not considered a data gap for this analysis. However, the lack of routinely collected benthic invertebrate samples is a limitation for characterizing benthic communities and assessing long-term trends in the study areas.

2.9 Tissue Chemistry

Tissue chemistry monitoring by King County or other agencies has been sporadic. Tissue chemistry monitoring was recently added to the County's routine monitoring program, but these data were not available for this assessment. Data for this assessment were compiled from a number of studies conducted by several agencies for specific projects:

- **Lake Union/Ship Canal.** No tissue chemistry data are available for this assessment. Tissue chemistry data for a number of Lake Union species were collected in 2016 as part of King County's freshwater tissue monitoring program.
- **Elliott Bay.** King County routinely collected clam tissue chemistry data from a single location in Elliott Bay between1970 and 2010. Samples were collected every other year and are sufficient to assess trends. The County collected flatfish and rockfish samples in 2015 and crab samples in 2014 from Elliott Bay (too recent to include in the assessment). The Washington State Department of Fish and Wildlife (WDFW) collected mussel tissue data (deployed mussel cages) in 2012 and 2013 as part of a pilot expansion of the Mussel Watch Program (WDFW, 2014a). WDFW also completed a crab and prawn tissue chemistry study in 2011 and 2012 (WDFW, 2014b). Both WDFW studies collected samples from Elliott Bay.

- **Green-Duwamish system.** The Lower Duwamish Waterway and East Waterway remedial investigations (Windward, 2010; Windward and Anchor QEA, 2014) and the West Waterway record of decision (EPA, 2003) reported tissue data for multiple resident species including fish, crab, and bivalves.

The lack of tissue chemistry data in both Lake Union/Ship Canal and Elliott Bay was considered a data gap for purposes of this water quality assessment. In summer 2016, King County started collecting tissue samples in Lake Union on a five-year rotation. Fish samples will be collected from Elliott Bay every other year; crab and other species of interest will be collected on a periodic rotation. Data are intended to represent typical species consumed by humans or species that are key indicators of ecological health.

2.10 CSO Water Quality Data

CSO water quality data were not considered a data gap. King County has collected CSO effluent water quality samples since 1985 and has analyzed them for a number of physical, metal, and organic parameters. A total of 173 samples collected from the entire wastewater service area were analyzed during this study. However, CSO discharges have not been monitored for many of the contaminants of emerging concern and sources of PCBs and PBDEs to the combined sewer basins have not been tracked.

2.11 Stormwater Quality Data

Stormwater quality data were not considered a data gap. Data were available from Ecology's National Pollutant Discharge Elimination System (NPDES) Phase 1 permit monitoring program (Ecology, 2015) and from the National Stormwater Quality Database (Pitt et al., 2004), which covers a broad range of locations and a variety of conditions. However, information is lacking on PCBs, PBDEs, and CECs in stormwater.

3.0 PROPOSED STUDIES TO FILL DATA GAPS

The project team, STRT, and King County management identified the following studies to fill the data gaps described in Chapter 2.

3.1 Identify Bacteria Sources and Pathways to the Study Areas

Lake Union/Ship Canal, Elliott Bay, and the Duwamish Estuary are on Ecology's 303(d) list of impaired waters for bacterial exceedance of state WQC (WAC 173-201A). Ambient water quality monitoring of fecal coliform bacteria has been conducted in these areas since the 1970s. The monitoring is designed to gather monthly data from stations in each waterbody to assess overall water quality and track bacterial contamination over time. The spatial density of this type of monitoring program is insufficient to identify bacteria sources or pathways in these surface waters.

Filling this data gap would require collection of bacterial samples in the three waterbodies at a spatial resolution sufficient to identify potential areas or pathways of concern. It would also be necessary to collect samples both during wet weather, when CSOs and storm drains are contributing flows to the study areas, and during dry weather when they are not. Microbial source tracking techniques would also help identify whether bacteria are of human origin and their sources.

3.2 Characterize Current Sediment Conditions in Lake Union/Ship Canal

The most recent data collected to characterize sediment quality in the Lake Union/Ship Canal area are approximately 14 years old. These data include results for metals and organic compounds such as hydrocarbons, phthalates, and physical parameters. Other recently collected sediment data are specific to outfalls or individual projects. The lack of recent sediment data limits the assessment of current sediment quality conditions in Lake Union/Ship Canal. A study to fill this data gap would involve sampling and analysis sufficient to characterize sediment quality in Lake Union/Ship Canal.

3.3 Assess Tissue Chemistry in Lake Union/Ship Canal and Elliott Bay

Resident fish can assimilate contaminants from their environment, resulting in adverse effects on their health and the health of people eating them. Although there are known sources of contaminants in Lake Union/Ship Canal and Elliott Bay, current tissue chemistry data from resident fish are lacking. This data gap limits the understanding of the fate of contaminants in these areas. A study to fill this data gap would include collection and analysis of tissue chemistry from a variety of species in Lake Union/Ship Canal and Elliott Bay.

