
Water Quality Assessment and Monitoring Study: Analysis of Existing Data on Elliott Bay

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King County

Department of Natural Resources and Parks
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Water Quality Assessment and Monitoring Study: Analysis of Existing Data on Elliott Bay

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Wastewater Treatment Division

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EXECUTIVE SUMMARY

King County completed a study of Elliott Bay, using data previously collected from a variety of monitoring studies, to characterize existing water quality and other indicators of health, evaluate long-term trends, describe potential sources of pollution, and identify limitations and gaps in current data. The study was prepared as part of a Water Quality Assessment and Monitoring Study, undertaken to explore ways to optimize water quality improvements in the three waterbodies where the County is planning combined sewer overflow (CSO) control projects—Elliott Bay, Lake Union/Ship Canal, and the Duwamish Estuary.

Background

King County updates its CSO control plan about every five years. Before each update, the County reviews its entire CSO Control Program against conditions that have changed since the last update. In September 2012, the King County Council passed Ordinance 17413 approving an amendment to the County’s long-term CSO control plan. The plan includes nine projects to control the County’s remaining 14 uncontrolled CSOs by 2030. The recommended projects involve construction of underground storage tanks, green stormwater infrastructure, wet weather treatment facilities, or a combination of approaches.

Ordinance 17413 also calls for completion of a Water Quality Assessment and Monitoring Study to inform the next plan update due to the Washington State Department of Ecology (Ecology) in 2019. This study of existing information on water quality in Elliott Bay addresses one of the assessment’s study questions: “What are the existing and projected water quality impairments in receiving waters (waterbodies) where King County CSOs discharge?” As a part of the assessment, similar studies are being completed for Lake Union/Ship Canal and the Duwamish Estuary. The final product of the assessment will be a synthesis report that incorporates the results of these studies and of other studies conducted to fill identified data gaps and analyze pollutant loadings to the three waterbodies.

Study Area

Elliott Bay is an estuarine system dominated by the marine water of Puget Sound and influenced by the fresh water of the Duwamish Estuary, which discharges into the southeastern corner of the bay. Much of present-day Elliott Bay used to be a complex tidal marsh habitat that frequently flooded. Beginning in the late 1800s, the estuary tidelands were filled, drained, and dredged to support increased industrial and port activities both in Elliott Bay and upstream in the Duwamish Estuary.

The Elliott Bay study area (Figure ES-1) is divided into two sections:

- Inner Elliott Bay, east of a line drawn between Duwamish Head in West Seattle and Magnolia Bluff near Smith Cove. Inner Elliott Bay includes all of King County's uncontrolled CSOs within the bay not currently undergoing upgrades.
- Outer Elliott Bay, east of a line drawn between Four Mile Rock and Alki Point. The outer boundary was chosen to be consistent with recent studies conducted by Ecology.

The study area is bordered on the east, north, and south by Seattle neighborhoods, including the downtown area to the east and industrialized Harbor Island in the southeast corner, and on the west by the waters of the Central Basin of Puget Sound. Much of the data used in this study were collected in Inner Elliott Bay. Data from Outer Elliott Bay and an area of the Central Basin waters (bordered to the west by a line drawn southward from the western tip of Discovery Park to just west of Alki Point) are also included to illustrate the impact of Inner Elliott Bay on these waters.

In addition to industrial and shipping activities, the study area hosts fishing, boating, scuba diving, and beach activities. As an estuary, it supports a high diversity of fish, invertebrate, bird, and mammal species and acts as a transitory pathway for salmon migrating through the Duwamish Estuary and into the Green River. In addition to salmon, several other federally threatened and endangered species use Elliott Bay either as a permanent habitat or as a migratory route. Humans, threatened/endangered species, and other organisms that use the waters of Elliott Bay are potentially at risk from historical and ongoing sources of contamination.

Sources and Pathways of Contamination

King County and the City of Seattle operate a total 17 CSO outfalls that discharge to the Elliott Bay study area and many more that discharge upstream in the Duwamish Estuary (Figure ES-2). Six of the CSOs in the study area currently discharge untreated wastewater and stormwater more often than the Washington State standard for "control" of once a year on a 20-year moving average. In addition, there are over 40 known outfalls that discharge only stormwater to the study area from the separated portion of the sewer system. The principal pollutants associated with stormwater and CSO discharges include pathogens, oxygen-depleting material, suspended solids, metals and organic compounds, nutrients, and trash/floatables.

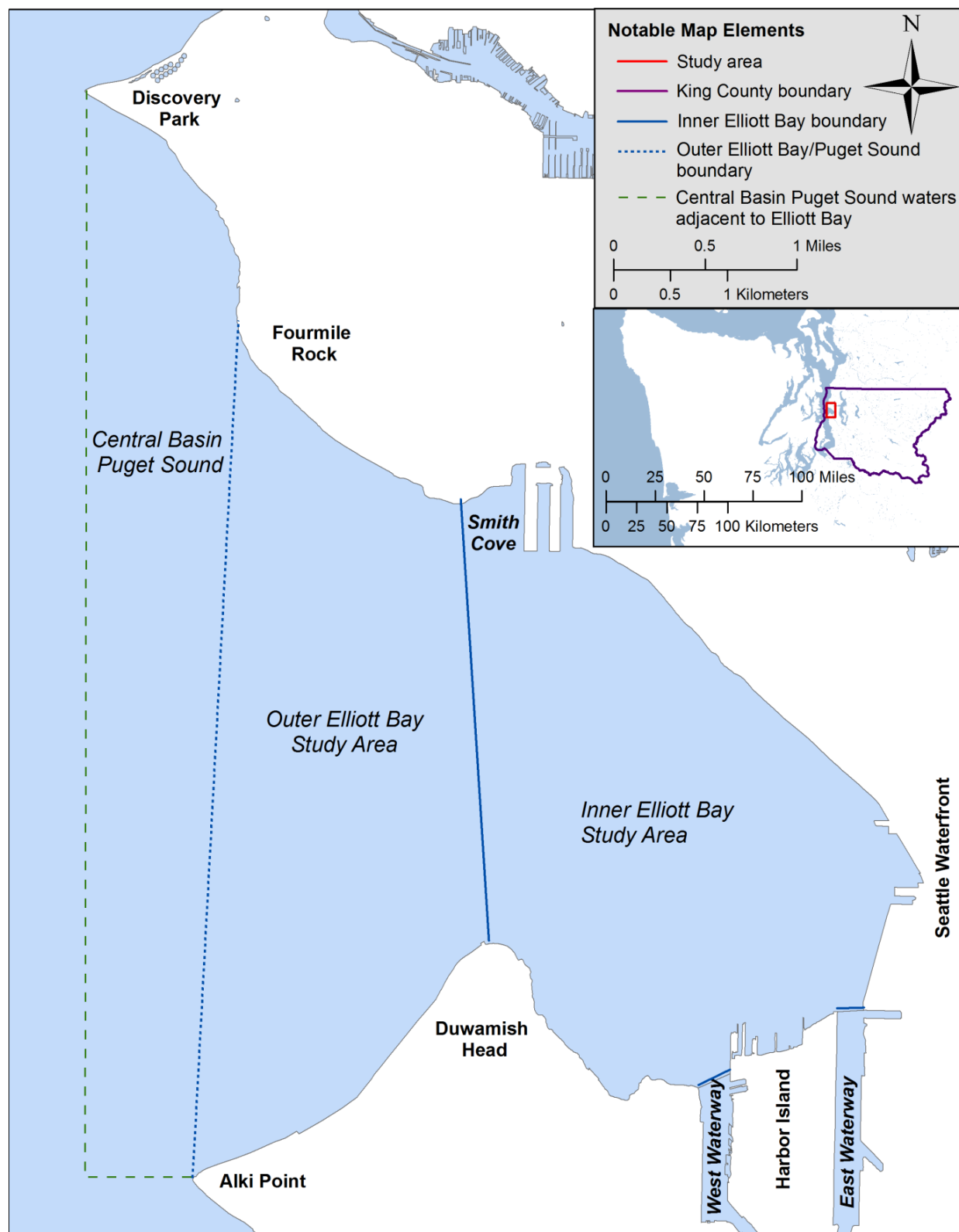


Figure ES-1. Study area including Inner and Outer Elliott Bay and adjacent Central Puget Sound waters.



Figure ES-2. Location of CSO, wastewater treatment plant, and stormwater outfalls in Elliott Bay and surrounding waters and the type of sewer and stormwater systems.

In addition to CSOs, there are many potential sources and pathways of contaminants to the bay. Port of Seattle activity is an ongoing pathway of pollution, including resuspension of contaminated sediments by large vessels. Additional pathways include contaminated groundwater, oil spills, illegal chemical dumping, atmospheric deposition, and continual inputs from upstream sources such as from the Green and Duwamish rivers. Water and sediments in the study area have been subject to years of discharges and spills from the shipping industry, untreated sewage, untreated stormwater, and other industrial discharges. Along with urbanization, these sources have produced much of the historical contamination existing today. Table ES-1 lists water quality parameters likely significantly altered in Elliott Bay by historical and current human activities since the late 1800s.

Table ES-1. Water quality parameters likely altered in Elliott Bay by human activities.

Activity	Bacteria	Temperature	Dissolved oxygen	pH	Water clarity	Nutrients	Metals	Organic compounds
Agriculture/livestock production	X	X	X	X	X	X		
Discharge of sewage and stormwater	X		X	X	X	X	X	X
Dredging/channelization/regarding	X				X		X	X
Industrial/shipping activities				X			X	X
Logging	X	X				X		

Highlighted rows indicate major ongoing activities.

The area has been, and still is, the focus of several efforts to clean up historical pollution, particularly in sediments, through Superfund and state-led programs.¹ Planned CSO control projects, increased green and other stormwater infrastructure, and various construction projects with environmental improvement components are expected to have positive impacts on nearshore water quality in Elliott Bay.

Findings

In general, the main water quality issues in Elliott Bay are high bacteria concentrations, high temperatures in surface waters in the summer, and low dissolved oxygen concentrations, particularly in the fall. More data on the seasonal and spatial variability of metals and organics concentrations are needed to fully evaluate their potential impact on overall water quality, although concentrations appear low. In sediments, mercury, polycyclic aromatic hydrocarbon (PAHs), phthalates, and polychlorinated biphenyls (PCBs) are the chemicals of highest concern; limited data are available on polybrominated diphenyl ethers (PBDEs) and dioxins/furans, which are also potentially of concern because of their bioaccumulative properties. Tissue data indicate that PAHs, PCBs, and PBDEs are

¹ Superfund is the federal environmental program established to address abandoned hazardous waste sites.

chemicals of highest concern for fish and shellfish. Details on these findings, current conditions, and long-term trends can be found below.

Water Quality

Conclusions from analysis of bacteria, temperature, dissolved oxygen, pH, nutrients, metals, and organics data for Elliott Bay waters are as follows:

- **Bacteria.** From a regulatory and human health standpoint, elevated bacteria concentrations (as measured by fecal coliforms) are a persistent water quality issue in Elliott Bay. Concentrations of fecal coliform are highest nearshore, particularly near the downtown Seattle waterfront. Nearshore bacteria concentrations have declined in the last several decades despite frequent Washington State water quality criteria (WQC) exceedances. This decline is likely due, in part, to increased CSO control. Nonetheless, bacteria concentrations are still elevated above WQC, especially near the shoreline.
- **Temperature.** WQC for temperature were set at levels to protect aquatic life including temperature-dependent species such as salmon. Water temperature exceeds WQC in much of Elliott Bay and may be too high for some aquatic organisms including salmonids, particularly in surface waters during the summer. Temperature in the bay is greatly influenced by large-scale climate patterns, and no definitive trend for the overall bay could be discerned from the data.
- **Dissolved oxygen.** WQC for dissolved oxygen (DO) are commonly exceeded in Elliott Bay, especially at depth and during fall. DO concentrations commonly fall below the state WQC at several locations in the bay and adjacent Puget Sound. Low DO environments can be detrimental to aquatic life. Concentrations are lowest in the deep waters of the bay and in the late summer/early fall when low-DO deep waters from the Pacific Ocean upwell into Puget Sound with subsequent de-stratification in Elliott Bay. In contrast, surface waters are typically saturated with DO from May to August when phytoplankton are at their peak abundances. DO concentrations in Elliott Bay have not significantly changed in the last 15–20 years.
- **pH.** pH, a measure of acidity or alkalinity, has not been reliably or consistently monitored in the last several decades in Elliott Bay. Monitoring pH is important because of the increasing concern regarding climate change and ocean acidification in the Puget Sound region. To address the lack of pH data, the National Oceanographic and Atmospheric Administration's Pacific Marine Environmental Laboratory is installing a pH monitoring station at the Seattle Aquarium, and in 2015, King County installed high-precision pH sensors at continuous monitoring stations in Central Puget Sound.
- **Nutrients.** Nitrogen, phosphorus, and silica concentrations in Elliott Bay are largely influenced by inputs from oceanic and freshwater sources and the growth and decay of phytoplankton. Elevated ammonia concentrations observed from routine monitoring at depth near the South Treatment Plant outfalls, located near the boundary of Elliott Bay and Puget Sound, are the only evidence of the presence of treated effluent. Throughout Elliott Bay, including waters surrounding other

outfalls, nutrients are well below WQC. No definitive trends were identified in nutrient concentrations over the past two decades, suggesting no substantial changes in nutrient loads.

- **Metals.** Recent water column data on metals concentrations are insufficient for assessing current water quality conditions in Elliott Bay. Metals have been analyzed at only one site in Elliott Bay in the last decade, and no data exist for the Seattle waterfront. The available data indicate that metals are well below Washington State WQC and U.S. Environmental Protection Agency (EPA) Human Health Criteria. Spatial and temporal patterns of metals in the bay could not be assessed because of data limitations.
- **Organic compounds.** Over the past decade, organic compounds were sampled at only two sites in Elliott Bay. Data indicate that chemical concentrations do not exceed Washington State WQC; however, concentrations of bis(2-ethylhexyl)phthalate and three high molecular weight PAHs (HPAHs) (benzo(a)anthracene, benzo(b)fluoranthene, and benzo(k)fluoranthene) occasionally exceed EPA Human Health Criteria. The mean concentration at any one site never exceeded the criteria. In addition, outdated analytical techniques have yielded samples with frequent blank contamination and detection limits above many of the state chronic WQC and EPA Human Health Criteria. Improved analytical methods would produce more reliable and informative data if future samples were to be collected. In addition, many chemicals currently not monitored are likely to enter the environment through point and nonpoint sources. Little is known about chemicals of emerging concern including pharmaceuticals, pesticides, and flame-retardants still in use. Future studies should consider inclusion of these chemicals.

Sediments

Pollutant concentrations in Elliott Bay marine sediments are spatially variable. Elevated sediment contaminant concentrations occur in discrete areas (“hot spots”) as the result of historical and/or current sources, including industrial discharges, port/maritime activity, stormwater and wastewater outfalls, surface runoff, combustion, and aerial deposition. Mercury, PAHs, PCBs, and phthalates are the priority pollutants that exceed Washington State Sediment Management Standards (SMS) most frequently and could, therefore, adversely affect sediment-dwelling organisms (benthos). Although there are no regulatory criteria and few data on PBDE and dioxin/furan concentrations, these chemicals are a concern because of their toxicity and propensity to bioaccumulate.

Overall, this study found that sediments in the nearshore areas of Inner Elliott Bay have the potential to adversely affect benthos because they often exceed the SMS. Sediments along the downtown Seattle waterfront are of particular concern. These sediments exceed criteria for metals (arsenic, copper, lead, mercury, silver, and zinc), PAHs, PCBs, 1,4-dichlorobenzene, dibenzofuran, N-nitrosodiphenylamine, and phthalates. Sediments in northeast Elliott Bay near the Denny Way CSO and in southern Elliott Bay near Harbor Island also exceed the SMS. Nearshore sites in Outer Elliott Bay, including those off of the Magnolia and 53rd Ave SW CSO outfalls, very rarely exceed sediment criteria. In deep

offshore sites in the center of the bay, mercury, silver, and PCBs were the only criteria that were exceeded more than once.

Improvements have been observed in concentrations of mercury, HPAHs, and PCBs in sediments. Although some chemical concentrations appear to be declining, sediment contamination remains. In a 1999 study, King County indicated that risks to sediment-dwelling organisms from organic enrichment, and possibly 1,4-dichlorobenzene and bis(2-ethylhexyl)phthalate, in the immediate vicinity of CSOs would be reduced as the result of CSO control. However, if no other action is taken, threats from other chemicals such as mercury, PAHs, and PCBs will remain after all CSO locations are controlled.

Source control and sediment cleanup projects have been completed in the study area, including in the vicinity of the Denny Way CSO outfall, and others are in progress. Additional projects could speed up these improvements at the many hot spots for sediment contamination in Elliott Bay that are not receiving immediate attention such as the downtown Seattle waterfront.

Marine Benthos

Data on marine benthos populations are useful for evaluating the impact of point sources, such as CSOs, on biological communities. Because of their close contact with sediments, the abundance and diversity of benthos can be indicators of stressed biological communities as the result of exposure to sediment-associated contaminants from nearby point sources.

Recent marine benthos data collected by King County in Elliott Bay are limited to sites in the vicinity of the outfalls for the Elliott West wet weather treatment facility and Denny Way CSO in northeastern Elliott Bay. Similar to elsewhere in Puget Sound, benthic community composition is highly influenced by depth and sediment grain size and to a lesser degree by chemical contaminants including some metals and PAHs. Benthic communities near the outfalls had significantly lower benthic indices (quantitative method for determining benthic community health) than communities at sites with similar depth and grain size. These data indicate that proximity to outfalls may have an effect on community composition. However, it should be noted that communities at shallow-water sites were more variable than those at deep sites including those near the outfalls. Data from a reference site are needed to make acceptable comparisons to benthic communities elsewhere in Puget Sound.

Ecology routinely evaluates sediment benthos throughout Elliott Bay, but does not target areas influenced by point sources. The evaluations have concluded that benthos at mid-depth sites near Magnolia Bluff and Pier 90, mid-depth sites north of Harbor Island, a shallow site north of Duwamish Head, and two deep depositional sites were “affected” or negatively impacted by contaminated sediment. Ecology has also conducted sediment toxicity testing. Toxicity was found for test organisms exposed to sediment at a single site near Magnolia Bluff; no toxicity was found from shallow sites along the downtown Seattle waterfront.

Ecology and King County benthos data are not comparable because of differences in sample collection and data analysis methods. Moreover, the limited data cannot be used to fully evaluate the effects of point sources, such as the Denny Way CSO, on benthic communities. In order to make acceptable comparisons between benthic communities at sites with point sources to communities elsewhere in Elliott Bay and Puget Sound, additional benthic sampling locations are needed.

Tissue Chemistry

Contaminant accumulation in shellfish tissue in Elliott Bay is influenced by several factors including location, lipid content, and time of year the samples are collected. Contaminants in organisms collected from heavily urbanized areas, such as Elliott Bay, appear to have higher concentrations of some chemicals including dichlorodiphenyltrichloroethane (DDT), PCBs, PAHs, and PBDEs than elsewhere in Puget Sound. However, metals concentrations in clams collected in the vicinity of southern Discovery Park, the only King County-monitored site near Elliott Bay, were below recommended health-based EPA screening values for metals concentrations.

PAHs, PCBs, PBDEs, and DDT were measured in mussel tissue from Elliott Bay collected during the Puget Sound Ecosystem Monitoring Program effort in winter 2012–2013. The highest PAH concentrations in Puget Sound were detected at four Elliott Bay locations (Myrtle Edwards Park, Four Mile Rock, Pier 59, and Smith Cove). Samples from these same locations had only moderately elevated PCBs and had lower PBDE and DDT concentrations than PAHs and PCBs. In comparison, crab and shrimp tissue samples from deeper water sites had lower PAH, PBDE, and DDT concentrations but higher PCB concentrations at similar locations in Elliott Bay.

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:

- Two reports describe existing conditions and long-term trends in two other study areas—Lake Union/Ship Canal and the Duwamish Estuary.
- A report documents the process used to assess identified data gaps for the study areas and select studies to fill prioritized gaps.
- 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.

ABBREVIATIONS AND ACRONYMS

2LAET	Second Lowest Apparent Effects Threshold
AET	Apparent Effects Threshold
ACOE	U.S. Army Corps of Engineers
ANOVA	analysis of variance
BNAs	base/neutral/acid extractable semivolatile compounds
CFU	colony forming unit
CSL	cleanup screening levels
CSO	combined sewer overflow
CTD	conductivity-temperature-dissolved oxygen
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DO	dissolved oxygen
dw	dry weight
EB/DRRP	Elliott Bay/Duwamish River Restoration Program
Ecology	Washington State Department of Ecology
EDC	endocrine disrupting compound
EIM	environmental information system
ENSO	El Niño Southern Oscillation
EPA	U.S. Environmental Protection Agency
FOD	frequency of detection
GSI	green stormwater infrastructure
HPAH	high molecular weight PAH
KCEL	King County Environmental Laboratory
LIMS	laboratory information management system
LOQ	limit of quantitation
LPAH	low molecular weight PAH
MDL	method detection limit
MDS	multidimensional scaling
MPN	most probable number
NOAA	National Oceanic and Atmospheric Administration

NOAA-PMEL	NOAA's Pacific Marine Environmental Laboratory
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit
OC	organic carbon
PAH	polycyclic aromatic hydrocarbon
PAR	photosynthetically active radiation
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
PDO	Pacific Decadal Oscillation
POP	persistent organic pollutant
PSEMP	Puget Sound Ecosystem Monitoring Program
PSU	practical salinity unit
QC	quality control
RCRA	Resource Conservation and Recovery Act
SCO	Sediment Cleanup Objective
SMS	Sediment Management Standards
SQS	Sediment Quality Standards
TOC	total organic carbon
TSS	total suspended solids
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife
WDOH	Washington State Department of Health
WSDOT	Washington State Department of Transportation
WTD	Wastewater Treatment Division
ww	wet weight

1.0 INTRODUCTION

This report summarizes existing information on water quality and other indicators of the environmental conditions of Elliott Bay, a Puget Sound estuarine bay bordered by downtown Seattle. The report was prepared as part of King County's Water Quality Assessment and Monitoring Study. The study was undertaken to explore ways to optimize water quality improvements in waterbodies where the County is planning combined sewer overflow control projects.

The following sections describe King County's wastewater system, its Combined Sewer Overflow Control Program, the Water Quality Assessment and Monitoring Study, and the scope and content of this report.

1.1 King County Wastewater System

King County owns and operates a regional wastewater system that serves 1.7 million people in a 420-square-mile area in Washington state. The area covers most of urban King County including Seattle, south Snohomish County, and a small portion of Pierce County (Figure 1-1).

The wastewater system is the largest in the Puget Sound region. It includes over 390 miles of pipelines that collect wastewater from 34 local sewer utilities. The pipelines carry the wastewater to three regional treatment plants—West Point Treatment Plant in the city of Seattle, South Treatment Plant in the city of Renton, and Brightwater Treatment Plant in south Snohomish County—that treat and disinfect the wastewater before discharging it to Puget Sound. The County also owns and operates two local treatment plants in the city of Carnation and on Vashon Island.

Through the early 20th century, most cities constructed combined sewers systems to collect both wastewater and stormwater in the same pipes. The combined sewers carried untreated wastewater directly to waterbodies. Today, combined flows are sent to treatment plants before being directly discharged to waterbodies. Untreated overflows occur only at designated locations during heavy storms when flows exceed the capacity of sewers and treatment plants. These combined sewer overflows (CSOs) serve as constructed relief points in preventing sewer backups into homes and streets.

In King County's regional wastewater system, combined sewers are located only in Seattle (Figure 1-1). Portions of this area contain separated sewers. King County owns and operates 38 CSO locations and the City of Seattle has 90 CSO locations in the city limits. The outfall pipes at these locations discharge wastewater diluted with stormwater to Puget Sound (including Elliott Bay), the Duwamish Estuary, Lake Union/Ship Canal, and Lake Washington during large storms. On average over the long term, about 350 CSO events occur from King County outfalls each year. Average annual volumes can be as low as zero at one location to over 200 million gallons (MG) at another; the total average annual volume discharged from all county locations is about 800 MG.

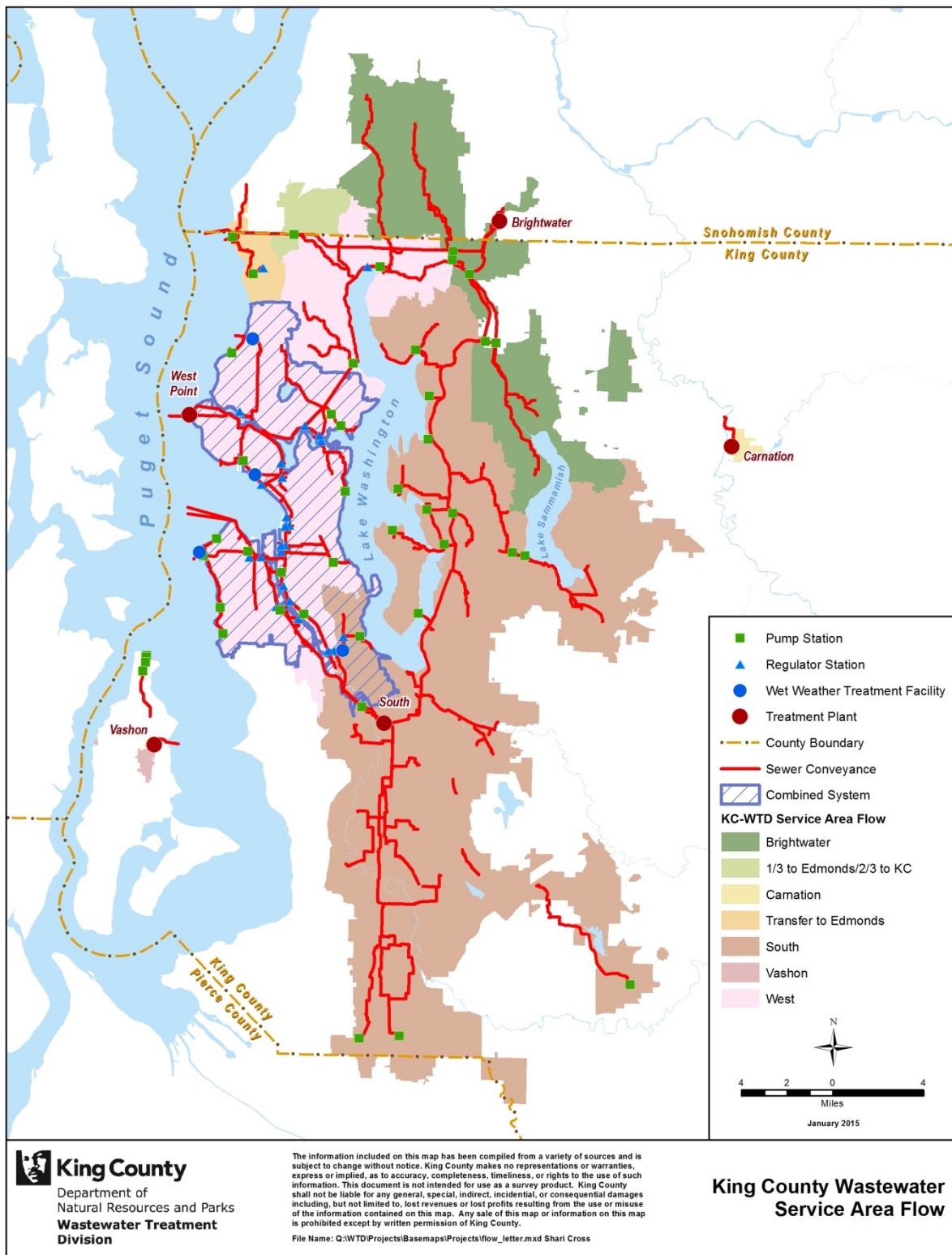


Figure 1-1. King County's Wastewater Treatment System.

1.2 CSO Control Program

CSO control is required by Washington State and federal law. “Control” means reducing the number of untreated overflows from each location to once per year on average. Because they contain both stormwater and wastewater, CSO discharges are more concentrated with harmful chemicals and disease-causing organisms than stormwater alone. Controlling CSOs protects public health and the environment. Since the regional wastewater system began operating in the 1960s, King County and the City of Seattle have reduced the volume of untreated sewage discharges by about 28 billion gallons a year. King County alone has invested \$389 million to reduce its CSO volumes from 2.3 billion gallons in the 1980s to about 1 billion gallons today. It is investing another \$117 million on projects that are under way. Only 14 of the County’s and about half of the City’s locations still require control.

King County updates its CSO control plan about every five years. Before each update, the County’s Wastewater Treatment Division (WTD) reviews its entire CSO Control Program against conditions that have changed since the last update—conditions such as population and wastewater flow, scientific developments, regulations, new technologies, and public priorities. The latest CSO Control Program review and plan update were completed in 2012. As a result, the King County Council approved an amendment in September 2012 to the County’s long-term CSO control plan (Ordinance 17413). The U.S. Environmental Protection Agency (EPA) also approved the plan in 2013, and the plan is incorporated into the consent decree that the County entered into with the U.S. Department of Justice, EPA, and the Washington State Department of Ecology (Ecology) in 2013.

The CSO control plan includes nine projects to control the remaining 14 uncontrolled CSOs by 2030. Four projects would be built in the Lake Union/Ship Canal area and five in the Duwamish Estuary/Elliott Bay area. The recommended projects involve construction of underground storage tanks, green stormwater infrastructure, and/or wet weather treatment facilities. 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 County Council approved the assessment’s scope of work through Motion 13966.

1.3 Water Quality Assessment and Monitoring Study

Work began in 2013 on the Water Quality Assessment and Monitoring Study. The objective of the assessment is to help ensure that investments in CSO control optimize water quality improvements in CSOs sub-basins. It includes a comprehensive scientific and technical analysis of existing water quality in the receiving waters 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. WTD will use the information to identify opportunities to lower the costs of implementing the

CSO control plan, establish baseline conditions for post-construction monitoring of CSO control projects, and decide whether to pursue an integrated CSO control plan based on EPA guidelines.

An integrated planning process has the potential to identify efficiencies in implementing competing requirements that arise from separate wastewater and stormwater projects, including capital investments and operation and maintenance requirements. This approach can build partnerships among agencies and jurisdictions and can lead to more sustainable and comprehensive solutions, such as green infrastructure, that improve water quality and support other attributes that enhance the vitality of communities.

The assessment sets out to generate information that will help answer the following questions:

1. What are the existing and projected water quality impairments in receiving waters (waterbodies) where King County CSOs discharge?
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?
7. What other possible ways, 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 the County and the region of completing all CSO control projects by 2030?

An external Scientific and Technical Review Team has been assembled to review methodology and results. A synthesis report will incorporate the results of the analyses, data gap studies, and additional assessments to evaluate how to maximize water quality benefits from CSO improvements. 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: <ul style="list-style-type: none"> • 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.	2,3	Data gap study reports: <ul style="list-style-type: none"> • Bacteria • Contaminants of emerging concern • Literature review of conservative sewage tracers 	2014–2017
Identify the current (2015) sources of impairments in the three waterbodies.	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.	1,4	Future Loadings Report	2015–2017
Analyze, synthesize, and summarize scientific and technical data collected and reviewed during the assessment.	2,3,4	Synthesis Report	2015–2017

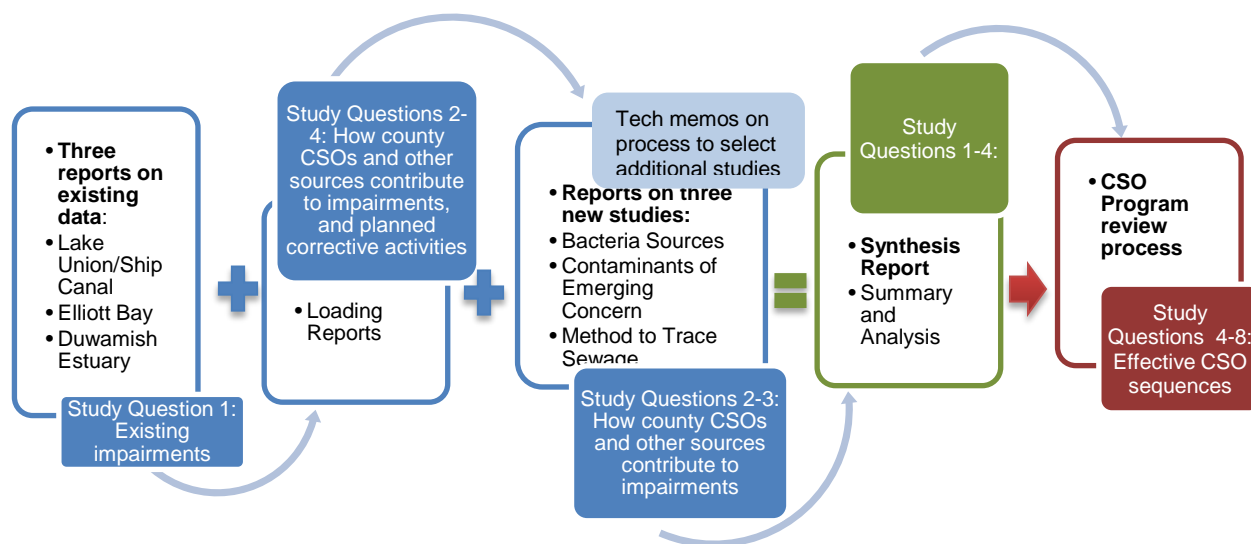


Figure 1-2. Reports and study questions answered as part of the Water Quality Assessment and Monitoring Study.

1.4 Scope and Content of this Report

The County owns five CSO outfalls in or near Elliott Bay. One is controlled, one is almost controlled, one will be controlled in 2016, and two are scheduled to be controlled by 2030. This “area” report documents existing information on water quality in Elliott Bay. It answers one of the assessment’s study questions: “What are the existing and projected water quality impairments in receiving waters (waterbodies) where King County CSOs discharge?” Similar reports are being produced for Lake Union/Ship Canal and the Duwamish Estuary (including the East and West Waterways of the river).

1.4.1 Geographic Limits

Water quality in Elliott Bay is influenced by Duwamish Estuary water that enters the bay through the East and West waterways. Two uncontrolled CSO locations in the East Waterway, in particular, are close to Elliott Bay and may influence its water quality. However, the East and West waterways and portions of the Lower Duwamish Waterway are Superfund sites and have been treated independently of Elliott Bay in previous studies. Maintaining this independence for the Water Quality and Assessment and Monitoring Study allows for manageable synthesis and documentation of the available data, both in terms of size and scope. Information from all area reports will be summarized in the synthesis report.

1.4.2 Sources and Quality of Data

King County and other agencies have collected data on water quality, sediment chemistry, benthic communities, and fish/shellfish tissue in Elliott Bay. These data were evaluated and summarized as a part of this assessment in order to describe current conditions, identify long-term trends, and review compliance with Washington State standards. Data include physical parameters in the water column (temperature, dissolved oxygen, salinity, pH, and turbidity/total suspended solids), chlorophyll-*a*, nutrients, fecal coliform bacteria, metals, and various groups of organic compounds. Data on metals and organic compounds in sediments, benthic community structure, and shellfish tissue were also analyzed.

Current water quality, marine benthos, and shellfish tissue conditions were assessed using the last 10 years of available data (2004–2013) to capture inter-annual variability while avoiding data that may not reflect the current state. The exception was in cases where parameters were added or removed or when substantial method detection changes occurred over time. Sites with over 10 years of data were used for evaluating long-term trends. Trend analyses were conducted over different timeframes because of changes in the location of sites monitored. Some sites lacked sufficient data to confidently detect trends. A longer data period (1990–2013) was used for assessing current sediment conditions because sediment data are not as temporally variable as other matrixes such as water.

To account for inconsistencies in the data, media- or parameter-specific considerations are discussed and data collection dates are given prior to presentation of results. Some parameters have been consistently monitored over the years as part of the County’s

routine monitoring program. Other parameters were monitored as part of short-term projects with different sample collection techniques, analytical methods, and overall data quality. Detection limits for compounds in samples collected at different times may vary substantially based on changes in analytical techniques and instrumentation between sampling events. In addition, the number of samples analyzed may vary for each study and chemical.

Data are summarized throughout this report. Raw data can be obtained by contacting Wendy.Eash-Loucks@kingcounty.gov.

1.4.3 Interpreting Box Plots

Much of the data in this report are displayed in box plots, which show the spread of data for a particular parameter and differences at various locations. Figure 1-3 describes each part of a typical plot. Letters above the boxes denote the statistical differences between sites; sites sharing the same letter are not statistically distinguishable at the $\alpha = 0.05$ level of significance. Sites that do not share a letter are significantly different at the $\alpha = 0.05$ level of significance.

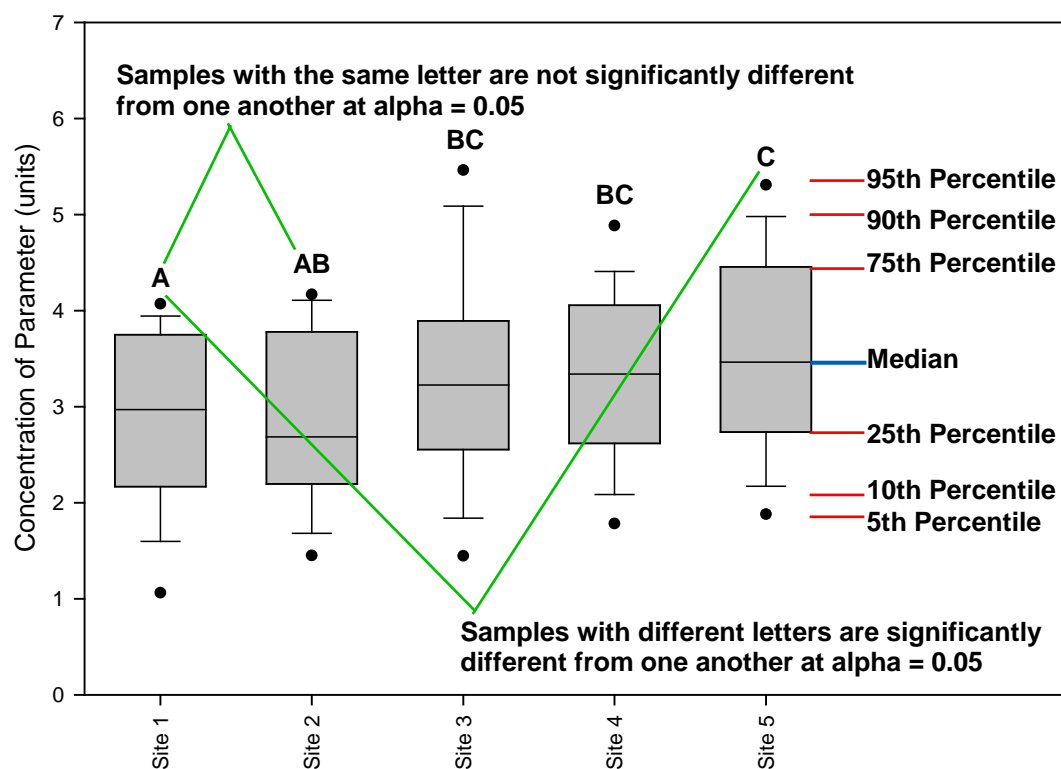


Figure 1-3. Explanation of parts of a typical box plot.

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2.0 STUDY AREA

For the purpose of this discussion, the Elliott Bay study area (Figure 2-1) is divided into two sections:

- Inner Elliott Bay, east of a line drawn between Duwamish Head in West Seattle and Magnolia Bluff near Smith Cove. Inner Elliott Bay includes all of King County's uncontrolled CSOs within the bay not currently undergoing upgrades.
- Outer Elliott Bay, east of a line drawn between Four Mile Rock and Alki Point. The outer boundary was chosen to be consistent with recent studies conducted by Ecology (for example, Ecology, 2009a).

The study area is bordered on the east, north, and south by parts of the city of Seattle and on the west by the waters of the Central Basin of Puget Sound. Much of the data presented in the document were collected in Inner Elliott Bay. Data from Outer Elliott Bay and an area of the Central Basin waters (bordered to the west by a line drawn southward from the western tip of Discovery Park to just west of Alki Point) are also included to illustrate the impact of Inner Elliott Bay on these waters.

This chapter describes general characteristics and current uses, sources of pollution, CSO discharge locations, cleanup of historical contamination, and other planned actions to address pollution in Elliott Bay.

2.1 Characteristics

Elliott Bay is a deep bay, reaching its maximum depth near the middle of its western edge at approximately 180 m (Figure 2-1). Although it is dominated by the marine water masses of Puget Sound, the bay is considered an estuarine system because outflow from the Duwamish Estuary discharges into the southeastern corner of the bay. During winter months and late spring when flow from the Duwamish Estuary is highest, a freshwater lens that moves counterclockwise from the river along the downtown Seattle waterfront and northward is evident in water quality monitoring data.

Much of Elliott Bay was previously a complex tidal marsh habitat that frequently flooded. Beginning in the late 1800s, the estuarine tidelands were filled, drained, and dredged to support increased industrial and port activities both within Elliott Bay and upstream in the Duwamish Estuary; this activity included the construction of Harbor Island (Blomberg et al., 1988).

Overwater structures, seawalls, and riprap dominate the shoreline; only 17 percent of the shoreline is exposed sand/mud substrate. With the reduction of much of the tidal marsh habitat, eelgrass beds are now limited to Outer Elliott Bay from Duwamish Head to Alki Point and along Magnolia Bluff to West Point (King County, 2001a). In contrast, kelp beds have likely increased in the last century from their colonization of additional hard substrates such as riprap (King County, 2004).

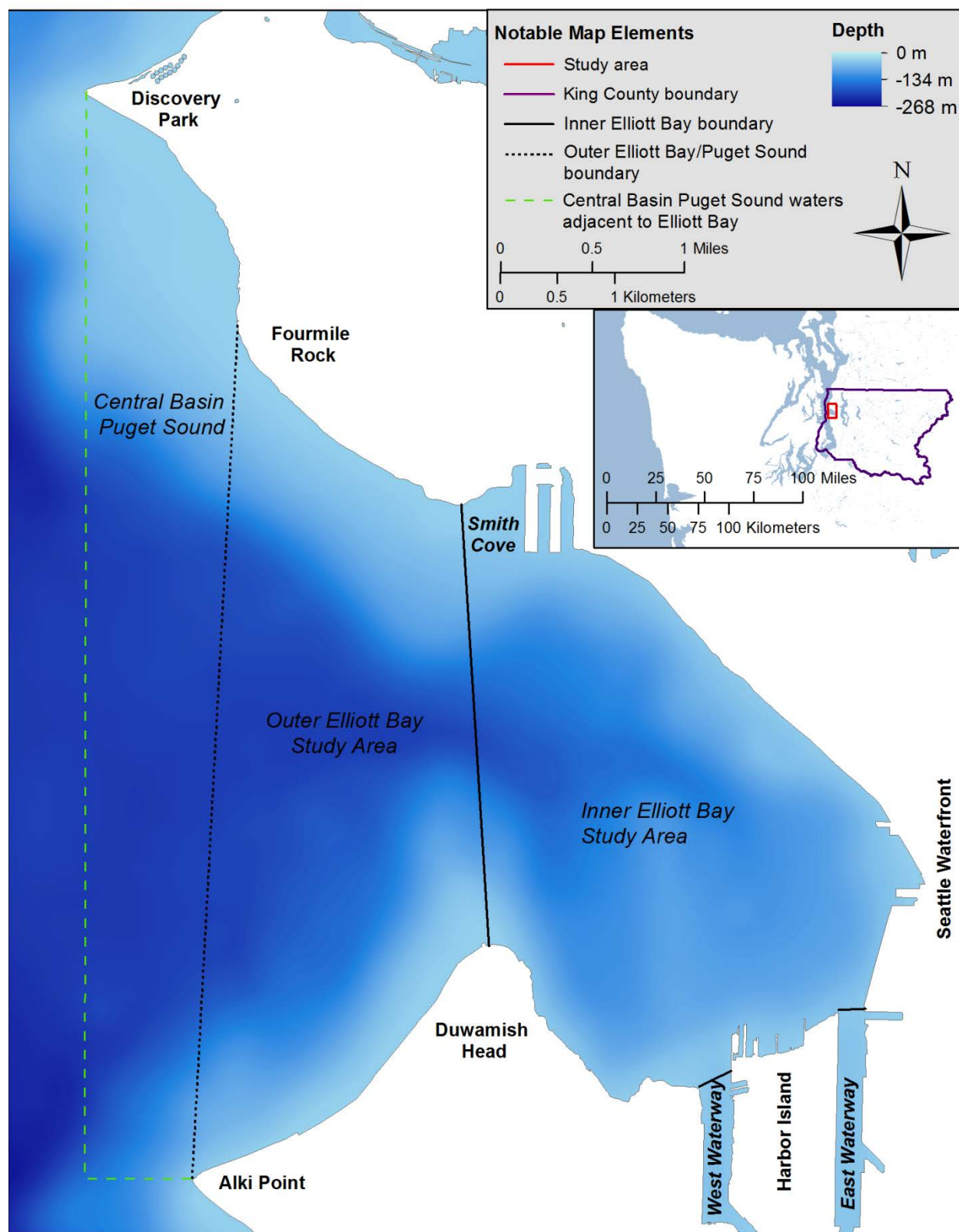


Figure 2-1. The distinction between Inner and Outer Elliott Bay and the adjacent Central Puget Sound waters included in this study.

2.2 Current Uses

Inner Elliott Bay is primarily devoted to commerce and is bordered by high-intensity development in the commercial and residential areas of downtown Seattle (Figure 2-2). Outer Elliott Bay is bordered by mixed-use lands including medium- to low-intensity development, developed open spaces, and forested/undeveloped lands, the largest of which includes Discovery Park.

The Port of Seattle, which in 2013 was the 14th largest seaport in the United States in terms of total vessel trade (Port of Seattle, 2014b), has a dominant presence in Elliott Bay. The Port owns and operates several piers, shipping and cruise terminals, parks, and the Bell Harbor Marina.

Additional uses of Elliott Bay include fishing, boating, scuba diving, and beach activities. Recreational fishing occurs at several docks and marinas. In addition, the Muckleshoot and Suquamish Indian tribes operate a net pen in the northeast corner of Inner Elliott Bay for raising juvenile coho salmon that have been relocated from tribal hatcheries for delayed release into the wild. Although public clamming beaches are present, mostly in the outer bay, they are often closed by the Washington State Department of Health because of their proximity to multiple sources of pollution.

Many species have used Elliott Bay as a nursery, particularly before the habitat was highly modified. The bay still supports a high diversity of fish, invertebrate, bird, and mammal species and acts as a transitory pathway for salmon migrating through the Duwamish Estuary and into the Green River (King County, 2004). Several federally threatened and endangered species use or may possibly use Elliott Bay either as a permanent or transitory habitat, including salmonids (Chinook and steelhead – threatened), killer whales (southern resident, particularly the J Pod – endangered), steller sea lion (North Pacific population – threatened), humpback whale (endangered), rockfish (canary, yelloweye – threatened; bocaccio – endangered), eulachon (threatened), and marbled murrelet (threatened) (City of Seattle, 2012a).

The U.S. Army Corps of Engineers and the Washington State Department of Natural Resources maintain a dredged sediment disposal site in the center of Inner Elliott Bay. This site contains sediments removed from the Duwamish Estuary as part of maintenance dredging operations. Prior to disposal in Elliott Bay, the material is tested to meet Dredged Material Management Program criteria.² If contaminated, the material is disposed of at an alternative upland site. Prior to 1987, a site off Four Mile rock was used to dispose of dredged sediments.

² The Dredged Material Management Program is a coordinated multi-agency approach to management of dredged materials in the state of Washington.

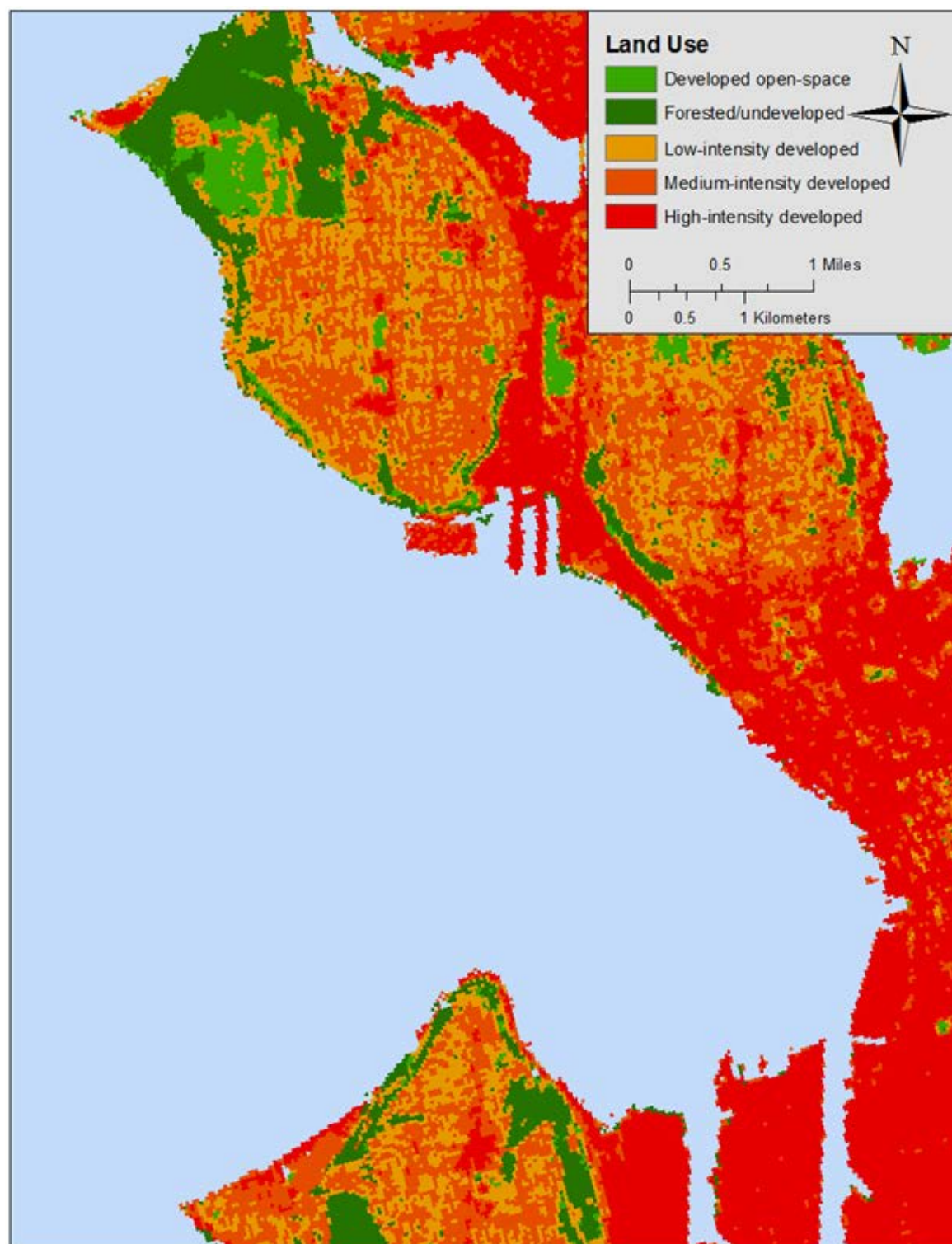


Figure 2-2. Land uses of area surrounding Elliott Bay, including the downtown Seattle.

2.3 EPA-Approved Listed Impairments

The federal Clean Water Act, adopted in 1972, requires that all states restore their waters so that they are “fishable and swimmable.” Section 303(d) of the Clean Water Act established a process to identify and clean up polluted waters. Every two years, states are required to perform a water quality assessment of their surface waters. Waters whose beneficial uses (drinking, recreation, aquatic habitat, and industrial uses) are impaired by pollutants are placed in the polluted water category on the water quality assessment (“303(d) list”). These water bodies fall short of state surface water quality standards and are not expected to improve in the succeeding two years.

The current (2012) EPA-approved 303(d) list of impairments in Elliott Bay is presented in Table 2-1.

Table 2-1. Current (2012) EPA-approved 303(d) list of pollutants that do not meet water quality standards in Elliott Bay.

Water Body	Medium	Parameter	Listing ID
Elliott Bay	Water	Bacteria	15802, 15803, 45577
	Sediment	Sediment Bioassay	506252, 621990
	Tissue	PCB	63659, 63710, 63717
		2,3,7,8-TCDD	64390
Central Puget Sound (Outer Elliott Bay)	Water	Bacteria	42492
	Tissue	Benzo(a)anthracene	63110, 63162
		Benzo(a)pyrene	63111, 63163
		Benzo(b)fluoranthene	63112, 63164
		Benzo(k)fluoranthene	63113, 63165
		Chrysene	63114, 63166
		Dibenzo(a,h)anthracene	63167
		Indeno(1,2,3-cd)pyrene	63123, 63175
		PCB	63129, 63181

2.4 Sources and Pathways of Pollution in Elliott Bay

Humans, threatened/endangered species, and other species that use the estuarine waters of Elliott Bay are potentially at risk from historical and ongoing sources and pathways of contamination. Elliott Bay and the Duwamish Estuary have been subject to years of discharges and spills from the shipping industry, wastewater pipes, stormwater outfalls, and other industrial discharges. Earlier, mining, logging, and shipping were major contributors of contamination. Along with urbanization, these sources and pathways have led to much of the historical contamination existing today. Table 2-2 generalizes historical and current human activities that have likely altered the water quality of Elliott Bay since the late 1800s.

Table 2-2. Water quality parameters likely altered by human activities.

Activity	Bacteria	Temperature	Dissolved oxygen	pH	Water clarity	Nutrients	Metals	Organic compounds
Agriculture/livestock production	X	X	X	X	X	X		
Discharge of sewage and stormwater	X		X	X	X	X	X	X
Dredging/channelization/regarding	X				X		X	X
Industrial/shipping activities				X			X	X
Logging	X	X				X		

Highlighted rows indicate major ongoing activities.

In much of Seattle, including the majority of the land surrounding Elliott Bay, sewer infrastructure is part of a combined sewer system that collects both stormwater and sewage in the same pipes. Some of the land bordering the outer bay is on a partially separated system, where home gutters drain to the treatment plant and stormwater from the streets is sent to a storm sewer that discharges directly to the bay. The area around Discovery Park has completely separated sewer and stormwater pipes (Figure 2-3).

Major ongoing sources and pathways of pollution into Elliott Bay are described below and illustrated in Figure 2-4:

- **Port of Seattle activity.** This activity includes introduction of vessel-related pollutants and resuspension of contaminated sediments by large vessels. See “Historical Contamination Cleanup Areas” below for the Port’s involvement in cleanup projects in the Elliott Bay study area.
- **Leaching of historical contaminants from groundwater at nearshore locations.** Sparse monitoring data are available from groundwater wells surrounding Elliott Bay. Four wells are within 600 m of the Elliott Bay shoreline; however, water height and water quality data are not available from these wells (King County, 2014). Groundwater samples near Elliott Bay have been collected only at contaminated cleanup sites.
- **Occasional spills.** The most recent known reported spill occurred in February 2007 when 143 gallons of fuel leaked from a grain carrier during fueling (Ecology, 2014). In addition to large spills, smaller illegal disposals of toxic contaminants into the bay likely occur.
- **Atmospheric deposition.** While bulk atmospheric deposition studies have been conducted upstream in the Green and Duwamish Rivers (King County, 2013), similar studies have not been conducted in Elliott Bay.
- **Duwamish Estuary.** The Duwamish Estuary discharges into Elliott Bay and is a potential pathway of pollutants.

- **Stormwater discharge.** Stormwater is considered to be one of the largest pathways of pollution to Puget Sound (Ecology and King County, 2011). Stormwater conveyance to Elliott Bay is largely the responsibility of the City of Seattle. The Port of Seattle and other industrial entities also discharge stormwater along the waterfront. The locations of known large stormwater outfalls in Elliott Bay and the Duwamish waterways are shown in Figure 2-3. Under its National Pollutant Discharge Elimination System (NPDES) stormwater permit requirements, the City is required to map stormwater pipes and outfalls over specified diameters (City of Seattle, 2014a). This effort is ongoing.

In addition, the City has developed a stormwater code to increase green stormwater infrastructure (GSI) and reduce flows (Seattle Code 22.800-22.808); encourages development of private stormwater facilities to improve water quality and decrease flows into receiving waters; has implemented various best management practices in its parks; and maintains roadways through street sweeping and snow/ice control programs (City of Seattle, 2014a). Despite these efforts, most stormwater remains untreated.

- **Treatment plant discharge.** King County operates three treatment plants, regulated under NPDES permits, that discharge in or near Elliott Bay (Figure 2-3):
 - The Elliott West wet weather treatment facility is located in Elliott Bay just north of the downtown area. It operates during heavy storms and discharges primary treated (remove suspended solids and pathogens), disinfected, and dechlorinated effluent into northeast Elliott Bay.
 - The outfall from the West Point Treatment Plant extends west into Puget Sound from Discovery Park at the north end of Elliott Bay. West Point provides secondary treatment for up to 300 mgd of wastewater. Additional flows up to 440-mgd receive CSO (primary) treatment and are mixed with secondary effluent for disinfection, dechlorination, and discharge.
 - Dual outfalls from the South Treatment Plant extend northwest from Duwamish Head at the south end of the bay and discharge secondary treated effluent into the denser deeper water layer near the boundary of Outer Elliott Bay and Central Puget Sound.



Figure 2-3. Combined and separated sewer systems, CSO outfalls, and stormwater outfalls in the Elliott Bay study area.

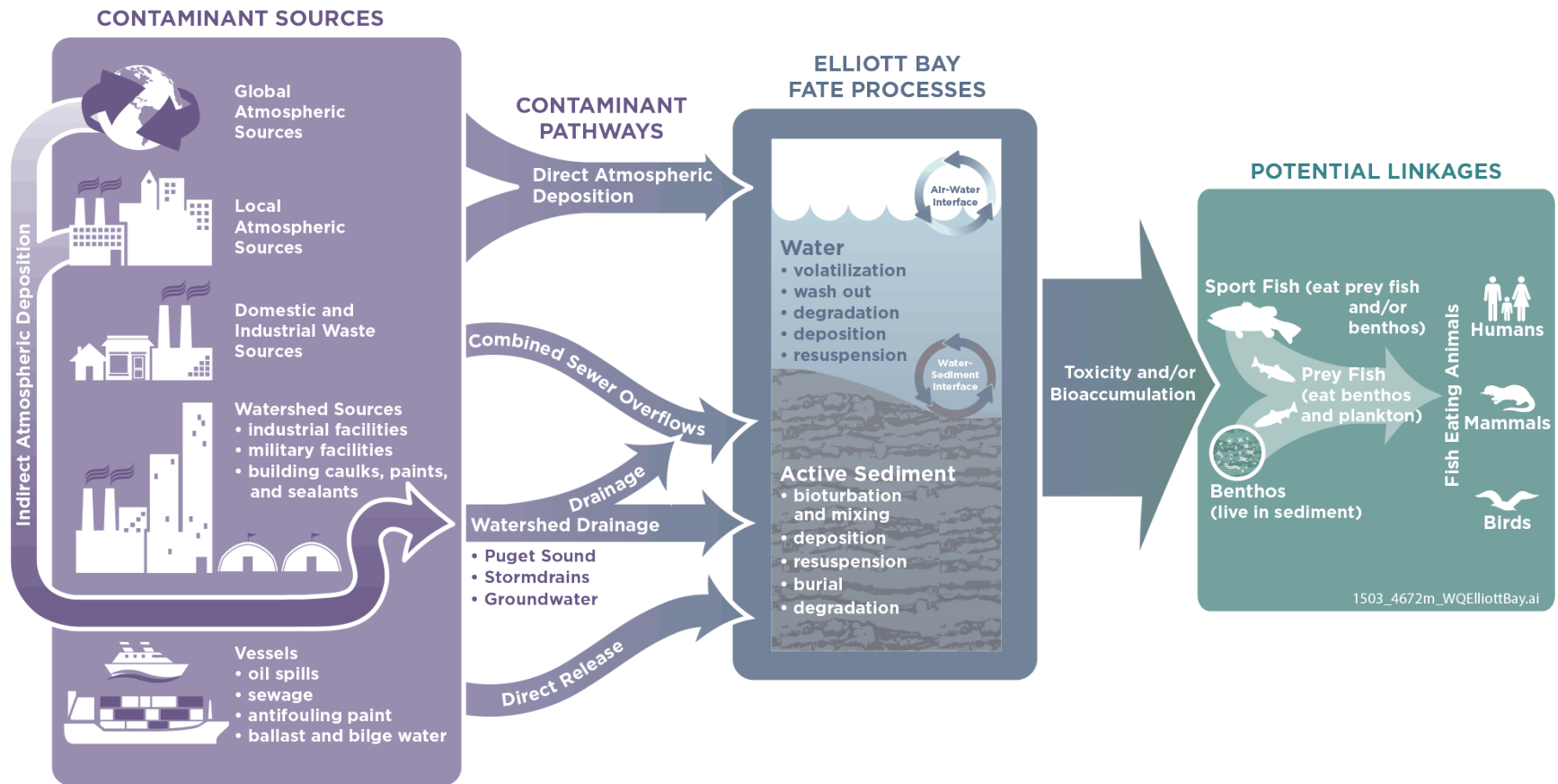


Figure 2-4. Contaminant sources, pathways, and fates in Elliott Bay.

- **CSO discharge.** Of the 17 CSO outfalls located in Elliott Bay, 12 are maintained by the City of Seattle and 5 are maintained by King County (Figure 2-3). CSO locations are also regulated by NPDES. In addition, the Duwamish Estuary contains numerous city and county CSOs, including the County's largest remaining uncontrolled outfall in the East Waterway. Both agencies have developed plans to control their CSOs by no later than 2030 to the Washington State standard of no more than one discharge on average over a 20-year moving average. The following section describes the Elliott Bay CSO sites in more detail.

Additional information on pollutant loadings to Elliott Bay will be described in a separate document prepared as part of this Water Quality Assessment and Monitoring Study.

2.5 CSO Discharge Sites

This section describes King County CSO locations in more detail as background to aid this Water Quality Assessment and Monitoring Study in examining water quality and guiding decisions for sub-basins where the County's uncontrolled CSOs discharge.

Although CSOs contribute only a portion of the pollution that enters Elliott Bay, CSOs may potentially harm aquatic ecosystems, impact human use, and pose other public health and environmental concerns. The following constituents may be found in CSOs:

- Pathogens (disease-causing bacteria, viruses, and parasites)
- Oxygen-depleting material (organic matter)
- Suspended solids, which can hamper sight-feeding fish and bury habitat
- Toxins, including metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), endocrine-disrupting compounds, and pesticides
- Nutrients (phosphorus and nitrogen), which may cause eutrophication and toxic algal blooms

The five county CSOs in Elliott Bay, from north to south, are as follows:

- **South Magnolia.** King County is constructing a 1.5-MG underground storage tank to control CSOs from this location. Stored flows will be sent to the West Point Plant when capacity in the downstream conveyance system allows. If storage capacity is exceeded before flows can be sent to West Point, the excess flow will be discharged to Elliott Bay. The project is scheduled for completion in 2017.
- **Denny Way.** Control of the Denny Way CSO in Myrtle Edwards Park was part of a larger CSO control project done in conjunction with the City of Seattle. Excess flows are stored in a tunnel and then sent to the West Point Plant after a storm. Flows in excess of tunnel capacity are sent to the Elliott West wet weather treatment facility for treatment and discharge to an outfall into Elliott Bay near the Denny Way Regulator. Flows beyond the capacity of the treatment plant discharge untreated through a new outfall from the regulator station. The project was completed in 2005. The new system has substantially decreased annual discharges from Denny

Way (King County, 2012). Adjustments continue to be made to achieve full control of the site.

- **King St.** The King Street Regulator Station sends flows to the Elliott Bay Interceptor on their way to the West Point Plant or, during heavy storms, to the King Street CSO outfall into Elliott Bay. Improved system efficiencies have reduced annual discharge volumes from the site. King County plans to build a new 151-mgd wet-weather treatment facility to control the King St and Kingdome CSOs into Elliott Bay along with the Lander and Hanford CSOs into the East Waterway. The facility's outfall will likely be located in either Elliott Bay or the waterway. The project will be completed by 2030.
- **Kingdome.** The Kingdome and Connecticut regulator stations regulate flows from the Kingdome Trunk and Connecticut Street storm drain, respectively. Both stations send flows to the Elliott Bay Interceptor during normal conditions and to the Connecticut Street storm drain, owned by the City of Seattle, for discharge into Elliott Bay during storm conditions. In 1994 the County, City, and Washington State Department of Transportation installed a pipeline that increased storage capacities near the Kingdome CSO, which aided in reducing annual discharges (King County, 2012). This CSO location will be controlled by 2030 through construction of a new CSO wet-weather treatment facility to control the King Street and Kingdome CSOs into Elliott Bay along with the Lander and Hanford CSOs into the East Waterway. The facility's outfall will likely be located in either Elliott Bay or the waterway.
- **53rd Ave SW.** This CSO outfall extends from the 53rd Avenue Pump Station in West Seattle, southwest of Duwamish Head. The pump station sends flows south to the 63rd Avenue Pump Station, which then sends flows to the West Seattle Tunnel that leads to the West Seattle Pump Station just west of the West Duwamish Waterway. The pump station connects to the Elliott Bay Interceptor. The tunnel and pump stations are part of a complex system that stores excess flows during heavy rains for later transport. If storage capacity is exceeded, flows may be sent to the Alki CSO Wet Weather Treatment Facility south of Alki Point for storage and possible treatment. The 53rd Ave NW CSO site was controlled in 1999 as part of the Alki transfer project. It serves as an emergency discharge point if available storage and treatment capacity is exceeded.

The City of Seattle is planning to control its CSO locations by 2030 through an integrated plan for reducing discharges from both CSO and storm drain systems (City of Seattle, 2015a). The projects are sequenced to maximize water quality benefits. No stormwater reduction projects have been planned for Elliott Bay; however, a 130,000 gallon storage project is proposed for the central waterfront.

Table 2-3 shows 2009–2013 average annual frequencies, average annual discharge volumes, and control status for both county and city CSO locations in Elliott Bay. It includes the County's Hanford #2 and Lander Street CSO locations in the East Waterway because of their proximity to Elliott Bay and their potential to impact its water quality. The Hanford #2 and Lander Street CSOs are discussed further in the Duwamish Estuary area report.

Table 2-3. Average annual frequency, volume (2009–2013), and control status of CSOs in the Elliott Bay study area (from north to south).

CSO	Average CSO Frequency (events/year) ^a	Average Annual CSO Volume (million gallons)	Control Status
Inner Elliott Bay			
Seattle 068	0.8	1.0	Controlled
King County Denny Way	2.2	3.2	Almost controlled; operational modifications are under way to achieve full control
Seattle 069	2.2	0.3	Uncontrolled
Seattle 070	0.4	<0.1	Controlled
Seattle 071	5.6	0.6	Uncontrolled
Seattle 072	0.2	<0.1	Controlled
King County King St	12.6	16.3	Uncontrolled (controlled by 2030)
King County Kingdome	6.6	18.4	Uncontrolled (controlled by 2030)
Seattle 078	0	0	Controlled
Seattle 080	0	0	Controlled
Outer Elliott Bay			
Seattle 061	0.2	<0.1	Controlled
Seattle 062	1.2	<0.1	Controlled ^b
Seattle 064	0	0	Controlled
King County South Magnolia	27.4	8.1	Uncontrolled (controlled by 2016)
Seattle 083	0	0	Controlled
King County 53rd Ave SW	0.2	0.1	Controlled
Seattle 085	0	0	Controlled
East Duwamish Waterway			
King County Lander St	16.8	337.2	Uncontrolled (controlled by 2030)
King County Hanford #2	16.4	165.5	Uncontrolled (controlled by 2030)

^a Frequency is calculated based on a 20-year rolling average.

^b This CSO is considered controlled even though the annual CSO frequency in 2009–2013 was greater than one (City of Seattle, 2015).

2.6 Cleanup of Historical Contamination

Several areas in Elliott Bay have been designated for cleanup of historical contamination, as described below. Their locations and the locations of dredged sediment disposal areas are shown in Figure 2-5.

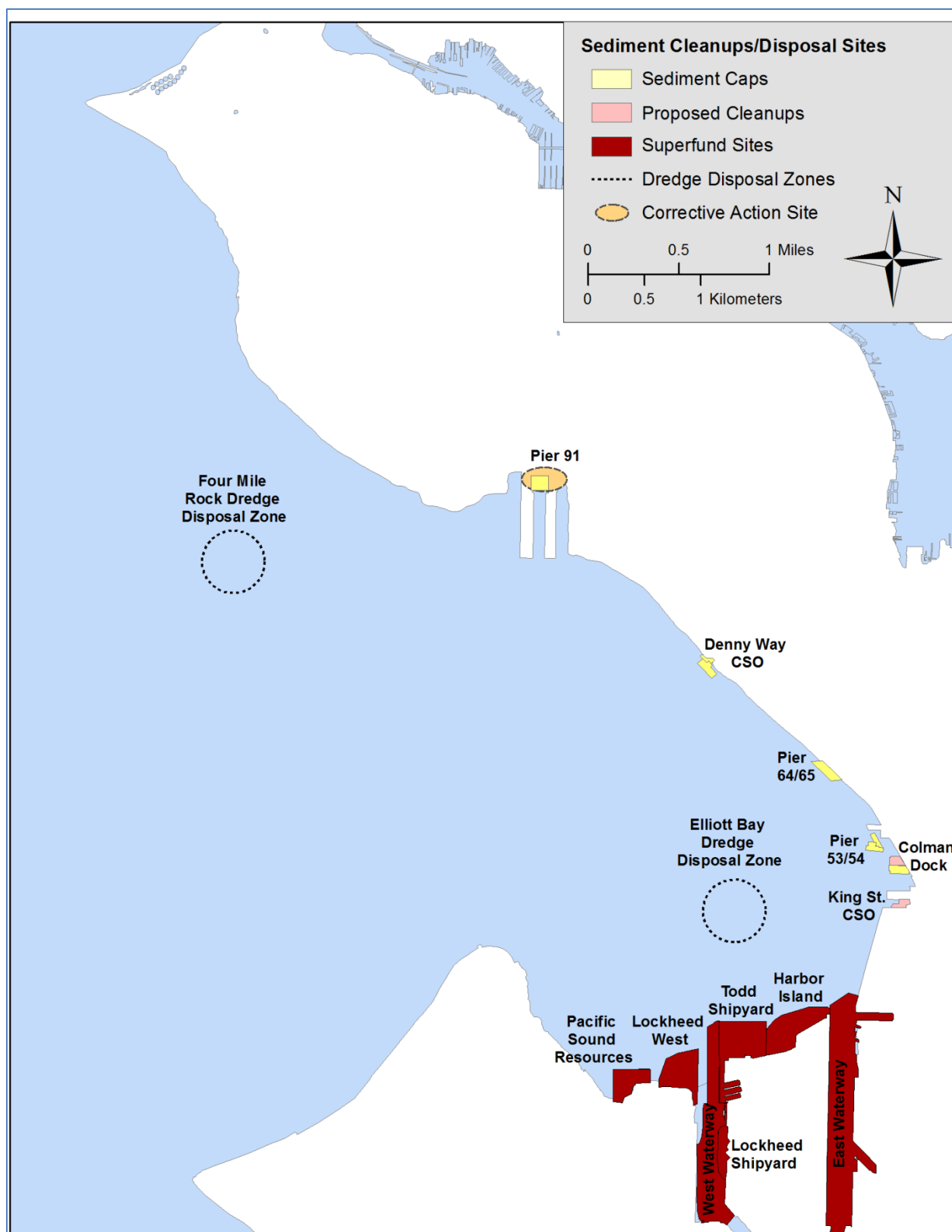


Figure 2-5. Sediment cleanup and disposal sites in Elliott Bay.

2.6.1 North Elliott Bay

A Corrective Action site under the Resource Conservation and Recovery Act (RCRA) is located on the north side of Elliott Bay at Pier 91 in Smith Cove. The site is undergoing cleanup and monitoring of groundwater and soil contaminated with petroleum, PAHs, metals, PCBs, and other volatile compounds (EPA, 1999). In the mid-1980s, the Port of Seattle constructed a nearshore disposal facility for contaminated sediments. The sediments were contained between two long berms between Piers 90 and 91 and capped with uncontaminated sediment before being paved with asphalt (Hotchkiss and Boatman, 1994). The Port operates a cruise terminal, seafood storage and processing facilities, a business complex, and various storage facilities on the site. The contamination is the result of activities by various owners and tenants over the years, including use as a permitted facility for storage and treatment of dangerous wastes and as a fuel storage and distribution tank farm.

In 1990, King County capped sediments near the old Denny Way CSO outfall and, in 2008, completed an additional capping, dredging, and backfilling project to clean up contaminated nearshore sediments at the site (King County, 2008). The outfall had been located in the intertidal zone, was exposed during normal low tide, and discharged directly across exposed intertidal sediment. The second project was undertaken because sediments collected in 1997 from inshore areas of the site contained concentrations of cadmium, copper, lead, mercury, silver, PAHs, PCBs, bis(2-ethylhexyl)phthalate, and butyl benzyl phthalate that exceeded standards. Monitoring of the cleanup's effectiveness will continue until 2016; then it will be determined whether additional cleanup is needed.

2.6.2 Downtown Area

Several sediment capping projects have been completed along downtown Seattle's central waterfront. In 1990, sediment quality was evaluated prior to renovation of the former Pier 64/65 and construction of the new Bell Street Marina. The sampling revealed elevated concentrations of PAHs and lead near the shore that declined with distance from the shore. The likely contaminant sources were creosote pilings and urban runoff. Sediments were capped in 1994. Recontamination was a concern when piling repair work was proposed for nearby Pier 62/63 in 1996. Sediment traps were deployed, and only low concentrations of PAHs were detected near the cap. Additional piling repair work conducted in 2002, however, likely contributed to elevated PAH concentrations on the sediment cap from resuspension of contaminated sediments (Romberg, 2005).

Contaminated sediments along Seattle's downtown waterfront, where a deep-water sewage outfall was previously located, were capped in 1992 (King County, 2010a). Clean sand was placed 1 to 3 feet thick on 4.5 acres of contaminated bottom sediments offshore of Piers 53, 54, and 55. Contamination consisted of a number of metals and organic chemicals, including pesticides, PCBs, and semivolatile organics. Monitoring results indicated that the cap is stable and is isolating contaminated sediments as designed. The work was done under the Elliott Bay/Duwamish River Restoration Program (EB/DRRP) to implement the sediment remediation, habitat development, and source control provisions

of a settlement through the Natural Resource Damage Assessment process. Agencies involved included the City of Seattle, King County, the U.S. Army Corps of Engineers, Ecology, the Washington State Department of Natural Resources, the Washington State Department of Fish and Wildlife, and EPA.

The Colman Ferry Terminal lies south of the Pier 53/54/55 cleanup site on the central Seattle waterfront. The old dock on the site, constructed in 1882 as a general-purpose wharf, was demolished in 1936 to make way for the Colman Dock (CH2M HILL, 1993). Sediments in the area surrounding the dock are contaminated; PAHs are the main concern. Possible historical sources of contamination include creosote-treated timbers, nearby CSO outfalls, contaminated waterfront fill, and the release of oil and coal from the pier, railway, or industrial activities. The Washington State Department of Transportation (WSDOT) placed a sediment cap in the south portion of the terminal (Pier 51) in 1989 (CH2M HILL, 1993). An additional capping project is proposed for the north portion of the terminal (Pier 52) as part of the Multimodal Terminal at Colman Dock project scheduled to be constructed in 2016–2021 (WSDOT, 2014).

2.6.3 South Elliott Bay

In addition to the upstream Lower Duwamish Superfund site, three federal Superfund sites are located in the southern portion of inner Elliott Bay where the Duwamish Estuary enters the bay³:

- The Harbor Island Superfund site encompasses both the industrialized upland area of the island and offshore sediment. The soils, sediments, and groundwater are contaminated with metals (lead and arsenic), PCBs, and petroleum products (EPA, 2010). Remediation efforts have begun in the East Waterway of the Duwamish Estuary, including the southeastern corner of Elliott Bay near Harbor Island, where it has been found that contaminant concentrations are lower in areas that had recently been maintenance-dredged (Port of Seattle, 2014a).
- The Todd Shipyards Sediments Superfund site is located on the north end of Harbor Island and is an operable unit of the Harbor Island Superfund site. A former shipyard, the site was contaminated by petroleum, PCBs, PAHs, and marine paint additives, which contributed to high metals concentrations in the sediments. Various dredging and capping projects have been completed at the site (EPA, 2010).
- The Lockheed West Seattle Superfund site is located west of the West Waterway of the Duwamish Estuary. A former shipyard, the property was sold to the Port of Seattle in 1992. The uplands portion was remediated under state authority and is now part of Terminal 5, one of the Port's container shipping facilities. The aquatic area has not yet been remediated. Paint, metal scrapings, and sandblast grit from boat refurbishing activities were discharged directly to Elliott Bay, resulting in

³ Superfund is the name given to the environmental program established to address abandoned hazardous waste sites. It is also the name of the fund established by the Comprehensive Environmental Response, Compensation and Liability Act of 1980, as amended.

contamination of the sediments. Contaminants include metals, PCBs, tributyl tin, and petroleum products (EPA, 2012).

- The Pacific Sound Resources site, formerly known as the Wyckoff West Seattle Wood Treating facility, is located on the south shore of Elliott Bay. Over half of the site is on either intertidal or subtidal lands. The upland property was purchased by the Port of Seattle in 1994. Creosote and related hazardous constituents were discharged onto the ground during operation, seeped into shallow groundwater, and eventually discharged into subtidal sediments immediately to the north. Hazardous constituents were also disposed of directly onto the site's intertidal areas. Cleanup of contaminants, including creosote and PAHs, was completed in 2005 and follow-up work is under way (EPA, 2009).

2.7 Other Planned Corrective Actions

In addition to efforts under way to control CSOs, manage stormwater, and clean up historical contamination, a number of in-progress or upcoming construction projects are planned for the study area. In combination, these projects will have positive impacts on nearshore water quality in Elliott Bay. This section describes two of the major projects. More detailed analysis of planned corrective actions and their effect on water quality in Elliott Bay will be discussed in the report on future loadings.

2.7.1 Elliott Bay Seawall Project

The City of Seattle's Elliott Bay Seawall project is replacing the existing seawall along the downtown Seattle waterfront. Phase 1 of the project is scheduled to be completed in mid-2016. Much of the existing seawall, constructed between 1911 and 1936, and some piers attached to it are deteriorating (City of Seattle, 2012b). The project will remove creosote-treated materials and replace them with materials such as steel and concrete (City of Seattle, 2006). Increased turbidity and sediment resuspension may occur during construction. However, the City is implementing plans to improve the marine habitat adjacent to the seawall. These proposed improvements would help restore a migratory corridor for juvenile salmonids and enhance the marine nearshore food web with a variety of substrate enhancement projects (City of Seattle, 2012b).

2.7.2 Multimodal Terminal at Colman Dock Project

The WSDOT Multimodal Terminal at Colman Dock project will replace portions of the Colman Dock located on the Seattle Waterfront. Project construction began in 2016. Contaminated sediments will be capped as part of the project (WSDOT, 2014). Water and sediment quality will be improved by removal of creosote-treated timber piles, remediation of contaminated sediments, and addition of stormwater treatment.

3.0 WATER QUALITY

This section summarizes data available from King County and Ecology long-term monitoring programs, which have monitored water quality in Elliott Bay since the early 1970s and 1990s, respectively. Both programs monitor fecal indicator bacteria (fecal coliforms), physical parameters, and nutrients monthly. Short-term programs have been developed to measure additional water quality parameters such as metals and organic compounds. In addition, King County maintains a mooring station at the Seattle Aquarium that takes continuous measurements of physical water quality parameters.

This chapter describes current conditions (2004–2013), compares them with water quality standards, and identifies long-term trends for these parameters when possible.

3.1 Data Parameters, Sampling Locations, and Collection Methods

King County has collected and analyzed water samples on a monthly basis at beach (nearshore) and offshore monitoring sites in Elliott Bay since as early as 1970; six of these sites are located near treatment plant and CSO outfalls (Table 3-1 and Figure 3-1). The following parameters have been monitored during the program's lifespan: fecal indicator bacteria (fecal coliforms), temperature, salinity, dissolved oxygen (DO), turbidity, total suspended solids (TSS), chlorophyll-*a*, nutrients (ammonia, nitrate + nitrite, total phosphorus or orthophosphate, and silica). These parameters are sampled from a boat at offshore sites; a smaller subset is sampled from beach sites. Parameters such as temperature and salinity are measured in the field; others such as nutrients and fecal coliforms are analyzed at the King County Environmental Laboratory (KCEL) from water samples collected in the field.

In addition to the monthly monitoring program, King County installed two YSI 6600 V2 data sondes at the Seattle Aquarium on the Seattle waterfront in January 2008. This in-situ monitoring system collects surface (~1 m) and deep (~10 m) data on depth, temperature, salinity, DO, chlorophyll-*a*, pH, and turbidity at 15-minute intervals. The sondes are calibrated monthly and replaced by freshly calibrated sondes approximately every four weeks. In-situ sensor specifications are shown in Table 3-2.

King County's marine monitoring data are available at <http://green2.kingcounty.gov/marine/>. Discrete data are available on request.

Ecology has collected comparable monthly water quality data since 1991 at one offshore site in Elliott Bay (Table 3-1 and Figure 3-1). Discrete samples collected by Ecology are analyzed at the University of Washington Marine Chemistry Lab. Ecology's marine monitoring data are available at http://www.ecy.wa.gov/programs/eap/mar_wat/data.html.

Table 3-1. Monthly water quality monitoring sites in Elliott Bay.

	Locator	Name	Northing	Easting	Ambient or Outfall	Greatest Depth Sampled (m)	Years Sampled
Beach	KSSN05 ^a	West Point South ^e	245272	1245980	Outfall	N/A	1970–pres.
	KSYV02 ^a	Magnolia Outfall ^d	234547	1254488	Outfall	N/A	1984–pres.
	LSGY01 ^a	Seacrest Park	218711	1258776	Ambient	N/A	1997–pres.
	LSHV01 ^a	Alki Beach ^d	216852	1253532	Outfall	N/A	1970–pres.
	LTBD27 ^a	Denny Way Outfall ^d	228851	1264297	Outfall	N/A	2007–pres.
	LTEH02 ^a	Seattle Waterfront	223134	1268961	Ambient	N/A	1981–2010
Offshore	ELB015 ^b	SW Elliott Bay ^d	221435	1261717	Ambient	30	1991–pres.
	LSEP01 ^a	South Plant Outfall ^e	223360	1247399	Outfall	180	1984–pres.
	LTBC43 ^a	Elliott West Outfall ^d	228985	1263430	Outfall	15	2005–pres.
	LTED04 ^a	Central Elliott Bay	223909	1264675	Ambient	75	1997–pres.
	SEAQYSI ^{a,c}	Seattle Aquarium	225168	1267840	Ambient	10	2007–pres.

^a Monitored by King County.

^b Monitored by Washington State Department of Ecology.

^c Mooring station that collects data at 15-minute intervals.

^d Located near CSO or CSO treatment plant outfall.

^e Located at or near treatment plant outfall.

Table 3-2. King County marine mooring specifications (SOP 208v2).

Parameter	Unit	Resolution	Accuracy
Temperature	°C	0.01	+/-0.15
Salinity	PSU	0.01	0.1
Dissolved oxygen	mg/L	0.01	+/-0.1
Turbidity	NTU	0.1	0.3
Chlorophyll-a	µg/L	0.1	0.1
pH	–	0.01	+/-0.2

3.1.1 Beach Sample Collection Methods

King County collects beach samples by wading into the water to approximately hip depth and inverting sampling containers just below the water surface; temperature is sampled using a Hydrolab®. At the Seattle Waterfront and Seacrest Park sites, a bucket is lowered from a pier and the contents are transferred to sample containers.

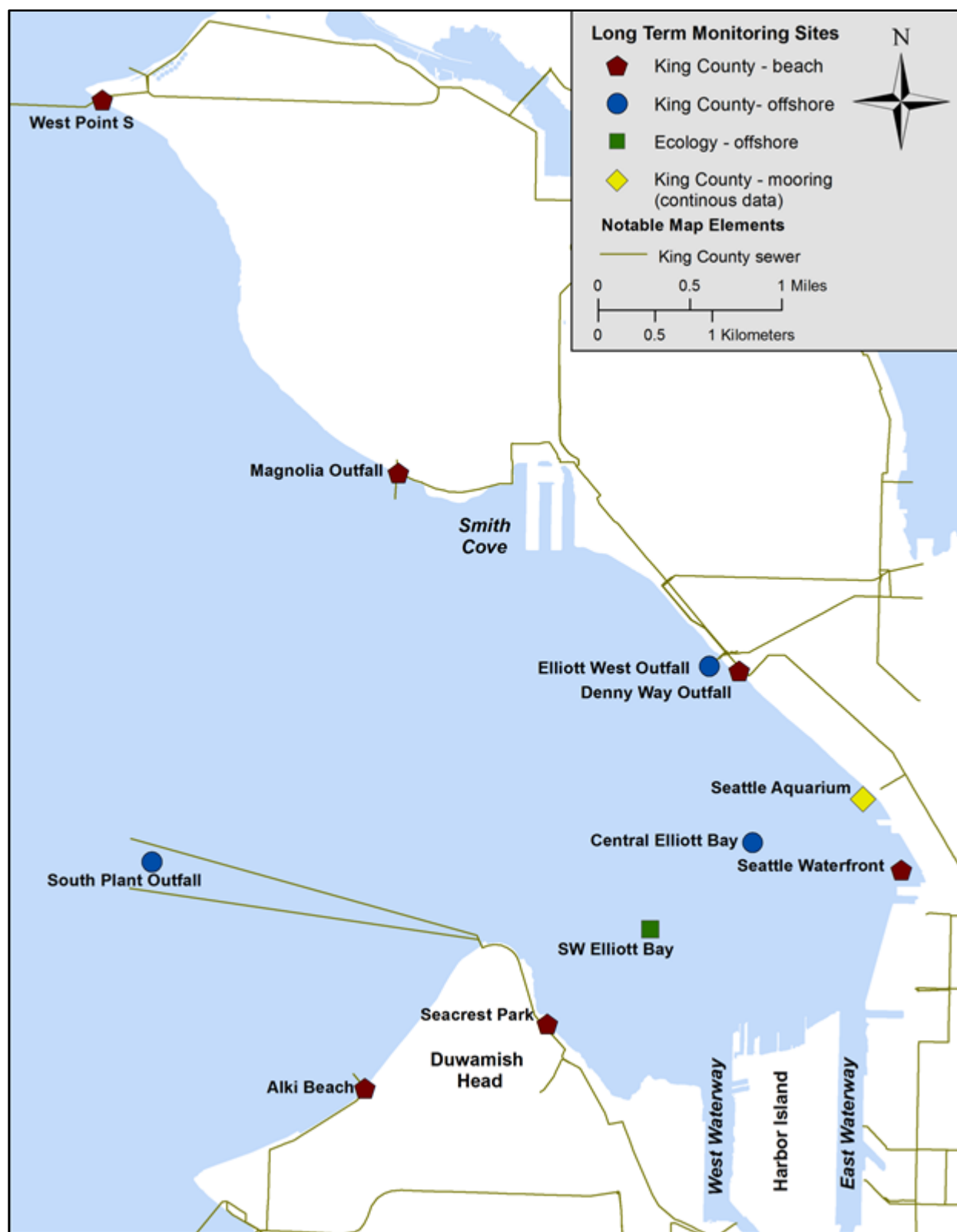


Figure 3-1 Long-term water quality monitoring sites in Elliott Bay.

3.1.2 Offshore Sample Collection Methods

Prior to 1998, King County collected offshore samples using triggered bottles attached to an oceanographic rosette, Van Dorn bottles hung on a hydrowire, or bottles on a stick secured by a silicone tube (for surface sampling) (Marc Patten and John Blaine, King County, pers. comm., Nov. 2013).

Since 1998, offshore samples have been collected according to the *Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissues in Puget Sound* (PSEP, 1997). A Sea-Bird SBE 25 SEALOGGER conductivity-temperature-depth (CTD) water column profiler collects data on temperature, salinity, DO, turbidity (prior to 2009), photosynthetically active radiation (PAR), and chlorophyll on the downcast. The CTD is attached to a rosette that has multiple Niskin bottles attached that collect water samples at discrete depths on the upcast for laboratory analysis of fecal coliforms, DO, chlorophyll-*a*, TSS, and nutrients. Ecology also uses a Sea-Bird CTD profiler at its SW Elliott Bay site.

3.2 Bacteria

Bacteria are naturally present in the marine environment throughout the water column and within sediments and are associated with marine vegetation such as kelp. Fecal coliforms, a specific type of bacteria, are found in the intestinal tracts and feces of humans and other warm-blooded animals. These bacteria can enter Elliott Bay through point sources such as wastewater and CSO discharges and non-point sources such as stormwater runoff. Although these bacteria are not typically pathogenic, they may occur with other forms of pathogenic fecal bacteria and can serve as an indicator of fecal contamination.

This study found that despite human population growth, fecal coliform concentrations have greatly diminished in the study area in the last half century. Contributing sources cannot be identified for some sites where concentrations have decreased but are still high. Decreasing concentrations of fecal coliforms have been observed over the past few decades at five of eight sites analyzed for long-term trends. The difference in long-term trends between two closely located offshore sites (Central Elliott Bay [decreasing] and SW Elliott Bay [increasing]), however, demonstrates the need for more information on sources of bacterial input into Elliott Bay. Current bacteria inputs need to be identified during wet- and dry-weather conditions so that these sources may be addressed.

The following sections present current fecal coliform concentrations, how they compare to State of Washington's water quality criteria (WQC), and long-term trends in the study area.

3.2.1 Current Conditions

Concentrations of fecal coliform in Elliott Bay were highest during months with the highest rainfall (November–January). Previous studies have demonstrated a positive relationship between rainfall and bacteria concentrations in coastal waters (Ackerman and Weisberg, 2003). The correlation between rainfall (sum of two days prior) and the square root of fecal coliform concentration in Elliott Bay was positive and highly significant ($p < 0.0001$).

Pearson's correlation coefficients ranged from 0.4033 to 0.6067 at five sites with frequently high fecal coliform concentrations (West Point South, Magnolia Outfall, Seacrest Park, Seattle Waterfront, and Central Elliott Bay). Sites with consistently low fecal coliform concentrations did not have as strong a correlation with rainfall or, in the case of the Denny Way Outfall site, had less than 10 years of data. This finding supports previous findings that fecal bacteria survive for one to two days in salt water (Lessard and Sieburth, 1983).

Fresh water, including runoff, stormwater, and CSO discharges that enter Elliott Bay, is inherently less dense than salt water and is a likely conduit for fecal coliforms. At two sites with data at more than one depth (South Plant Outfall – seven depths; Elliott West Outfall – two depths), mean ranks of fecal coliform concentrations were significantly different with depth as determined by a non-parametric Kruskal-Wallis one-way analysis of variance (ANOVA) ($p < 0.0001$). A post-hoc Gao test (Gao et al., 2008), using R package nparcomp (Konietschke, 2012), demonstrated that fecal coliform concentrations at both sites were highest at the surface. Therefore, the highest risk to human health exists at the surface where fecal coliforms and human activities are concentrated.

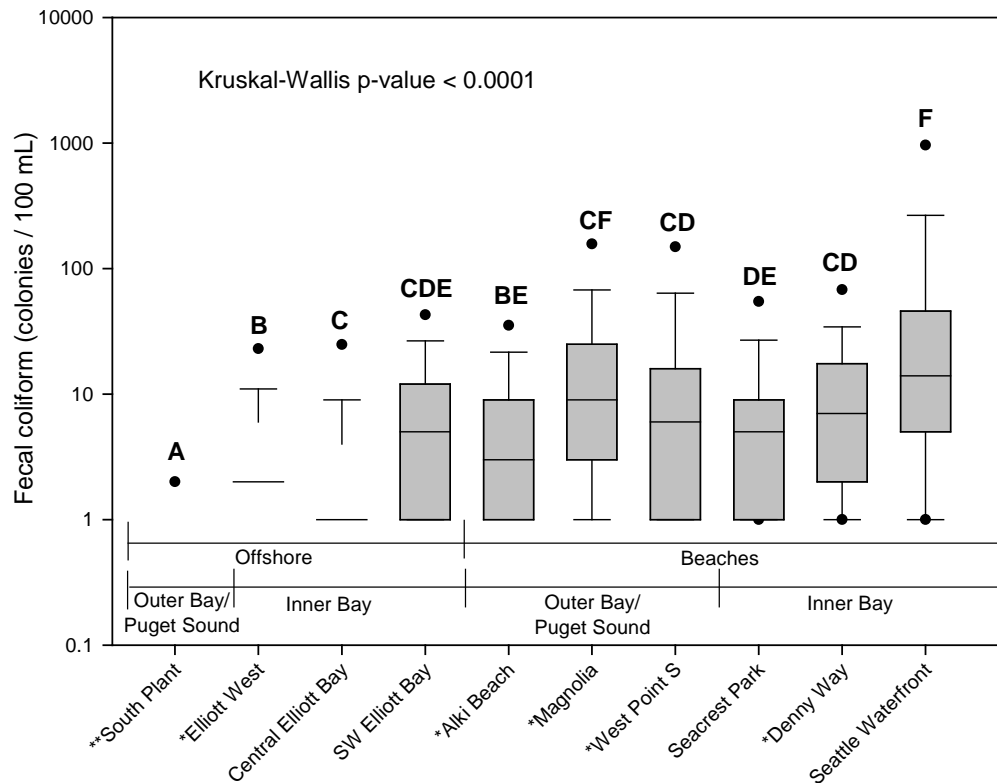


Figure 3-2 Fecal coliform concentrations collected monthly from offshore and beach monitoring sites in Elliott Bay/Puget Sound (2004–2013). Note Log-scale. (* = CSO and CSO treatment plant outfall site; ** = treatment plant outfall site)

Fecal coliform concentrations differed significantly among sites (Kruskal-Wallis p-value < 0.0001). Concentrations ranged from non-detected (0 colonies/100 mL) at many sites to as high as 7,400 colonies/100 mL at the Seattle Waterfront site (surface – December 2006).

Concentrations were higher at beach sites than most offshore sites, likely because sources of fecal coliforms such as runoff and CSO discharges are diluted offshore (Figure 3-2).

In addition, concentrations were typically higher in Inner Elliott Bay along the waterfront than in Outer Elliott Bay. There is an abundance of point and non-point sources in the inner bay including the Duwamish Estuary, which contains 12 uncontrolled CSOs (King County and Seattle CSOs) and over 70 stormwater outfalls. The Seattle Waterfront site, which has the highest fecal coliform concentrations, is located near a City of Seattle CSO, several stormwater outfalls, and the mouth of the Duwamish Estuary that regularly contain high concentrations of fecal coliform. The site is also downstream of several uncontrolled CSOs in southern Elliott Bay and the East Duwamish Waterway.

3.2.2 Comparison to Criteria

Elliott Bay is listed on Ecology's 303(d) list of impaired waters because of high bacteria concentration (fecal coliforms). Ecology's Surface Water Criteria (WAC-173-201A-210) define water quality impairments. For primary contact recreation, the criteria specify both geometric mean and peak limitations: "Fecal coliform organism levels must not exceed a geometric mean value of 14 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 43 colonies /100 mL."

All offshore sites (ambient and outfall locations at all depths) were below the geometric mean criteria (Figure 3-3). Samples from the Central Elliott Bay, SW Elliott Bay, and Elliott West Outfall sites occasionally surpassed 43 colonies/100 mL, but these samples numbered less than 10 percent of all samples collected excluding the Central Elliott Bay site at 1 m between February 2004 and January 2005.

Failure of WQC occurred more frequently at beach sites; five of six sites exceeded one or both criteria more than 10 percent of the time over the last 10 years (Figure 3-3). The five sites that frequently failed WQC are West Point South, Magnolia Outfall, Denny Way Outfall, Seacrest Park, and Seattle Waterfront. Overall, sites located within the influence of the Duwamish Estuary plume had the highest concentrations of bacteria. Seattle Waterfront had the highest median concentrations, followed by Magnolia Outfall, Denny Way Outfall, and West Point South. There is no beach access near Seattle Waterfront. Beaches with high bacteria concentrations in recent years where people may come into contact with contaminated water are Myrtle Edwards Park (near Denny Way Outfall), the 32nd Ave W Park (near Magnolia Outfall), and the south beach of Discovery Park (near West Point South). Seacrest Park, while still an area of potential concern, has had lower median bacteria concentrations than the other four sites and has not failed WQC since 2006.