3.4 Identify Sources of PCBs and PBDEs to CSO Basins

Previous monitoring studies found PCBs and PBDEs in the discharge from CSO basins. The spatial distribution of available data is insufficient to identify sources for targeting source control efforts to remove these compounds from sewage and/or stormwater. A study to fill this data gap would collect samples from CSO basins draining to Lake Union/Ship Canal and Elliott Bay in order to trace PCBs and PBDEs to their sources. This study would be similar to the efforts by the Duwamish Source Control Workgroup, which is made up of Ecology, City of Seattle, EPA, and King County, to trace sources of organic and other contaminants draining to the Duwamish Waterway.

3.5 Assess Contaminants of Emerging Concern in the Water Column in the Study Areas

A growing body of research shows that pharmaceuticals, personal care products, and other consumer chemicals may affect human and environmental health. Additionally, new and enhanced analytical methods are now available to test for compounds that were not available previously. No information is available on the presence of these compounds in Lake Union/Ship Canal, Elliott Bay, and the Duwamish Estuary. A study to fill this data gap would include collection and analysis of water column samples in the three study areas.

3.6 Identify Sewage Tracers in the Study Areas

For years, researchers have been investigating the potential for using common chemicals present in sewage to trace the fate of sewage in surface waters. Recent advancements in methods to detect new chemicals in surface waters have led researchers to include pharmaceuticals, personal care products, or artificial sweeteners to the list of chemicals that could be used to track sewage. These chemicals, or tracers, could be used to determine if fecal contamination in surface waters was related to sewage or other sources. The presence and concentration of tracers in the study areas could be used to prioritize CSO control projects and would be a useful post-construction monitoring tool that would allow King County to document a reduction in sewage discharges to its receiving waters.

3.7 Collect Data on Metals and Organic Compounds in the Water Column in Elliott Bay and Duwamish Estuary

Existing data for water column metals in Elliott Bay are over a decade old and have only been collected at a few locations. No metals data are available along the Seattle waterfront, where contaminated sediments are a known concern. Current water column data for organic compounds are also not available; the most recent samples were collected in 2004.

Knowledge of the effects of PCBs and PBDEs on human and aquatic health has improved in the last 10 years, as have methods of detection. PCBs and PBDEs are a concern for both

human and aquatic health because of their bioaccumulative potential. PCB congener data are available for one site in Elliott Bay; no PBDE data are available for Elliott Bay or the Duwamish Estuary.

A study to fill these data gaps would measure water column concentrations of metals, organic compounds, and PCB and PBDE congeners in Elliott Bay and along the Seattle waterfront and PBDE congeners in the Duwamish Estuary.

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4.0 PRIORITIZATING AND SELECTING DATA GAP STUDIES

Once the existing data were assessed for gaps, project staff and the STRT discussed how to rank gaps by importance and evaluate the feasibility of conducting studies to fill some of them within the timeframe and budget of the Water Quality Assessment and Monitoring Study. The STRT suggested a process used by the City of Philadelphia to rank concerns raised during an update of its long-term CSO control plan (City of Philadelphia, 2009). Philadelphia developed a priority matrix to identify the most important concerns facing the City and the CSO control program. King County adapted this matrix to prioritize data gaps and select which gaps to fill by new studies during the Water Quality Assessment and Monitoring Study.

This chapter describes prioritization criteria, criteria scoring, and prioritization scores for each proposed study to fill data gaps in the study areas, and then summarizes the rationale for deciding which studies to implement and which to forego.

4.1 Prioritization Criteria

King County staff and management worked with the STRT to develop prioritization criteria to assess the importance of a data gap study in light of Water Quality Assessment and Monitoring Study questions and goals. The prioritization criteria are described below:

- **Current conditions.** The ability of a potential data gap study to improve the understanding of current conditions in the study areas was used as a criterion to prioritize projects. Lack of data to describe current conditions for some parameters and media in the three study areas was identified as a data gap. For example, the most recent sediment chemistry data collected from Lake Union is about 14 years old.
- **Source/pathway identification.** The degree to which a potential data gap study can help identify sources and pathways of contaminants was used as a criterion. While existing data provide an indication of the extent of water and sediment quality issues, only limited information is available to identify the source or pathway of contaminants. An understanding of sources and pathways is critical for developing solutions to these issues and answering study questions. For example, elevated bacteria levels are a concern in the study areas, yet there is limited information on specific bacteria sources and pathways.
- **Human health.** Potential data gap studies were evaluated for their ability to provide information on water quality issues with human health implications. For example, high bacteria concentrations may cause an increased risk of gastrointestinal illness.
- **Aesthetics.** If a waterbody has an unpleasant odor, is unsightly, or is generally perceived to be unpleasant, public use of the waterbody may be diminished. For example, in addition to a potential negative water quality affect, discharge of

untreated sewage from CSOs into a waterbody may elicit a negative reaction to swimming or wading there.

- **Aquatic health.** The degree to which a potential data gap study provides information on water quality concerns with impacts to aquatic life was used as a criterion. For example, concentrations of heavy metals can be toxic to fish and other aquatic organisms.
- **Regulatory concern.** The degree to which a potential data gap study addresses data gaps associated with a parameter that exceeds a water, sediment, or tissue quality criterion was used to prioritize studies. The study areas are listed on Ecology's 303(d) list of impaired water for some parameters. Additional data to better characterize these parameters are needed to address sediment and water quality concerns.
- **Known concern.** This criterion was used to ensure that known water quality issues were evaluated regardless of whether an established WQC was available or not. For example, there are no WQC for flame retardants (PBDEs), but these compounds are known to bioaccumulate and may cause adverse environmental effects.
- **CSO contribution.** The degree to which a data gap study would address a contaminant contributed by CSOs was considered. For example, CSOs are the largest contributor of bacteria in the study areas.

Additional criteria used to prioritize data gap studies are cost and timeframe. It was important that selected studies be performed within the scope and budget of the Water Quality Assessment and Monitoring Study and that they are completed during 2014 for incorporation prior to study completion in 2016.

4.2 Criteria Scoring

The project team, King County management, and STRT assigned weighted scores for prioritization measures for each criterion, as shown in Table 4-1.

Table 4-1. Criteria and prioritization measures for scoring proposed data gap studies.

Criteria	Prioritization Measure	Score
Human health	Potential acute concern	15
	Potential chronic concern	10
	No concern	0
Aesthetics	Aesthetics issue	5
	No aesthetics issue	0
Aquatic health	Aquatic health concern	10
	Unknown concern	5
	No concern	0
Are ambient data needed to assess current conditions?	Yes, no data are available	10
	Yes, data outdated or spatially limited	5
	No, adequate data are available	0
Ability to identify sources?	Yes	10
	Possibly	5
	No	0
Regulatory concern?	Regulatory criteria are available	10
	No criteria, but guidelines are available	5
	No regulatory standards	0
Known water quality concern?	303(d) listing	15
	Bioaccumulation potential	15
	Parameter of concern (exceeds threshold)	12
	Unknown problem	8
	No concern	0
Do CSOs contribute?	Yes, major pathway	10
	Yes, minor pathway	5
	No	0
Ability to complete in timeframe?	Based on best professional judgement, a study can be completed within the timeframe	Yes/No
Ability to complete within budget?	Based on best professional judgement, a study can be completed with the budget	Yes/No
Total possible score		85

4.3 Data Gap Study Prioritization Scores

The criteria scores and the total score for each data gap study for Lake Union/Ship Canal, Elliott Bay, and the Duwamish Estuary are shown in Tables 4-2 through 4-4.

Table 4-2. Prioritization scores for Lake Union/Ship Canal data gap studies.

Potential Study	Human Health	Aesthetics	Aquatic Health	Need for Data on Ambient Conditions	Ability to Identify Sources/ Pathways	Regulatory Concern	Known Water Quality Concern	Do CSOs Contribute?	Total Score	Within Budget	Within Schedule
Identify sources of bacterial contamination	15	5	0	0	5	10	15	10	60	Y	Y
Identify sources of PCBs to King County's combined sewer system	10	0	10	0	5	10	15	5	55	N	N
Identify sources of PBDEs to King County's combined sewer system	10	0	10	0	5	5	15	5	50	N	N
Ambient sediment characterization (including PCBs and PBDE congeners)	10	0	10	5	0	10	15	5	55	Y	Y
Fish tissue chemistry	10	0	10	10	0	10	8	5	53	Y	N
Identify contaminants of emerging concern (ambient water)	0	5	10	10	0	0	8	10	43	Y	Y
Identify conservative sewage tracer	15	5	0	0	5	0	15	10	65	Y[a]	Y[a]
Total possible score									85		

[a] Literature review.

Table 4-3. Prioritization scores for Elliott Bay data gap studies.