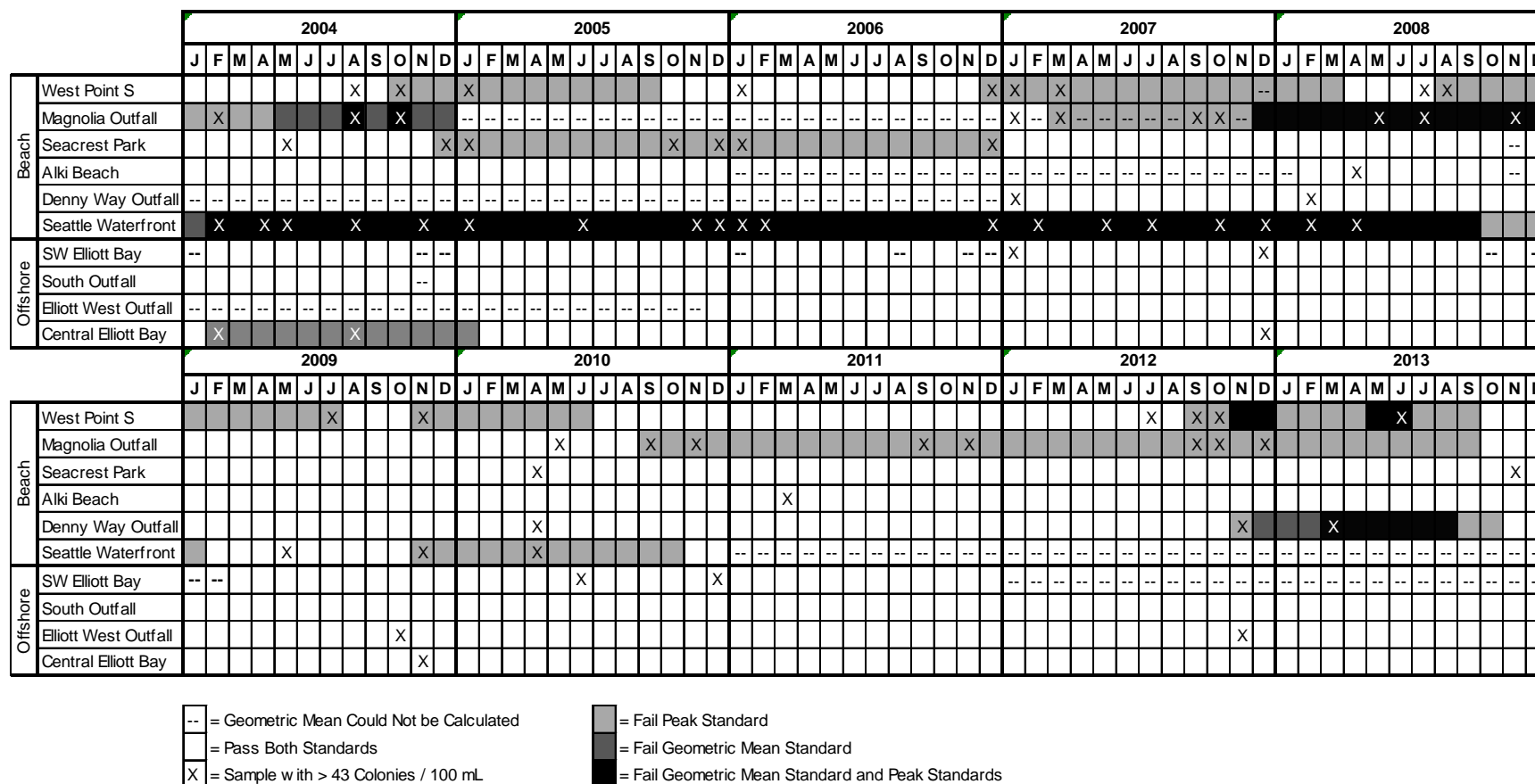


Figure 3-3. Occurrences of bacteria criteria failure at beach and offshore sites in Elliott Bay and adjacent Puget Sound. Geometric means were calculated using the 12 most recent fecal coliform concentrations not exceeding one year. If only 11 samples were taken that year, the geometric mean was calculated using 11 samples. Note that peak criteria failure and samples with > 43 colonies/100 mL are illustrated.

3.2.3 Long-Term Trends

Although earlier data exist for some sites, only data collected after 1980 were analyzed for long-term trends in bacteria levels because methods used before 1980 were not as precise as later methods. There were insufficient data to evaluate trends for two sites (Denny Way Outfall and Elliott West Outfall). A seasonal Mann-Kendall test, which tests for long-term trends while taking into consideration seasonal (monthly) variability, was used to examine long-term (> 10 years) changes in surface water bacteria concentrations. Rainfall was used as a covariate because of the correlation of fecal coliform concentrations with rainfall. One-day prior rainfall was used for beach sites, and three-days prior rainfall was used for offshore sites.

Five of the eight sites evaluated showed significant decreasing trends, ranging from -0.150 to -2.19 colonies/100 mL per year (Table 3-3; Figures 3-4 and 3-5). Decreases were greatest at beach sites where bacteria concentrations are generally higher. The sites that did not have significant trends had very low concentrations of fecal coliform bacteria throughout the time period. This demonstrates that despite frequent criteria failures at some sites, conditions have improved over time. The one exception was an offshore site (SW Elliott Bay), which had a small but significant positive trend (0.111 colonies/100 mL per year). This site is located near the Central Elliott Bay site, which had a strong negative trend and a lower mean concentration of fecal coliforms.

Table 3-3. Results of seasonal (monthly) Mann-Kendall test of fecal coliform concentrations in Elliott Bay over time with Theil-Sen's slopes.

	Site	Years Evaluated	Significance	Trend	p-value	Slope of Trend (colonies/year)
Beach	West Point South	1980–2013	***	↓	0.0011	-0.3333
	Magnolia Outfall	1985–2013	***	↓	0.0004	-0.5000
	Seacrest Park	1997–2013	n.s.	—	0.9839	0.0000
	Alki Beach	1985–2013	***	↓	0.0003	-0.1500
	Denny Way Outfall	2007–2013	Insufficient data to evaluate trends			
	Seattle Waterfront	1981–2010	***	↓	<0.0001	-2.1962
Offshore	SW Elliott Bay	1991–2011	**	↑	0.0150	0.1111
	South Plant Outfall	1997–2013	n.s.	—	0.7029	0.0000
	Elliott West Outfall	2005–2013	Insufficient data to evaluate trends			
	Central Elliott Bay	1997–2013	***	↓	0.0006	-0.2000

Adjusted p-values were calculated using a covariate of rainfall (one-day prior for beach stations and three-days prior for offshore stations) and corrected for inter-block covariance.

n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05-0.10$); ** = significant ($p = 0.01-0.05$); *** = highly significant ($p < 0.01$).

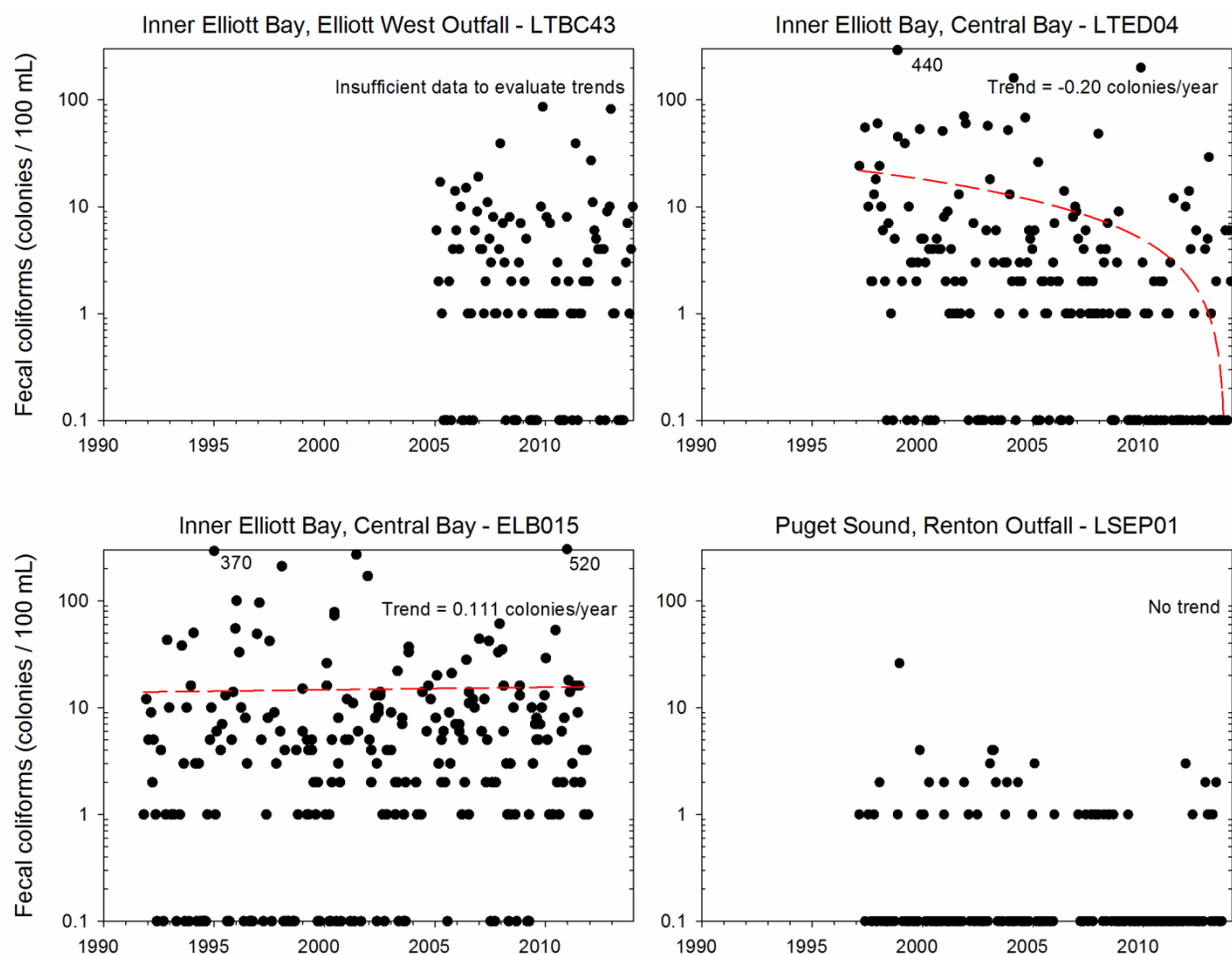


Figure 3-4. Concentrations of fecal coliforms at offshore sites in Elliott Bay and adjacent Puget Sound (1991–2013). Note log-scale. All non-detects are represented as values of 0.1. Dashed red line indicates a statistically significant ($p < 0.05$) trend in fecal coliform concentrations over the time period.

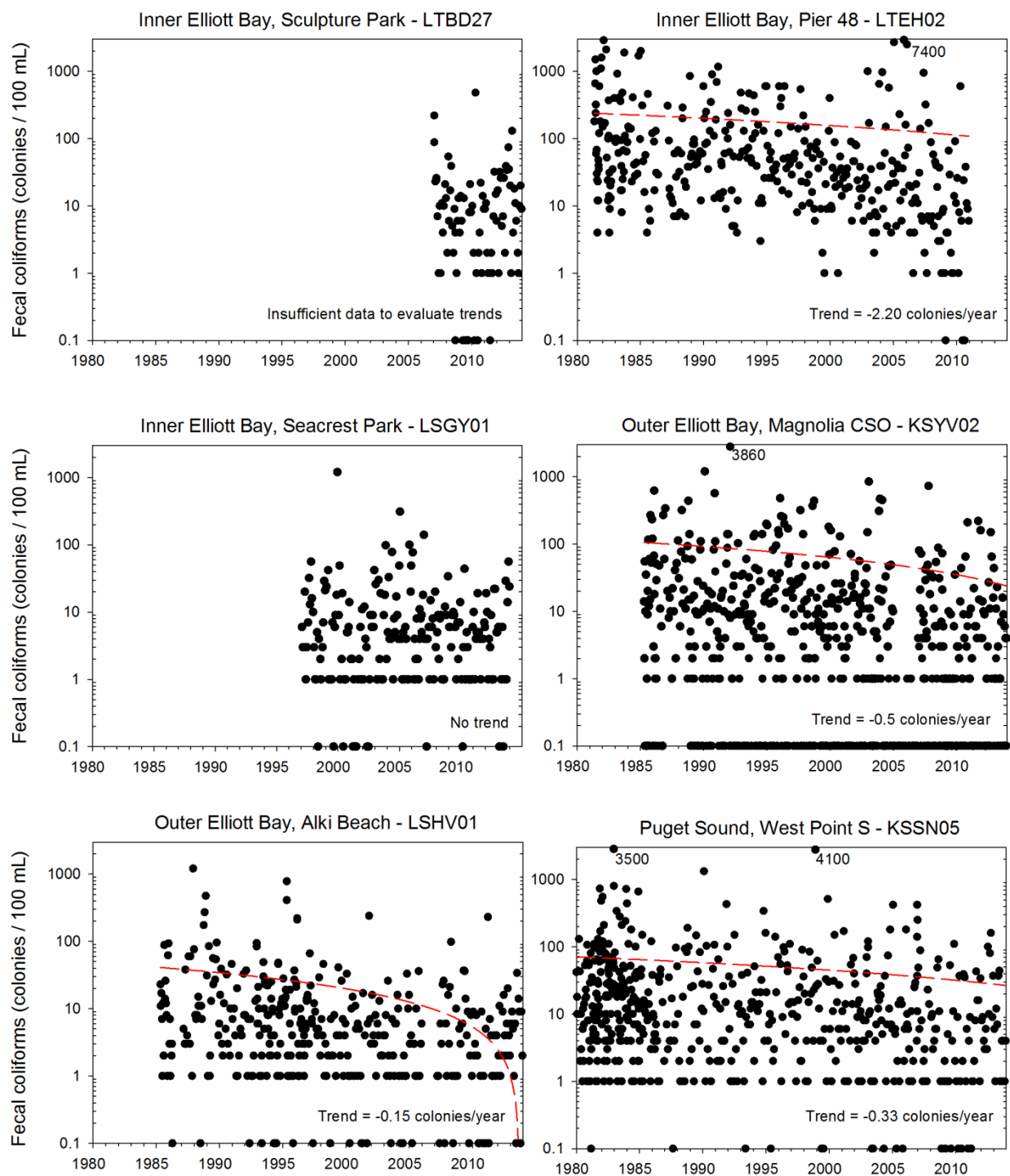


Figure 3-5. Concentrations of fecal coliforms at beach sites in Elliott Bay and adjacent Puget Sound (1980–2013). Note log-scale. All non-detects are represented as values of 0.1. Dashed red line indicates a statistically significant ($p < 0.05$) trend in fecal coliform concentrations over the time period.

Although the specific reasons for reduced bacteria concentrations over time in Elliott Bay are not known, decreased sewage and CSO discharges are likely factors.

Bacteria surveys conducted in summer 1949, which quantified the most probable number (MPN) rather than actual bacteria counts, indicated that most beaches in Elliott Bay from Alki Beach to Magnolia were unsuitable for recreation. Mean bacteria concentrations of 830 to 53,300 MPN/100 mL were found in samples taken near the surface compared to an estimated background concentration of 23 MPN/100 mL. At that time, the sewage outfall at Washington Street (now Seattle CSO 071) overflowed 50 percent of the year and sewage and sewage odor were evident along the Seattle waterfront most of the year (Sylvester et al., 1949). From 2004–2010, the Seattle Waterfront site had a mean concentration of 215 CFU/100 mL, which was the highest fecal coliform concentration measured in the bay during this period. This value is much lower than the mean of 53,000 MPN/100 mL at a comparable site in 1949. Although differences in methods do not allow for direct comparison between values, the data from 1949 and 2004–2010 generally demonstrate that despite human population growth, fecal coliform concentrations in Elliott Bay have greatly diminished in the last half-century.

In the past few decades, King County and the City of Seattle have been working to control CSOs in Elliott Bay. The largest project in the Elliott Bay basin was the County's Elliott West wet-weather treatment plant, which was completed in 2005. This facility reduced annual flows from the Denny Way CSO outfall from 502 MG to 0.3 MG (King County, 2012). To investigate if control projects may have contributed to declines in bacteria concentrations, trends in bacteria concentrations at three beach sites in Elliott Bay and adjacent Puget Sound (West Point South, Magnolia Outfall, and Alki Beach) were analyzed using a seasonal Mann-Kendall test (with one-day rainfall as a covariate and corrected for inter-block covariance). The trends for two time periods, 1985–1998 and 2000–2013, were calculated. Sites were chosen for this analysis based on the length of their data records.

Findings were as follows:

- In 2000–2013, there was a significant ($p = 0.0468$) reduction in bacteria concentrations at Magnolia Outfall (-0.375 colonies/100 mL per year); no significant change occurred at this site in 1985–1998.
- The two sites located in Outer Elliott Bay/Puget Sound (West Point South and Alki Beach) did not show significant changes in fecal coliform concentrations over either time period despite declining overall concentrations at these sites from 1988 and 1985 (respectively) to 2013.

Although the Magnolia CSO outfall is not yet controlled, the Magnolia Outfall site is influenced by the net circulation patterns of Elliott Bay that move surface waters north and west along the Seattle waterfront and past the Denny Way outfall. The large volume reduction of Denny Way CSO discharges that occurred during the last decade may have contributed to decreased fecal coliform concentrations in the inner bay, but the benefit appears to be diluted in the outer bay and Puget Sound. Future CSO control efforts in southeastern Elliott Bay and the East Duwamish Waterway are likely to further reduce bacteria concentrations in Inner Elliott Bay.

3.3 Physical Parameters

The following sections describe current conditions in the Elliott Bay study area, compare conditions with WQC where available, and analyze long-term trends for temperature, salinity, DO, turbidity, TSS, and pH.

3.3.1 Temperature

While not likely impacted by CSO discharges, temperature in Elliott Bay is important to growth and survival of marine life, particularly temperature-dependent species such as salmon. Because of the high variability in surface water temperatures, increased sampling frequency at routine monitoring sites is necessary to determine whether temperatures in Elliott Bay pose a threat to wildlife including migratory salmon.

This section describes current temperatures, how they compare to criteria, and long-term trends in the study area.

Current Conditions

Monthly temperature data are available from beach sites in Elliott Bay from as early as 1970 and from offshore sites since 1997. From 2004 through 2013, temperatures ranged from 6.2 to 19.2 °C at beach sites (minimum and maximum at West Point South in December 2008 and September 2006, respectively) and 6.8 °C to 15.1 °C at offshore sites (Elliott West Outfall, 1 m – January 2008; South Plant Outfall, 1 m – July 2004).

Temperatures vary seasonally; the warmest temperatures occur in July and August and the coolest temperatures occur between January and March (Figure 3-6). Temperatures are most stratified during the late summer from July through September when surface waters are the warmest. Typically in September and October, winds and deep water that upwelled from the Pacific Ocean to Puget Sound, including Elliott Bay, forces colder, less-oxygenated deep water to the surface. This upwelling mixes the waters and creates uniform temperatures in the center of the bay that largely persist through winter (Figure 3-7).

Temperatures near the surface (about 1 m) do not differ significantly among offshore sites on an annual basis (Kruskal-Wallis p-value = 0.8383). However, temperatures do significantly differ when only summer months are considered (Kruskal-Wallis p-value > 0.0001). During the summer, beach sites directly influenced by the Duwamish Estuary (north of its discharge into the bay) have significantly higher temperatures than offshore sites and other beach sites located outside of the direct influence of the river (Figure 3-8).

In addition to monthly samples, temperatures have been collected at 15-minute intervals from two depths at the Seattle Aquarium since 2008. These continuous data demonstrate the daily variability in temperature and the difference between near-surface (1 m) and near-bottom (10 m) temperatures throughout the year. Temperature is more variable at the surface than at the 10-m depth largely because of the influence of air temperature

(Figure 3-9). Temperatures at the two depths converge during October as the result of upwelled waters and the breakdown of thermal stratification.

Comparison to Criteria

Sites in Elliott Bay are held to two different water quality criteria. Inner Elliott Bay is considered “Excellent” waters and therefore must not exceed a one-day maximum temperature of 16 °C; Outer Elliott Bay and adjacent Puget Sound are classified as “Extraordinary” and are held to the higher standard of a 13 °C one-day maximum (WAC-173-201A-210). These temperature criteria were established to protect aquatic life, including salmon, based on use.

In the last 10 years, four beach sites (Seattle Waterfront, Alki Beach, West Point South, and Magnolia Outfall) and one offshore site (South Plant Outfall) exceeded state water quality criteria for temperature (Figure 3-10):

- Seattle Waterfront exceeded criteria in July 2008.
- Alki Beach, Magnolia Outfall, and West Point South exceeded criteria 18, 33, and 34 times, respectively.
- South Plant Outfall exceeded criteria 13 times at the surface (~1 m) during the months of June–September (Figure 3-8). However, temperatures at this site do not significantly differ from other offshore sites in Inner Elliott Bay.

These exceedances are more likely influenced by natural dynamics than anthropogenic activities. In addition, CSO and stormwater discharge volumes are lowest during the summer when rainfall is low and are not likely to greatly affect water temperatures during the critical period.

At the Seattle Aquarium from 2008 through 2013, temperatures above 16 °C (one-day maximum water quality criterion) were recorded on 15 days (maximum = 16.96 °C in July 2012). Temperatures varied as much as 4.82 °C a day at the surface and 2.21 °C near the bottom, and the daily average temperature never exceeded the criterion (maximum mean daily temperature = 15.38 °C).

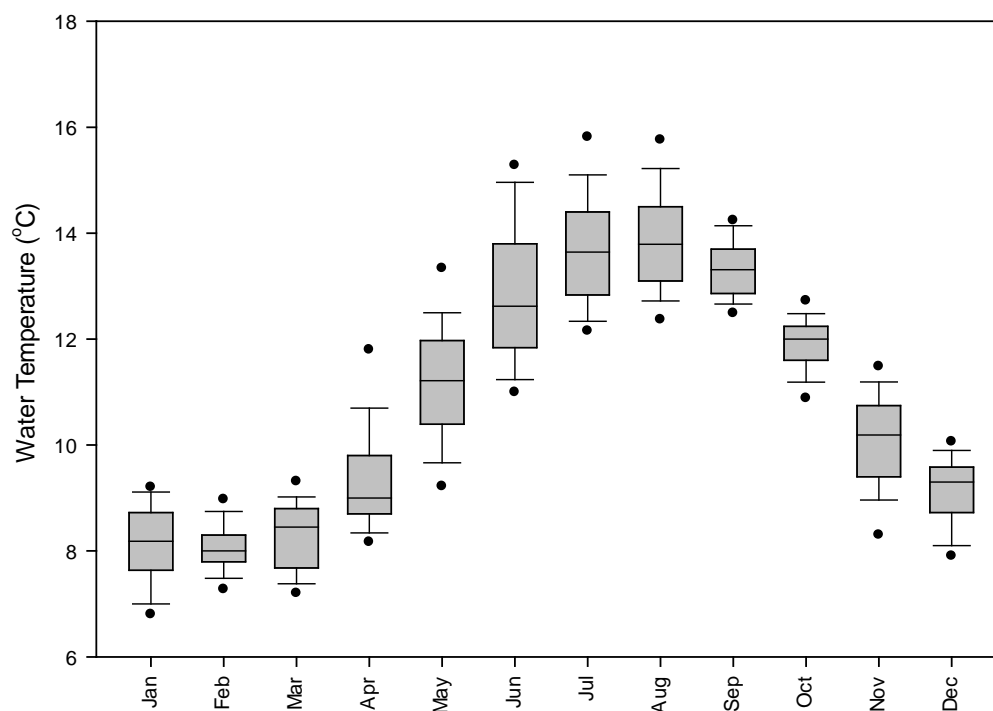


Figure 3-6. Water temperature (°C) at ~ 1 m depth by month at all sites in Elliott Bay and adjacent Puget Sound (2004–2013).

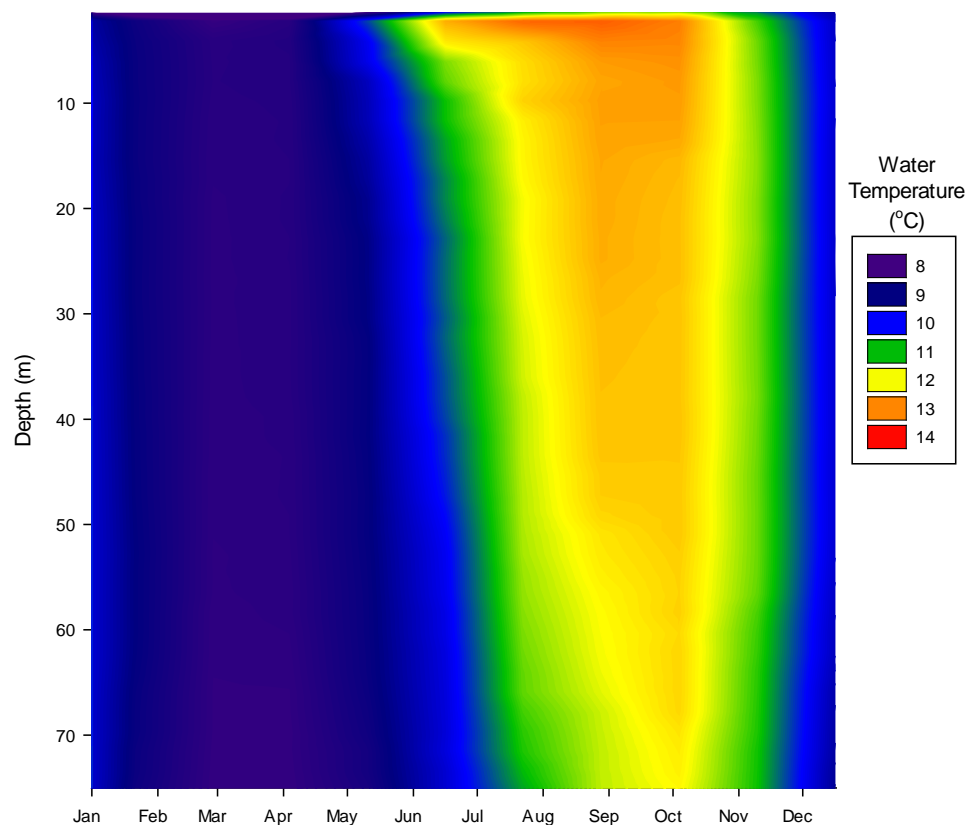


Figure 3-7. Water temperature (°C) profile at 1.5–75 m depths at the Central Elliott Bay site (2013).

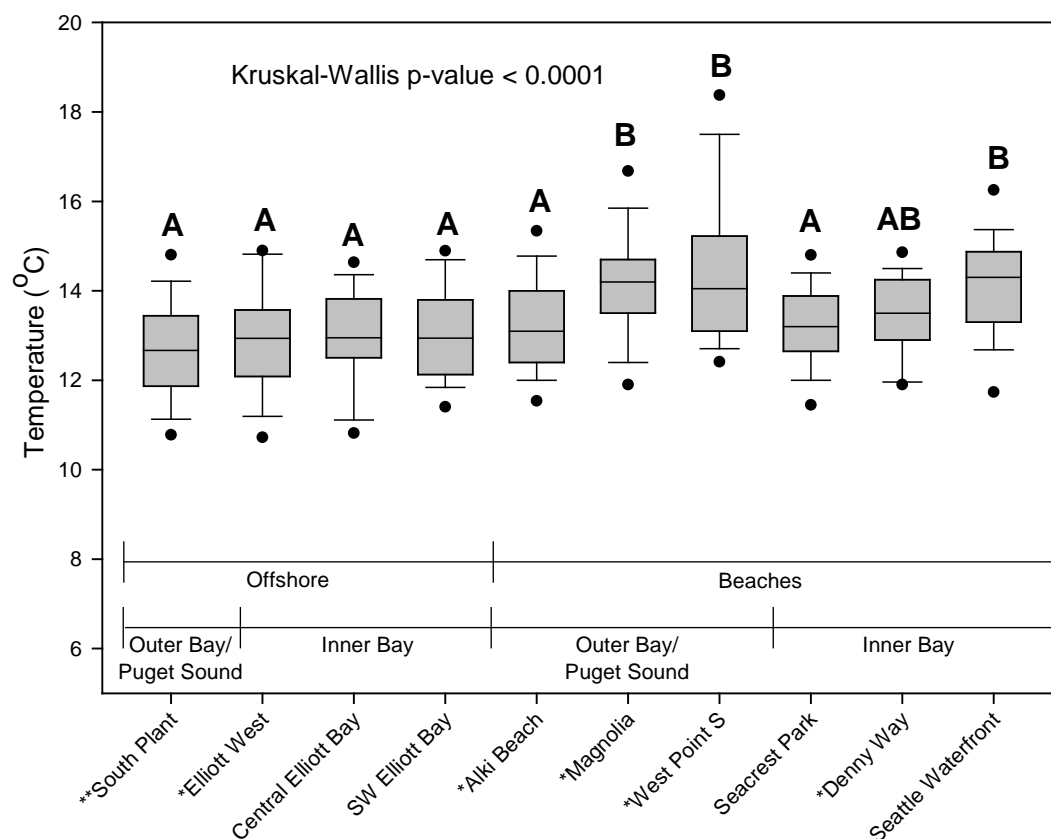


Figure 3-8. Summer (June–August) temperatures (°C) at ~1 m depth at sites in Elliott Bay and adjacent Puget Sound (2004–2013). (* = CSO and CSO treatment plant outfall site; ** = Treatment plant outfall site)

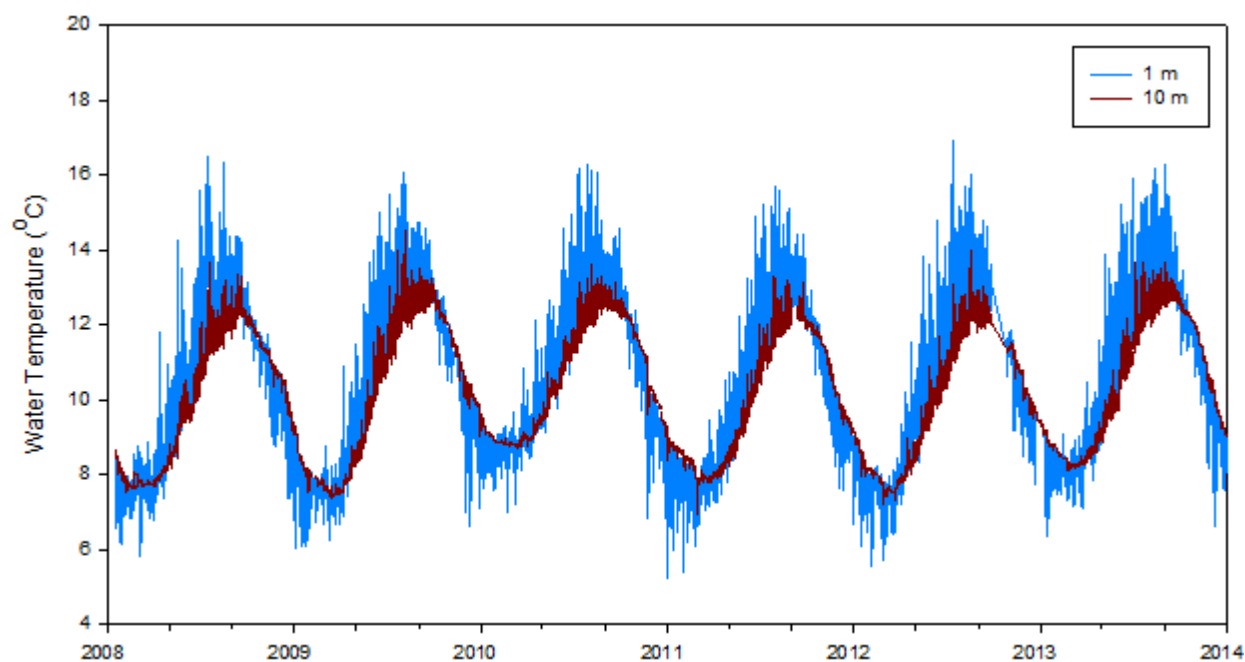


Figure 3-9. Water temperature (°C) at 1-m and 10-m depths at Seattle Aquarium (2008–2013).

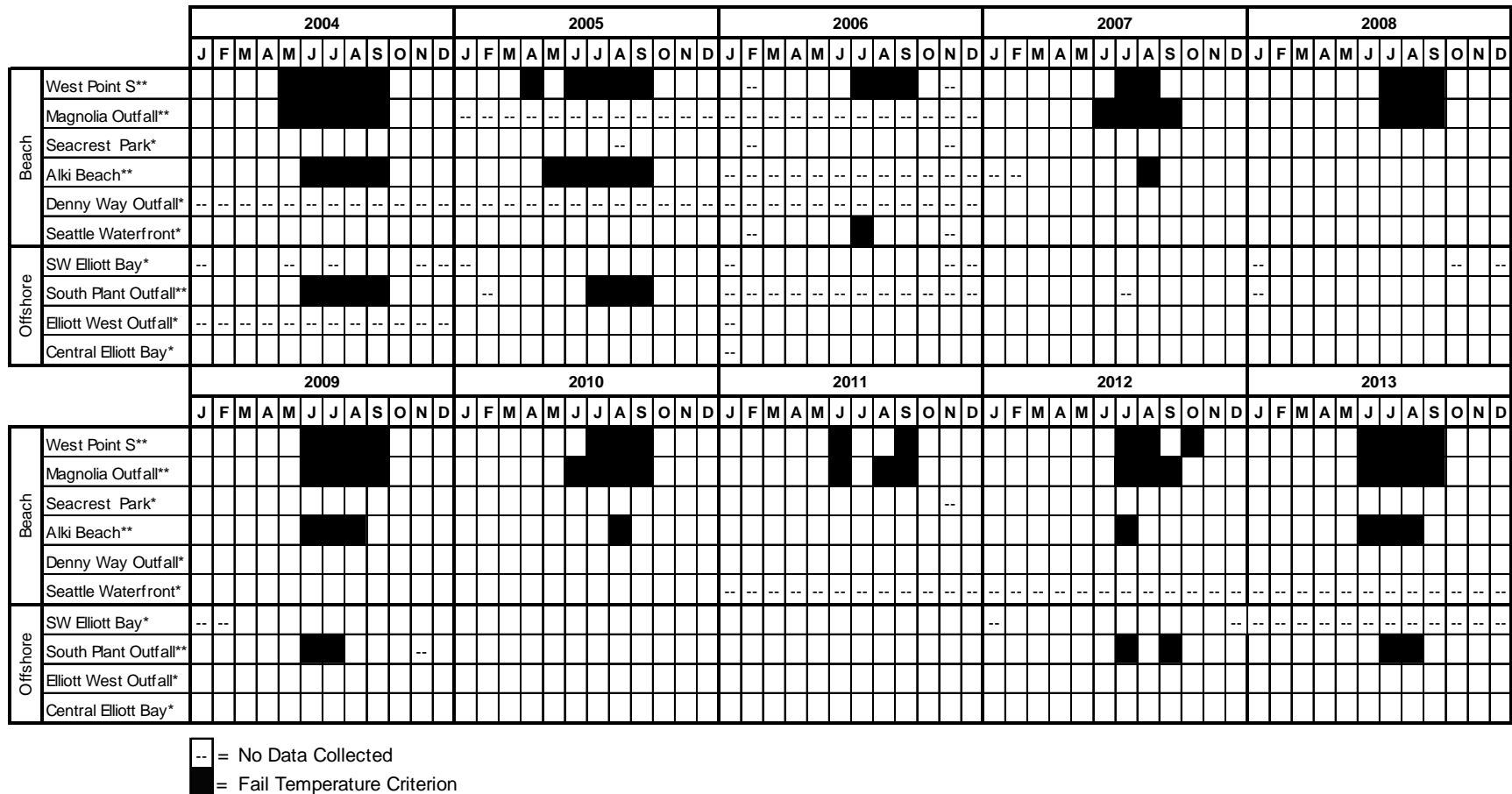


Figure 3-10. Occurrences of state water temperature criteria failure at beach and offshore sites in Elliott Bay and adjacent Puget Sound. (*Excellent waters temperature criterion = 16 °C; **Extraordinary waters temperature criterion = 13 °C).

Long-Term Trends

Surface temperatures in the Pacific Ocean shift between warm and cool phases on a decadal scale; this phenomenon is known as the Pacific Decadal Oscillation (PDO) and is detected as positive or negative monthly temperature anomalies (Mantua et al., 1997). The PDO is likely affected by El Niño Southern Oscillation (ENSO) events (Newman et al., 2003). These large-scale warming and cooling cycles were included as covariates in determining long-term trends in Elliott Bay.

The long-term trend analysis indicates that many beach sites do not demonstrate a significant change in temperature over time. However, one site (Seattle Waterfront) located near the mouth of the Duwamish Estuary, with data from 1981 through 2010, showed a significant increasing trend of 0.0267 °C per year (Table 3-4). In contrast, two offshore sites (Central Elliott Bay and South Plant Outfall) saw significant decreases in temperature at all depths. The decreases ranged from -0.0231 to -0.0528 °C per year from 1997 through 2013 (Table 3-4). The largest decreases were seen at depth.

Possible explanations for the difference in direction of temperature changes between the beach and two offshore sites are as follows:

- Deep marine waters may have a greater buffering capacity because of the larger water mass than shallow waters at the mouth of the Duwamish Estuary that experience direct freshwater inputs. Seattle Waterfront is the site most influenced by the Duwamish Estuary. Temperature increases in the Duwamish Estuary are more likely to affect this site than others in Elliott Bay.
- The cool phase of the PDO has been dominant for the past 15 years. The period from 1997 through 2013 has been called a “global warming hiatus” (Tollefson, 2014). Tropical trade winds were weakened during this period, reducing the strength of El Niño and sequestering warm waters into the deep ocean. Because all the offshore samples were collected during this time, the “hiatus” may be masking long-term temperature trends that surpass the length of the dataset. Thus, the larger issue may be that the data available from offshore sites are not sufficient for evaluating temperature trends that are influenced by a decadal cycle.
- The significant trends could be random false positives.

Table 3-4. Results of seasonal (monthly) Mann-Kendall test of temperature in Elliott Bay over time, with Theil-Sen's slopes.

	Site	Depth (m)	Years Evaluated	Significance	Trend	p-value	Slope of Trend (°C/year)
Beach	West Point S	NA	1970–2013	n.s.	–	0.807	0.0012
	Magnolia Outfall	NA	1985–2013	n.s.	–	0.723	–0.0035
	Seacrest Park	NA	1997–2013	n.s.	–	0.225	–0.0217
	Alki Beach	NA	1970–2013	n.s.	–	0.765	–0.0015
	Denny Way Outfall	NA	2007–2013	Insufficient data to evaluate trends			
	Seattle Waterfront	NA	1981–2010	***	↑	< 0.001	0.0267
Offshore	SW Elliott Bay	1	1991–2012	n.s.	–	0.885	–0.0016
		10	1991–2012	n.s.	–	0.761	0.0030
		30	1992–2012	n.s.	–	0.812	–0.0027
	South Plant Outfall	1	1997–2013	***	↓	0.002	–0.0441
		15	1997–2013	***	↓	0.007	–0.0336
		25	1997–2013	***	↓	0.009	–0.0343
		35	1997–2013	**	↓	0.017	–0.0345
		55	1997–2013	***	↓	0.008	–0.0379
		100	1997–2013	**	↓	0.020	–0.0368
		180	2003–2013	***	↓	0.003	–0.0528
	Elliott West Outfall	1	2005–2013	Insufficient data to evaluate trends			
		15	2005–2013	Insufficient data to evaluate trends			
	Central Elliott Bay	1	1997–2013	*	↓	0.088	–0.0231
		15	1997–2013	**	↓	0.015	–0.0290
		25	1997–2013	**	↓	0.017	–0.0321
		35	1997–2013	**	↓	0.018	–0.0345
		55	1997–2013	**	↓	0.011	–0.0436
		75	1997–2013	***	↓	0.006	–0.0507

Adjusted p-values were calculated using PDO and ENSO indexes as covariates and corrected for inter-block covariance. n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05$ - 0.10); ** = significant ($p = 0.01$ - 0.05); *** = highly significant ($p < 0.01$).

3.3.2 Salinity

Elliott Bay is an estuarine system. Its greatest freshwater influence comes from the Duwamish Estuary; its greatest source of marine waters comes from Puget Sound via the Pacific Ocean. This section describes current salinity and long-term trends in the study area. There are no WQC for salinity.

Current Conditions

From 2004 through 2013, salinities measured at discrete depths ranged from 12.66 practical salinity units (PSU) (Denny Way Outfall, surface – January 2011) to 30.61 PSU

(Alki Beach – October 2009) at beach sites and 16.50 PSU (SW Elliott Bay, 1 m – February 2006) to 31.00 PSU (South Plant Outfall, 180 m – October 2009) at offshore sites. Surface salinities tend to be lower than at depth, and a freshwater lens is apparent in surface waters especially in Inner Elliott Bay; below approximately 10 m, the waters tend to be well mixed and saline (Figure 3-11).

Sites located near the Duwamish Estuary have significantly lower salinity than those located in adjacent Central Puget Sound (Figure 3-12). Discharges from the Duwamish Estuary overwhelm any freshwater signature of CSO discharges into Elliott Bay. Surface water salinities tend to decrease in May and June as the result of increased snowmelt and in November through February as the result of high rainfall. This relationship is demonstrated in the negative correlation between surface (1 m) salinity at the Seattle Aquarium site and discharges from upstream in the Green River (U.S. Geological Survey [USGS] site 12113000) (Spearman-rank correlation $p < 0.0001$; $\rho = -0.78$) (Figure 3-13).

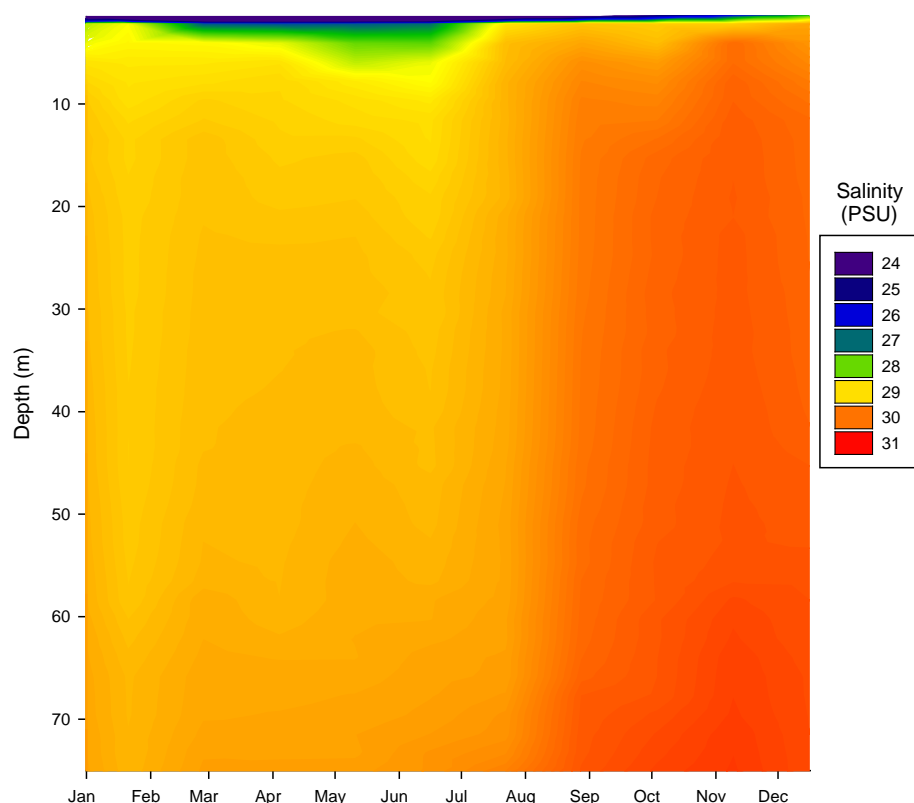


Figure 3-11. Salinity (PSU) profile at 1.5–75 m depths in Central Elliott Bay (2013).

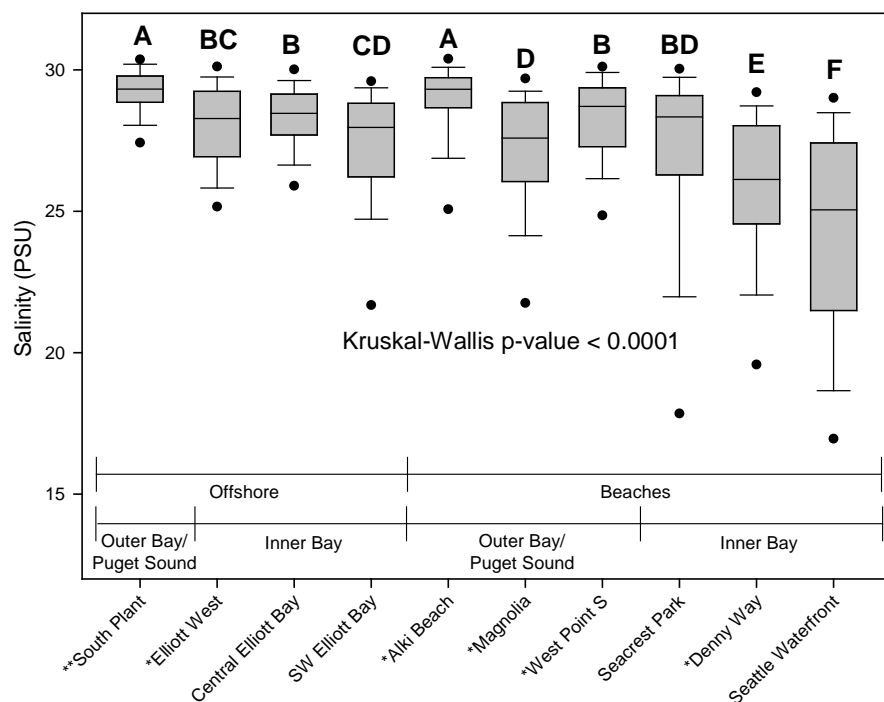


Figure 3-12. Salinity (PSU) at ~1 m depth at all sites in Elliott Bay and adjacent Puget Sound (2004–2013). (* = CSO and CSO treatment plant outfall site; ** = treatment plant outfall site)

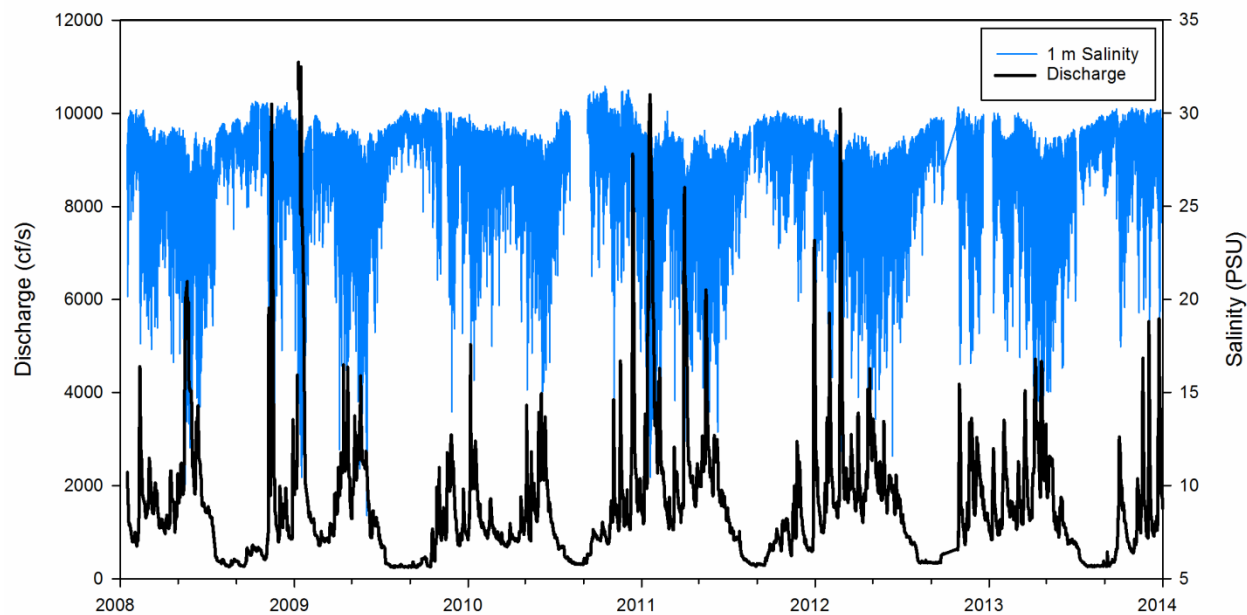


Figure 3-13. Salinity (PSU) at Seattle Aquarium vs. discharge (cfs) upstream of the Duwamish River in the Green River (USGS 12113000) at 15-minute intervals (2008–2013).

Comparison to Criteria

There are no state WQC for salinity in marine waters.

Long-Term Trends

Current conditions were compared to earlier data to evaluate long-term trends in salinity, which has been consistently measured since as early as 1985. Despite all trends at both beach and offshore sites indicating a decrease in salinity over time in Elliott Bay, none of the sites had significantly negative trends (Table 3-5). This lack of significance may be due to the high inter-annual variability of salinity. Salinity may continue to decrease, at least briefly, in the coming years if snowmelt increases as the result of climate change.

Table 3-5. Results of seasonal (monthly) Mann-Kendall test of salinity in Elliott Bay over time, with Theil-Sen's slope.

	Site	Depth	Years Evaluated	Significance	Trend	p-value	Slope of Trend (PSU/year)
Beach	West Point South	NA	1985–2013	n.s.	–	0.487	–0.0174
	Magnolia Outfall ^a	NA	1989–2013	n.s.	–	0.104	–0.0288
	Seacrest Park ^a	NA	1999–2013	n.s.	–	0.602	–0.0172
	Alki Beach ^a	NA	1985–2013	n.s.	–	0.3	–0.0143
	Denny Way Outfall	NA	2007–2013	Insufficient data to evaluate trends			
	Seattle Waterfront ^a	NA	1999–2010	Insufficient data to evaluate trends			
Offshore	SW Elliott Bay	1	1991–2012	n.s.	–	0.885	–0.0016
		10	1991–2012	n.s.	–	0.761	0.0030
		30	1992–2012	n.s.	–	0.812	–0.0027
	South Plant Outfall ^{II}	1	1998–2013	n.s.	–	0.355	–0.0176
		15	1998–2013	n.s.	–	0.393	–0.0167
		25	1998–2013	n.s.	–	0.387	–0.0168
		35	1998–2013	n.s.	–	0.406	–0.0142
		55	1998–2013	n.s.	–	0.470	–0.0115
		100	1998–2013	n.s.	–	0.547	–0.0096
		180	2000–2013	n.s.	–	0.111	–0.025
	Elliott West Outfall	1	2005–2013	Insufficient data to evaluate trends			
		15	2005–2013	Insufficient data to evaluate trends			
	Central Elliott Bay	1	1998–2013	n.s.	–	0.375	–0.0170
		15	1998–2013	n.s.	–	0.361	–0.0149
		25	1998–2013	n.s.	–	0.375	–0.0162
		35	1998–2013	n.s.	–	0.373	–0.0155
		55	1998–2013	n.s.	–	0.476	–0.0151
		75	1998–2013	n.s.	–	0.439	–0.0103

Adjusted p-values were calculated using three-day prior rainfall as a covariate and corrected for inter-block covariance.

n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05-0.10$); ** = significant ($p = 0.01-0.05$); *** = highly significant ($p < 0.01$).

^a Data not available for 2002–2006.

3.3.3 Dissolved Oxygen

Low concentrations of DO can be harmful to wildlife, including many oxygen-sensitive fish species such as salmonids, if values approach hypoxic (oxygen-limited) conditions. This section describes current DO levels, compares levels with WQC, and analyzes long-term trends.

Current Conditions

DO concentrations measured monthly at discrete depths at offshore Elliott Bay sites from 2004 through 2013 range from 4.7 mg/L (Central Elliott Bay, 75 m – October 2004) to 13.5 mg/L (South Plant Outfall, 1 m – May 2009). DO is significantly higher in surface waters than at depth. (Figure 3-14 shows representative sites.) DO does not differ significantly between sites near the surface (~1 m), indicating that monitoring sites influenced by outfalls are not significantly impacted. (Figure 3-15 shows representative sites.)

Elliott Bay experiences the highest surface water DO concentrations when phytoplankton concentrations are high, typically with the first bloom near May and with the second bloom in late summer or early fall. DO concentrations are typically at their lowest throughout the water column around October after deep oxygen-poor water upwells from the Pacific Ocean into Puget Sound in late summer and de-stratification occurs in Elliott Bay (for example, Figure 3-16 that shows the Central Elliott Bay site).

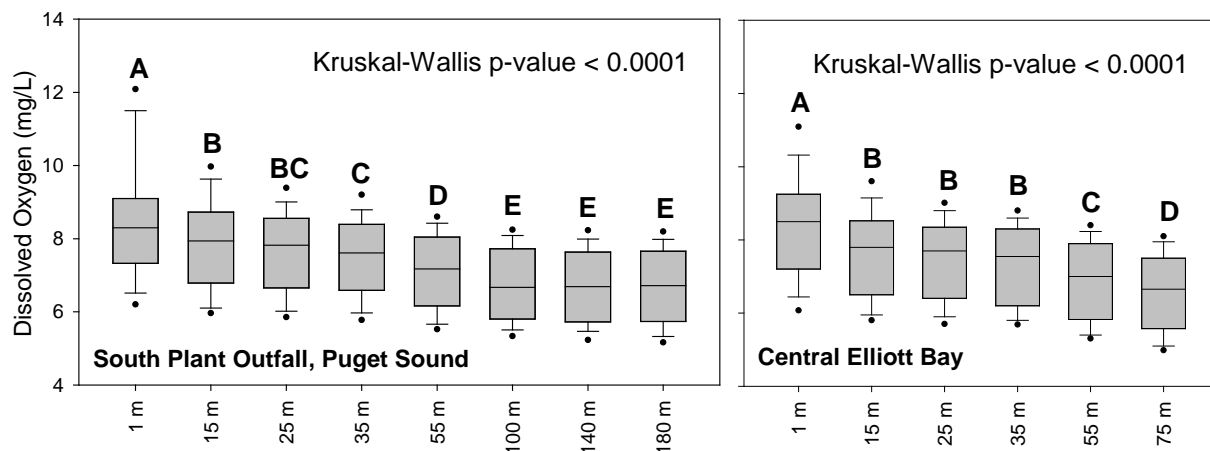


Figure 3-14. Dissolved oxygen (mg/L) at depth for two representative sites: Central Elliott Bay and South Plant Outfall in adjacent Puget Sound (2004–2013).

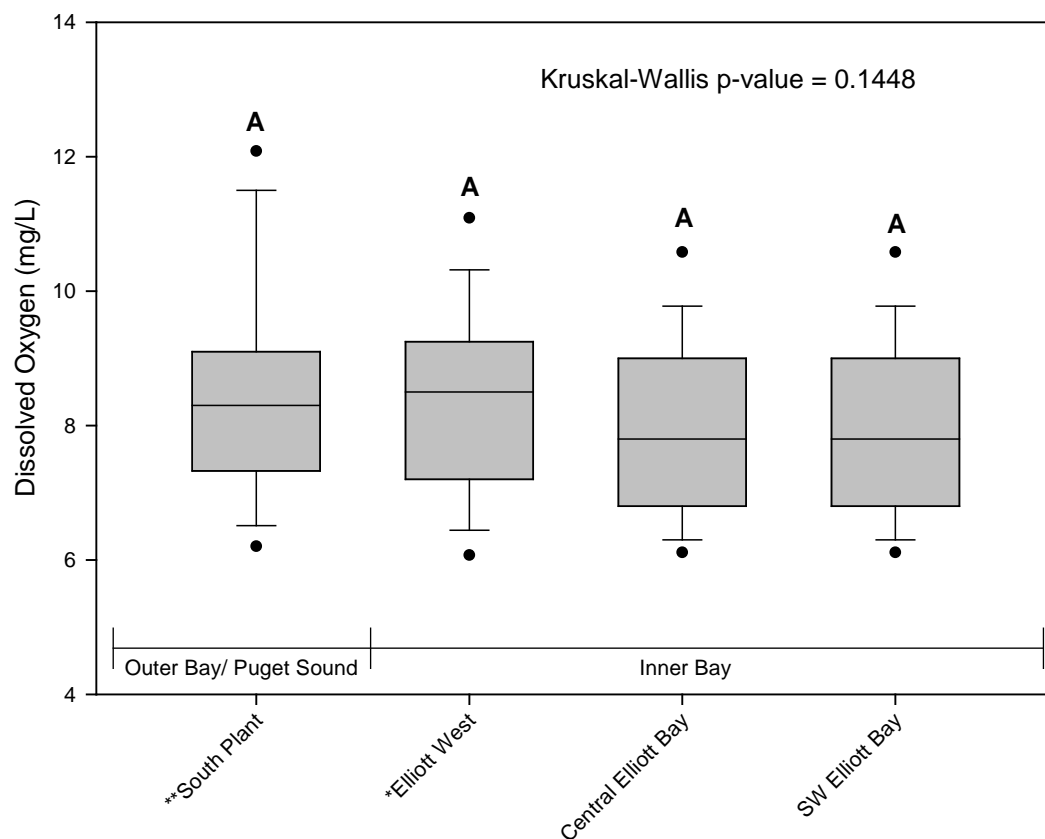


Figure 3-15. Dissolved oxygen (mg/L) at ~1 m depth at sites in Elliott Bay and adjacent Puget Sound (2004–2013). (* = CSO treatment plant outfall site; ** = treatment plant outfall site)

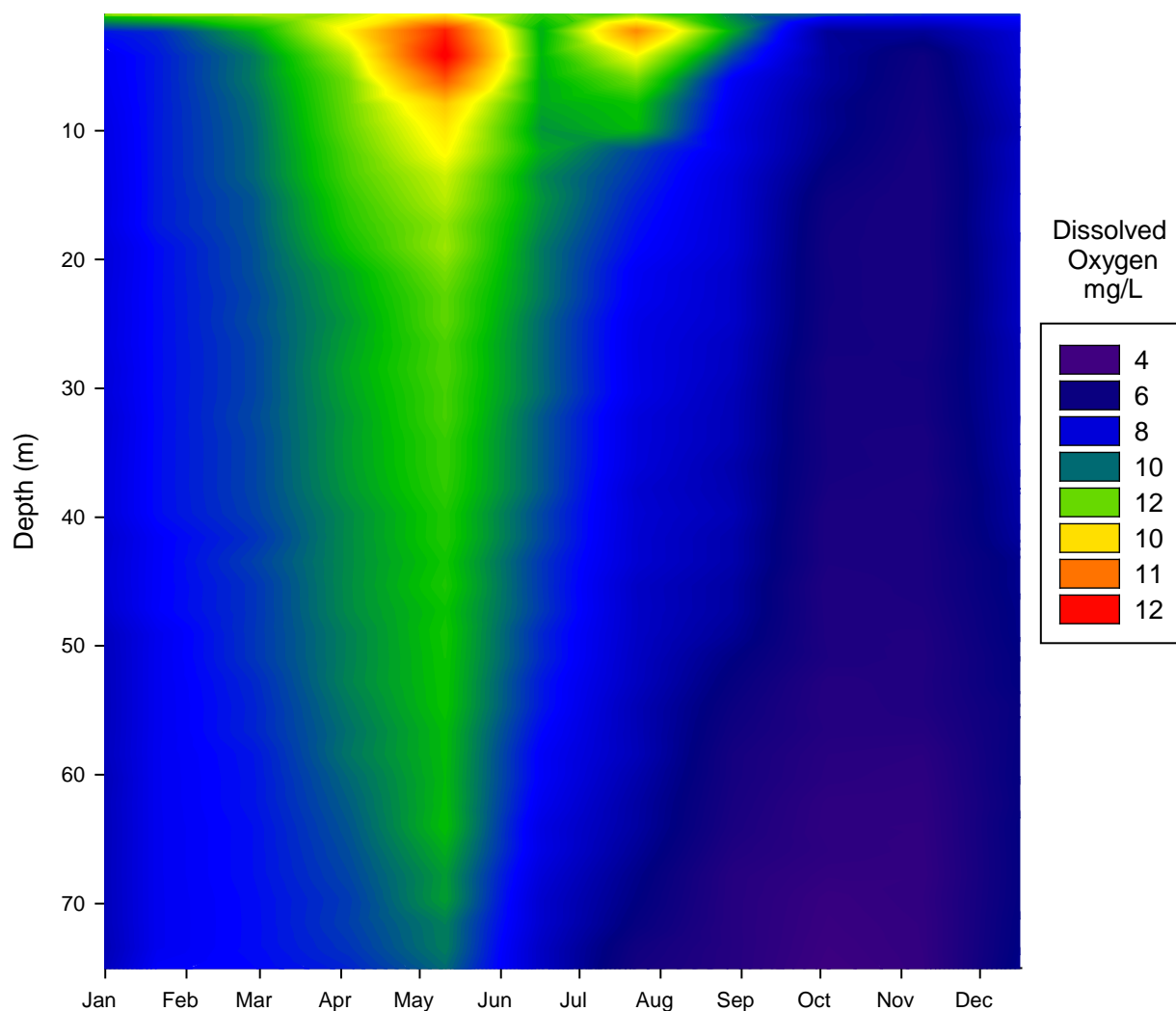


Figure 3-16. Dissolved oxygen (mg/L) profile at 1.5–75 m depths at Central Elliott Bay site (2013).

Comparison to Criteria

Elliott Bay is listed on Ecology’s 303(d) list of impaired waters because of low DO concentrations. As a result of the natural upwelling that occurs throughout Puget Sound, sites in Elliott Bay frequently exceed marine WQC for DO. For Inner Elliott Bay, the Excellent quality criterion requires that DO concentrations, measured as a one-day minimum, be no less than 6.0 mg/L more than once every 10 years on average. For Outer Elliott Bay/Puget Sound, the minimum for Extraordinary quality is 7.0 mg/L. These minimums are frequently exceeded in Elliott Bay at monthly monitoring sites, particularly at deep sites in the latter half of the year (Figure 3-17). During most years, the criterion in Inner Elliott Bay was exceeded multiple times per day, especially near the bottom of the water column. The 15-minute data from 2008 through 2013 at the Seattle Aquarium illustrates criterion exceedances (Figure 3-18).

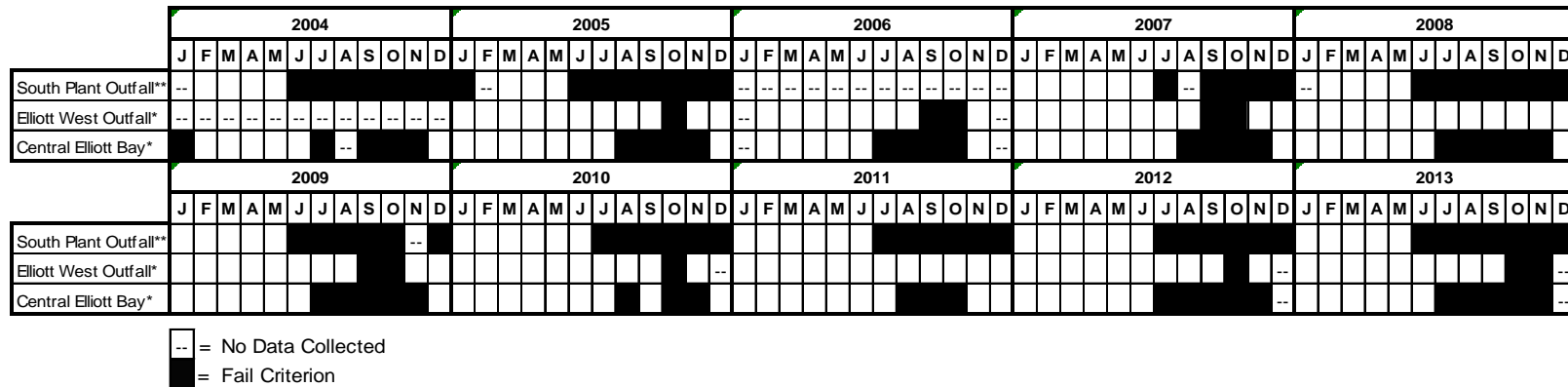


Figure 3-17. State WQC failures for dissolved oxygen at offshore sites in Elliott Bay and adjacent Puget Sound (2004–2013). The lowest DO concentration measured at discrete sampling depths was compared to WQC to determine pass/fail. (** = Extraordinary quality [criterion of 7 mg/L]; * = Excellent quality [criterion of 6 mg/L]).

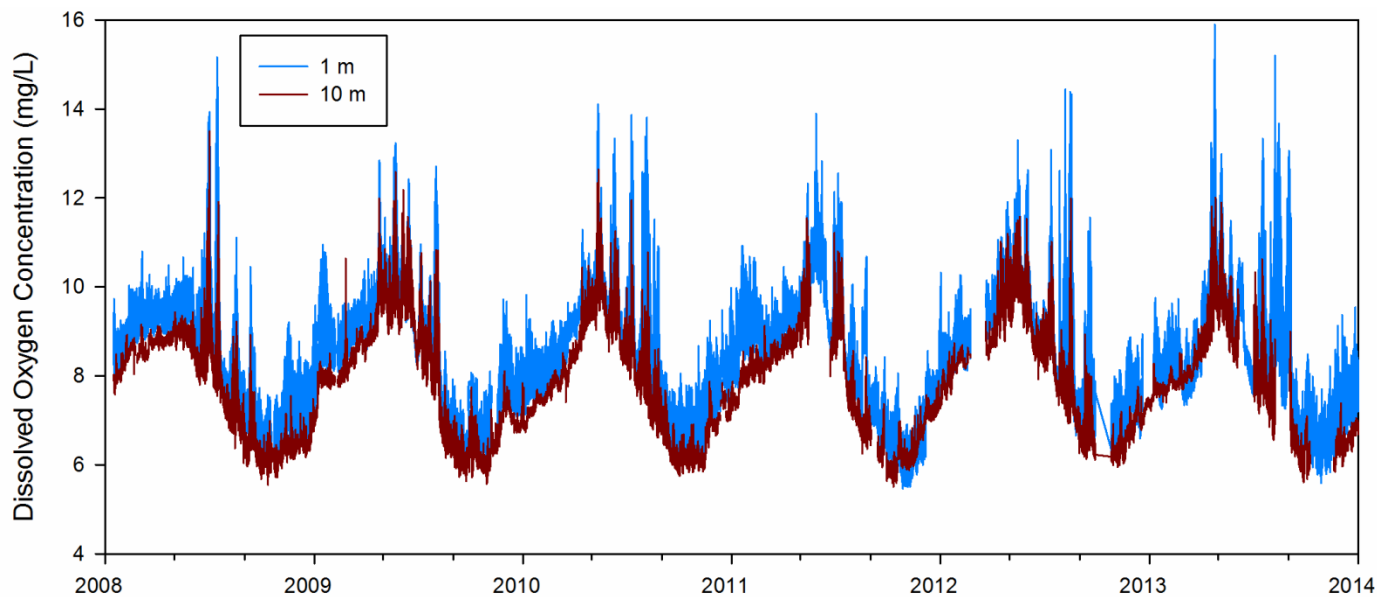


Figure 3-18. Dissolved oxygen concentration (mg/L) at ~1- and 10-m depths at the Seattle Aquarium at 15-minute intervals (2008–2013). The dashed red line illustrates the water quality criterion at that site (6 mg/L).

Long-Term Trends

Although DO concentrations frequently fail WQC at offshore sites, long-term trends indicate that the problem is not getting worse. DO concentrations in Elliott Bay from 1998 through 2013 did not significantly change, although the three sites included in the trend analysis (South Plant Outfall, Elliott West Outfall, and Central Elliott Bay) and all depths show a slight increase (Table 3-6). This change is not likely to be biologically significant.

Table 3-6. Results of seasonal (monthly) Mann-Kendall test for dissolved oxygen at offshore sites in Elliott Bay over time, with Theil-Sen's slopes.

Offshore Site	Depth	Years Evaluated	Significance	Trend	p-value	Slope of Trend (mg/L/year)
South Plant Outfall	1	1998–2013	n.s.	–	0.460	0.0200
	15	1998–2013	n.s.	–	0.462	0.0087
	25	1998–2013	n.s.	–	0.484	0.0064
	35	1998–2013	n.s.	–	0.384	0.0058
	55	1998–2013	n.s.	–	0.603	0.0055
	100	1998–2013	n.s.	–	0.288	0.0122
	180	2000–2013	n.s.	–	0.382	0.0131
Elliott West Outfall	1	2005–2013	Insufficient data to evaluate trends			
	15	2005–2013	Insufficient data to evaluate trends			
Central Elliott Bay	1	1998–2013	n.s.	–	0.186	0.0250
	15	1998–2013	n.s.	–	0.510	0.0000
	25	1998–2013	n.s.	–	0.199	0.0160
	35	1998–2013	n.s.	–	0.388	0.0093
	55	1998–2013	n.s.	–	0.760	0.0000
	75	1998–2013	n.s.	–	0.268	0.0045

Adjusted p-values were calculated using three-day prior rainfall as a covariate and corrected for inter-block covariance.

n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05-0.10$); ** = significant ($p = 0.01-0.05$); *** = highly significant ($p < 0.01$).

3.3.4 Turbidity and Total Suspended Solids

Turbidity and TSS are influenced by phytoplankton biomass, resuspended sediment, and inputs of particles from stormwater outfalls, CSO outfalls, and surface runoff. CSO and stormwater discharges contain organic and inorganic matter, which may discolor the water, cause murkiness, disrupt visual-feeding fish, and be aesthetically displeasing. As the solids settle, they may bury benthic habitat and displace or destroy the benthic community (EPA, 2004). Turbidity and TSS are measured in the following ways:

- Turbidity is a measure of the cloudiness of water and is quantified by determining the scattering of light particles in a sample of water. Individual particles in turbid water are often too small to be visible to the naked eye and may not be captured by filtration for analysis of TSS. Dissolved and suspended solids, which include detritus, plankton, and particulates, increase turbidity in marine waters. Highly turbid waters

are known to negatively impact salmon and other fishes (Berg et al., 1985; Lin et al., 1992; Bash et al., 2001).

- The measure of TSS is the total mass of particles greater than 1.5 microns in diameter in a sample of water, generally measured by dry weight (dw) after filtration.

Current Conditions and Comparison to Criteria

King County's TSS and turbidity data are similar to the data in studies by the National Oceanic and Atmospheric Administration (NOAA). The studies found that suspended particulate matter in Elliott Bay is most variable near the bottom as the result of tidal activity and that the surface is more influenced by freshwater discharges (NOAA, 1982, 1998). These natural increases in turbidity from upstream sources make it difficult to define background turbidity and determine how to apply WQC.

Because of the potential for turbidity to affect aquatic health, Washington State surface water criteria applied to Elliott Bay limit turbidity to 5 nephelometric turbidity units (NTUs) over background, when the background is 50 NTUs or less, as a one-day maximum. Turbidity in Elliott Bay is measured by the mooring station at the Seattle Aquarium. Turbidity at this site is typically below 10 NTUs but commonly exceeds the 5 NTU over background criterion because of the site's proximity to the Duwamish Estuary. This level of turbidity is usual for a bay near a freshwater input. Turbidity may spike with increased discharges from upstream in the Green River (and subsequently the Duwamish Estuary) (Figure 3-19).

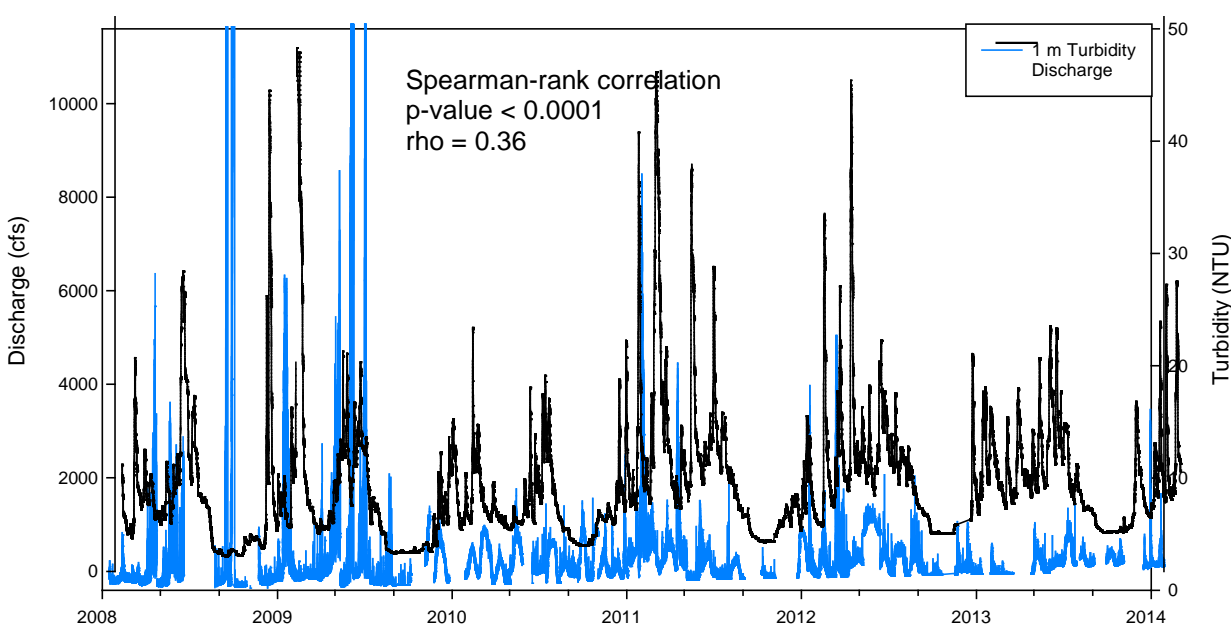


Figure 3-19. Turbidity (NTUs) at the Seattle Aquarium vs. discharge (cfs) upstream of the Duwamish River (USGS 12113000) at 15-minute intervals (2008–2013). Data above 50 NTUs may be due to equipment malfunctions.

Unlike turbidity, there are no state WQC for TSS in marine waters. TSS was measured monthly at discrete depths at offshore sites in Elliott Bay. Between 2005 and 2013, TSS ranged from below detection limits (minimum method detection limit [MDL] of 0.5 mg/L) at all sites to 10.2 mg/L at the South Plant Outfall site (180 m – December 2005). At the 1-m depth, TSS measured at two treatment plant outfall sites (Elliott West and South Plant) did not significantly differ from TSS measured at the Central Elliott Bay site (Figure 3-20). TSS was significantly higher near the bottom and near the surface than in the middle of the water column at a deep site (Central Elliott Bay) but did not significantly differ at the shallow Elliott West Outfall site (Figure 3-21).

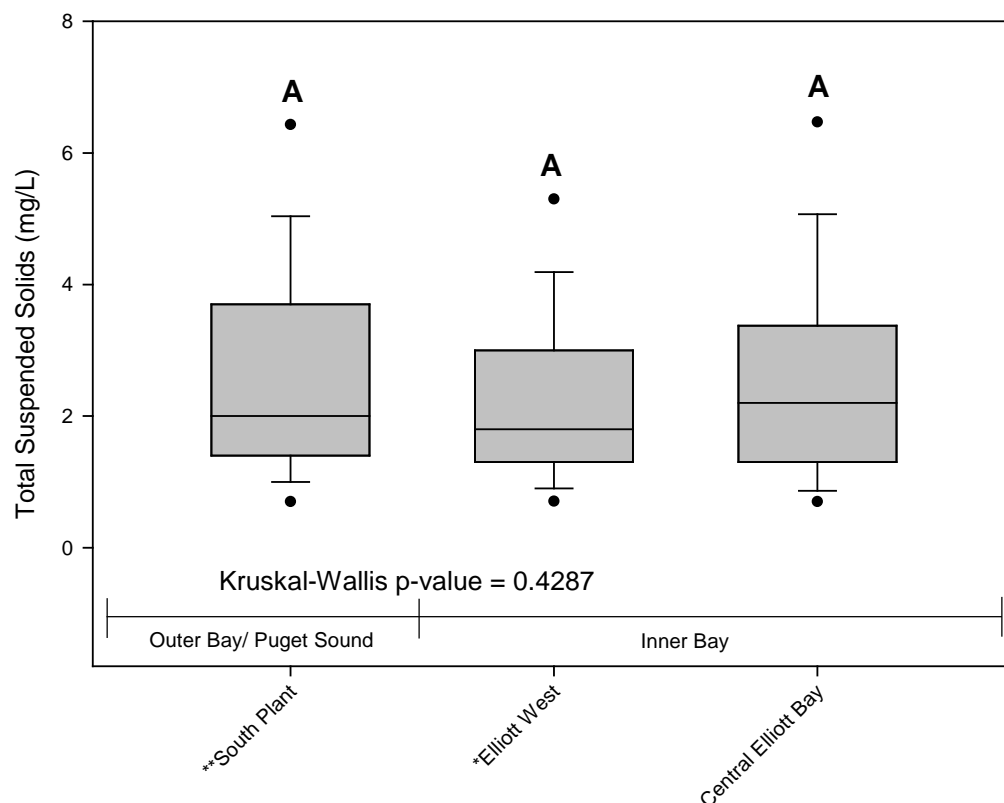


Figure 3-20 Total suspended solids (mg/L) at ~1 m-depth at three offshore sites in Elliott Bay and adjacent Puget Sound (2004–2013). (* = CSO treatment plant outfall site; ** = treatment plant outfall site)

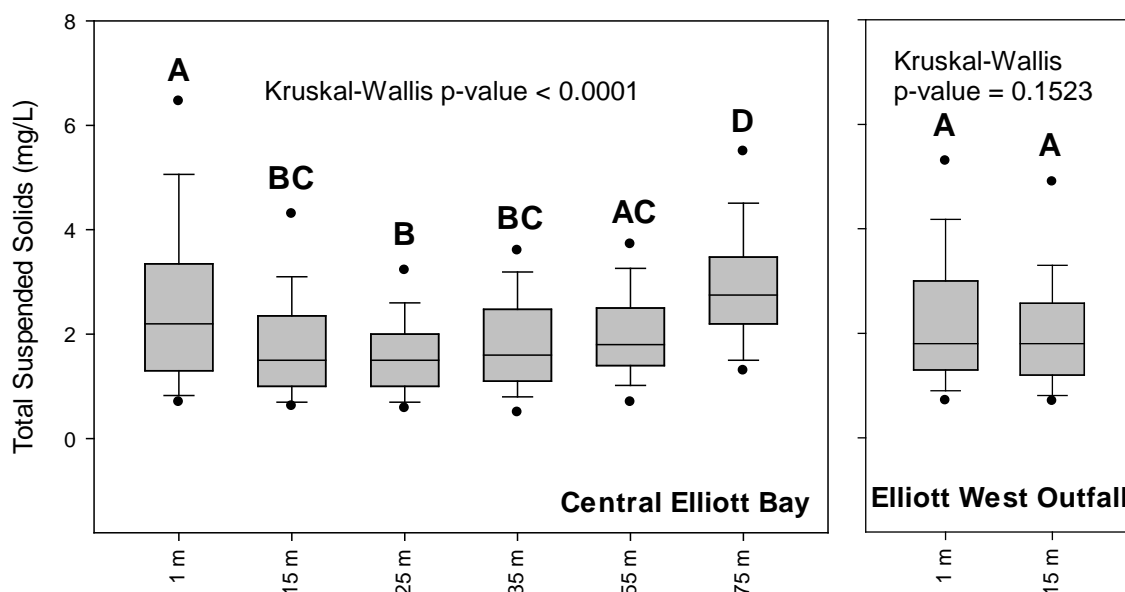


Figure 3-21. Total suspended solids (mg/L) at various depths at two representative sites in Inner Elliott Bay (2004–2013).

Long-Term Trends

TSS has been measured at offshore sites in Elliott Bay since 1997. These data were used to evaluate long-term trends in TSS. Data from January to July 2011 were removed prior to analysis because of laboratory quality control issues. There were no significant trends in TSS during 1997–2013. Central Elliott Bay at 75 m had a marginally significant increasing trend ($p = 0.072$). However, based on the mixed results of other site/depth combinations, it appears that there were no overall changes in TSS since 1997 (Table 3-7).

Table 3-7. Results of seasonal (monthly) Mann-Kendall test of total suspended solids in at offshore sites in Elliott Bay over time, with Theil-Sen's slopes.

Offshore Site	Depth	Years Evaluated	Significance	Trend	p-value	Slope of Trend (mg/L/year)
South Plant Outfall	1	1997–2013	n.s.	–	0.345	–0.0500
	15	1997–2013	n.s.	–	0.605	–0.0100
	25	1997–2013	n.s.	–	0.509	0.0143
	35	1997–2013	n.s.	–	0.973	0.0000
	55	1997–2013	n.s.	–	0.513	–0.0140
	100	1997–2013	n.s.	–	0.560	–0.0158
	180	2003–2013	n.s.	–	0.104	–0.1333
Elliott West Outfall	1	2005–2013	Insufficient data to evaluate trends			
	15	2005–2013	Insufficient data to evaluate trends			
Central Elliott Bay	1	1997–2013	n.s.	–	0.672	–0.0111
	15	1997–2013	n.s.	–	0.916	0.0000
	25	1997–2013	n.s.	–	0.301	–0.0200
	35	1997–2013	n.s.	–	0.616	0.0145
	55	1997–2013	n.s.	–	0.704	0.0131
	75	1997–2013	*	↑	0.072	0.0500

Adjusted p-values were calculated using three-day prior rainfall as a covariate and corrected for inter-block covariance.

Data from 2011 were removed due to quality control failures.

n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05-0.10$); ** = significant ($p = 0.01-0.05$); *** = highly significant ($p < 0.01$).

3.3.5 pH

pH has not historically been measured as part of King County's ambient monitoring program. pH data measured continuously at the Seattle Aquarium mooring and monthly data from Ecology were deemed unreliable.

Current Conditions

Samples were collected during monthly sampling events in 2011 at 1-m depth at three offshore sites in Elliott Bay and adjacent Puget Sound (Elliott West Outfall, Central Elliott Bay, and South Plant Outfall). Analysis of this limited number of samples indicates that pH is highest in the spring following the first phytoplankton bloom and decreases during the winter as the result of upwelling of low-pH deep water (Figure 3-22).

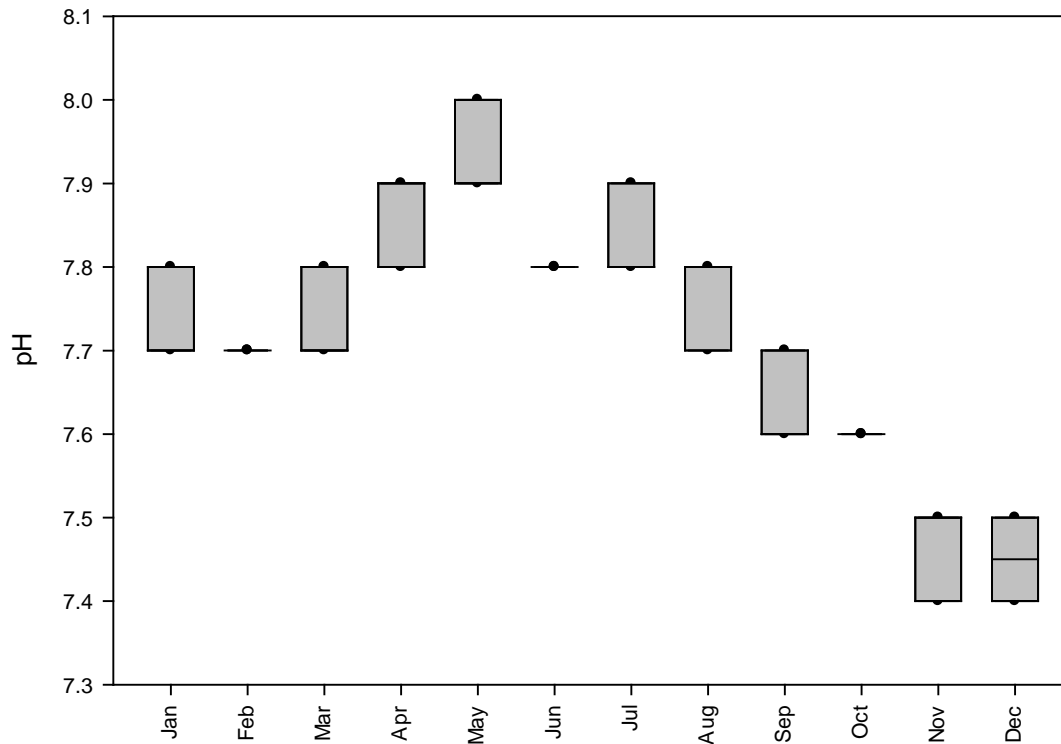


Figure 3-22. pH at about 1-m depth by month at all three King County offshore sites in Elliott Bay and adjacent Puget Sound (2011).

Comparison to Criteria

The limited data collected in 2011 indicate that pH was well within the range of Ecology's WQC for pH (7.0–8.5).

Long-Term Trends

Although no data were available for analyzing long-term trends in pH, Washington State, has recently been taking an interest in recent changes in ocean acidification (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). As a result, more precise pH data in Elliott Bay and Central Puget Sound will be collected in the future. NOAA's Pacific Marine Environmental Laboratory (PMEL) installed a SeaFET® pH monitoring system in 2014 at the seawater intake of the Seattle Aquarium near King County's mooring station. In addition, King County installed SeaFET® sensors in 2015 at two sites in Central Puget Sound as part of a new ocean acidification program.

3.4 Chlorophyll

Phytoplankton are microscopic photosynthetic organisms that are the major primary producers in marine systems. While phytoplankton are a food source to many organisms, large blooms can lead to low DO as blooms die off and organisms decompose. Different phytoplankton groups contain different photosynthetic pigments. Chlorophyll-*a* is the most widespread and is often used as an indicator of overall phytoplankton biomass.

Current Conditions

From 2004 through 2013, chlorophyll-*a* concentrations at offshore sites in Elliott Bay ranged from not detected (minimum MDL = 0.05 µg/L) to 39.8 µg/L (Elliott West Outfall, 1 m – August 2006). Concentrations were typically highest in surface waters (1-m depth) from April through September, with peaks corresponding to blooms in May and July/August (Figure 3-23). The blooms tend to be highly concentrated at approximately 5 m as shown in the 2013 profile in Figure 3-24.

No significant differences in chlorophyll concentrations were observed in monthly discrete surface samples among sites when concentrations from all months were used (Kruskal-Wallis p-value = 0.0907). However, when data from only the bloom season (April–September) were used, significant differences were apparent (Kruskal-Wallis p-value < 0.0001). Concentrations in adjacent Puget Sound waters (South Plant Outfall) were higher than those near the Elliott West Outfall, but neither differed significantly from the two sites in the middle of Inner Elliott Bay (Figure 3-25). Other studies have noted that chlorophyll concentrations in Inner Elliott Bay may be inhibited by turbidity associated with the Duwamish Estuary (King County, 2006b); in fact, previous studies indicate that Elliott Bay is estimated to be two-thirds less productive than the rest of the Central Basin throughout the year (Strickland, 1983).

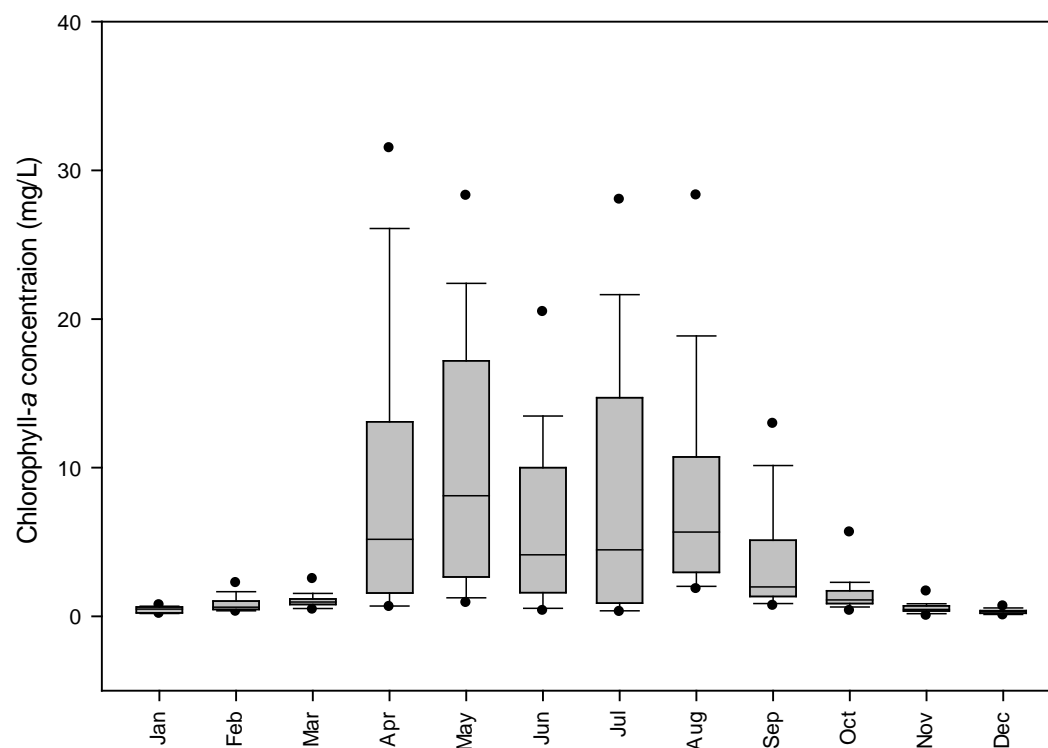


Figure 3-23. Concentrations of chlorophyll-*a* (µg/L) at ~ 1-m depth by month at all offshore sites in Elliott Bay and adjacent Puget Sound (2004–2013).

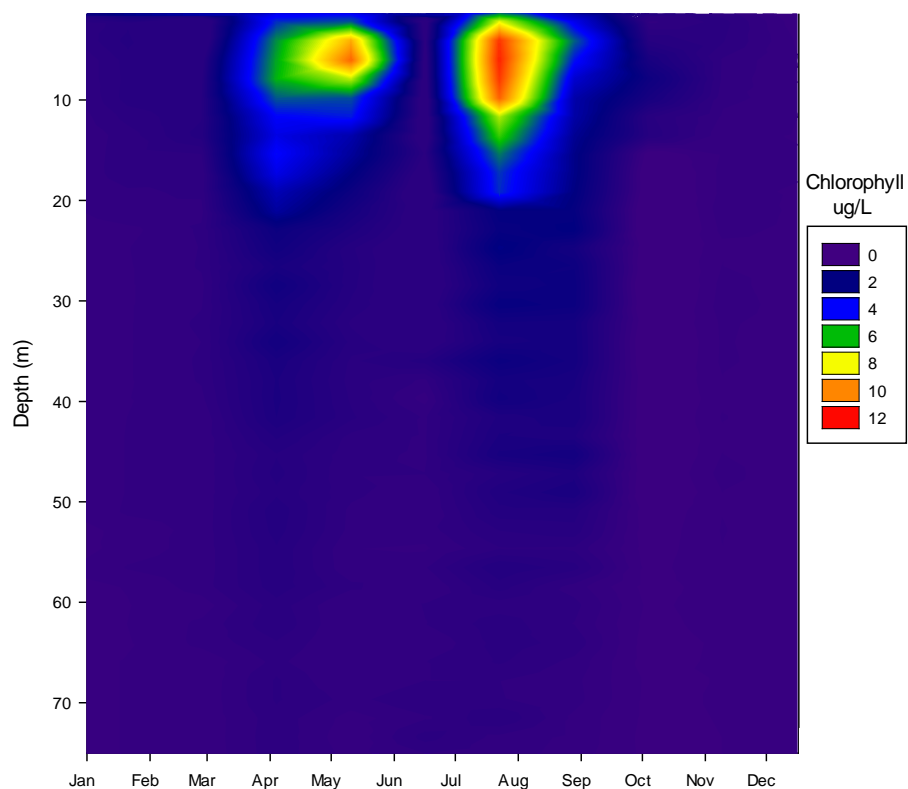


Figure 3-24. Chlorophyll-*a* (µg/L) profile in 2013 at 1.5–75 m depths in Central Elliott Bay.

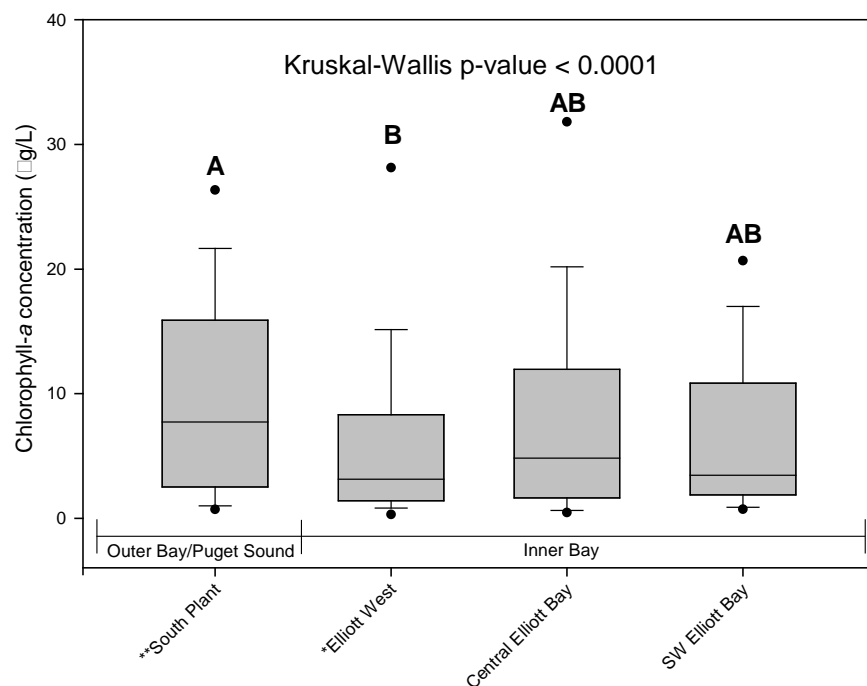


Figure 3-25. Concentrations of chlorophyll-*a* (µg/L) at ~ 1-m depth in Elliott Bay and adjacent Puget Sound during the bloom season (April–September) (2004–2013). (* = CSO treatment plant outfall site; ** = treatment plant outfall site)

Comparison to Criteria

There are no state WQC for chlorophyll in marine waters.

Long-Term Trends

King County has measured chlorophyll-*a* in Elliott Bay since 1998; Ecology has measured it since 1993 at the SW Elliott Bay site. Long-term trend analysis indicates that there has not been a significant change in chlorophyll for most sites and depths in Elliott Bay over time (Table 3-8). The exception is at the surface of SW Elliott Bay, which had a significantly negative (decreasing) trend of $-0.0327 \mu\text{g/L}$ per year. Trends may be apparent at this Ecology site and not at others because it has been sampled longer than other sites. Despite the significance of this trend, the magnitude is likely biologically inconsequential and may be influenced by a shift from warm and cool phases of the PDO. Overall, the data indicate that concentrations have not changed over the last 15–20 years.

Table 3-8. Results of seasonal (monthly) Mann-Kendall test of chlorophyll-*a* at offshore sites in Elliott Bay over time, with Theil-Sen's slopes.

Offshore Site	Depth	Years Evaluated	Significance	Trend	p-value	Slope of Trend ($\mu\text{g/L/year}$)
SW Elliott Bay	1	1993–2012	**	↓	0.023	–0.0327
	10	1993–2012	n.s.	–	0.111	–0.0208
	30	2009–2012	Insufficient data to evaluate trends			
South Plant Outfall	1	1998–2013	n.s.	–	0.253	–0.0127
	15	1998–2013	n.s.	–	0.156	–0.0105
	25	1998–2013	n.s.	–	0.317	–0.0063
	35	1998–2013	n.s.	–	0.383	–0.0040
Elliott West Outfall	1	2005–2013	Insufficient data to evaluate trends			
	15	2005–2013	Insufficient data to evaluate trends			
Central Elliott Bay	1	1998–2013	n.s.	–	0.251	–0.0082
	15	1998–2013	n.s.	–	0.498	–0.0025
	25	1998–2013	n.s.	–	0.780	0.0010
	35	1998–2013	n.s.	–	0.930	0.0006

Slopes corrected for inter-block covariance.

n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05$ – 0.10); ** = significant ($p = 0.01$ – 0.05); *** = highly significant ($p < 0.01$).

3.5 Nutrients

Nutrient inputs can have considerable effects on water quality, particularly in habitats where nutrients are limited. In marine habitats, nitrogen is typically the limiting nutrient (Gruber, 2008), meaning that it largely controls aquatic plant growth under otherwise favorable conditions. Excess nitrogen and other nutrients can enter marine waters from point sources such as wastewater or stormwater discharges, non-point sources (runoff), and riverine or oceanic sources. Eutrophication of a waterbody occurs when it receives abnormally high nutrient levels (nitrogen and/or phosphorus) that cause excess algal

growth. As the algae die and decompose, the decaying process can deplete oxygen concentrations in the water column, making the environment inhospitable to other aquatic life (Voss, 2011). Wastewater treatment plants and CSOs, to a lesser extent, are significant sources of nutrients in receiving waters (EPA, 2004; Ecology, 2011).