Potential Study	Human Health	Aesthetics	Aquatic Health	Need for Data on Ambient Conditions	Ability to Identify Sources/ Pathways	Regulatory Concern	Known Water Quality Concern	Do CSOs Contribute?	Total Score	Within Budget	Within Schedule
Identify sources and pathways of bacterial contamination	15	5	0	0	5	10	15	10	60	Y	Y
Collect PBDE data (ambient water)	10	0	10	10	0	0	8	10	48	Y	Y
Collect PCB congener data (ambient water)	10	0	10	5	0	10	15	10	60	Y	Y
Identify sources of PCBs to King County's combined sewer system	10	0	10	0	5	10	15	5	55	N	N
Identify sources of PBDEs to King County's combined sewer system	10	0	10	0	5	5	15	5	50	N	N
Collect organic chemical data (ambient water)	0	0	10	5	0	10	0	5	30	Y	Y
Collect metals data from Seattle waterfront (ambient water)	0	0	10	5	0	10	0	5	30	Y	Y
Identify contaminants of emerging concern in ambient conditions	0	5	10	10	0	0	8	10	43	Y	Y
Identify conservative sewage tracer	15	5	0	0	5	0	15	10	65	Y[a]	Y[a]
Total possible score									85		

[a] Literature review.

Table 4-4. Prioritization scores for Duwamish Estuary data gap studies.

Potential Study	Human Health	Aesthetics	Aquatic Health	Need for Data on Ambient Conditions	Ability to Identify Sources/ Pathways	Regulatory Concern	Known Water Quality Concern	Do CSOs Contribute?	Total Score	Within Budget	Within Schedule
Identify sources of bacterial contamination	15	5	0	0	5	10	15	10	60	Y	Y
Collect data on PBDE concentrations (ambient water)	10	0	10	10	0	0	8	10	48	Y	Y
Identify contaminants of emerging concern in ambient conditions	0	5	10	10	0	0	8	10	43	Y	Y
Identify conservative sewage tracer	15	5	0	0	5	0	15	10	65	Y[a]	Y[a]
Total possible score									85		

[a] Literature review.

4.4 Selection of Data Gap Studies

Prioritization scores were discussed among the project team, STRT, and King County management to identify studies for implementation. This section describes the rationale for the decisions regarding which studies to forego and which to implement during the course of the Water Quality Assessment and Monitoring Study. While not all data gaps will be filled as a part of the study, this data gap assessment has informed other monitoring efforts in the County. Some high priority data gaps not filled as part of the study, such as Lake Union sediments and fish tissue, are being addressed as part of other county environmental monitoring.

4.5 Data Gap Studies Selected for Implementation

The following three studies were selected for implementation:

- **Bacteria sources/pathways in the three study areas.** This study scored highest in each of the study areas because bacteria levels are a known water quality impairment and a public health concern. It was deemed feasible to conduct such a study within the timeframe and budget of the Water Quality Assessment and Monitoring Study. This study was completed and results appear in King County 2017d.
- **Conservative sewage tracers (literature review).** An investigation of sewage tracers was proposed as a literature review because implementation of a field

investigation was beyond the study timeframe and budget. This study was completed and results appear in King County 2017e.

- **Contaminants of emerging concern in surface waters in the three study areas.** A survey-level evaluation was proposed in which ambient water quality samples would be collected and analyzed for a select group of contaminants of emerging concern in order to better understand the presence and general distribution of these compounds in the study areas. The survey design could be implemented within the timeframe and budget. This study was completed and results appear in King County 2017f.

4.5.1 Data Gap Studies Not Selected for Implementation

Potential studies that were not selected for completion are as follows:

- **Source identification of PCBs and PBDEs in King County's combined sewer basins.** This study was not undertaken because it was outside the scope, schedule, and budget for the Water Quality Assessment and Monitoring Study.
- **Chemical concentrations in fish tissue.** While this is an important data gap, the logistics of obtaining fish collection permits and completing sample collection within the schedule was not feasible. King County recently initiated a tissue monitoring program as part of its ongoing monitoring efforts. Tissue samples were collected from Lake Union in spring 2016 for analysis of a suite of parameters including PCBs. However, the data will not be available in time for inclusion in the Water Quality Assessment and Monitoring Study. Samples are scheduled to be collected from Elliott Bay in 2017.
- **Lake Union sediment chemistry analysis.** Older data on Lake Union sediment chemistry were used to answer study questions. The gap in more recent data is being filled as part of an additional monitoring effort carried out in 2015; however, these data will not be available in time for inclusion in the Water Quality Assessment and Monitoring Study.
- **Elliott Bay ambient water column organics and metals chemistry study.** A study of the ambient water column concentrations of PBDEs, PCBs, other organic compounds, and metals in Elliott Bay was not conducted because it did not score as high as other studies and was outside the budget of the Water Quality Assessment and Monitoring Study.
- **Duwamish Estuary ambient water column PBDE study.** A study of the ambient water column concentrations of PBDEs in the Duwamish Estuary was not conducted because it did not score as high as other studies and was outside the budget of the Water Quality Assessment and Monitoring Study.

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