Data on nutrients in Elliott Bay are available for the six beach sites and four offshore sites from 1997 through 2013, depending on location. However, because detection limits for nutrients were greatly improved in 2009 and non-detects were frequently encountered in the earlier nutrient data, only data from 2009 through 2013 (five years) were used to describe current conditions in Elliott Bay. Ecology monitors nutrients at its SW Elliott Bay site and reports nutrient values in micromoles. King County reports nutrients in mg/L. All data from Ecology were converted to mg/L prior to analysis.

The data show that the Duwamish Estuary appears to be the greatest influence on nutrient concentrations in Elliott Bay, as indicated by elevated silica and ammonia concentrations at sites closer to the river. Ammonia concentrations at depth at the South Plant Outfall site appear to be the only signal of the presence of effluent in samples collected near the outfall. Without samples specifically targeting stormwater outfalls, conclusions cannot be made on the influence of stormwater on nutrient concentrations in Elliott Bay.

The following sections present more detail on the current data, how nutrients (ammonia) concentrations compare to criteria, and long-term trends regarding nutrients in the study area. The nutrients discussed are nitrogen, phosphorus, and silica.

3.5.1 Nitrogen

Nitrogen occurs in several chemical forms including ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-), with nitrate being the predominant form. King County reports dissolved ammonia concentrations as ammonia-N (NH_3) and reports nitrate and nitrite as a single value of nitrate + nitrite-N. Ecology measures nitrate and nitrite separately. The concentrations of dissolved nitrate and nitrite reported by Ecology were combined to a single number for comparison to King County data.

The concentration of nitrogen compounds, ammonia in particular, in marine waters can fall below the MDL (left-censored). Because replacement of non-detect values with half or another fraction of the MDL biases the trends to reflect shifting MDLs rather than the analyte trend, a process of multiple imputation was employed for evaluating trend data. The left-censored values were replaced with potential random values based on a log normal distribution function calculated using maximum likelihood estimators. Seasonal Mann-Kendall tests for monotonic trends were applied to 1,000 iterations of imputation. Three-day precipitation was used as a covariate and month as the block group. Interquartile ranges for p-values and Theil-Sen slopes were reported, and the third quartile p-value was used as a statistic for conservatively determining significance of nitrogen trends.

Nitrate + Nitrite-N

Nitrate and nitrite ($\text{NO}_3^-/\text{NO}_2^-$) ions are dissolved inorganic forms of nitrogen. Nitrate and nitrite are analyzed together and concentrations are reported as a single value.

Current Conditions

From 2009 through 2013, concentrations of nitrate + nitrite-N at beach sites ranged from less than an MDL of 0.01 mg/L to 0.719 mg/L (Magnolia Outfall – November 2009); the mean of detected samples was 0.304 mg/L. At offshore sites, concentrations ranged from less than an MDL of 0.01 mg/L to 0.484 mg/L (Central Elliott Bay, 25 m – January 2009); the mean of detected samples was 0.334 mg/L. One percent of the samples were non-detects.

The highest concentrations of nitrate + nitrite-N at all sites occurred during the winter (Figure 3-26). Concentrations typically increased after the phytoplankton bloom season, during upwelling of deep nutrient-rich water in October and input from upstream sources from increased rainfall. Concentrations decreased in April concurrent with the spring phytoplankton bloom, which typically depletes nitrate + nitrite-N; the lowest concentrations were typically recorded in May through July (Figure 3-26).

Concentrations of nitrate + nitrite-N were not significantly different among depths at offshore sites. In addition, there were no significant spatial differences in concentrations throughout Elliott Bay between offshore and beach sites at 1-m depth (Kruskal-Wallis p-value = 0.1639) (Figure 3-27).

Comparison to Criteria

There are no state WQC for nitrate and nitrite in marine waters.

Long-Term Trends

It appears that nitrate + nitrite-N concentrations in Elliott Bay have been stable from 1997 through 2013, suggesting that no new nitrogen sources are present. Only the South Plant Outfall at 100 m offshore in adjacent Puget Sound had a marginally significant increase in nitrate + nitrite-N ($p = 0.0598$; 0.0013 mg/L/year). Most other sites and depths showed increasing trends, but none were statistically significant (Table 3-9). The increasing trend at South Plant Outfall demonstrates the need for continued monitoring.

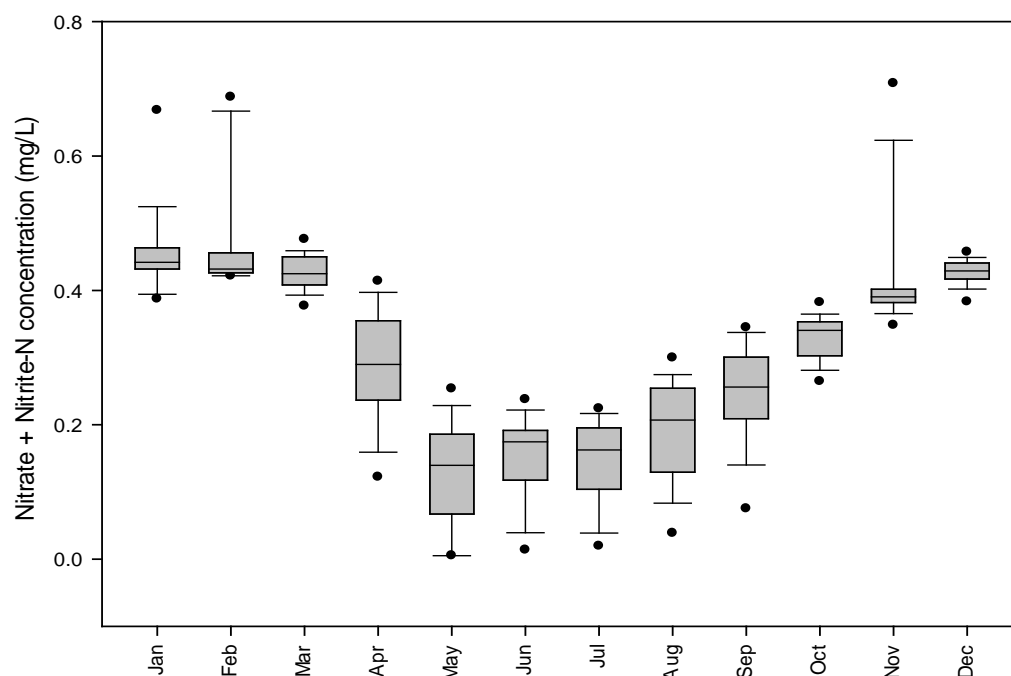


Figure 3-26. Concentration of nitrate + nitrite-N (mg/L) at ~ 1 m depth by month at all sites in Elliott Bay and adjacent Puget Sound (2009–2013).

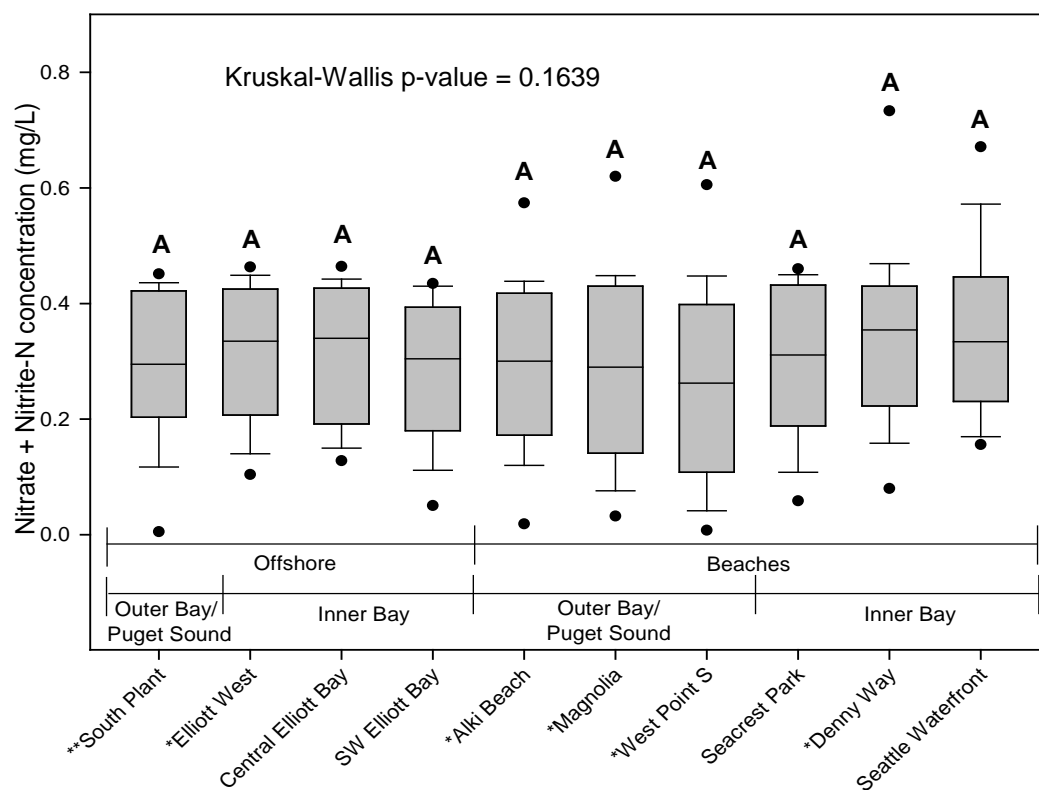


Figure 3-27. Concentrations of nitrate + nitrite-N (mg/L) at ~ 1 m depth at all sites in Elliott Bay and adjacent Puget Sound (2009–2013). (* = CSO and CSO treatment plant outfall site; ** = treatment plant outfall site)

Table 3-9. Results of seasonal (monthly) Mann-Kendall test of nitrate + nitrite-N concentrations (mg/L) in Elliott Bay over time, with Theil-Sen's slopes.

	Site	Depth (m)	Years Evaluated	Significance	Trend	Interquartile Range of p-values		Interquartile Range of Slope of Trends (mg/L/year)	
Beach	West Point South	1	1998–2013	n.s.	–	0.3357	0.3357	–0.0012	–0.0012
	Magnolia Outfall ^a	1	1998–2013	n.s.	–	0.8871	0.8871	0.0003	0.0003
	Denny Way Outfall	1	1998–2013	n.s.	–	0.1914	0.1914	–0.0026	–0.0026
	Seacrest Park ^b	1	1998–2013	n.s.	–	0.8174	0.8174	0.0003	0.0003
	Alki Beach ^a	1	2007–2013	Insufficient data to evaluate trends					
	Seattle Waterfront ^b	1	1998–2010	n.s.	–	0.6665	0.6665	0.0008	0.0008
Offshore	SW Elliott Bay	1	1999–2012	n.s.	–	0.729	0.729	–0.0003	–0.0003
		10	1999–2012	n.s.	–	0.1672	0.1672	0.0014	0.0014
		30	1999–2012	n.s.	–	0.1181	0.1181	0.0023	0.0023
	South Plant Outfall	1	1997–2013	n.s.	–	0.3573	0.3573	0.0005	0.0005
		15	1997–2013	n.s.	–	0.1703	0.1703	0.0011	0.0053
		25	1997–2013	n.s.	–	0.2324	0.2324	0.0009	0.0009
		35	1997–2013	n.s.	–	0.1668	0.1668	0.0011	0.0011
		55	1997–2013	n.s.	–	0.1086	0.1086	0.0014	0.0014
		100	1997–2013	*	↑	0.0598	0.0598	0.0013	0.0013
		180	2003–2013	n.s.	–	0.7866	0.7866	0.0003	0.0003
	Elliott West Outfall	1	2005–2013	Insufficient data to evaluate trends					
		15	2005–2013	Insufficient data to evaluate trends					
	Central Elliott Bay	1	1997–2013	n.s.	–	0.2893	0.2893	0.0009	0.0009
		15	1997–2013	n.s.	–	0.4589	0.4589	0.0008	0.0008
		25	1997–2013	n.s.	–	0.2001	0.2001	0.0011	0.0011
		35	1997–2013	n.s.	–	0.2069	0.2069	0.0011	0.0011
		55	1997–2013	n.s.	–	0.1878	0.1878	0.0015	0.0015
		75	1997–2013	n.s.	–	0.174	0.174	0.0016	0.0016

Values less than the detection limit were estimated using maximum likelihood estimators, and estimated values were applied to 1,000 iterations of the seasonal Mann-Kendall tests for monotonic trends.

Adjusted p-values were calculated using a covariate of rainfall (three days prior) and corrected for inter-block covariance.

Interquartile ranges for p-values and Theil-Sen slopes were reported.

n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05-0.10$); ** = significant ($p = 0.01-0.05$); *** = highly significant ($p < 0.01$).

^a Data not available for 2002–2006.

^b Data not available for 2002–2005.

Ammonia

Ammonia is an essential natural product of the nutrient cycle and is assimilated by bacteria and phytoplankton. It sinks to the bottom as the phytoplankton decay or is released through the natural grazing of phytoplankton by zooplankton (Voss, 2011). In marine waters, ammonia can be found at elevated concentrations as a byproduct of sewage (municipal and septic) and agricultural practices, including fertilization, and can temporarily increase during/after large phytoplankton blooms. Because ammonia can be toxic to marine plants and animals at high concentrations, it is the only nutrient in marine waters that has a designated water quality criterion.

Current Conditions

From 2009 through 2013, concentrations of ammonia at beach sites in Elliott Bay ranged from less than an MDL of 0.002 mg/L to 0.273 mg/L (Seacrest Park – June 2012); the mean of detected samples was 0.028 mg/L, and 13 percent of the samples were non-detects. Concentrations of ammonia at offshore sites ranged from less than an MDL of 0.002 mg/L to 0.153 mg/L (South Plant Outfall, 180 m – June 2009); the mean of detected samples was 0.029 mg/L, and 36 percent of the samples were non-detects.

The highest concentrations of ammonia at all sites in Elliott Bay were typically recorded in June, between the early and late phytoplankton blooms as the spring bloom is decomposing (Figure 3-28). The reduction of chlorophyll and the increase in ammonia have coincided with large blooms of *Noctiluca* in recent years (Stark, 2014). These large dinoflagellates, which can feed on other phytoplankton species, sequester ammonia. A second smaller spike in ammonia typically occurs in fall, after the second phytoplankton bloom begins to deteriorate and decompose.

In addition to seasonal differences, spatial patterns in ammonia concentrations were observed in Elliott Bay. Within surface waters (~ 1-m depth), offshore sites have significantly lower concentrations of ammonia than beach sites. Concentrations of ammonia at beach sites tend to be highest in Inner Elliott Bay and the north part of the outer bay and Central Puget Sound (Figure 3-29). The spatial differences in ammonia concentrations coincide with the flow of Duwamish Estuary discharge, which has higher concentrations of ammonia than the bay, to the surface of Elliott Bay along the waterfront and northwest out to Puget Sound. The exception is the Denny Way Outfall site, which has lower concentrations of ammonia than nearby sites (Figure 3-29).

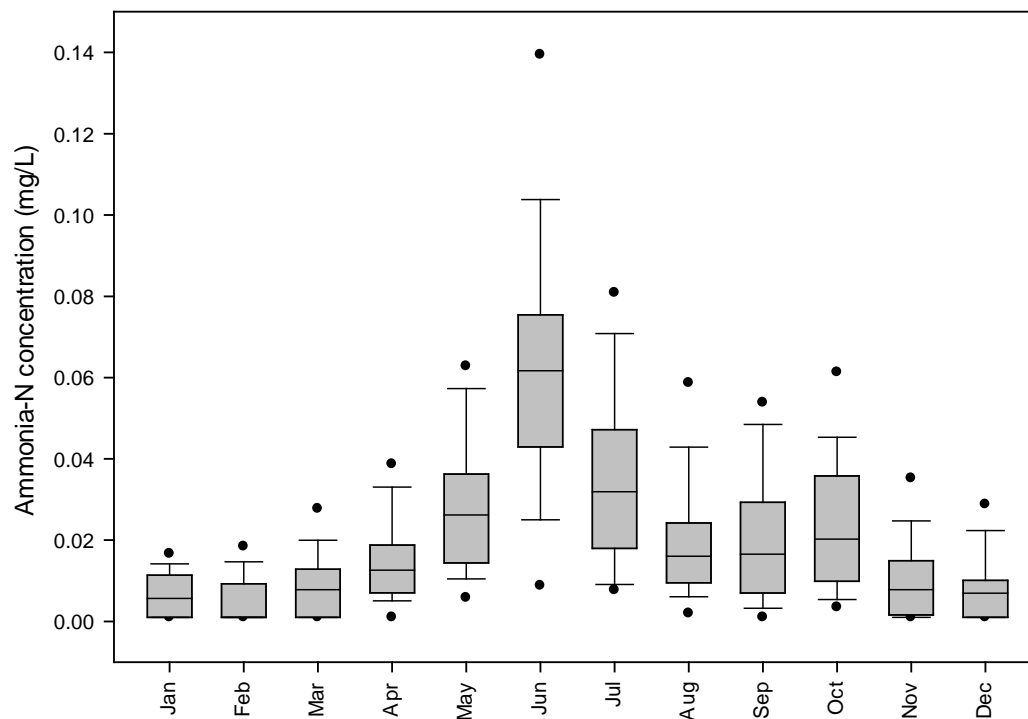


Figure 3-28. Combined concentrations of ammonia (mg/L) at ~1-m depth by month at all sites in Elliott Bay and adjacent Puget Sound (2009–2013).

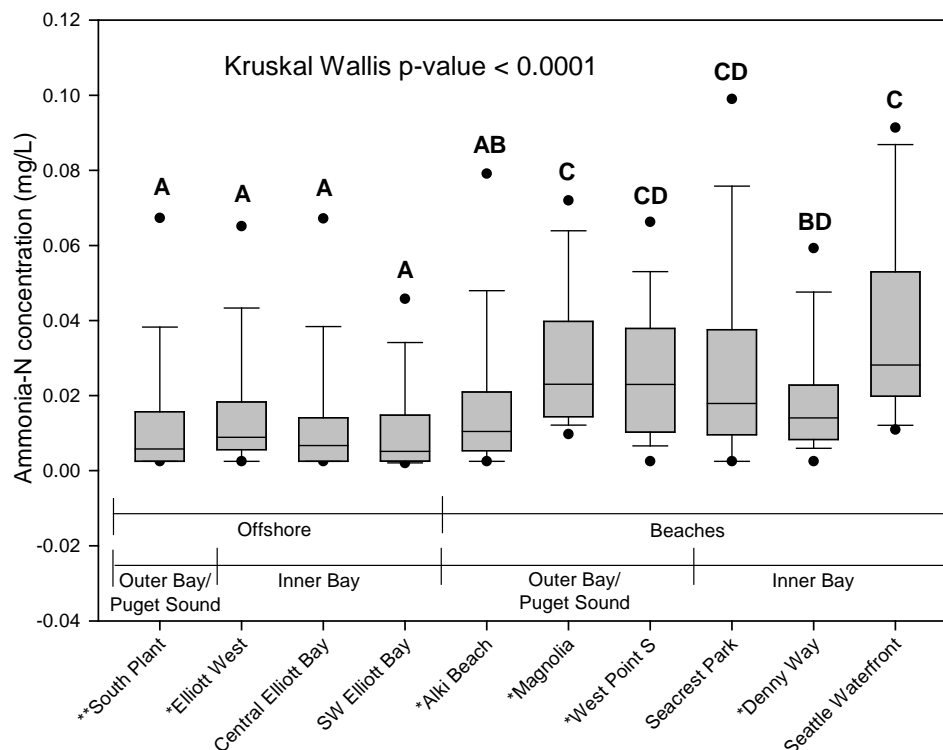


Figure 3-29. Concentrations of ammonia at ~1-m depth at all sites in Elliott Bay and adjacent Puget Sound (2009–2013). (* = CSO and CSO treatment plant outfall site; ** = treatment plant outfall site)

No differences in ammonia concentrations among depths were observed at offshore sites, with the exception of the South Plant Outfall in Central Puget Sound. The site is located between the outfall diffusers of the South Treatment Plant, which continuously discharge treated effluent into Puget Sound at approximately 190-m depth. At the upper layers of the site (1–55 m), ammonia concentrations are similar to each other and to concentrations throughout Puget Sound and Elliott Bay; at 100 m and below, the concentrations are significantly higher, with maximum concentrations recorded at 180 m. Figure 3-30 compares concentrations by depth at the South Plant Outfall and Central Elliott Bay sites.

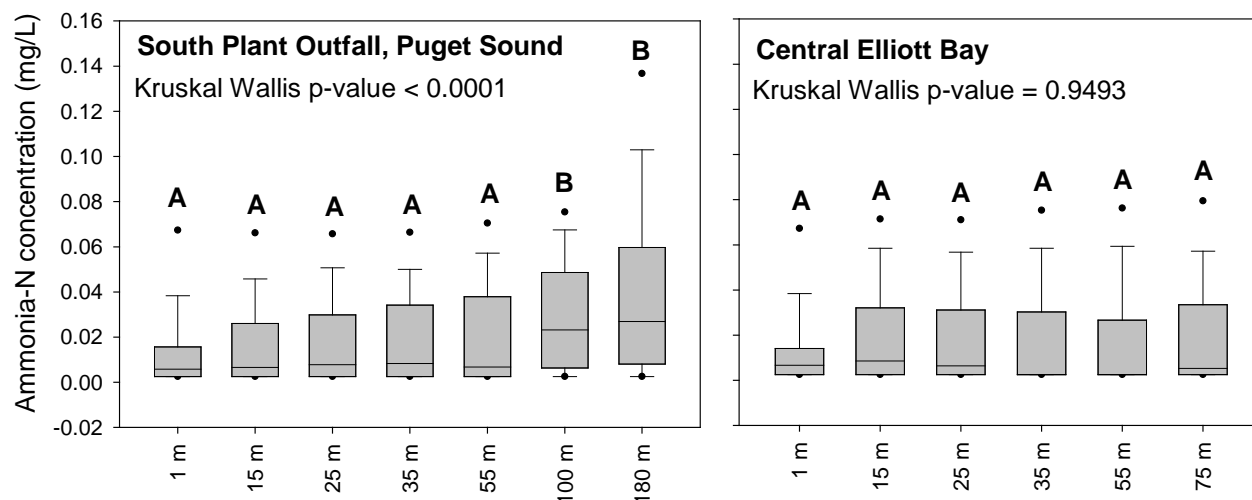


Figure 3-30. Concentrations of ammonia (mg/L) by depth at the South Plant Outfall site in Puget Sound and the Central Elliott Bay site (2009–2013).

Comparison to Criteria

Data from 2004 through 2013 were used to compare ammonia concentrations to WQC. Even though there were more non-detects in the earlier years, it is still possible to compare data to criteria.

King County measures total ammonia. Because Washington State’s marine surface water criteria for ammonia are based on un-ionized ammonia, the County’s total ammonia data were converted to un-ionized ammonia using temperature, salinity, and pH as outlined by EPA 440/5-88-004 (ambient WQC for ammonia [salt water] – 1989) (EPA, 1989). The comparable un-ionized ammonia criteria are 0.035 mg/L (chronic) and 0.233 mg/L (acute). For sites with multiple depths (offshore), the highest ammonia concentration was compared to the criteria.

From 2004 through 2013, no site in Elliott Bay exceeded either the chronic or the acute criterion for ammonia (Figure 3-31). Although ammonia concentrations are elevated near the discharge of the South Treatment Plant relative to shallower depths, these concentrations are still well below WQC that are protective of aquatic life.

Long-Term Trends

Concentrations of ammonia at most sites have not significantly changed between 1997 and 2003 (Table 3-10), suggesting that there are no new sources of ammonia to Elliott Bay. One offshore site (SW Elliott Bay) had significant decreases in concentrations over the last 15 years; estimated rates range from -0.0002 mg/L/year to -0.0007 mg/L/year at some depths. On the other hand, one beach site (Alki Beach) had marginally significant (estimated $p = 0.0552$ – 0.0581) increasing concentrations of ammonia (0.0007 mg/L/year). Although most trends were not significant, offshore sites tended to have more decreasing trends than beach sites, which tended to be increasing. These differences may be due to missing data at many beach sites in the early 2000s.

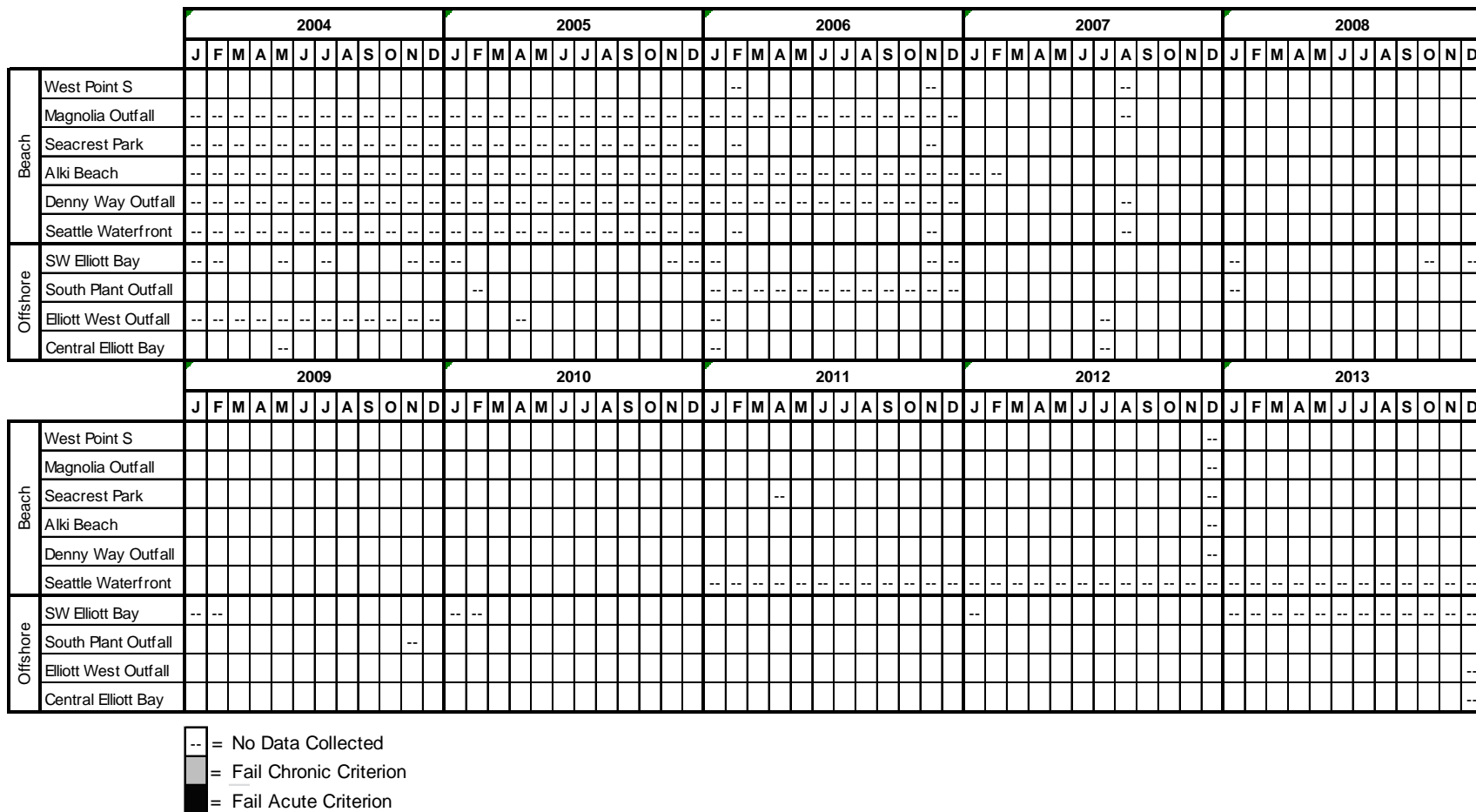


Figure 3-31. Ammonia water quality criteris (WQC) exceedances at offshore and beach sites in Elliott Bay and adjacent Puget Sound (2004–2013). Criteria concentrations are based on the conversion of total ammonia to un-ionized ammonia using temperature, salinity, and pH as outlined by EPA 440/5-88-004 (ambient WQC for ammonia [salt water], 1989). The comparable un-ionizable ammonia criteria are 0.035 mg/L (chronic) and 0.233 mg/L (acute). For sites with multiple depths (offshore), the highest ammonia concentration was compared to the criteria.)

Table 3-10. Results of seasonal (monthly) Mann-Kendall test of ammonia concentrations (mg/L) in Elliott Bay over time, with Theil-Sen's slopes.

	Site	Depth (m)	Years Evaluated	Significance	Trend	Interquartile Range of p-values		Interquartile Range of Slopes of Trends (mg/L/year)	
Beach	West Point South	1	1998-2013	n.s.	—	0.281	0.336	0.0004	0.0004
	Magnolia Outfall ^a	1	1998-2013	*	↑	0.055	0.058	0.0007	0.0007
	Seacrest Park ^b	1	1998-2013	n.s.	—	0.106	0.161	0.0004	0.0005
	Alki Beach ^a	1	1998-2013	n.s.	—	0.625	0.915	-0.0001	0.0000
	Denny Way Outfall	1	2005-2013	Insufficient data to evaluate trends					
	Seattle Waterfront ^b	1	1998-2010	n.s.	—	0.169	0.191	0.0009	0.0009
Offshore	SW Elliott Bay	1	1999-2012	***	↓	0.002	0.002	-0.0007	-0.0007
		10	1999-2012	n.s.	—	0.824	0.956	0.0000	0.0000
		30	1999-2012	*	↓	0.029	0.054	-0.0002	-0.0002
	South Plant Outfall	1	1997-2013	n.s.	—	0.180	0.481	-0.0001	-0.0001
		15	1997-2013	n.s.	—	0.277	0.655	0.0000	0.0040
		25	1997-2013	n.s.	—	0.396	0.784	0.0000	0.0000
		35	1997-2013	n.s.	—	0.113	0.329	-0.0001	-0.0001
		55	1997-2013	n.s.	—	0.093	0.253	-0.0001	-0.0001
		100	1997-2013	n.s.	—	0.889	0.974	0.0000	0.0001
		180	2003-2013	n.s.	—	0.730	0.906	0.0002	0.0002
	Elliott West Outfall	1	2005-2013	Insufficient data to evaluate trends					
		15	2005-2013	Insufficient data to evaluate trends					
	Central Elliott Bay	1	1997-2013	n.s.	—	0.065	0.238	-0.0001	-0.0001
		15	1997-2013	n.s.	—	0.356	0.726	-0.0001	-0.0001
		25	1997-2013	n.s.	—	0.226	0.520	-0.0001	-0.0001
		35	1997-2013	n.s.	—	0.029	0.102	-0.0002	-0.0002
		55	1997-2013	n.s.	—	0.050	0.186	-0.0001	-0.0001
		75	1997-2013	n.s.	—	0.246	0.628	-0.0001	-0.0001

Values less than the detection limit were estimated using maximum likelihood estimators, and estimated values were applied to 1,000 iterations of the seasonal Mann-Kendall tests for monotonic trends; adjusted p-values were calculated using a covariate of rainfall (three days prior) and corrected for inter-block covariance; Interquartile ranges for p-values and Theil-Sen slopes were reported.

n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05$ - 0.10); ** = significant ($p = 0.01$ - 0.05); *** = highly significant ($p < 0.01$).

^a Data not available for 2002–2006.

^b Data not available for 2002–2005

3.5.2 Phosphorus

Phosphorus occurs in aquatic systems in organic and inorganic forms, dissolved and as particulates. Photosynthetic organisms, in particular, use the dissolved inorganic form of phosphorus (orthophosphate), which is the most abundant form in marine water.

From 1997 through 2009, King County measured total phosphorus (all forms of inorganic and organic phosphorus) as part of the marine ambient monitoring program. In 2010, the County switched to measuring orthophosphate. Ecology has measured orthophosphate since 1999. Because there is no consistent correlation between these two measures in marine waters, only data for orthophosphate are discussed for current conditions (2010 through 2013). Ecology's data were analyzed for long-term trends in orthophosphate, and King County data were analyzed for long-term trends in total phosphorus.

Current Conditions

From 2010 through 2013, concentrations of orthophosphate ranged from 0.0107 mg/L (South Plant Outfall, 1 m – May 2013) to 0.0928 mg/L (Seacrest Park, 1 m – Jan. 2013) with a mean of 0.0595 mg/L. Concentrations are highest during the winter months after the phytoplankton concentrations have decreased, upwelling of deep nutrient-rich water has begun, and rainfall has increased (Figure 3-32). Concentrations are lowest during the summer, particularly during phytoplankton blooms when nutrient uptake is greatest (typically May and July).

The concentrations of orthophosphate in surface water (1-m depth) tend to be similar at offshore and beach sites, with no significant spatial differences in surface waters between outfall and non-outfall sites (Kruskal-Wallis p-value = 0.1511; Figure 3-33). However, significant differences in concentrations by depth were observed at all offshore sites, with concentrations increasing with depth. In addition, decreased variability occurred with increasing depth. Figure 3-34 shows concentrations at various depths at two representative offshore sites (Central Elliott Bay and South Plant Outfall). Variability in surface waters is mostly the result of seasonal uptake of nutrients by phytoplankton.

Comparison to Criteria

There are no state WQC for any form of phosphorus in marine waters.

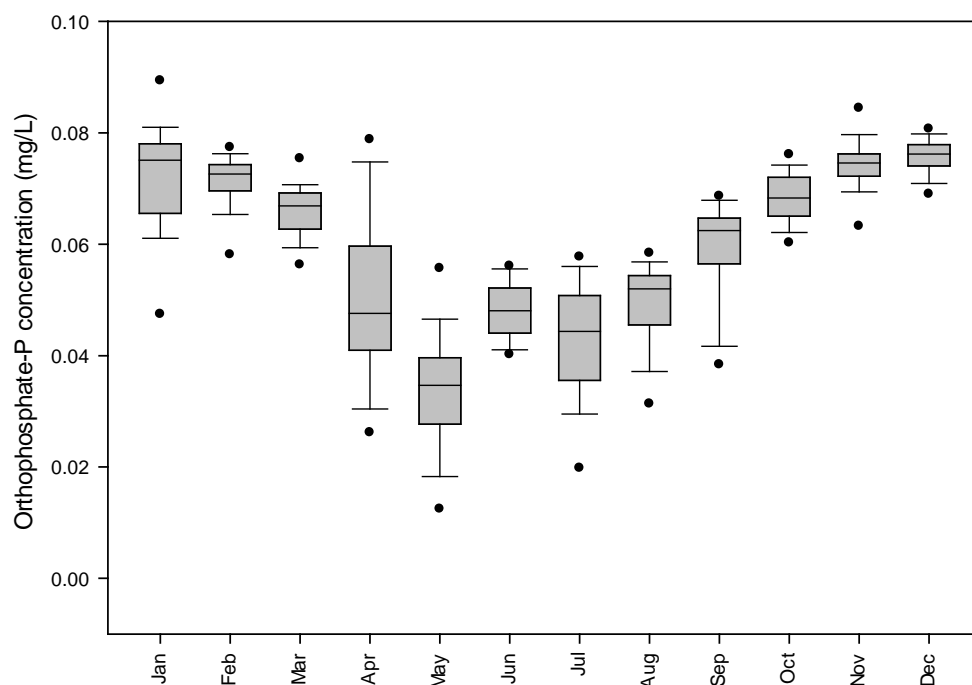


Figure 3-32. Monthly concentrations of orthophosphate (mg/L) at ~1 m depth at all Elliott Bay and adjacent Puget Sound sites (2010–2013).

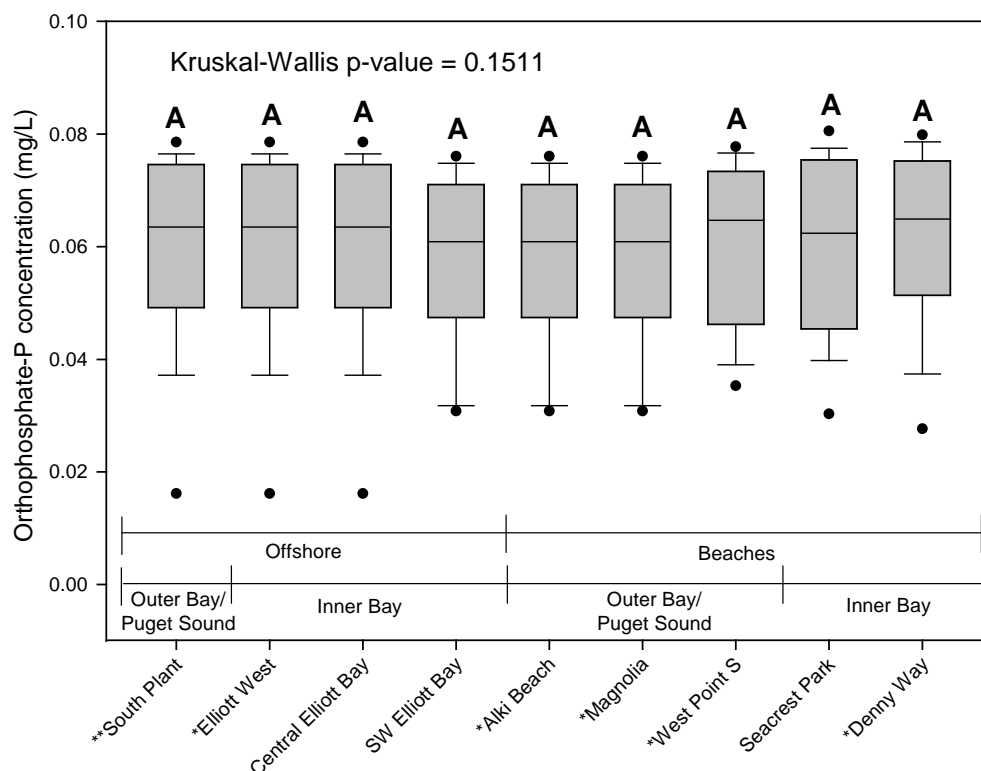


Figure 3-33. Concentrations of orthophosphate (mg/L) at ~1 m depth in Elliott Bay and adjacent Puget Sound (2010–2013). (* = CSO and CSO treatment plant outfall site; ** = treatment plant outfall site)

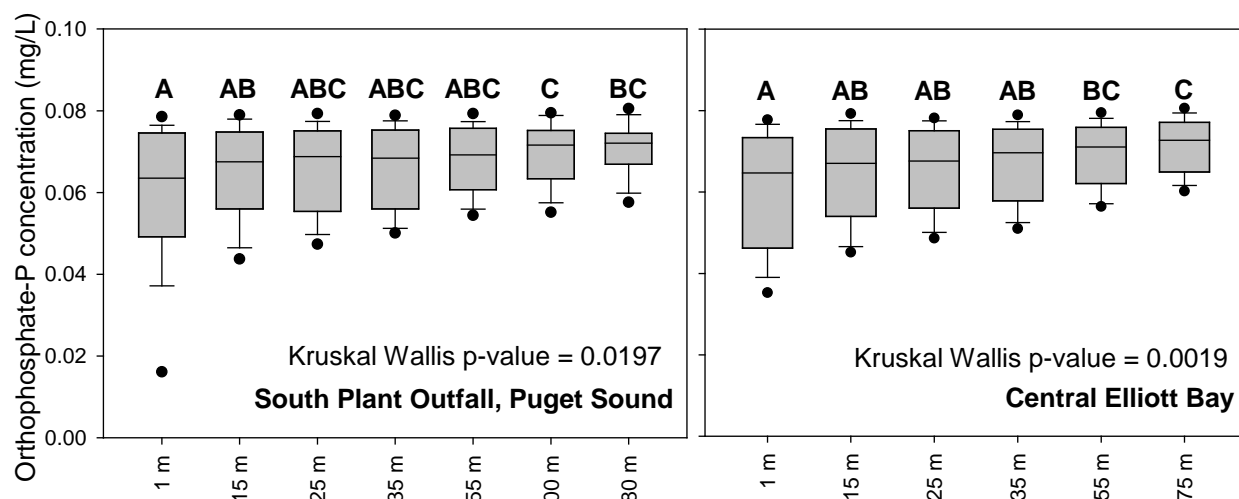


Figure 3-34. Concentrations of orthophosphate (mg/L) by depth at two representative offshore sites (2010–2013).

Long-Term Trends

Data from Ecology's SW Elliott Bay site were analyzed for long-term trends in orthophosphate. No significant trends in orthophosphate concentrations were observed from 1999 through 2012 (Table 3-11).

For total phosphorus, the seven sites with sufficient data (10 years or more) to evaluate long-term trends, only the South Plant Outfall site in Puget Sound adjacent to Elliott Bay had a significant change in concentrations during the time period (1997 through 2009). Four depths, including the surface layer, at this site had increasing concentrations of total phosphorus in the range of 0.0002 mg/L/year to 0.0004 mg/L/year (Table 3-12). The data indicate that waters adjacent to Elliott Bay may be experiencing increasing phosphorus concentrations while waters in the inner bay, which are influenced by more concentrated point sources, are not experiencing an increase in phosphorus levels.

Table 3-11. Results of Seasonal (monthly) Mann-Kendall test of orthophosphate concentrations (mg/L) at the SW Elliott Bay site over time, with Theil-Sen's slopes.

Site	Depth (m)	Years Evaluated	Significance	Trend	p-value	Slope of Trend (mg/L/year)
SW Elliott Bay (offshore)	1	1999–2012	n.s.	–	0.3244	0.0002
	10	1999–2012	n.s.	–	0.4422	0.0003
	30	1999–2012	n.s.	–	0.3159	0.0002

Adjusted p-values were calculated using a covariate of rainfall (three days prior for offshore stations) and corrected for inter-block covariance.
 n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05$ -0.10); ** = significant ($p = 0.01$ -0.05); *** = highly significant ($p < 0.01$).

Table 3-12. Results of seasonal (monthly) Mann-Kendall test of total phosphorus concentrations in Elliott Bay over time, with Theil-Sen's slopes.

	Site	Depth (m)	Years Evaluated	Significance	Trend	p-value	Slope of Trend (mg/L/year)
Beach	West Point South	1	1998–2010	n.s.	–	0.5429	–0.0008
	Magnolia Outfall ^a	1	1998–2010	n.s.	–	0.6402	–0.0001
	Seacrest Park ^b	1	1998–2010	n.s.	–	0.5522	0.0002
	Alki Beach ^a	1	1998–2010	n.s.	–	0.5556	0.0003
	Denny Way Outfall	1	2007–2010	Insufficient data to evaluate trends			
	Seattle Waterfront ^b	1	1998–2010	n.s.	–	0.9593	–0.0001
Offshore	South Plant Outfall	1	1997–2010	**	↑	0.0285	0.0003
		15	1997–2010	n.s.	–	0.3388	0.0001
		25	1997–2010	*	↑	0.0596	0.0002
		35	1997–2010	*	↑	0.0813	0.0003
		55	1997–2010	**	↑	0.0333	0.0004
		100	1997–2010	n.s.	–	0.5200	0.0002
		180	2003–2010	Insufficient data to evaluate trends			
	Elliott West Outfall	1	2005–2013	Insufficient data to evaluate trends			
		15	2005–2013	Insufficient data to evaluate trends			
	Central Elliott Bay	1	1997–2010	n.s.	–	0.4848	0.0001
		15	1997–2010	n.s.	–	0.3827	0.0001
		25	1997–2010	n.s.	–	0.4031	0.0001
		35	1997–2010	n.s.	–	0.4004	0.0002
		55	1997–2010	n.s.	–	0.2796	0.0001
		75	1997–2010	n.s.	–	0.5472	0.0001

Adjusted p-values were calculated using a covariate of rainfall (three days prior) and corrected for inter-block covariance.

n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05-0.10$); ** = significant ($p = 0.01-0.05$); *** = highly significant ($p < 0.01$).

^a Data not available for 2002–2006.

^b Data not available for 2002–2005.

3.5.3 Silica

Silica is a necessary nutrient for skeletal growth of diatoms, a type of phytoplankton. These microscopic photosynthetic plant-like organisms concentrate near the surface and are key components in the regulation of silica concentrations in marine systems. Because rivers and streams are the main source of silica in marine systems, anthropogenic alterations of freshwater inputs such as damming can impede concentrations of silica from reaching downstream systems (Tréguer and De La Rocha, 2012).

King County has routinely monitored silica at three offshore sites in the study area since as early as 1997. Ecology has monitored silica at one offshore site since 1999. Because beach sites have not been monitored for silica since the early to mid-2000s, silica concentrations at beach sites are not discussed here.

Current Conditions

Silica concentrations for all offshore sites monitored from 2009 through 2013 ranged from 0.54 mg/L (South Plant Outfall, 1 m – June 2009) to 6.58 mg/L (Elliott West Outfall, 1 m – Jan. 2011), with a mean concentration of 3.26 mg/L. Concentrations of silica in Elliott Bay were the lowest during the summer months when freshwater input is typically low and diatoms increase in biomass. Concentrations increase during the winter when diatoms decrease and rainfall and freshwater input increases (Figure 3-35).

Figure 3-36 shows concentrations at various depths at two representative sites (Elliott West Outfall and Central Elliott Bay). Concentrations were fairly consistent among different depths. Concentrations at one site only, the site closest to the shoreline (Elliott West Outfall), differed significantly with depth (Kruskal-Wallis p-value = 0.0070). This site is influenced by runoff and the Duwamish Estuary surface plume.

Comparison of surface water samples for spatial variability among sites in Elliott Bay indicates that sites nearest the influence of the Duwamish Estuary in the inner bay, particularly at the Elliott West Outfall, had higher concentrations of silica than the single offshore site in adjacent Puget Sound (South Plant Outfall) (Figure 3-37).

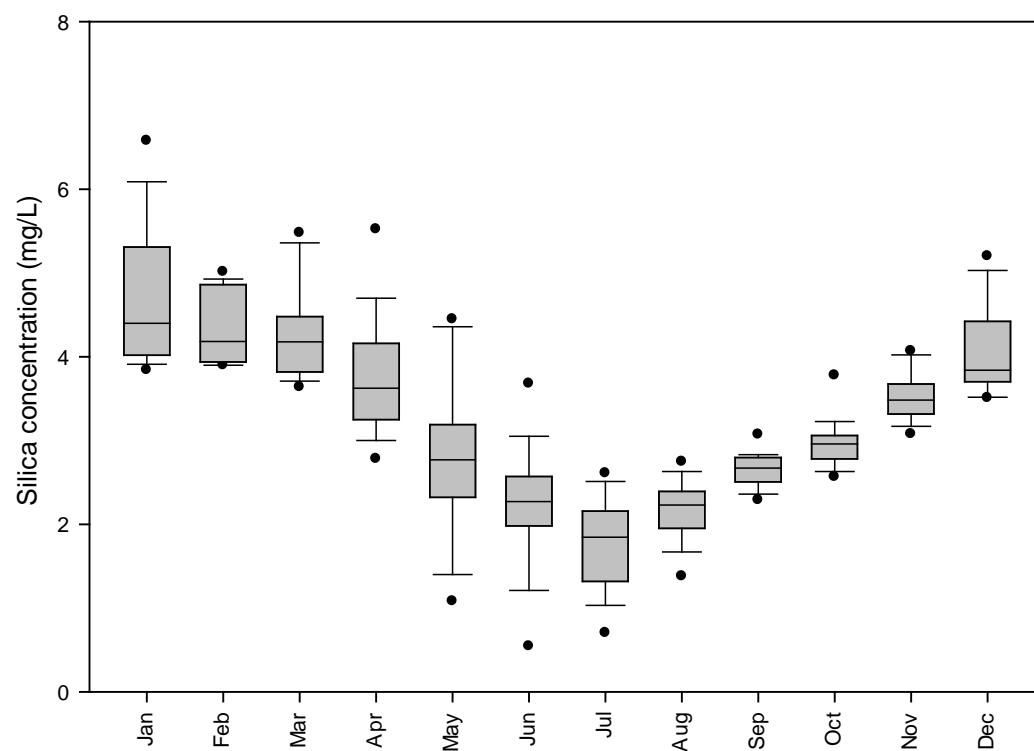


Figure 3-35. Monthly concentrations of silica (mg/L) at ~1-m depth at all offshore Elliott Bay and adjacent Puget Sound sites (2009–2013).

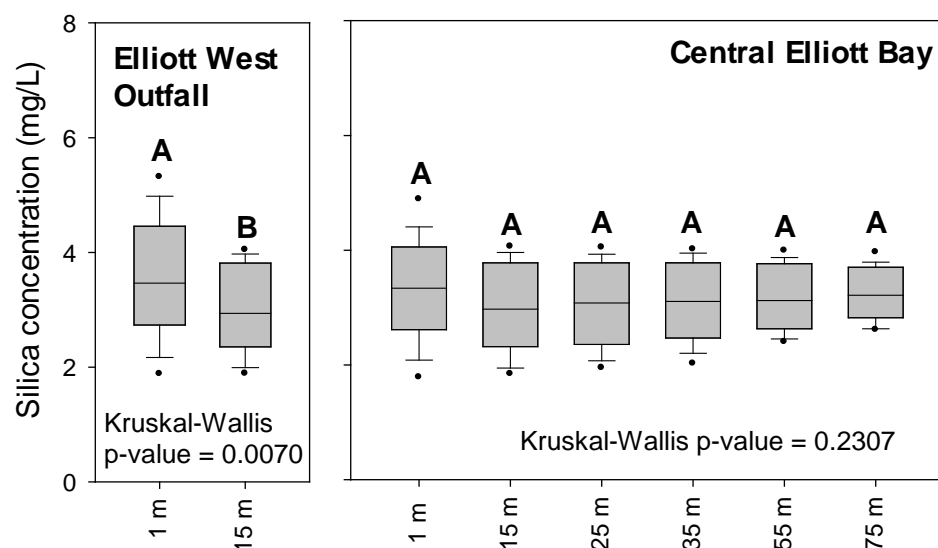


Figure 3-36. Concentrations of silica (mg/L) at various depths at two representative sites in Inner Elliott Bay (2009–2013).

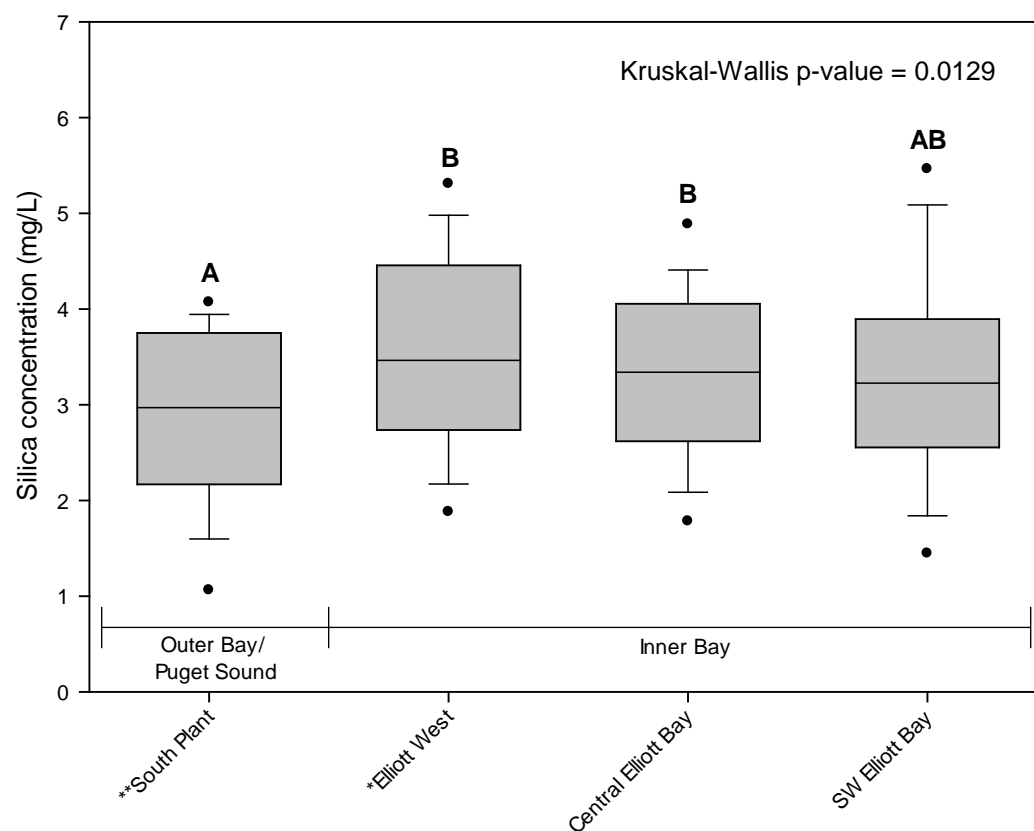


Figure 3-37. Concentrations of silica (mg/L) at ~1-m depth in Elliott Bay and adjacent Puget Sound (2009–2013). (* = CSO and CSO treatment plant outfall site; ** = treatment plant outfall site)

Comparison to Criteria

There are no state WQC for silica in marine waters.

Long-Term Trends

Despite seasonal and spatial variability, silica concentrations have not significantly changed from 1997 through 2013 at offshore sites in Elliott Bay (Table 3-13). The Howard A. Hanson Dam, located in the upper Green River, was completed in 1961, predating the data analyzed here and precluding the opportunity to analyze any differences in silica concentrations from upstream damming.

Table 3-13. Results of Seasonal (monthly) Mann-Kendall test of silica concentrations (mg/L) in Elliott Bay over time, with Theil-Sen's slopes.

	Site	Years Evaluated	Depth (m)	Significance	Trend	p-value	Slope of Trend (mg/L/year)
Offshore	SW Elliott Bay	1999–2012	1	n.s.	–	0.8002	–0.0031
		1999–2012	10	n.s.	–	0.3792	–0.0082
		1999–2012	30	n.s.	–	0.2798	–0.0046
	South Plant Outfall	1997–2013	1	n.s.	–	0.5675	0.0040
		1997–2013	15	n.s.	–	0.6309	0.0050
		1997–2013	25	n.s.	–	0.4497	0.0092
		1997–2013	35	n.s.	–	0.4030	0.0075
		1997–2013	55	n.s.	–	0.1895	0.0113
		1997–2013	100	n.s.	–	0.3091	0.0036
		2003–2013	180	n.s.	–	0.3284	0.0188
	Elliott West Outfall	2005–2013	1	Insufficient data to evaluate trends			
		2005–2013	15	Insufficient data to evaluate trends			
	Central Elliott Bay	1997–2013	1	n.s.	–	0.5294	–0.0081
		1997–2013	15	n.s.	–	0.6268	0.0035
		1997–2013	25	n.s.	–	0.5988	0.0050
		1997–2013	35	n.s.	–	0.2267	0.0089
		1997–2013	55	n.s.	–	0.2127	0.0113
		1997–2013	75	n.s.	–	0.2726	0.0102

Adjusted p-values were calculated using a covariate of rainfall (three days prior) and corrected for inter-block covariance.
n.s. = not significant ($p > 0.10$); * = marginally significant ($p = 0.05$ - 0.10); ** = significant ($p = 0.01$ - 0.05); *** = highly significant ($p < 0.01$).

3.6 Metals

Water column metals are not part of King County's routine marine monitoring program, and metals monitoring in Elliott Bay has been patchy, both spatially and temporally. Thus, the review of current conditions is deficient and long-term trend analysis is not possible.

Laboratory procedures used for analysis of metals were as follows:

- The dissolved ($< 0.45 \mu\text{m}$) and total fractions of metals in the water column were analyzed by KCEL using ICP-MS (EPA1640).
- Total and dissolved mercury were analyzed using Cold Vapor Atomic Fluorescence Spectrometry (EPA1631[E]) by Frontier Geosciences of Seattle, Washington, prior to 2001 and by KCEL later.

Dissolved and total antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc were analyzed, as described below. Mean values of analytes with the presence of non-detects were calculated using the Kaplan-Meier estimator.

Metals data are listed in Appendix A and are organized by offshore and beach sites. A conservative approach was used to analyze these data:

- If samples were analyzed past their hold times (qualified with “H”), the data were not used.
- If contamination was detected in analytical method blanks and the sample concentration was less than five times the concentration of that sample blank, the sample was qualified with “B” and was considered a non-detect. If the value was greater than five times the concentration of that sample blank, the value was included in the summary results. Appendix A (Table A-1) describes how blank contamination was handled.
- Dissolved antimony, chromium, copper, lead, nickel, and zinc and total antimony, lead, and zinc were detected in analytical method blanks; dissolved zinc was the most common laboratory contaminant.

If sampling intensity were to increase, statistical comparisons could be made between sites that may reveal spatial patterns in metals distributions. Potential ambient sites for future metals sampling include the area along the downtown Seattle waterfront where historical metal contamination and sediment re-suspension are common.

3.6.1 Current Conditions

Offshore Metals

The most recent offshore metals data in the study area were collected from two sites (South Plant Outfall and Central Elliott Bay):

- Monthly metals data were collected from April 1999 through June 2000 at three depths (5, 50, and 130 m) from the South Plant Outfall site.
- Four samples were collected at three depths (5, 50, and 75 m) from the Central Elliott Bay site in July and December 2011 and 2012.

Total Metals

Detection of total metals was as follows:

- Arsenic, cadmium, chromium, copper, and nickel were detected in all samples (n=54).
- Thallium was monitored only at the South Plant Outfall site (n=42) and was detected in all samples.
- Silver was detected in half of the samples (6 of 12) collected at the Central Elliott Bay site, with a maximum concentration of 0.033 µg/L; it was not detected in South Plant Outfall site samples (n = 39), although the detection limit was much higher (0.06 µg/L) at this site.
- Antimony was monitored only at the South Plant Outfall site and was detected in most samples (39 of 42). The three samples where antimony was not detected had blank contamination.
- Lead was detected in 52 of 53 samples (not at the 5-m depth at the Central Elliott Bay site); however, other detected values were greater than two times the detection limit for the non-detect sample. The mean total lead concentration at 75 m was over two times the mean concentration at 5 m and 50 m.
- Mercury was detected in all samples (n = 39) at the South Plant Outfall site and in 10 of 12 samples at Central Elliott Bay. The likely reason for observed differences in frequency of detection (FOD) may be due to differences in maximum detection limits (0.0001 µg/L for South Plant Outfall and 0.0002 µg/L for Central Elliott Bay). Mercury concentrations at both sites ranged from 0.00017 µg/L to 0.00199 µg/L.
- Zinc was detected in most samples (50 of 54) at the South Plant Outfall and Central Elliott Bay sites. The four samples where zinc was not detected were located at the South Plant Outfall site and had blank contamination.

Because 14 samples were collected at each depth at South Plant Outfall, it was possible to conduct statistical analysis to compare metals concentrations between depths at this site. The Peto & Peto modification of the Gehan-Wilcoxon test was used because some data were censored. The analysis found that concentrations of four metals—cadmium, chromium, copper, and lead—significantly differed by depth (Figure 3-38). Cadmium, chromium, and lead concentrations were higher at depth, while copper concentrations were higher at the surface. Many trace metals have higher concentrations at depth than at the surface because they are depleted by marine organisms near the surface. However, copper is readily released into a soluble phase during the decomposition of plankton whose concentrations are higher near the surface than at depth (Reynolds and Hamilton-Taylor, 1992). Future sampling at multiple depths at additional sites in Elliott Bay and Puget Sound can confirm whether a similar pattern exists elsewhere.

Dissolved Metals

Detection of dissolved metals in the water column was similar to that observed for total metals:

- Arsenic, cadmium, and copper were detected in all samples (n=54).
- Antimony, chromium, nickel, and zinc were detected in all samples except those with blank contamination.

- Silver was detected in Central Elliott Bay samples but not at South Plant Outfall; however, the detection limit at South Plant Outfall was higher than the maximum value detected at Central Elliott Bay.
- Dissolved lead was detected in less than half of the samples at both sites.
- Dissolved mercury was detected in most samples (39 of 42) at South Plant Outfall but was not detected in any samples at Central Elliott Bay.

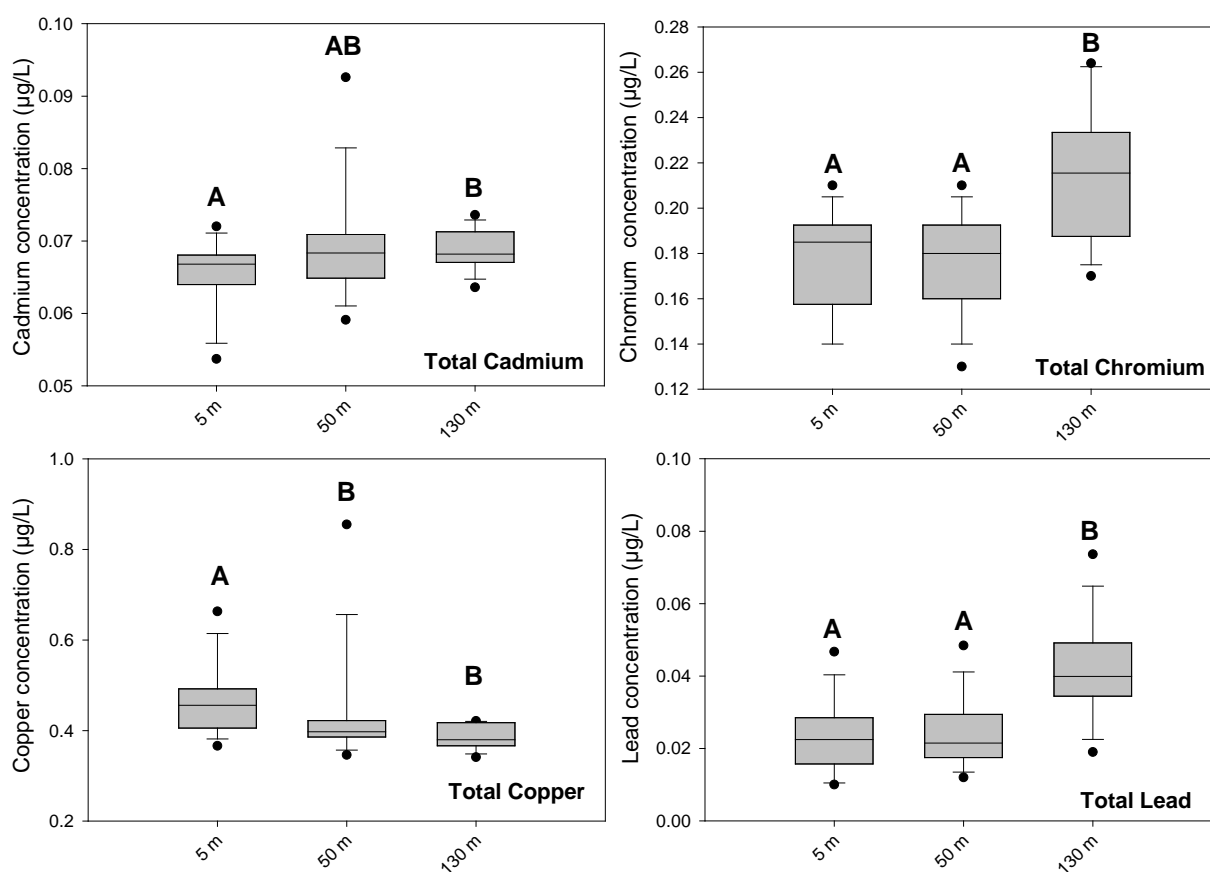


Figure 3-38. Concentrations of total metals (µg/L) that varied significantly with depth at the South Plant Outfall site in Puget Sound adjacent to Elliott Bay (1999–2000).

Beach Metals

Beach water samples were collected from a single depth, just below the surface, at two sites (West Point South and Magnolia Outfall) in August 1999, 2001, and 2002 as part of a point-source monitoring project. Samples from West Point South were analyzed for total and dissolved metals; samples from Magnolia Outfall were analyzed for dissolved metals.

Total Metals

Total metals were analyzed in one sample collected at the West Point South site (Puget Sound) in 1999. Antimony, arsenic, cadmium, chromium, copper, lead, nickel, thallium, and zinc, were detected; selenium and silver were not detected. Other samples from Puget

Sound outside the study area were collected at the same time as part of King County's point-source study and the marine outfall siting study. In comparison to those sites, West Point South metals concentrations were below the maximum of all samples collected but were higher than the mean (King County, 2002).

Dissolved Metals

Dissolved metals were analyzed in samples from the West Point South and Magnolia Outfall sites.

Results are as follows:

- Antimony, arsenic, cadmium, chromium, copper, nickel, and thallium were always detected.
- Lead was detected in just over half of the samples (three of five).
- Dissolved selenium and silver were never detected.
- All samples tested for zinc contained blank contamination. All but one sample value was less than five times the level of blank contamination; therefore, only one value was recorded as detected.

3.6.2 Comparison to Criteria

Washington State has promulgated WQC for the protection of aquatic life for nine of the metals analyzed. Except for mercury, all metals and criteria are reported as the dissolved fraction. Mercury is reported as total mercury for the chronic criterion. Additionally, EPA has established recommended Human Health Criteria (40 CFR Part 131.36) for eight metals, including five metals measured in this study. Inorganic arsenic, cyanide, and dissolved manganese were not analyzed, and cannot be compared to EPA criteria. The EPA criteria aim to prevent adverse effects on humans. For marine waters, the criteria are protective based on consumption of organisms.

Dissolved concentrations for most metals were compared to the criteria (Table 3-14). The exceptions were inorganic arsenic (not measured), total chromium, and total mercury. The limited data demonstrate that metals concentrations in Elliott Bay are low. All measured metals were well below the Washington State chronic and acute WQC and the EPA Human Health Criteria (Table 3-14). Of the detected metals, copper had the highest concentration in relation to the state's chronic criterion but was less than half of the criterion.

Table 3-14. Comparison of maximum detected concentrations of metals (µg/L) in Elliott Bay and adjacent Puget Sound (West Point South, Magnolia Outfall, Central Elliott Bay, and South Plant Outfall sites) to marine Water Quality Criteria.

Analyte	FOD	Max Detect	Highest Site/ Depth Mean	Min. MDL for Non-Detects	Max. MDL for Non-Detects	Human Health for Consumption of Organism Only	WA State Aquatic Life Criteria	
							Acute	Chronic
Antimony, Dissolved ^a	44/47	0.115	0.0944	0.0681	0.0783	4,300		
Arsenic, Dissolved	59/59	1.39	1.34	NA	NA	— ^b	69	36
Arsenic, Inorganic						0.14 ^b		
Cadmium, Dissolved	59/59	0.0763	0.0712	NA	NA	—	42	9.3
Chromium (III)						—	11,000	50
Chromium (VI)						—		
Chromium, Total	55/55	3.54	0.214	NA	NA	—		
Copper, Dissolved	59/59	1.23	0.533	NA	NA	—	4.8	3.1
Cyanide						220,000	9.1	2.8
Lead, Dissolved ^a	19/59	0.0276	0.00562	0.0049	0.0249	—	210	8.1
Mercury, Dissolved	37/51	0.000616	0.000214	0.0001	0.0002	—	1.8	
Mercury, Total	49/51	0.00199	0.000447	0.0002	0.0002	0.15		0.025
Nickel, Dissolved ^a	56/59	0.545	0.497	0.547	0.572	4,600	74	8.2
Selenium, Dissolved	0/47	NA	<MDL	0.15	0.15	—	290	71
Silver, Dissolved	6/59	0.028	<MDL	0.01	0.06	—	1.9	
Thallium, Dissolved	47/47	0.012	0.0106	NA	NA	6.3		
Zinc, Dissolved ^a	31/59	2.81	0.874	0.737	1.51	—	90	81

FOD = frequency of detection.

^a Blank contamination present in at least some samples analyzed (treated as non-detects and handled according to Table A-1 in Appendix A).

^b The criterion is based on carcinogenicity of 10⁻⁶ risk. Alternative risk levels may be obtained by moving the decimal point. (For example, for a risk level of 10⁻⁵, the decimal point in the recommended criterion would be moved one place to the right.) The recommended water quality criterion for arsenic refers to the inorganic form only.

3.7 Organic Chemicals

Similar to metals, water column organic chemicals (organics) are not part of King County's routine marine monitoring program. Organics data for Elliott Bay, therefore, are sporadic and long-term trend analysis is not possible.

3.7.1 Data Limitations

More organics data are needed to characterize conditions in the Elliott Bay water column. Sampling has been patchy, both spatially and temporally. Data from the last 10 years are available for only two sites, and earlier data are available for one other site. The sites transect the north/south center of the bay from the waterfront to the border of Outer Elliott Bay and Puget Sound. If additional sampling were to occur, the spatial distribution of the three sites would be useful in assessing ambient water throughout the bay.

The largest issues associated with assessing available organics data are the detection limits for most parameters and the abundance of blank contamination. Analytical methods have greatly improved over the past decade and many detection limits have decreased, which may increase the usefulness of future data collected. Furthermore, KCEL has greatly reduced the amount of phthalates in the analytical lab to reduce the occurrence of blank contamination. With decreased detection limits and temporal consistency, statistical comparisons could be made between sites that may reveal spatial patterns in the distribution of organic compounds.

In addition to the analytes discussed, many other chemicals that are likely to enter the environment through point and non-point sources are not monitored in Elliott Bay. There are no data on polybrominated diphenyl ethers (PBDEs) in the water column, which are common sediment contaminants that bioaccumulate in the food chain. In addition, little is known about chemicals of emerging concern including many pharmaceuticals and pesticides currently in use. The possible impacts of many of these chemicals are unknown.

3.7.2 Current Conditions

The following sections describe current conditions for phthalates and other endocrine disrupting compounds, PAHs, acid and alcohol compounds, tracer compounds, and PCBs from the 55 samples (plus 4 PCB congener samples) in Elliott Bay and adjacent Puget Sound. Endocrine disrupting compounds are chemicals of concern because of their potential to impact the endocrine system including reproductive success.

The assessment of current conditions is based on data collected since 1999 from three sites in the study area as part of three different studies:

- Monthly organics samples were collected from April 1999 through April 2000 from one Puget Sound site at the South Plant Outfall as part of an ambient and outfall monitoring study. Samples were collected from three depths (5, 50, and 130 m). All samples were analyzed (except for September 1999) for base/neutral/acid-extractable semivolatile compounds (BNAs) and less frequently for chlorinated pesticides, chlorinated herbicides, organophosphorus pesticides, and PCB Aroclors.
- Quarterly data were collected from March 2003 through January 2004 from the Central Elliott Bay and Seattle Waterfront sites. Samples were taken from three depths in Central Elliott Bay (1, 50, and 75 m) and one depth at the Seattle Waterfront (1 m). These samples were analyzed for BNAs, chlorinated pesticides,

PCB Aroclors, and endocrine disrupting compounds. Fewer semivolatile compounds were analyzed than in the 1999–2000 effort described above.

- From August through December 2004, King County conducted a survey of PCB congeners focused on the Duwamish River. Four samples from 15-m depth at one site in Central Elliott Bay were used for comparison to upstream sites in the Duwamish and Green rivers.

In general, the studies found the following:

- None of the 21 chlorinated pesticides, 9 chlorinated herbicides, 7 organophosphorus pesticides, and 7 PCB Aroclors were detected.
- Of the 72 semivolatile compounds analyzed, 23 were detected. Five were low molecular weight PAHs (LPAHs) and seven were high molecular weight PAHs (HPAHs).
- Two of ten non-phthalate endocrine disrupting compounds were reliably detected.
- Various PCB congeners were detected.

Data from these studies are summarized in Appendix B. KCEL detected some organics at higher frequencies than reported in the appendix, but many of the compounds were affected by quality control failures including blank contamination. Detected parameters and those that were difficult to analyze are discussed below. For a comprehensive list of all parameters analyzed, see King County, 2001b, 2003, 2006a, and 2007.

Phthalates

Phthalates are plasticizers and have been classified as potential endocrine disruptors. Because they are ubiquitous in the environment, phthalates are particularly troublesome in laboratory analyses. Phthalates that were present in the analytical laboratory were regularly detected in method blanks despite the care that was taken to minimize contamination. A sample was qualified with “B” if blank contamination was detected in analytical method blanks and the sample concentration was less than five times the concentration of the sample blank; a summary of how blank contamination was treated is available in Appendix A (Table A-1).

Results of phthalate analyses are as follows:

- All six phthalates analyzed were reliably detected: bis(2-ethylhexyl)phthalate, benzyl butyl phthalate, dimethyl phthalate, diethyl phthalate, di-N-octylphthalate, and di-N-butyl phthalate. All but dimethyl phthalate contained blank contamination in one or more samples. These phthalates were detected at frequencies of 18, 5, 4, 8, 5 and 4 percent, respectively, when samples with blank contamination were considered non-detects.
- Most phthalates were detected (without blank contamination) at the South Plant Outfall site in Puget Sound. However, these data do not provide much information on the spatial distribution of phthalates because benzyl butyl phthalate was detected reliably in only one sample from the Central Elliott Bay site and

bis(2-ethylhexylphthalate was reliably detected in one sample from the Central Elliott Bay and Seattle Waterfront sites.

Other Endocrine Disrupting Compounds

Bisphenol A, bis(2-ethylhexyl)adipate, and total 4-nonylphenol proved to be difficult compounds to analyze because samples were plagued with blank contamination. Bis(2-ethylhexyl)adipate and total 4-nonylphenol were the only endocrine disrupting compounds reliably detected in samples. Detection of bis(2-ethylhexyl)adipate in five samples (26 percent) from Central Elliott Bay and the Seattle Waterfront sites was deemed reliable despite containing blank contamination because the detected values were greater than five times the concentration of blank contamination. Similarly, only one sample (5 percent) of total 4-nonylphenol was reliably detected in Central Elliott Bay.

Polycyclic Aromatic Hydrocarbons

PAHs are constituents in creosote (wood preservative) and asphalt sealants and are byproducts of fossil fuel combustion. They are associated with urbanization and transported to marine waters through runoff, atmospheric deposition, and creosote-treated pilings.

The most frequently detected LPAH was phenanthrene, and the most frequently detected HPAH was fluoranthene. Both had a 14 percent FOD at all sites. The HPAH pyrene was detected in 7 percent of samples; it was detected at its maximum concentration near the waterfront.

PAHs were infrequently detected at the South Plant Outfall site in Puget Sound. They were detected more frequently and at higher concentrations at the Seattle Waterfront site. The detection limits were much higher for the South Plant Outfall samples, which could explain the differences between the two sites. However, the detection limits for the Central Elliott Bay site, located between the South Plant Outfall and Seattle Waterfront sites, were similar to those of the Seattle Waterfront, yet few PAHs were detected at that site. It is likely that the highest concentrations exist near the waterfront where creosote-soaked wood pilings and urban runoff occur. In Central Elliott Bay, PAHs were detected only near the surface.

Acid and Alcohol Compounds

Benzoic acid and benzyl alcohol were analyzed at the South Plant Outfall site only. They were detected in 12 percent of samples. Benzoic acid analysis is problematic because of blank contamination. Additionally, benzoic acid and benzyl alcohol are naturally present in many plants or as metabolic byproducts in some organisms.

Phenol is a precursor to many household products, including cough and cold medicines, herbicides, plastics, and cleaning products. It was detected in 29 percent of samples from the South Plant Outfall site and at all depths. It was not detected at the two Inner Elliott Bay sites (Central Elliott Bay and Seattle Waterfront), but the detection limit at these sites is five times the highest concentration recorded at the South Plant Outfall site.

Tracer Compounds

Caffeine and coprostanol (a degradate of cholesterol) are potential conservative tracers for the presence of wastewater effluent in receiving waters. Coprostanol was analyzed only at the South Plant Outfall site and was not detected. Caffeine was the most detected organic compound in the study area, with an FOD of 65 percent at the South Plant Outfall site. It was detected in one sample (25 percent) from Seattle Waterfront and not detected in the samples from Central Elliott Bay.

The detection limits for nearly all tracer compounds analyzed from the Seattle Waterfront and Central Elliott Bay are higher than the highest concentrations recorded at the South Plant Outfall. Coordinated sampling at multiple sites and analysis of samples at similar detection limits would allow for accurate comparisons between sites, including an analysis of concentrations near CSO outfalls.

Polychlorinated Biphenyls

PCB Aroclors were analyzed as part of the 1999–2001 and 2003–2004 studies. These compounds are difficult to detect in water because of weathering, and none were detected. Samples from 2005 in Central Elliott Bay targeted and detected PCB congeners using lower detection limits than previous studies. During all four sampling events, PCB congeners were detected. These values were recorded as a sum of detected congeners after samples with blank contamination were removed.

3.7.3 Comparison to Criteria

Washington State has promulgated marine WQC for organic compounds. The maximum concentration of PCBs detected (89.5 pg/L [0.0000895 µg/L]) was well below the acute and chronic criteria of 10.0 µg/L and 0.030 µg/L, respectively. None of the other detected organic compounds regulated by the state were detected in any of the samples in Elliott Bay and adjacent Puget Sound (Table 3-15). Detection limits for most regulated compounds were high. For all compounds except endosulfan and pentachlorophenol, the detection limits were above the chronic criteria. The detection limit for chlorpyrifos was higher than both the acute and chronic water quality criteria.

Washington's 305(b) list includes waters north of Pier 70 as Category 2 waters of concern for endosulfan based on one sample that exceeded the chronic criterion taken on May 12, 1977, at a site just north of Pier 70. No record of the sample could be found in the County's LIMS (laboratory information management system) database or the state's EIM (environmental information management system) database. The listing may be in error because it is unlikely that detection limits for endosulfan would have been low enough in 1977 to detect the compound in a water sample and because data searches did not find a record of endosulfan detection in any other water samples in Elliott Bay.

In addition to state WQC, EPA has also promulgated marine WQC for organic compounds (40 CFR Part 131.36) to be protective of human health considering consumption of organisms. A few samples were above EPA's Human Health Criteria. One sample each at the

Seattle Waterfront site (2 percent) of the HPAHs benzo(a)anthracene, benzo(b)fluoranthene, and benzo(k)fluoranthene exceeded the Human Health Criteria. The maximum MDL for most of these samples was above the Human Health Criteria, similar to several other HPAHs, chlorinated herbicides and pesticides, total PCB aroclors, and two semivolatile organic compounds (Table 3-15).

In addition, bis(2-ethylhexyl)phthalate exceeded the human health criterion of 5.9 µg/L. The highest concentration recorded was 10.5 µg/L. The mean of 1.51 µg/L did not exceed the criterion. Blank contamination is frequently an issue for phthalates, but bis(2-ethylhexyl)phthalate was reliably detected in 10 samples (17 percent). It was most commonly detected at the South Plant Outfall site, with the highest concentration detected near the surface at 5 m.

Table 3-15. Comparison of maximum detected concentrations of organic compounds (µg/L) in water samples at sites in Elliott Bay and adjacent Puget Sound (1999–2004) to water quality criteria. Highest mean for a monitoring station/depth is provided. Exceedances of EPA Human Health Criteria are highlighted in red; exceedances of WA State aquatic life criteria are in bold. Method detection limits above the state chronic criteria are in bold; limits above Human Health Criteria are highlighted in yellow.

Analyte	FOD	Max. Detect	Highest Site/Depth Mean	Min. MDL for Non-Detects	Max. MDL for Non-Detects	EPA Human Health Criteria		WA State Aquatic Life Criteria	
						Consumption of Organism Only	Notes	Acute	Chronic
Chlorinated Herbicides and Pesticides									
4,4'-DDD	0/48	NA	<MDL	0.0047	0.0048	0.00084	c	0.13	0.001
4,4'-DDE	0/48	NA	<MDL	0.0047	0.0048	0.00059	c	0.13	0.001
4,4'-DDT	0/48	NA	<MDL	0.0047	0.0048	0.00059	c	0.13	0.001
Aldrin	0/48	NA	<MDL	0.0047	0.0048	0.00014	c	0.71	0.0019
Alpha-BHC	0/48	NA	<MDL	0.0047	0.0048	0.013	c		
Beta-BHC	0/48	NA	<MDL	0.0047	0.0048	0.046	c		
Chlordane	0/29	NA	<MDL	0.024	0.024	0.00059		0.09	0.004
Dieldrin	0/48	NA	<MDL	0.0047	0.0048	0.00014	c	0.71	0.0019
Endosulfan I	0/48	NA	<MDL	0.0047	0.028	2		0.034	0.0087
Endosulfan II	0/48	NA	<MDL	0.0047	0.0048	2		0.034	0.0087
Endosulfan Sulfate	0/48	NA	<MDL	0.0047	0.0048	2			
Endrin Aldehyde	0/48	NA	<MDL	0.0047	0.0048	0.81			
Endrin	0/48	NA	<MDL	0.0047	0.0048	0.81		0.037	0.0023
Gamma-BHC (Lindane)	0/48	NA	<MDL	0.0047	0.0048	0.063		0.16	
Heptachlor Epoxide	0/48	NA	<MDL	0.0047	0.0048	0.00011	c		
Heptachlor	0/48	NA	<MDL	0.0047	0.0048	0.00021	c	0.053	0.0036
Hexachlorocyclopentadiene	0/9	NA	<MDL	0.24	0.24	17,000			
Toxaphene	0/48	NA	<MDL	0.047	0.048	0.00075	c	0.21	0.0002
Organophosphate Pesticides									
Chlorpyrifos	0/3	NA	<MDL	0.032	0.032			0.011	0.0056

Analyte	FOD	Max. Detect	Highest Site/Depth Mean	Min. MDL for Non-Detects	Max. MDL for Non-Detects	EPA Human Health Criteria		WA State Aquatic Life Criteria	
						Consumption of Organism Only	Notes	Acute	Chronic
LPAHs									
Anthracene	1/56	0.019	<MDL	0.0047	0.14	111,000			
Fluorene	3/56	0.0336	<MDL	0.0047	0.14	14,000			
HPAHs									
Benzo(a)anthracene	1/56	0.041	<MDL	0.012	0.14	0.031	c		
Benzo(a)pyrene	1/56	0.015	<MDL	0.0047	0.24	0.031	c		
Benzo(b)fluoranthene	2/56	0.0734	<MDL	0.0047	0.38	0.031	c		
Benzo(k)fluoranthene	1/56	0.0386	<MDL	0.0047	0.38	0.031	c		
Dibenzo(a,h)anthracene	0/56	NA	<MDL	0.024	0.38	0.031	c		
Chrysene	1/56	0.0616	<MDL	0.012	0.14	0.031	c		
Fluoranthene	8/56	0.0813	0.034	0.0047	0.14	370			
Indeno(1,2,3-Cd)Pyrene	0/56	NA	<MDL	0.024	0.24	0.031	c		
Pyrene	4/56	0.0388	0.0187	0.0047	0.14	11,000			
PCBs									
Total Aroclors	0/48	NA	<MDL	0.047	0.048	0.00017	c	10	0.03
Total PCBs (congeners) ^a	4/4	0.0000895	0.0000744			0.00017	c	10	0.03
Semivolatile Organic Compounds (SVOCs)									
1,2-Dichlorobenzene	0/56	NA	<MDL	0.024	0.14	17,000			
1,2-Diphenylhydrazine	0/9	NA	<MDL	0.047	0.47	0.54	c		
1,3-Dichlorobenzene	0/56	NA	<MDL	0.024	0.14	2,600			
1,4-Dichlorobenzene	0/56	NA	<MDL	0.024	0.14	2,600			
2,4-Dichlorophenol	0/57	NA	<MDL	0.047	0.49	790	c		
2,4-Dinitrophenol	0/24	NA	<MDL	0.47	0.48	14,000			
2,4-Dinitrotoluene	0/37	NA	<MDL	0.024	0.096	9.1	c		
2,4,6-Trichlorophenol	0/57	NA	<MDL	0.024	0.96	6.5	c		

Analyte	FOD	Max. Detect	Highest Site/Depth Mean	Min. MDL for Non-Detects	Max. MDL for Non-Detects	EPA Human Health Criteria		WA State Aquatic Life Criteria	
						Consumption of Organism Only	Notes	Acute	Chronic
Benzidine	0/9	NA	<MDL	5.7	5.8	0.00054	^c		
Bis(2-Chloroethyl)Ether	0/37	NA	<MDL	0.0047	0.14	1.4	^c		
Bis(2-Ethylhexyl)Phthalate ^b	10/56	10.5	1.51	0.0723	1.54	5.9	^c		
Di-N-Butyl Phthalate ^b	2/56	0.0601	<MDL	0.0267	0.24	12,000			
Diethyl Phthalate ^b	2/56	0.0235	<MDL	0.0119	0.24	120,000			
Dimethyl Phthalate	3/37	0.013	<MDL	0.0047	0.096	2,900,000			
Hexachlorobenzene	0/52	NA	<MDL	0.012	0.14	0.00077	^c		
Hexachlorobutadiene	0/35	NA	<MDL	0.024	0.24	50	^c		
Hexachloroethane	0/37	NA	<MDL	0.012	0.24	8.9	^c		
Isophorone	0/37	NA	<MDL	0.0047	0.24	600	^c		
N-Nitrosodimethylamine	0/37	NA	<MDL	0.012	0.96	8.1	^c		
N-Nitrosodiphenylamine	0/37	NA	<MDL	0.12	0.24	16	^c		
Nitrobenzene	0/37	NA	<MDL	0.0047	0.24	1,900	^c		
Pentachlorophenol	0/57	NA	<MDL	0.059	0.98	8.2	^c	13	7.9
Phenol	11/57	0.092	0.0559	0.047	0.96	4,600,000			

FOD = frequency of detection.

^a Total PCB congeners after blank quantification (King County, 2006a).

^b Blank contamination present in at least some samples analyzed (treated as non-detects and handled according to Table A-1 in Appendix A).

^c The criterion is based on carcinogenicity of 10⁻⁶ risk. Alternative risk levels may be obtained by moving the decimal point. (For example, for a risk level of 10⁻⁵, the decimal point in the recommended criterion would be moved one place to the right.)

4.0 SEDIMENT QUALITY

Sediments can provide a historical record of pollution in a waterbody. While pollution discharged into marine waters may quickly become diluted, many chemical pollutants settle to the bottom and bind to sediments. Chemicals that accumulate in sediments may adversely affect marine organisms and humans who consume these organisms or have direct contact with the sediments.

This chapter summarizes results of the analysis of sediment data collected in Elliott Bay and then presents the methodology and results of the analysis in more detail. Appendix C describes an extensive analysis of recent King County sediment monitoring efforts, and Appendix D compares data from all sites analyzed with state sediment standards.

4.1 Summary of Sediment Conditions

Contaminants associated with sediment at many nearshore sites in central Elliott Bay may cause adverse effects to aquatic organisms. Exceptions include areas where remediation projects, including dredging and capping, have been conducted (see Chapter 2). Mercury, PAHs, PCBs, and phthalates are the most widespread sediment contaminants in the bay. Concentrations of certain chemicals including some metals, PAHs, and PCBs appear to be slowly changing over time.

Risks to sediment-dwelling organisms in the immediate vicinity of CSOs from organic enrichment and possibly 1,4-dichlorobenzene and bis(2-ethylhexyl)phthalate are predicted to be reduced by CSO control (King County, 1999). However, threats from other chemicals such as mercury, PAHs, and PCBs will remain after all county CSOs are controlled if no other actions are taken. Additional remediation projects could speed up natural recovery processes at many sediment contaminant hot spots in Elliott Bay that are not receiving immediate attention, especially the downtown Seattle waterfront where criteria are often exceeded.

4.2 Methodology

Sediment data from a total of 283 sampling sites in Elliott Bay were reviewed, both from three recent King County sediment monitoring studies and from routine and compliance monitoring projects conducted by various agencies.

Between 2010 and 2013, King County conducted three sediment monitoring studies in Elliott Bay. These studies yielded a total of 31 samples that were analyzed for conventional parameters (particle size distribution, total organic carbon, and total solids) and for the 47 pollutants listed as part the state of Washington's Sediment Management Standards (SMS) (Chapter 173-204 WAC) (Ecology, 2013b). The studies are as follows:

- **Marine Ambient Sediment Monitoring Program.** Eight sites in Elliott Bay, sampled every two years, most recently sampled in 2013.

- **Sediment Management Program.** Six sites near the Magnolia and 53rd Ave SW CSO outfalls, sampled in 2011.
- **Denny Way/Lake Union CSO Control Project.** Seven sites near the new outfall, capped sediments, and natural recovery areas, most recently sampled in 2012.

These King County studies provide valuable data on sections of Elliott Bay, including time series data from the ambient monitoring program, that can be used for trend analysis (see Appendix C). However, they do not cover enough of the bay to identify current hot spots of sediment contamination or potential sources of contamination. To further understand the spatial patterns of sediment contamination, a larger data set was analyzed at a high level. Data from Inner and Outer Elliott Bay, collected by Ecology, City of Seattle, King County, and other agencies, were compiled from Ecology's EIM database (<http://www.ecy.wa.gov/eim/>), King County's LIMS database, and sediment cleanup efforts (Figure 4-1). Because of the limitations described below, the data displayed here should not be used to designate sediment cleanup sites.

The spatial and temporal distribution of the data used for this analysis is displayed in Figure 4-2. To assess conditions spatially, data from 1990 to present (2013) were included in the analysis. Net sedimentation rates in Elliott Bay average 1.45 cm per year (Baker et al., 1983). Rates vary widely along the downtown Seattle waterfront, ranging from 0.2–4.0 cm per year with a mean of 1.6 ± 0.88 cm per year; rates are most variable in areas with high vessel traffic (Ecology, 1995). Nonetheless, data from 1990 to present should provide a spatial understanding of conditions because much of the sampled sediment is likely still within the top 10 cm (biologically active zone) today. (Note that changes in some chemical concentrations have been observed throughout Elliott Bay over the last several decades, as shown in the trend data in Appendix C.) Data collected at cleanup sites prior to dredging and capping activities were excluded from the data set.

For this analysis, no effort was made to distinguish sampling methods. Although most sediment data are collected for regulatory purposes with a van Veen grab from 0–10 cm, both core and van Veen grab samples were analyzed. The top stratum of core samples (typically 30 cm) was used. The analysis also included sediment samples from ambient sediment monitoring programs (such as Ecology, 2009a, and King County, 2010b, 2011a), which analyze sediment chemistry from the top 2 or 3 cm. These shallow samples are distinguished from deeper samples in summary tables and maps. Although samples from this depth do not contain the full biologically active zone and should not be compared to the SMS for regulatory purposes, the data are included for determining contamination in recently deposited sediments.

Because samples were collected over the course of 24 years by various entities, analysis methods varied. Different laboratories conducted the chemical analyses. Detection limits changed over time, which may result in non-detects for some chemicals particularly organic compounds that occur at low concentrations. Chemicals below the detection limit were not compared to SMS because the true value is not known. Data rejected from the laboratory were removed from the dataset, but data with possible blank contamination or hold-time exceedances were included.

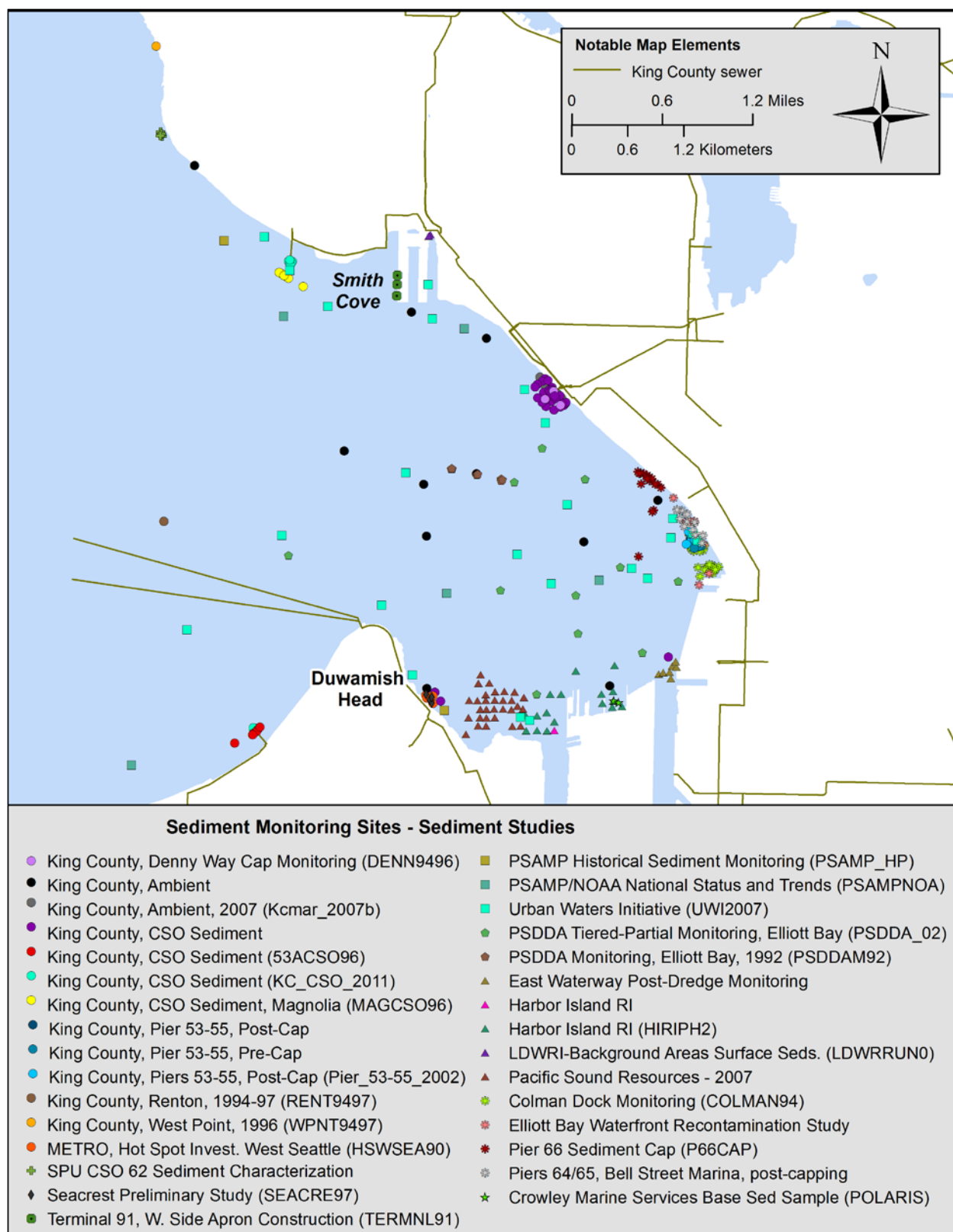


Figure 4-1. Studies for which sediment data were collected. Ecology's EIM code, if available, is included in parenthesis.

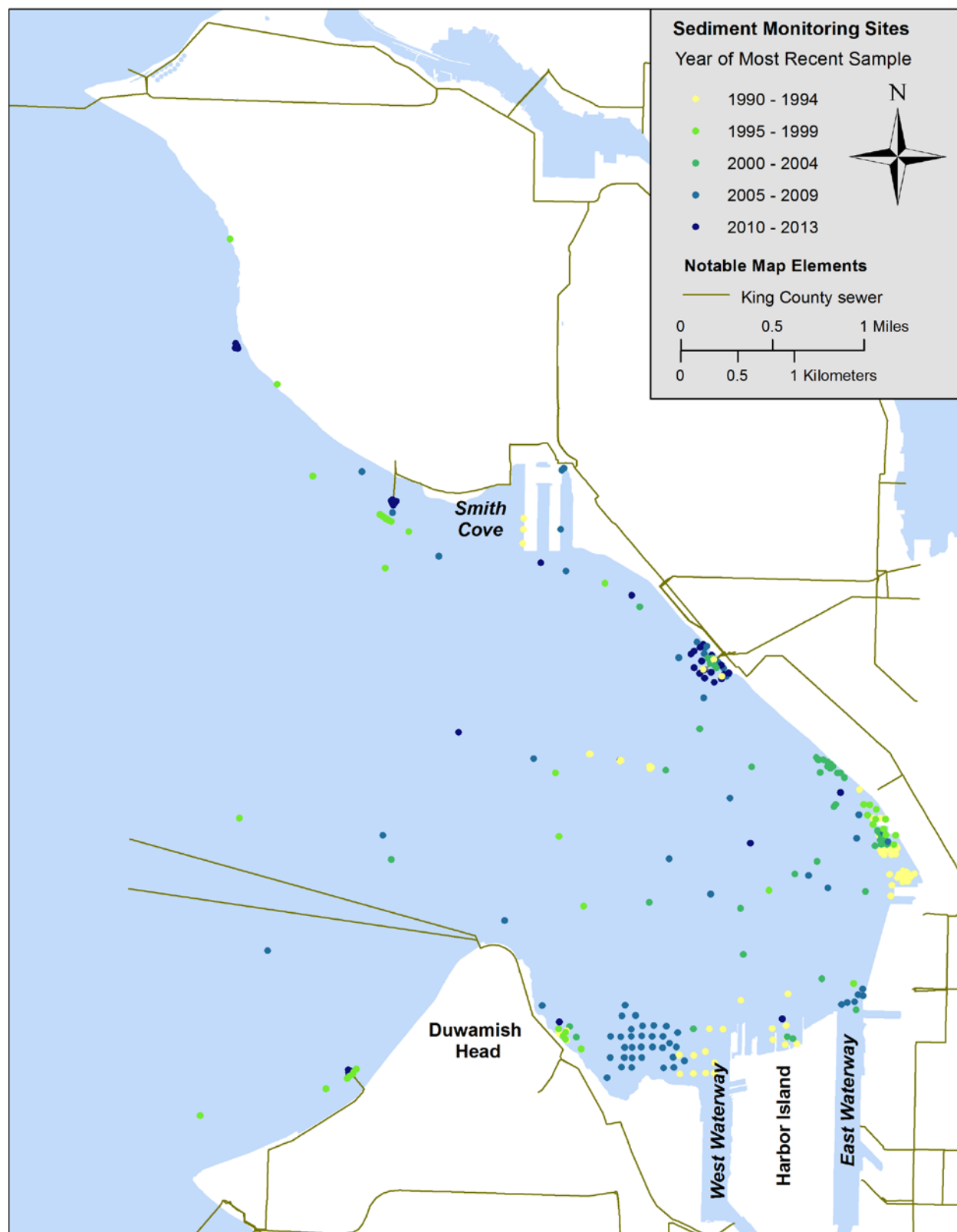


Figure 4-2. Spatial and temporal distribution of sediment data in Elliott Bay summarized for this analysis (1990–2013).

The sediment chemistry data were compared to the SMS. The marine SMS were developed to be protective of benthic organisms and consist of two levels of criteria:

- The Sediment Quality Standards (SQS) are a “no adverse effects” level (WAC 173-204-320), meaning sediment concentrations below this level are expected to have no adverse effects on the benthic community. The same criteria values are also known as the Sediment Cleanup Objective (SCO) (WAC 173-204-562), which are used as a sediment quality goal for Washington state sediments.
- The Cleanup Screening Level (CSL) is the “minor adverse effects” level (WAC 173-204-562), which is used as an upper regulatory level for source control and cleanup decision making.

Concentrations falling between the SQS/SCO and CSL have the potential to cause minor adverse effects on the benthic community. For simplicity, SQS and CSL are used to refer to no adverse effects and minor adverse effects levels, respectively.

For comparison to the SMS, dry weight concentrations were used for metals and concentrations of most organic compounds were normalized to organic carbon content. Normalization to organic carbon can produce biased results if the organic carbon content of the sample is very low or high (Ecology, 1992). When organic carbon content in a sample is near 0.1 percent or 0.2 percent (1,000 to 2,000 mg/kg dw), even background concentrations of certain organic compounds can exceed the SMS. Conversely, when organic carbon content of a sample is high, organic carbon normalized values may be biased low. Therefore, if the organic carbon content at any particular site was below 0.5 percent or above 4 percent dry weight, then dry weight-normalized results for non-ionizable/lipophilic organic compounds were compared to the Lowest Apparent Effects Threshold (LAET) or Second Lowest Apparent Effects Threshold (2LAET) rather than the SQS or CSL, respectively (EPA, 1988). The LAET and 2LAET relate to benthos toxicity data. If no organic carbon data were available for a particular sample, concentrations were compared to Apparent Effects Thresholds (AET). For simplicity, this chapter refers to either AET or SMS exceedances as SMS exceedances.

Data from six organic compounds, including all phenolic compounds, benzyl alcohol, and benzoic acid, are included in data tables. They are not shown on maps that compare sites with SMS and are not discussed below because of their ubiquity throughout Puget Sound, transitory nature, natural sources, and/or the lack of confidence in analytical precision and laboratory detection limits (Ecology, 2009a; Lower Duwamish Waterway Group, 2011).

4.3 Physical Structure of Sediments

The physical structure of marine sediments affects the distribution and concentration of metals and organic chemicals. Chemical concentrations are often expected to be higher at sites with a greater portion of fine particles because of the increased surface area for chemicals to bind and because higher concentrations of total organic carbon (TOC) can increase binding of some organic compounds (Wenning et al., 2005). The percentage of fine sediments (silt and clay) in Elliott Bay is highly variable, ranging from 0.1 percent to 95.3

percent with a mean of 30.3 percent. The deep depositional areas of Elliott Bay tend to have the highest fraction of fine particles, while nearshore sediments in Outer Elliott Bay tend to consist of a high percentage of sand and gravel (Figure 4-3). Sediments near the downtown Seattle waterfront were the most variable for percent of fine sediment.

TOC content in Elliott Bay ranges from < 0.1 percent to 11 percent, with a mean of 2.0 percent. Despite a high percentage of fines, TOC concentrations in deep depositional areas of Elliott Bay were typically between 0.5 percent and 2 percent. The highest concentrations of TOC were found nearshore along the downtown Seattle waterfront and near the Denny Way CSO (Figure 4-4).

Depth, TOC, and the percentage of fine sediment in samples collected from Elliott Bay (from the sites with data on these parameters) tend to be related to one another. The results of a Spearman rank analysis demonstrated that all were positively correlated with each other (for example, when depth increased, so did the percent of fines and TOC). The relationship between percent fines and both TOC and depth was very strong ($p < 0.0001$, $\rho = 0.667$ and 0.607 , respectively) while the relationship between depth and TOC was still significant but less strong ($p = 0.0007$, $\rho = 0.256$). This weaker relationship is probably due to the high level of variation of TOC, particularly along the shallow waterfront.

Appendix D includes locators, coordinates, percent TOC, percent fines, and exceedances in chemical groups for each of the 283 sites analyzed for this report.

4.4 Comparison to Criteria

Nearly all SMS chemicals exceed either the SQS or CSL at one or more sites in Elliott Bay. The exceptions were 1,2,4-trichlorobenzene, 1,2-dichlorobenzene, hexachlorobenzene, N-nitrosodiphenylamine, diethyl phthalate, and di-n-octyl phthalate (Table 4-1). PCBs, PAHs, and several metals (particularly mercury) exceed the SMS most frequently. Total HPAHs were almost always measured at higher concentrations than total LPAHs. HPAHs are more likely to be associated with sediments and are harder to break down than LPAHs. The higher HPAH concentrations could be due to larger inputs of HPAHs or to the biased breakdown, photochemical oxidation, dissolution, and microbial degradation that can remove PAHs with low molecular weights from the environment (Merrill and Wade, 1985).

The contaminants of highest concern in Elliott Bay are mercury, PAHs, total PCBs (Aroclors), and bis(2-ethylhexyl)phthalate. More than 10 percent of all sites had concentrations of these chemicals above the SMS (Table 4-1). The SMS are most frequently exceeded for mercury at a rate of 27 percent, and 25 percent of sites exceed criteria for total PCBs (Aroclors). Historical contaminant sources include industrial discharges, port/maritime activity, stormwater and municipal wastewater outfalls (including CSOs), surface runoff, combustion, and atmospheric deposition.

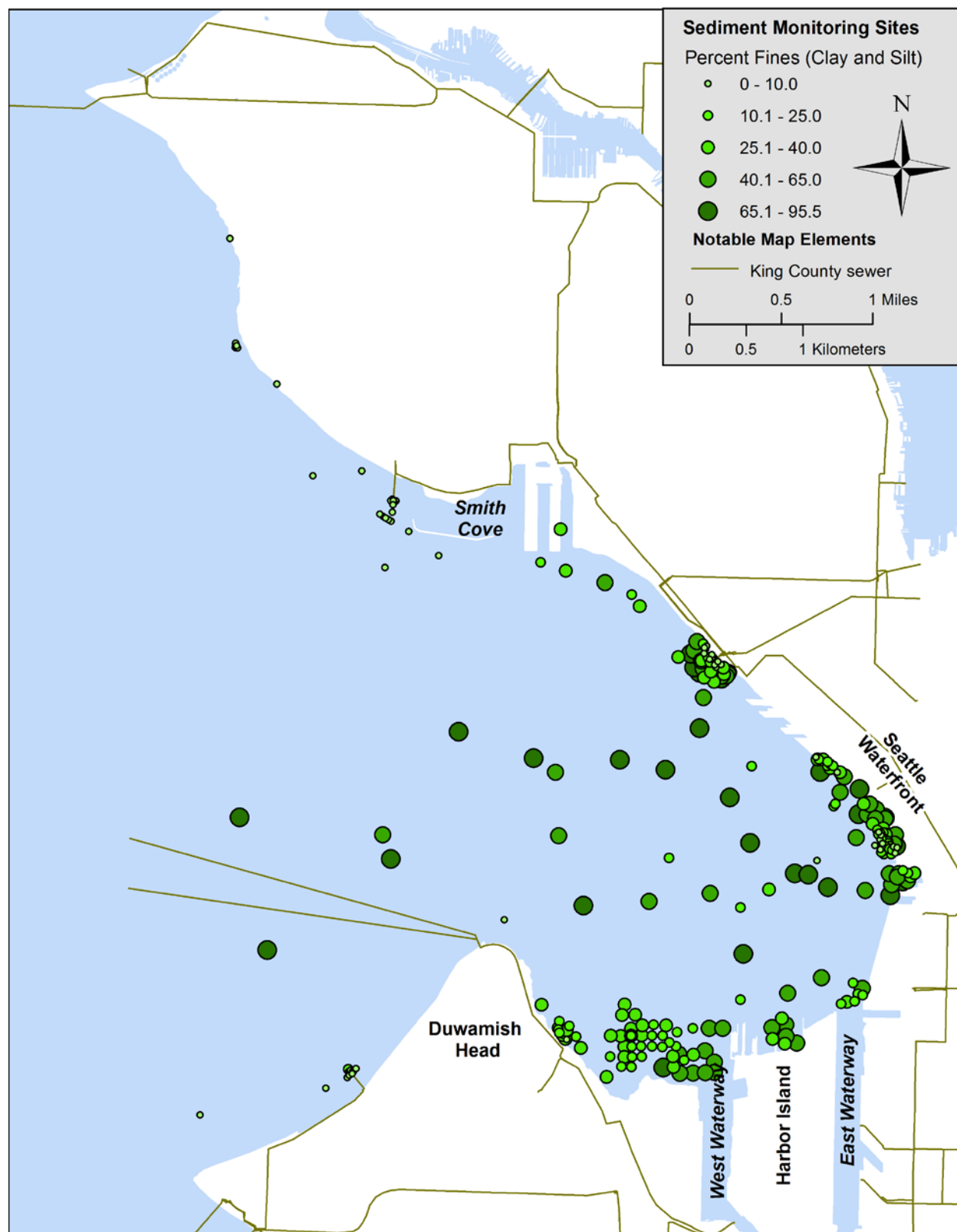


Figure 4-3. Percent fines in sediments at sites sampled in Elliott Bay (1990–2013).

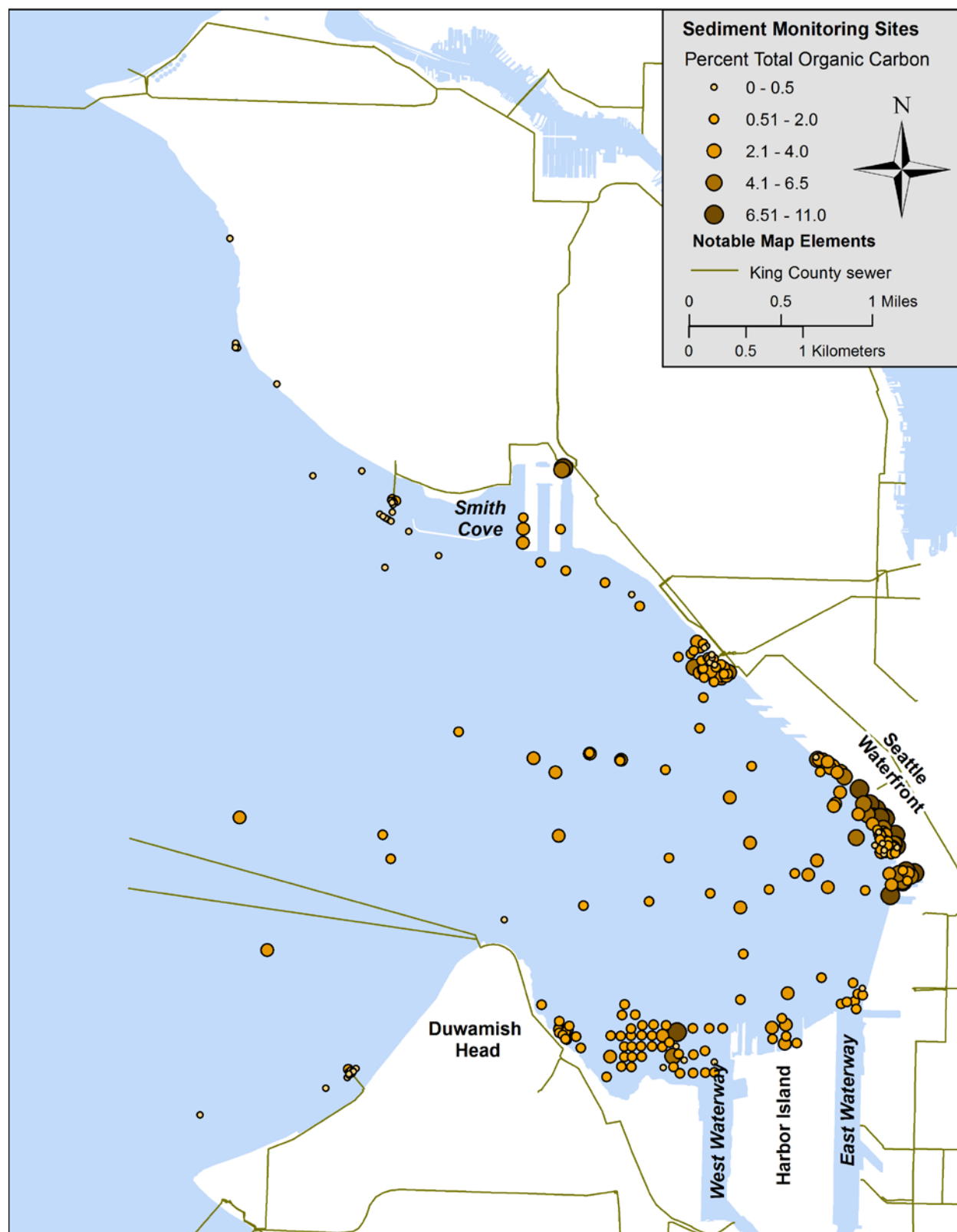


Figure 4-4. Percent total organic carbon at sites sampled in Elliott Bay (1990–2013).

Table 4-1. Frequency of detection and exceedances of Sediment Management Standards in Elliott Bay (1990–2013). Samples with < 0.5% or > 4% total organic carbon were compared to Apparent Effects Thresholds. * = exceedances not shown in Figures 4-5 and 4-6. All depths of sediment sampled are included.

		SMS		AETs		Detection Rate		
		SQS	CSL	LAET	2LAET			
	Metals	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	Detects	≥ SQS	≥ CSL
Metals	Arsenic	57	93	57	93	223/254	4/254	1/254
	Cadmium	5.1	6.7	5.1	6.7	157/228	7/228	1/228
	Chromium	260	270	260	270	199/201	2/201	2/201
	Copper	390	390	390	390	259/259	5/259	5/259
	Lead	450	530	450	530	253/255	2/255	1/255
	Mercury	0.41	0.59	0.41	0.59	247/267	71/267	57/267
	Silver	6.1	6.1	6.1	6.1	135/217	6/217	6/217
	Zinc	410	960	410	960	256/256	13/256	0/256
Lipophilic Organics		mg/kg OC	µg/kg dw	µg/kg dw	µg/kg dw	Detects	≥ SQS	≥ CSL
LPAHs	Naphthalene	99	170	2100	2100	170/274	11/274	6/274
	Acenaphthylene	66	66	1300	1300	154/274	5/274	5/274
	Acenaphthene	16	57	500	500	176/273	37/273	26/273
	Fluorene	23	79	540	540	191/274	39/274	28/274
	Phenanthrene	100	480	1500	1500	249/274	49/274	35/274
	Anthracene	220	1200	960	960	235/274	26/274	26/274
	2-Methylnaphthalene	38	64	670	670	143/274	11/274	8/274
	Total LPAHs	370	780	5200	5200	250/274	37/274	28/274
HPAHs	Fluoranthene	160	1200	1700	2500	255/274	53/274	31/274
	Pyrene	1000	1400	2600	3300	259/274	35/274	32/274
	Benzo(a)anthracene	110	270	1300	1600	112/135	17/135	13/135
	Chrysene	110	460	1400	2800	254/274	51/274	29/274
	Total Benzofluoranthenes	230	450	3200	3600	60/68	6/68	4/68
	Benzo(a)pyrene	99	210	1600	1600	248/274	43/274	35/274
	Indeno(1,2,3-cd)pyrene	34	88	600	690	239/274	47/274	34/274
	Dibenzo(a,h)anthracene	12	33	230	230	148/241	48/241	34/241
	Benzo(g,h,i)perylene	31	78	670	720	120/167	15/167	10/167
	Total HPAHs	960	5300	12000	17000	260/274	51/274	28/274
Chloro-benzenes	1,2,4-Trichlorobenzene	0.81	1.8	31	51	5/231	0/231	0/231
	1,2-Dichlorobenzene	2.3	2.3	35	50	14/226	0/226	0/226
	1,4-Dichlorobenzene	3.1	9	110	110	45/221	2/221	2/221
	Hexachlorobenzene	0.38	2.3	22	70	2/212	0/212	0/212
Phthalates	Dimethyl phthalate	53	53	71	160	11/224	1/224	1/224
	Diethyl phthalate	61	110	200	>200	19/224	0/224	0/224
	Di-n-butyl phthalate	220	1700	1400	1400	93/166	1/166	1/166
	Benzyl butyl phthalate	4.9	64	63	900	65/230	11/230	0/230

		SMS		AETs				
		SQS	CSL	LAET	2LAET	Detection Rate		
Misc. Organics	Bis(2-ethylhexyl)phthalate	47	78	1300	1900	108/134	14/134	8/134
	Di-n-octyl phthalate	58	4500	6200	6200	1/230	0/230	0/230
	Dibenzofuran	15	58	540	540	136/249	20/249	13/249
	Hexachlorobutadiene	3.9	6.2	11	120	1/212	1/212	1/212
	N-Nitrosodiphenylamine	11	11	28	40	2/212	0/212	0/212
	Total PCBs (Aroclors)	12	65	130	1000	182/246	61/246	11/246
Hydrophilic Organics	Hydrophilic Organics	µg/kg dw		µg/kg dw		Detects	≥ SQS	≥ CSL
	Phenol*	420	1200	420	1200	68/230	7/230	1/230
	2-Methylphenol*	63	63	63	63	2/166	0/166	0/166
	4-Methylphenol*	670	670	670	670	0/33	0/27	0/27
	2,4-Dimethylphenol*	29	29	29	29	30/220	16/220	16/220
	Pentachlorophenol*	360	690	360	690	2/196	0/196	0/196
	Benzoic acid*	650	650	650	650	87/226	7/226	7/226
	Benzyl alcohol*	57	73	57	73	26/238	8/238	0/238

SMS = Sediment Management Standards; AET = Apparent Effect Threshold; SQS = Sediment Quality Standards; CSL = Cleanup Screening Level; LAET = Lowest Apparent Effects Threshold; 2LAET = Second Lowest Apparent Effects Threshold.

More than half (56 percent) of all 283 sites do not exceed SMS for any chemical; 14 percent of the sites exceed SQS/LAET criteria only; and 30 percent of the sites exceed one or more CSL/2LAET criteria. In general, chemical exceedances were concentrated in nearshore pockets (“hot spots”) throughout Elliott Bay (Figures 4-5 and 4-6) that are reflected in the sampling pattern. With the exception of King County and Ecology ambient sediment monitoring programs, most sediment sampling efforts target suspected or known areas of contamination in nearshore areas. Therefore, the percentages of sites with chemical concentrations above the SMS do not accurately reflect overall conditions in the bay and are biased toward areas with historical contamination. Exceedances in areas surrounding CSO outfalls and in hot spots for sediment contamination are shown in Figure 4-6 and summarized in Table 4-2.

Exceedances at sites other than CSO and/or hot spot sites are as follows:

- Despite typically having higher percent fines, sediments at sites offshore in deeper parts of the bay tend to have low concentrations of most contaminants compared to nearshore sites. Mercury and silver are the only chemicals that exceed the CSL at one or more offshore sites; the exceedances are likely due to widespread historical contamination.
- One site nearshore and east of Pier 90 exceeds SQS criteria for total PCBs.
- Four other sites, located near the Elliott Bay dredge disposal site, exceed the SQS criteria for total PCBs; one of these sites also exceeds the criteria for dibenzofuran and the HPAH indeno(1,2,3-c,d)pyrene.

Throughout Elliott Bay, many of the contaminant concentrations (both metals and organic compounds) are higher when percent TOC is higher. Several sites deviate from the standard regression line relating the various compounds to organic carbon content. Some of the sites were above the upper 95 percent predictive bounds for several chemicals; these sites have concentrations above what would be expected for Elliott Bay sediments at their correlating TOC value and, therefore, have higher than expected contamination levels (Figures 4-7 and 4-8). “Outlier” sites vary from compound to compound, but for both metals and organics, these sites are most often located near the Seattle waterfront. Other areas with sites frequently considered outliers are located near Piers 90/91 and in South Elliott Bay. No sites near the Magnolia and 53rd Ave SW CSO outfalls exceed the 95 percent predictive bounds for metals or organics concentrations. Near the Denny Way CSO outfall, one site is above the 95 percent predictive bounds for the chemicals chromium, zinc, and bis(2-ethylhexy)phthalate.

The following subsection describes the exceedances for each CSO and hot spot area shown in Figure 4-6, followed by another subsection that describes where the chemicals frequently exceeding the SMS were detected in sediment.

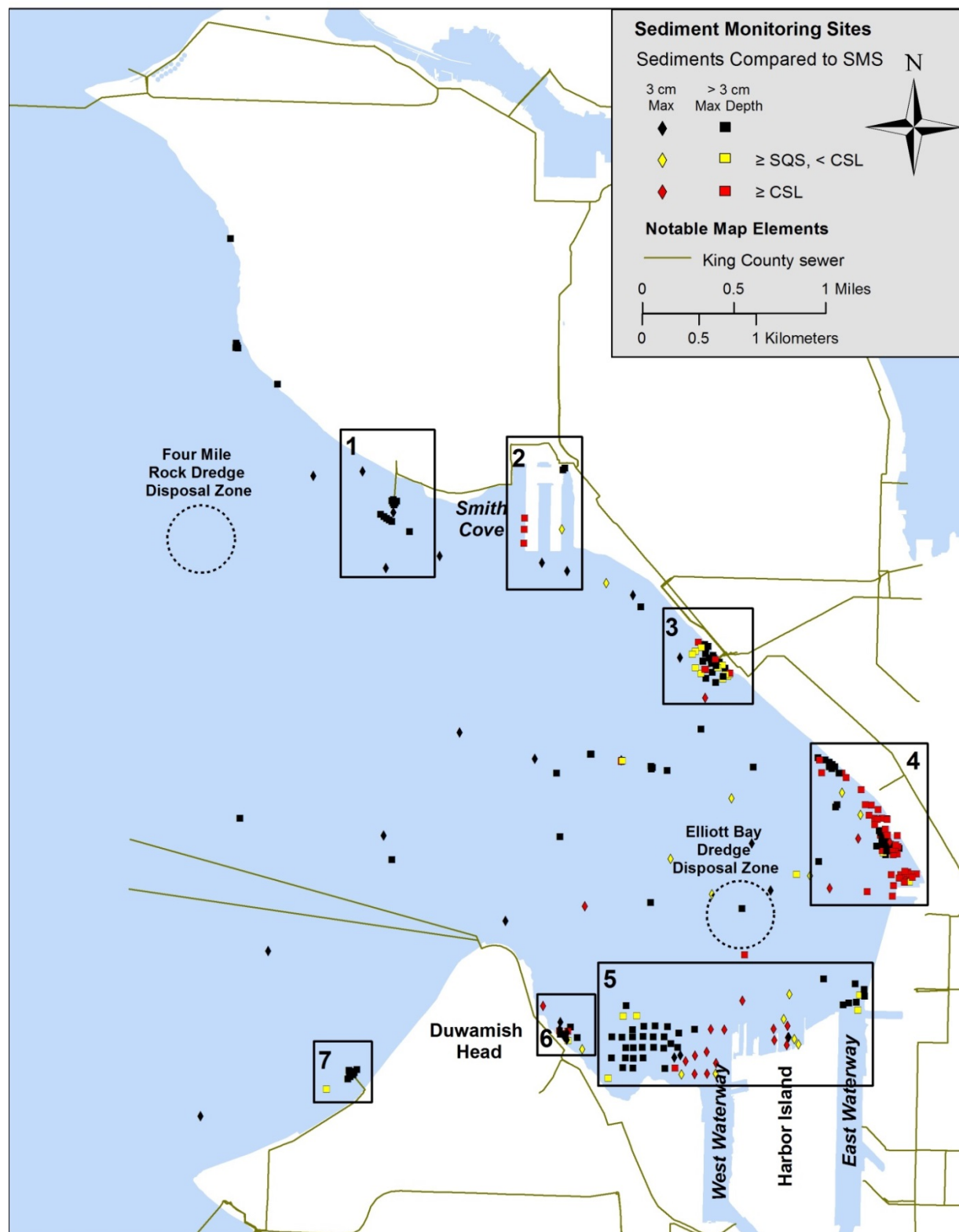


Figure 4-5. Sediment samples in Elliott Bay compared to Sediment Management Standards. Samples with < 0.5% or > 4% total organic carbon are compared to Apparent Effects Thresholds. See Figure 4-6 for detail on numbered areas.

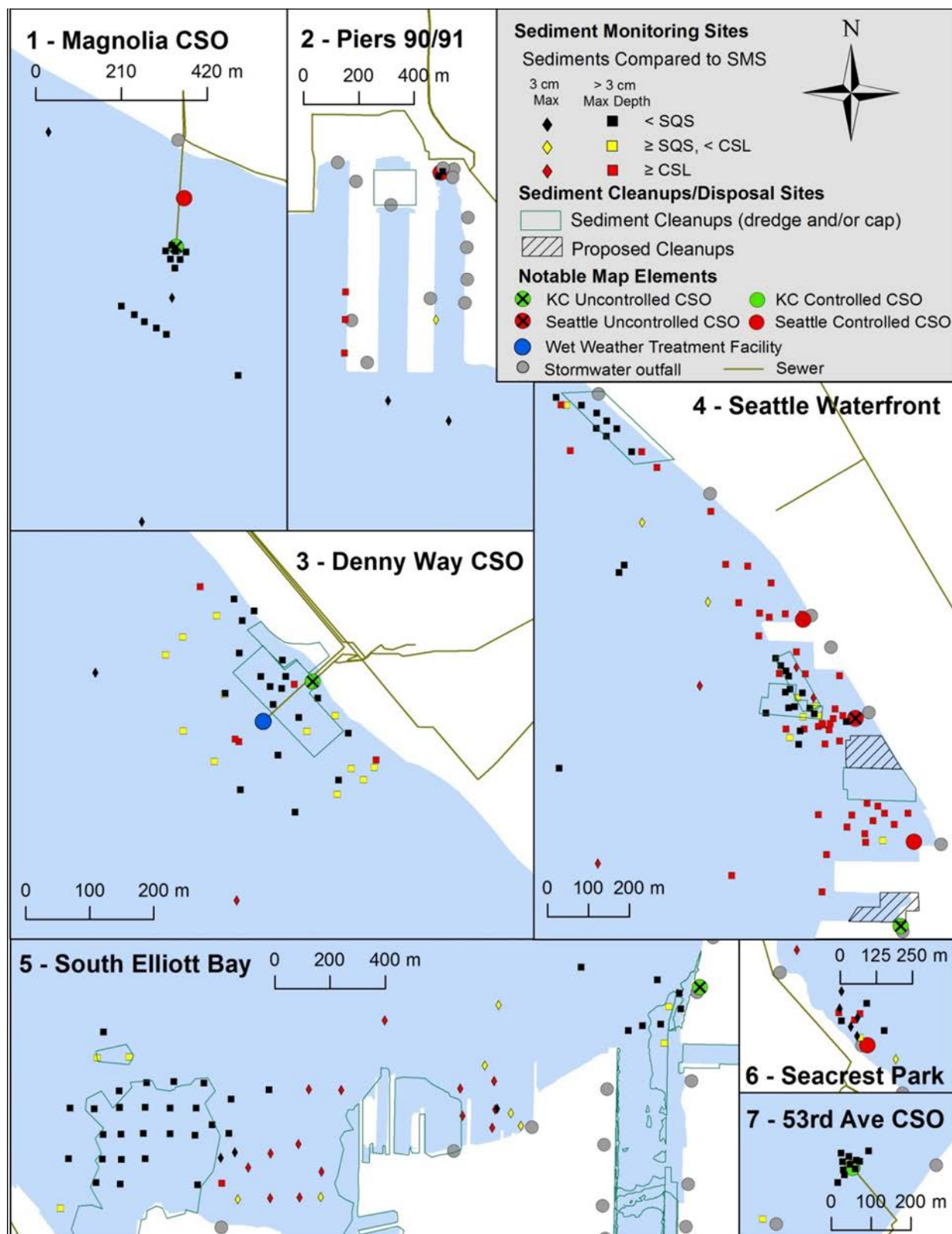


Figure 4-6. Sediment samples in “hot spots” and near CSO outfalls in Elliott Bay compared to Sediment Management Standards. Samples with < 0.5% or > 4% total organic carbon are compared to Apparent Effects Thresholds.

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Table 4-2. Summary of exceedances of Sediment Management Standards in Elliott Bay by area. Samples with < 0.5% or > 4% total organic carbon were compared to Apparent Effects Thresholds. Yellow boxes indicate that sediment at one or more site in that area exceeds Sediment Quality Standards; red boxes indicate that the Cleanup Screening Level is exceeded. See Appendix D for site-specific chemical group exceedances.

		Metals										LPAHs										HPAHs									
Area	n	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Silver	Zinc	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	2-Methylnaphthalene	Total LPAHs	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Total Benzo(a)anthracenes	Benzo(a)pyrene	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	Total HPAHs				
1 - Magnolia CSO	16																														
2 - Piers 90/91	8		SQS				CSL		SQS	CSL		CSL	CSL	CSL		CSL	CSL	CSL	CSL		CSL		CSL	CSL	CSL		CSL				
3 - Denny Way CSO	37						CSL					CSL	CSL	CSL	CSL			CSL	CSL	CSL	CSL		CSL	CSL	CSL	CSL	CSL				
4 - Seattle Waterfront	85	SQS			CSL	CSL	CSL	CSL	SQS	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL				
5 - South Elliott Bay	65	CSL	CSL	CSL	CSL		CSL		SQS			CSL	CSL	CSL		SQS	CSL	SQS	CSL	CSL	SQS	SQS	SQS	CSL	CSL	CSL	SQS				
6 - Seacrest Park	14			CSL	CSL	SQS	CSL		SQS		CSL	SQS					SQS							SQS	SQS						
7 - 53rd Ave CSO	12																														
Other (most offshore)	46						CSL	CSL																SQS							
Elliott Bay Overall	283	CSL	CSL	CSL	CSL	CSL	CSL	CSL	SQS	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL	CSL				

		Chlorobenzenes				Phthalates				Misc. Organics				Hydrophilic Organics								
Area	n	1,2,4-Trichlorobenzene	1,2-Dichlorobenzene	1,4-Dichlorobenzene	Hexachlorobenzene	Dimethyl phthalate	Diethyl phthalate	Di-n-butyl phthalate	Benzyl butyl phthalate	Bis(2-ethylhexyl)phthalate	Di-n-octyl phthalate	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phenol*	2-Methylphenol*	4-Methylphenol*	2,4-Dimethylphenol*	Pentachlorophenol*	Benzoic acid*	Benzyl alcohol*
1 - Magnolia CSO	16																					
2 - Piers 90/91	8										CSL				SQS			CSL				
3 - Denny Way CSO	37				CSL			SQS	CSL		SQS			CSL						CSL		
4 - Seattle Waterfront	85		CSL				CSL	SQS	CSL		CSL			CSL	CSL			CSL				SQS
5 - South Elliott Bay	65							SQS	CSL		CSL	CSL		CSL	SQS							
6 - Seacrest Park	14							SQS			SQS			SQS				CSL		CSL		
7 - 53rd Ave CSO	12							SQS						SQS								
Other (most offshore)	46									SQS				SQS				CSL		CSL		
Elliott Bay Overall	283		CSL		CSL		CSL	SQS	CSL		CSL	CSL		CSL	CSL			CSL		CSL		SQS

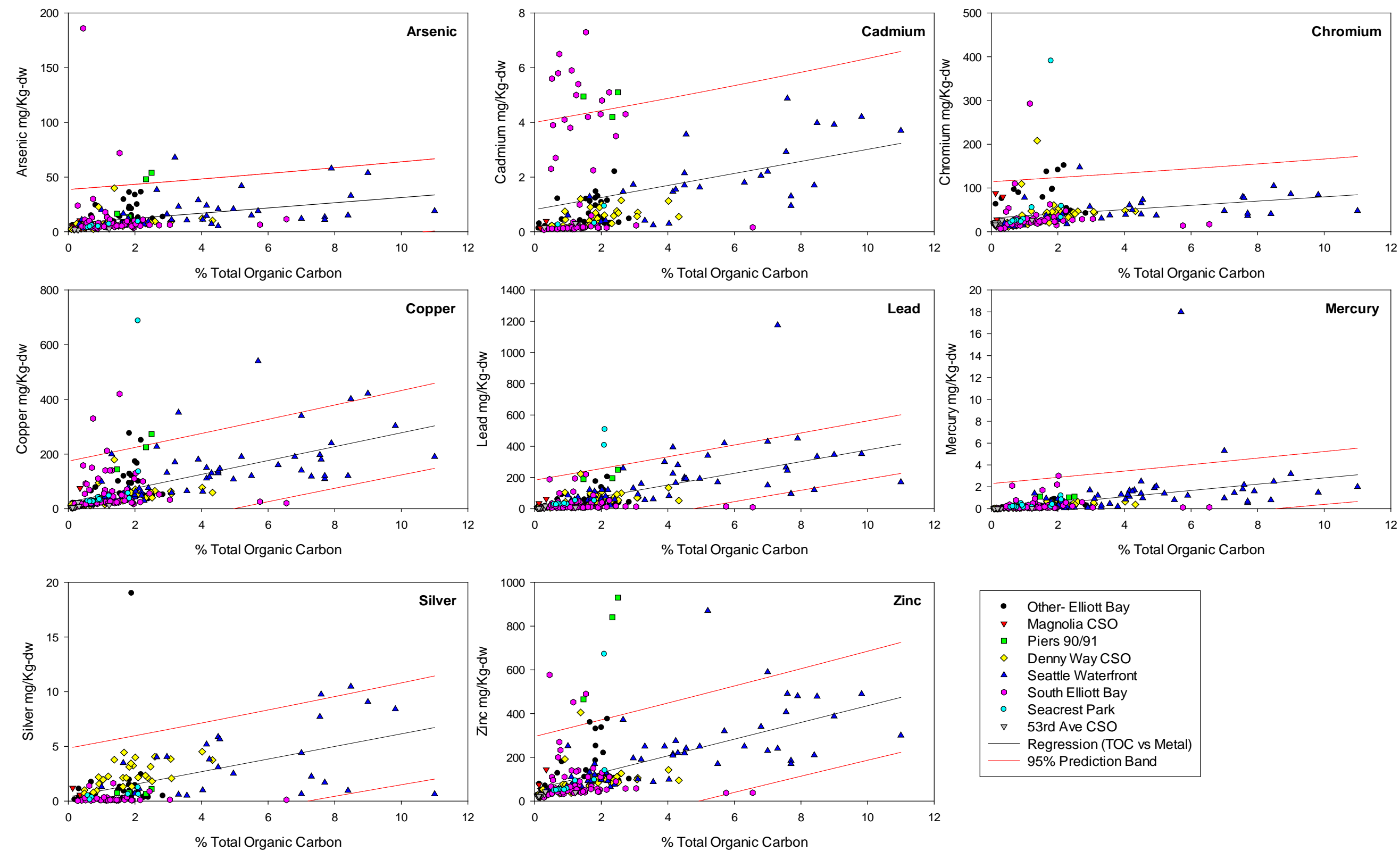


Figure 4-7. Concentrations of metals (mg/kg dw) at sites in Elliott Bay.

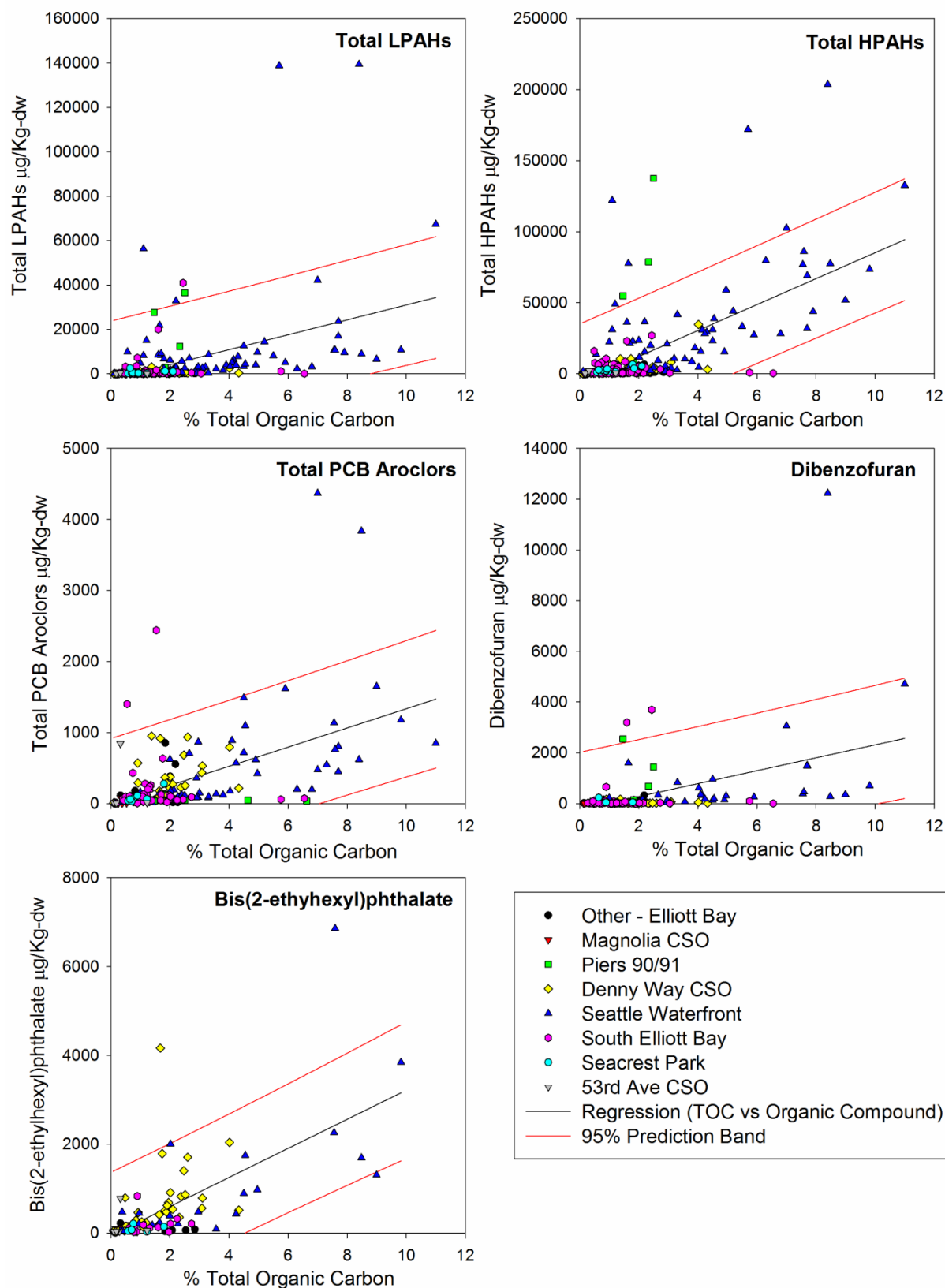


Figure 4-8. Concentrations of organic compounds (mg/kg dw) at sites in Elliott Bay.

4.4.1 Sediment Management Standard Exceedances Near CSOs and Hot Spot Areas

Area 1 – Magnolia CSO

King County's uncontrolled Magnolia CSO is located in Outer Elliott Bay, and a controlled City of Seattle CSO (064) is located nearby. The sediments surrounding this site have a low percentage of fine sediments (silt and clay) (mean = 5.3 percent) and low concentrations of TOC (mean = 0.3 percent). No sediment criteria were exceeded at sites surrounding the Magnolia CSO (latest samples were collected in 2011).

Area 2 – Piers 90/91

Very little sampling has been done around Piers 90 and 91 in northern Elliott Bay. The nearby Port of Seattle Terminal 91 Corrective Action Site is undergoing cleanup and monitoring of groundwater and soil contaminated with petroleum, metals, PAHs, PCBs, and other volatile compounds. The piers receive vessel traffic, including cruise ships. Over a dozen stormwater outfalls and one controlled CSO outfall (Seattle 068) are in the vicinity.

Recent sediment samples collected in the area surrounding the piers exceed criteria for metals (cadmium, mercury, and zinc), PAHs, and dibenzofuran. One of three sites that exceed the CSL is located approximately 25 m from a stormwater outfall; all of these sites are located along the west side of Pier 91. In addition, one site approximately 75 feet from a stormwater outfall along the east side of Pier 90 exceeds SQS criteria for two HPAHs (benzo(a)pyrene and indeno(1,2,3-c,d)pyrene). No samples collected near the Seattle 068 CSO outfall exceed sediment criteria.

Area 3 – Denny Way

The area surrounding King County's Denny Way CSO outfall has a long history of contamination and cleanups. The site was contaminated by over 40 years of raw sewage discharge and another 40 years of CSOs discharging directly onto the exposed intertidal zone during low tides. Sediments near the outfall were capped in 1990. Additional nearshore sediments were dredged and capped in 2008 after a new longer outfall (extends 122 m offshore) was completed in 2005. Current point sources at this site include the new Denny Way CSO outfall and the Elliott West wet weather treatment facility outfall, which was also completed in 2005.

Chemicals currently exceeding the SMS in the vicinity of the Denny Way CSO include mercury, HPAHs, PCBs, dibenzofuran, dimethyl phthalate, benzyl butyl phthalate, and bis(2-ethylhexyl)phthalate. PCBs, mercury, and bis(2-ethylhexyl)phthalate most frequently exceed sediment criteria (41, 29, and 17 percent of samples, respectively). Mercury, PCBs, and phthalates exceed the SMS near the new Elliott West outfall; however, these chemicals exceeded the SMS prior to outfall construction based on data collected in 1994. Despite remediation efforts, the SMS are exceeded at some sites surrounding the former and current outfalls.

Reduced overflow events and natural recovery could aid in the reduction of chemical concentrations in these sediments. The Denny Way/Lake Union CSO Control project was completed in 2005, but control has not yet been achieved at the Denny Way outfall. King County is making modifications to reduce overflows and continues to monitor sediments in the area.

Area 4 – Downtown Seattle Waterfront/King Street CSO

The largest hot spot for sediment contamination in Elliott Bay, both in size and frequency of criteria exceedance, is along the downtown Seattle waterfront. The waterfront area was identified as a high priority problem decades ago, but less regulatory enforcement has occurred there than in areas like the Lower Duwamish Waterway and Harbor Island because of the lack of industrial activity (Metro, 1988). Current point sources in this area include four CSOs (uncontrolled King County King St CSO and Seattle 071 CSO; controlled Seattle 070 and 072 CSOs) and six known stormwater outfalls. The area also includes the Seattle Ferry Terminal (Colman Dock). Ferries and other vessels increase net current speeds, affect near bottom current speeds, and can cause resuspension of potentially contaminated sediments (EBDRP, 1995).

Several cleanup projects were undertaken in the late 1980s to early 1990s in this area, including dredging and capping near the Seattle Ferry Terminal (1989), Pier 53/54 (1992), and Piers 64/65 at the Bell Street Marina (1994). Despite these efforts, the Seattle waterfront remains a hot spot for sediment contamination. Nearly all samples, except those within the boundaries of cleanups, exceed the SMS for one or more chemicals.

Sediment samples collected along the downtown Seattle waterfront exceed sediment quality criteria for metals (arsenic, copper, lead, mercury, silver, and zinc), PAHs, PCBs, 1,4-dichlorobenzene, dibenzofuran, di-n-butyl phthalate, benzyl butyl phthalate, and bis(2-ethylhexyl)phthalate. The chemicals that most frequently exceed the SMS are mercury (47 percent of samples) and HPAHs (46 percent), followed by LPAHs (35 percent) and then PCBs (31 percent). Mercury is the contaminant that most frequently exceeds the CSL along the waterfront (45 percent).

Sediments in the Pier 53/54 cleanup area exceed the SMS for PAHs, dibenzofuran, and PCBs. The CSL is only exceeded within the 30-cm cap for various HPAHs (fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, and dibenzo(a,h)anthracene). Most samples in the zone covered with the 1-m sediment cap no longer exceed the SMS, with the exception of four sites that exceed the SQS for various PAHs. All sites sampled within the boundary of the Pier 64/65 capping project are below all the SMS, with the exception of one site which exceeds the SMS for mercury, PAHs, and PCBs.

This analysis does not include data for samples collected in the late 1980s near the King Street CSO, located in the southern area of the waterfront, because of the age of the data. However, the older data indicate that arsenic, mercury, silver, zinc, PAHs, PCBs, bis(2-ethylhexyl)phthalate, and dibenzofuran exceed the SMS (King County, 2009). The state has

identified the area as contaminated and has proposed that it undergo future cleanup (Ecology, 1996).

Area 5 – Southern Elliott Bay/Kingdom CSO

The sediments near Harbor Island in southern Elliott Bay are heavily contaminated from historical and, in some cases, ongoing activities. EPA and Ecology have designated much of this area as Superfund sites, including (from east to west) the East Waterway Operable Unit, Todd and Lockheed Shipyards Operable Units, West Waterway Operable Unit (all part of the larger Harbor Island Superfund site); Lockheed West Seattle Superfund site; and Pacific Sound Resources Superfund site.

Much of the contaminated sediment in southern Elliott Bay has been removed. Remaining sediment contamination is mostly in areas that have not been dredged (Lockheed West Seattle and the area north of Harbor Island on either side of the Todd Shipyard Operable Unit). (For more information on the history of these sites, see Chapter 2.)

North of East Waterway

As part of maintenance dredging of the East Waterway, some sediment in the Elliott Bay study area (in the East Waterway Operable Unit) was removed in 2000 and 2005. Remaining sediment contamination was identified at two sites in the mouth of the East Waterway and includes SMS exceedances of various PAHs.

A stormwater outfall and King County's uncontrolled Kingdom CSO are located near the dredged area. Sediments located west of the Kingdom CSO were contaminated with copper, PAHs, PCBs, bis(2-ethylhexyl)phthalate, benzyl butyl phthalate, 1,4-dichlorobenzene, and dibenzofuran when last sampled in the mid-1990s (King County, 2009). However, most of the sediment where these samples were collected has been removed through dredging of the East Waterway. Only one site, located farthest from the outfall, has not been dredged. Data from this site collected in 1995 suggest that chemical concentrations do not exceed the SMS. New samples collected in 2009 adjacent to the outfall did not exceed the SMS.

Harbor Island

Sediments in the northeast corner of Harbor Island exceed SMS criteria for cadmium, mercury, PAHs, PCBs, dibenzofuran, and bis(2-ethylhexyl)phthalate. These sediments are not part of the Harbor Island Superfund Site, and no timeline has been set for removing and/or capping these sediments.

Nearby sediments along the northwest corner of Harbor Island were dredged as part of the Todd Shipyards Operable Unit remediation (completed in February 2007). Contamination included petroleum, PCBs, PAHs, and marine paint additives, which contribute to high metals concentrations. Post-cleanup monitoring data were not available to evaluate the current status of sediment surrounding that site, although the most recent five-year review for Harbor Island reported that sediments are below the SMS for all priority pollutants except at 6 of the 43 sites. These six sites exceed the SQS for mercury (EPA, 2010).

In the surrounding area north and east of Todd Shipyards (north of the West Waterway), sediments exceed the SMS for metals (arsenic, cadmium, copper, and mercury), PAHs, PCBs, and benzyl butyl phthalate.

North of West Waterway

To the north and west of the West Waterway is the Lockheed West Seattle Superfund site. Historical contamination occurred as the result of paint, metal scraping, and sandblasting grit from boat refurbishing activities discharged directly into Elliott Bay. Dredging and capping of this former shipyard area was proposed in 2013, but has not been started. Sediments at this site exceed the SMS for metals (arsenic, cadmium, chromium, mercury, and zinc), PCBs, PAHs, and hexachlorobutadiene. Tributyl tin and petroleum products are additional known contaminants at this site (EPA, 2012).

West Seattle

Much of the area west of the Lockheed West Seattle Superfund site and east of Duwamish Head is part of the Pacific Sound Resources Superfund Site, formerly Wyckoff West Seattle. These sediments, previously contaminated by creosote and related hazardous chemicals discharged from the former wood treating facility, were removed as part of the site's cleanup program completed in 2005. Post-dredging monitoring of this site and surrounding area (2007) indicates that chemical concentrations at most sites are below the SMS; only three sites exceed the SQS (for total PCBs and two HPAHs).

Area 6 – Seacrest Park in West Seattle

There are three stormwater outfalls and one controlled CSO (Seattle 078) in the vicinity of Seacrest Park in West Seattle. Beach use and recreational diving are popular in the vicinity and, therefore, sediment contamination is a potential concern from a human health standpoint.

Sediment samples collected between 1990 and 1995 in the area surrounding Seacrest Park exceed the SMS for metals (chromium, copper, lead, mercury, and zinc), PCBs, and benzyl butyl phthalate. Samples that exceeded CSL were farther offshore, not adjacent to the CSO or stormwater outfalls. The contamination is suspected to be linked to historical pier activities (EBDRP, 1994). Sediment samples collected from 1997 to present do not exceed the SMS, indicating that natural recovery may be occurring in subtidal sediments off the park. The exception is one site north of Seacrest Park, located between the Don Armeni Boat Launch and the King County Ferry Terminal (water taxi); various PAHs in sediments collected from this site exceeded the SMS in 2007.

King County will continue to monitor sediment chemistry in the subtidal waters offshore of Seacrest Park every two years as part of its ambient monitoring program.

Area 7 – 53rd Ave CSO

Sediments surrounding King County's controlled 53rd Ave SW CSO have very low concentrations of contaminants. Nearshore sediments in Outer Elliott Bay tend to have a high percentage of sand and/or gravel and very low percentages of fines (silt and clay). Sites in this area have a mean of 3.4 percent fines and low TOC (mean = 0.3 percent).

No recent sediment samples from the area surrounding the 53rd Ave CSO exceed the SMS (latest collected in 2011). One site, located approximately 250 m southwest of the CSO outfall, exceeds the SQS for PCBs and benzyl butyl phthalate. This site is located approximately 35 m northwest of a stormwater outfall.

4.4.2 Locations of Frequently Exceeded Chemicals

The following eight chemicals or groups of chemicals exceed the CSL (minor adverse effects level) or 2LAET (sediments with < 0.5 percent or > 4 percent TOC) at five or more of the 283 sites in the Elliott Bay study area:

- Mercury
- Copper
- Silver
- Total HPAHs (total benzofluoranthenes are the only HPAHs that do not exceed criteria at more than five sites [4 of 68])
- Total LPAHs (all individual LPAHs exceed the CSL at five or more sites)
- Bis(2-ethylhexyl)phthalate
- Dibenzofuran
- Total PCBs

Figures 4-9 through 4-16 show the magnitudes of exceedances of these chemicals; the sections below describe locations of the exceedances.

Mercury

Mercury exceeds the CSL in 57 out of 267 samples (Figure 4-9):

- Thirty-eight exceedances along the downtown Seattle waterfront, including samples with the greatest magnitudes of exceedance
- Eight exceedances in southern Elliott Bay
- Two exceedances near Seacrest Park
- Four exceedances near the Denny Way CSO
- Exceedances at all three sites along the western side of Pier 91 in Smith Cove
- Two exceedances in the center of the bay
- Lowest concentrations relative to the CSL in Outer Elliott Bay

Copper

Copper exceeds the CSL in 5 of 259 samples (Figure 4-10); no concentration is greater than five times the CSL:

- Three exceedances along the downtown Seattle waterfront
- One exceedance in southern Elliott Bay north of the West Waterway
- One exceedance near Seacrest Park
- Lowest concentrations relative to the CSL in Outer Elliott Bay.

Silver

Silver exceeds the CSL in 6 of 217 samples (Figure 4-11); no concentration is greater than five times the CSL:

- Five exceedances along the downtown Seattle waterfront
- One site deep in the center of the bay
- Lowest concentrations relative to the CSL at sites near the recently remediated sediments surrounding the Pacific Sound Resources Superfund site

Total HPAHs

Total HPAHs exceed the CSL in 28 of 274 samples (Figure 4-12):

- Twenty-six exceedances along the downtown Seattle waterfront, including the highest concentrations of HPAHs
- One exceedance in the nearshore surrounding the Denny Way CSO
- One exceedance near the western edge of Pier 91 in Smith Cove

Total LPAHs

Total LPAHs exceed the CSL in 28 of 274 samples (Figure 4-13):

- Twenty-three exceedances along the downtown Seattle waterfront, including the highest concentrations of LPAHs
- Three exceedances in southern Elliott Bay north of Harbor Island
- Two exceedances near the western edge of Pier 91 in Smith Cove

Bis(2-ethylhexyl)phthalate

Fewer data are available on bis(2-ethylhexyl)phthalate, particularly in the center of Elliott Bay, than on most other chemicals with frequent CSL exceedances. Bis(2-ethylhexyl)phthalate exceeds the CSL in 8 of 134 samples (Figure 4-14):

- Four exceedances along the downtown Seattle waterfront, including the site with the highest relative concentration

- Three exceedances near the Denny Way CSO, including at the end of the Elliott West outfall
- One exceedance in southern Elliott Bay at the north end of Harbor Island
- Lowest concentrations relative to the CSL in the deep parts of the bay and in the outer bay

Dibenzofuran

Dibenzofuran exceeds the CSL in 13 of 249 samples (Figure 4-15):

- Nine exceedances along the downtown Seattle waterfront, including the highest detected concentrations
- Three exceedances in southern Elliott Bay, north of Harbor Island
- One site west of Pier 91 in Smith Cove
- Lowest concentrations relative to the CSL in recent cleanup sites (Denny Way CSO and Pacific Sound Resources Superfund site)

Total PCBs

Total PCBs exceed the CSL in 11 of 246 samples (Figure 4-16):

- Eight exceedances near the downtown Seattle waterfront, including the site with the highest concentration of PCBs
- Two exceedances north of the West Waterway in southern Elliott Bay
- One exceedance near the Denny Way CSO
- Lowest concentrations relative to the CSL in recent cleanup sites (Denny Way CSO and Pacific Sound Resources Superfund site) and in Outer Elliott Bay

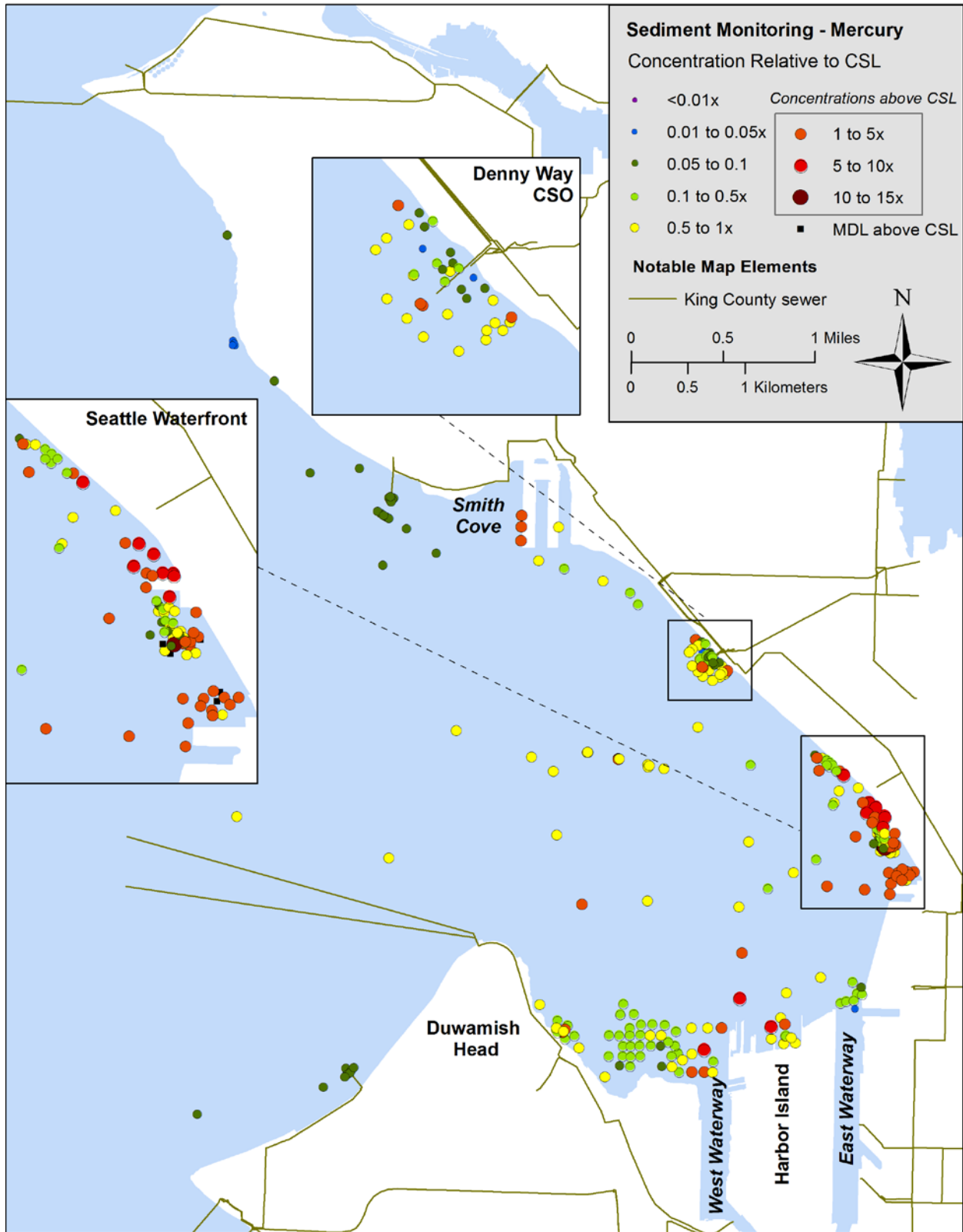


Figure 4-9. Comparison of mercury concentrations in Elliott Bay to Cleanup Screening Level.

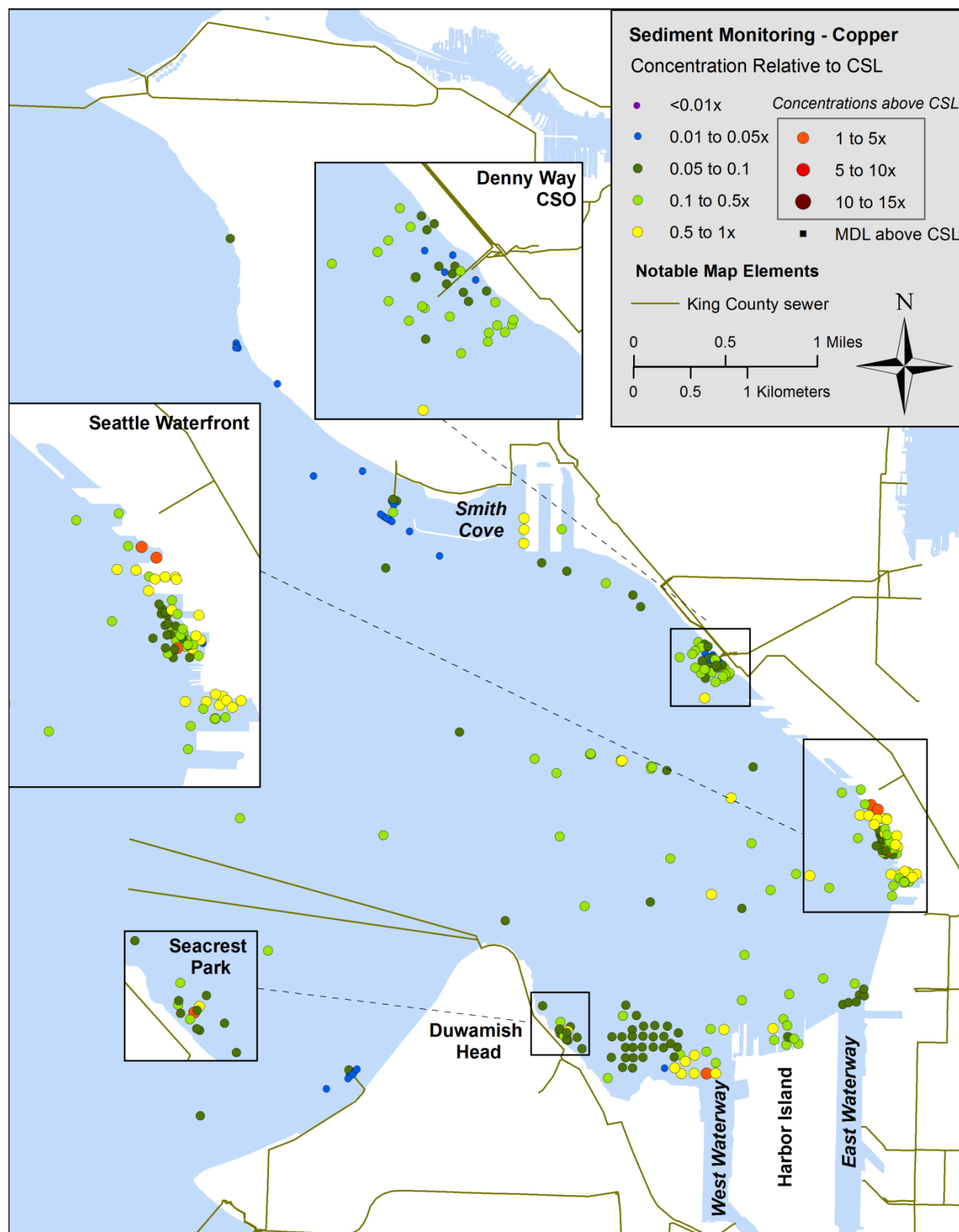


Figure 4-10. Comparison of copper concentrations in Elliott Bay to Cleanup Screening Level.

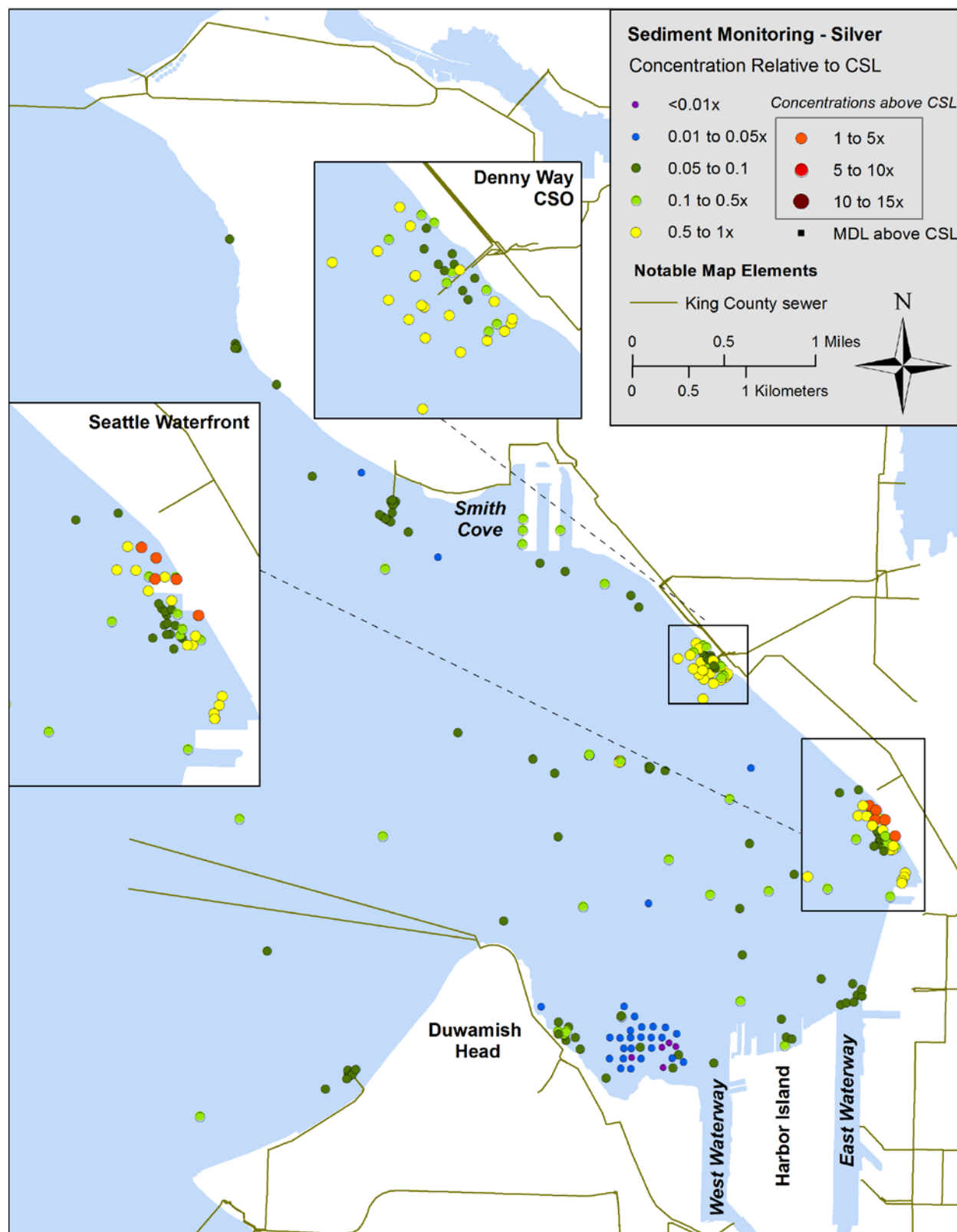


Figure 4-11. Comparison of silver concentrations in Elliott Bay to Cleanup Screening Level.

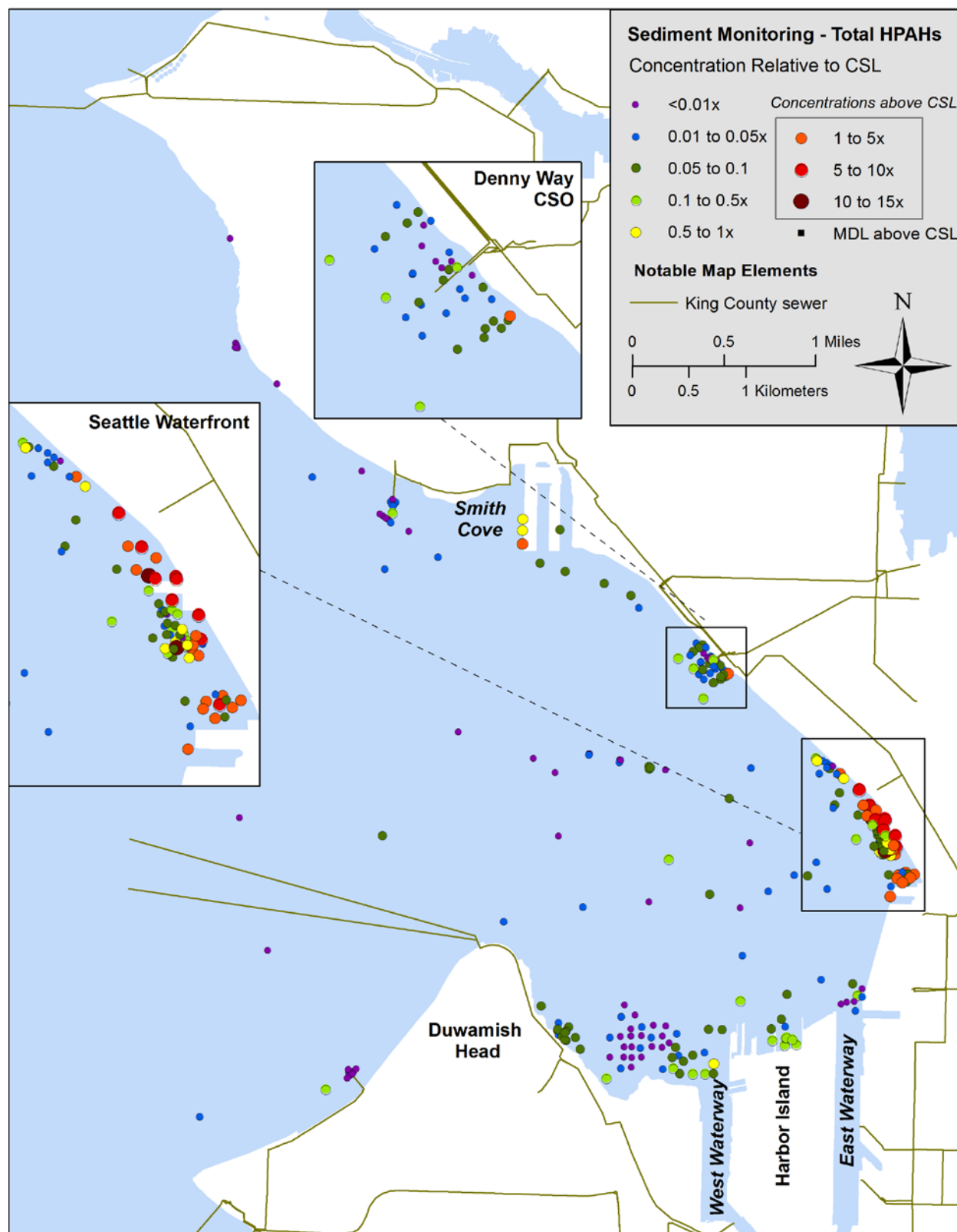


Figure 4-12. Comparison of total HPAH concentrations in Elliott Bay to Cleanup Screening Level. Samples with < 0.5% or > 4% total organic carbon are compared to Second Lowest Apparent Effects Threshold.

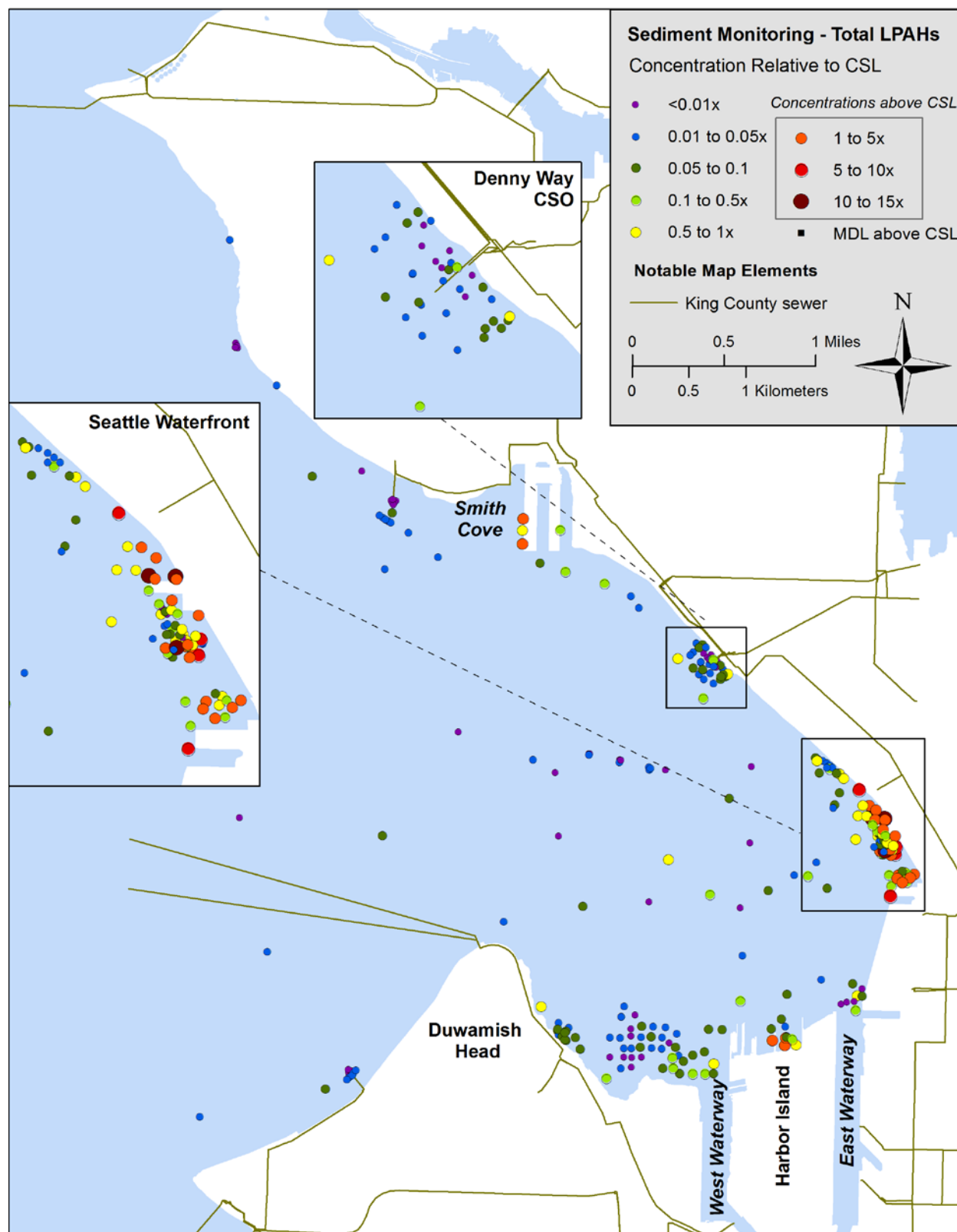


Figure 4-13. Comparison of total LPAH concentrations in Elliott Bay to Cleanup Screening Level. Samples with < 0.5% or > 4% total organic carbon are compared to Second Lowest Apparent Effects Threshold.

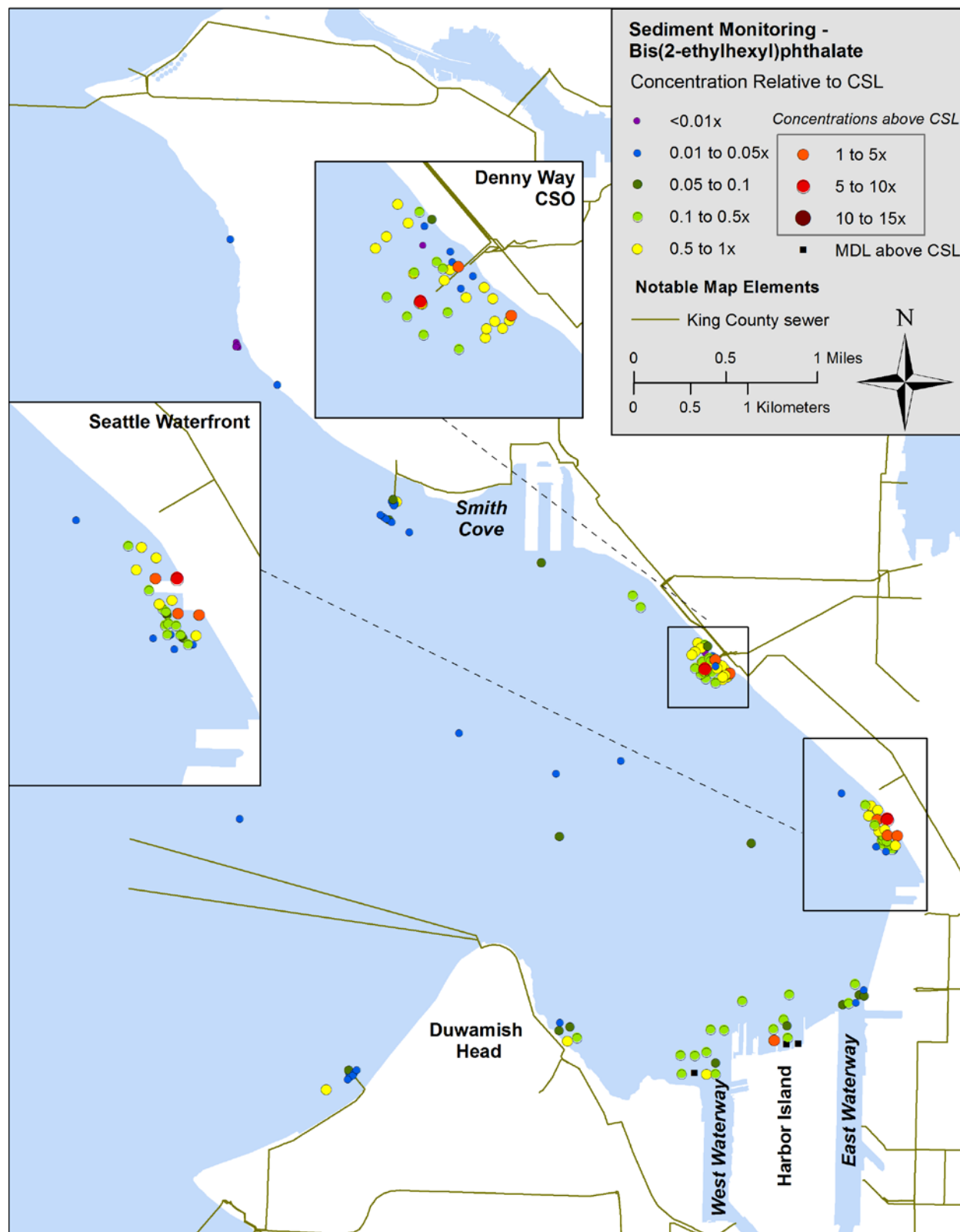


Figure 4-14. Comparison of bis(2-ethylhexyl)phthalate concentrations in Elliott Bay to Cleanup Screening Level. Samples with < 0.5% or > 4% total organic carbon are compared to Second Lowest Apparent Effects Threshold.

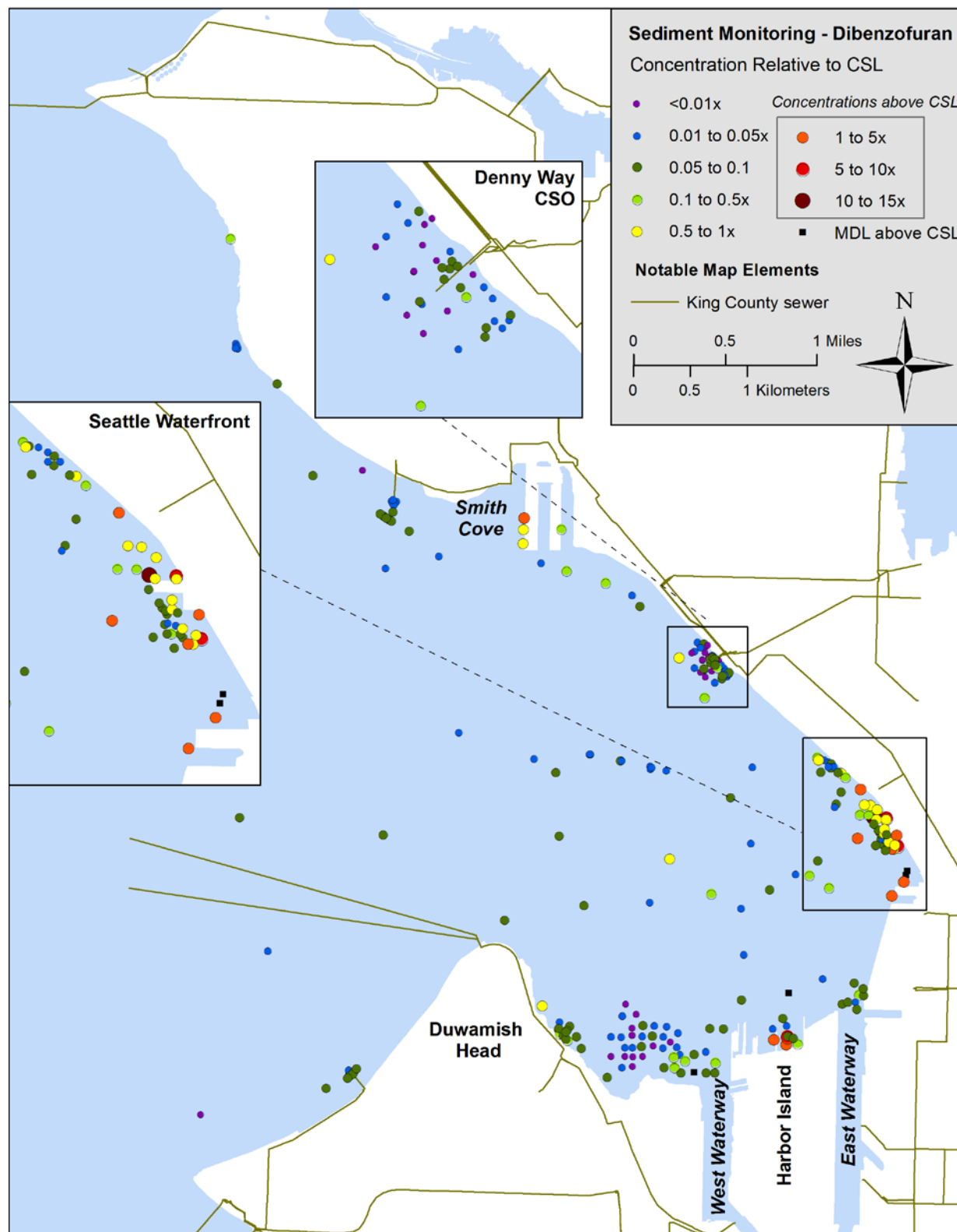


Figure 4-15. Comparison of dibenzofuran concentrations in Elliott Bay to Cleanup Screening Level. Samples with < 0.5% or > 4% total organic carbon are compared to Second Lowest Apparent Effects Threshold.

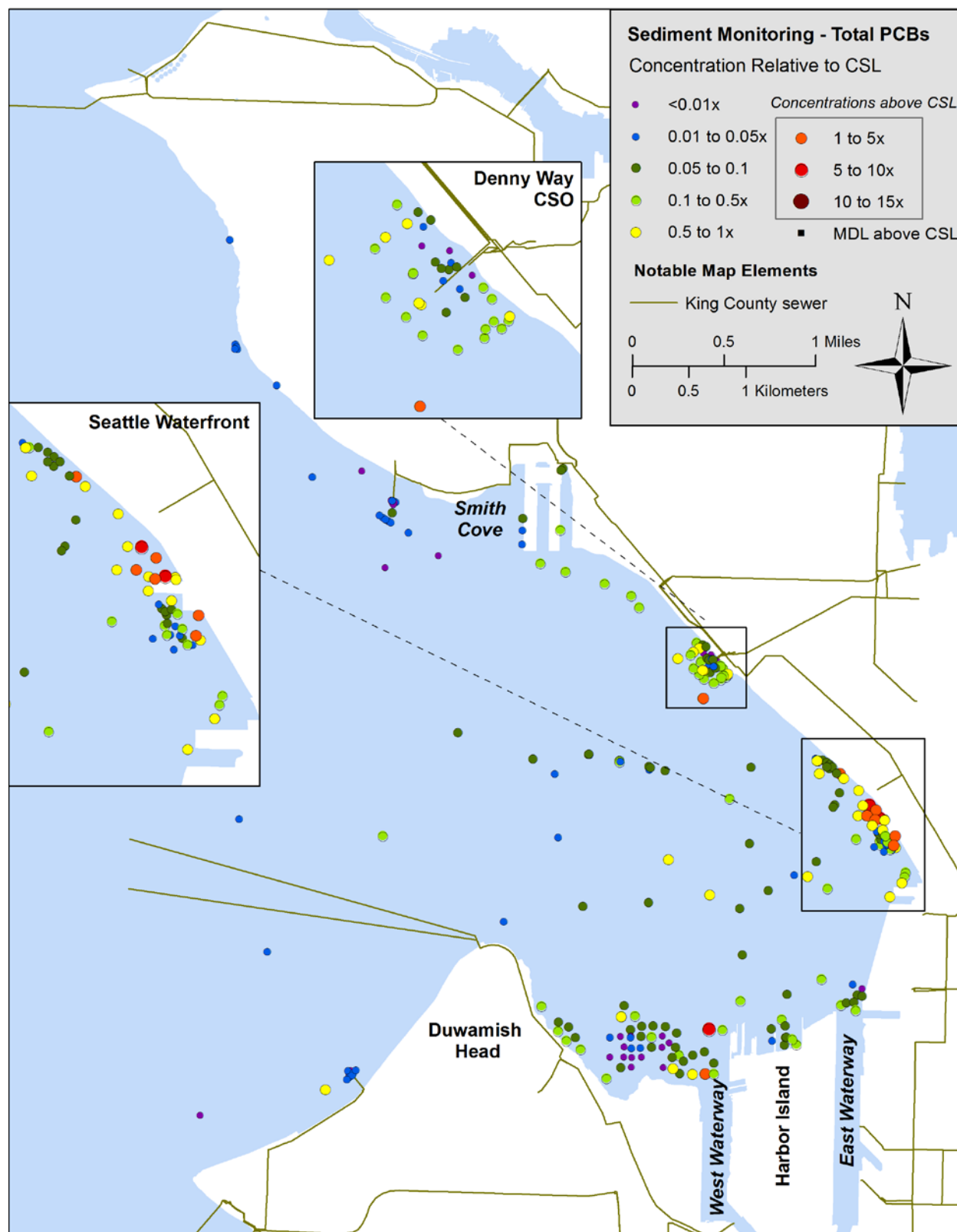


Figure 4-16. Comparison of total PCB (Aroclor) concentrations in Elliott Bay to Cleanup Screening Level. Samples with < 0.5% or > 4% total organic carbon are compared to Second Lowest Apparent Effects Threshold.

4.5 Chemicals without Sediment Quality Criteria

PBDEs (flame retardants) and dioxins and furans (byproducts of manufacturing processes such as for herbicides) are not included in Washington State's list of sediment quality criteria. However, they have increasingly been considered as chemicals of concern because of their potential environmental and human health effects. Fewer data are available for these chemicals compared to the chemicals with sediment quality criteria. The studies that have examined their concentrations in Elliott Bay are summarized below.

4.5.1 Polybrominated Diphenyl Ethers

In 2007, Ecology measured PBDE congeners as part of its Elliott Bay sediment monitoring program. Findings were as follows:

- The congeners PBDE-47, -99, and -209 were the most prevalent in the top 2 cm of sediment; PBDE-209 had the highest concentrations.
- Concentrations of total PBDEs averaged 4.75 µg/kg dw (sum of detected congeners).
- The highest concentration of total PBDEs in Elliott Bay (29.70 µg/kg dw) was found at a deep depositional site in the outer bay, likely because of the binding affinity of PBDEs to organic matter.

These concentrations were high compared to most Puget Sound samples collected during a similar timeframe, excluding samples collected in other industrialized embayments (such as Commencement Bay) where high concentrations of PBDEs were also observed (Ecology, 2009a, 2009b). In the same studies, total PBDE concentrations in the Duwamish Estuary were generally higher than at sites in Elliott Bay (average 18.51 µg/kg dw; highest 33.90 µg/kg dw).

In 2013, King County measured PBDE concentrations in the top 2 cm of sediment at eight subtidal routine monitoring sites in Elliott Bay. (Data, including TOC-normalized values, are included in Appendix C.) Findings were as follows:

- Total dry weight PBDE congener concentrations (sum of detected congeners) at the eight sites ranged from 0.797 µg/kg dw to 13.022 µg/kg dw.
- The highest concentration (13.022 µg/kg dw) was measured at a site north of Harbor Island, followed by a site near the downtown Seattle waterfront (8.051 µg/kg dw).
- The lowest concentration (0.072 µg/kg dw) was measured near the grain terminal in northeast Elliott Bay.

Intertidal sediment samples collected in 2010 were also analyzed for PBDEs but had blank contamination in all detected congener analyses. PBDE-209 was measured at the highest concentration of all congeners.

PBDEs in shellfish tissue collected in the study area as a part of other studies are discussed in Chapter 6.

4.5.2 Dioxins/Furans

During routine monitoring of Elliott Bay in 2007, Ecology sampled chlorinated dioxin and furan (dioxin/furan) congeners (Ecology, 2008, 2009a). The concentrations ranged over more than four orders of magnitude. Concentrations were highest for the heaviest (most chlorinated) compounds (Ecology, 2008). Median converted toxic equivalency (TEQ-weighted toxicity) values for dioxins/furans at 0–2 cm depth were 7.7 ng/kg dw TEQ and at 0–10 cm depth were 5.9 ng/kg dw TEQ. For both depths combined, the values for total dioxin/furan TEQs ranged from 0.67 ng/kg dw to 97.6 ng/kg dw. The highest concentration collected from any depth was a 0–10 cm sample collected near the waterfront (97.6 ng/kg dw); the highest concentration from 0–2 cm was recorded near Pier 90 (26.6 ng/kg dw).

Also in 2007, a survey evaluated dioxin/furan concentrations in the top 10 cm of sediment at the U.S. Army Corps of Engineers and Washington State Department of Natural Resources dredged sediment disposal site in the center of Inner Elliott Bay (Science Applications International Corporation, 2008). The average TEQ was 7.91 ± 4.18 ng/kg dw, which is similar to concentrations detected elsewhere in Elliott Bay in Ecology's 2007 study. Concentrations of dioxins/furans within the disposal zone (one site) were comparatively lower than the surrounding sediments. The highest concentration for total dioxin/furan TEQ was 17.03 ng/kg dw, located within the disposal site (area surrounding the disposal zone). At three stations that were also sampled in 2005, TEQs were higher in 2007 than in 2005. The increase at two of the sites was a very small (< 0.3 ng/kg dw).

4.6 Discussion

Concentrations of sediment associated contaminants at many nearshore sites in Inner Elliott Bay may cause adverse effects for aquatic organisms. Exceptions include areas where remediation projects, including dredging and capping, have been conducted. Mercury, PAHs, PCBs, and phthalates are ongoing problems for nearshore sediment contamination. Concentrations of certain chemicals appear to be changing slowly over time. Ecology has noted decreased concentrations of some metals including mercury, most LPAHs and HPAHs, and PCBs, while zinc, some LPAHs, and bis(2-ethylhexyl)phthalate concentrations appear to be increasing (Ecology, 2009a). Similarly, analysis of King County's long-term monitoring data indicate that total HPAHs, mercury, and silver concentrations have decreased at some sites and arsenic, cadmium, and zinc concentrations have increased. (See discussion in Appendix C.)

Concentrations of PAHs in fish tissue from Elliott Bay have also declined since the 1990s; however, PCB concentrations in tissue have not declined, likely from recycling of contaminants through the food web (WDFW, 2007; WDFW, 2011).

From a human health standpoint, the Washington State Department of Health has identified carcinogenic PAHs and dioxins/furans as the principal contaminants of concern (WA DOH, 2009). Yet there are no regulatory sediment criteria and few data on dioxin/furans in addition to PBDEs despite their toxicity and propensity to bioaccumulate.

According to a 1999 modeling effort, risks to sediment-dwelling organisms in the immediate vicinity of CSOs from organic enrichment and possibly 1,4-dichlorobenzene and bis(2-ethylhexyl)phthalate are predicted to be reduced by CSO control (King County, 1999). However, if no other actions are taken, threats to aquatic organisms from other chemicals such as mercury, PAHs, and PCBs will remain after all county CSOs are controlled.

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5.0 MARINE BENTHOS

Examining the community composition of marine sediment-dwelling invertebrates (benthos) at a site can provide insight into the health of the benthic habitat. Absorption or ingestion of pollutants may have a negative impact on individual species, particularly pollution-sensitive species, and may alter the community structure. Benthos data are typically collected with sediment chemistry data and frequently with bioassay data to aid in evaluating sediment quality and/or disturbance at a particular site. The data can be used as an additional line of evidence when evaluating the quality of the benthic habitat at a site and can be compared to a reference site in determining impacts of point sources such as CSO and stormwater outfalls on biological communities.

King County and Ecology have led efforts to monitor benthos and assess community health in Elliott Bay in recent years. Datasets from these studies are not comparable. The studies employed different collection timeframes, collection methods, taxonomists used to identify benthos, calculation of various benthic indices, and other methodologies. Thus, each study is discussed separately in this chapter.

In general, King County and Ecology data demonstrate that similar to elsewhere in Puget Sound, benthic community composition in Elliott Bay is highly influenced by depth and sediment grain size. The exceptions were benthic communities near the Denny Way CSO outfall, which were significantly different from those at nearby sites with similar depth and grain size. The benthic communities at this location had depressed benthic indices, suggesting that the outfall may have an effect on community composition. However, conclusions cannot be made regarding the overall effects of point sources on benthic communities in Elliott Bay given the limited data near CSO outfalls and the lack of data from comparable reference sites.

Ecology's sediment benthos data provide good spatial coverage of Elliott Bay. Analysis found that benthos near Magnolia Bluff, Pier 90, north of Harbor Island, north of Duwamish Head, and two deep depositional sites were "affected" or negatively impacted. However, replicates were not taken, and the data therefore do not capture variability at a given site and cannot be used to evaluate the effects of point sources on benthic communities because of the spatial coverage. Additional benthic sampling should be added to the current routine monitoring program in order to compare benthic communities at sites influenced by point sources, such as the Denny Way CSO, to communities elsewhere in Elliott Bay and Puget Sound.

5.1 King County Targeted Sampling

King County typically monitors benthos as part of targeted monitoring programs associated with regulatory requirements such as NPDES wastewater discharge permits, outfall leases, or in-water construction permits. In Elliott Bay, recent (within the last 10 years) benthos monitoring data are limited to the area surrounding the Denny Way CSO and Elliott West outfalls in inner Elliott Bay as part of the Denny Way/Lake Union

Combined Sewer Overflow Control Project and the Denny Way CSO Nearshore Interim Sediment Cleanup Project (King County, 2008). The control project, completed in 2005, included a storage tunnel, CSO treatment plant, and two new outfalls into Elliott Bay from Myrtle Edwards Park. Contaminated sediments in the vicinity of the old outfall were dredged and replaced with clean material. The cleanup was completed in 2008. For information on the cleanup project with a link to the CSO control project, see <http://www.kingcounty.gov/environment/wastewater/SedimentManagement/Projects/DennyWay.aspx>.

The methodology and most recent results of the monitoring are described below.

5.1.1 Methodology

Benthic infauna samples were collected less frequently than sediment chemistry samples in the vicinity of the Denny Way outfall. Chemistry samples were collected in 2012; the most recent benthos samples were collected in 2010 (five years after the new Denny Way outfall went online and two years after the nearshore sediment remediation project was complete). All sampling followed PSEP (1987) sampling protocols. Three replicate sediment grabs were collected with a dual tandem 0.1 m² van Veen grab sampler; one side was used for chemistry and the other for benthos (King County, 2008). The three replicate samples were averaged to provide summary statistics for various benthic indices.

Marine benthos samples were collected from eight sites in 2010 at depths between 5 m and 30 m. Two sites were located near the outfalls (DWMP-08, -09); one was at the sediment remediation site (DWMP-10); and five were at natural-recovery sites (DWMP-01, -03, -05, -14, -15) where sediments contain historical contamination and clean sediments are expected to naturally deposit and cover contaminated sediments over time (Table 5-1 and Figure 5-1).

Table 5-1. Coordinates and depths of Denny Way outfall marine benthos sampling sites (2010).

Locator	Northing	Easting	Site Type	Depth (m)	Distance and Direction from Denny Way Outfall (m)	Distance and Direction from Elliott West Outfall (m)
DWMP-01	228813	1264047	Natural recovery	9	190 SE	158 SE
DWMP-03	228638	1263846	Natural recovery	17	163 SE	180 SE
DWMP-05	229041	1263836	Natural recovery	5	118 NE	64 SE
DWMP-08	228907	1263341	Outfall	26	45 SW	150 SW
DWMP-09	228806	1263215	Outfall	30	95 SW	198 SW
DWMP-10	229326	1263565	Remediation site	6	105 NE	59 NW
DWMP-14	229553	1263228	Natural recovery	15	182 NW	182 NW
DWMP-15	229444	1263053	Natural recovery	24	182 NW	215 NW

5.1.2 Results

The following sections describe the results of the King County benthos monitoring associated with the Denny Way outfall sites.

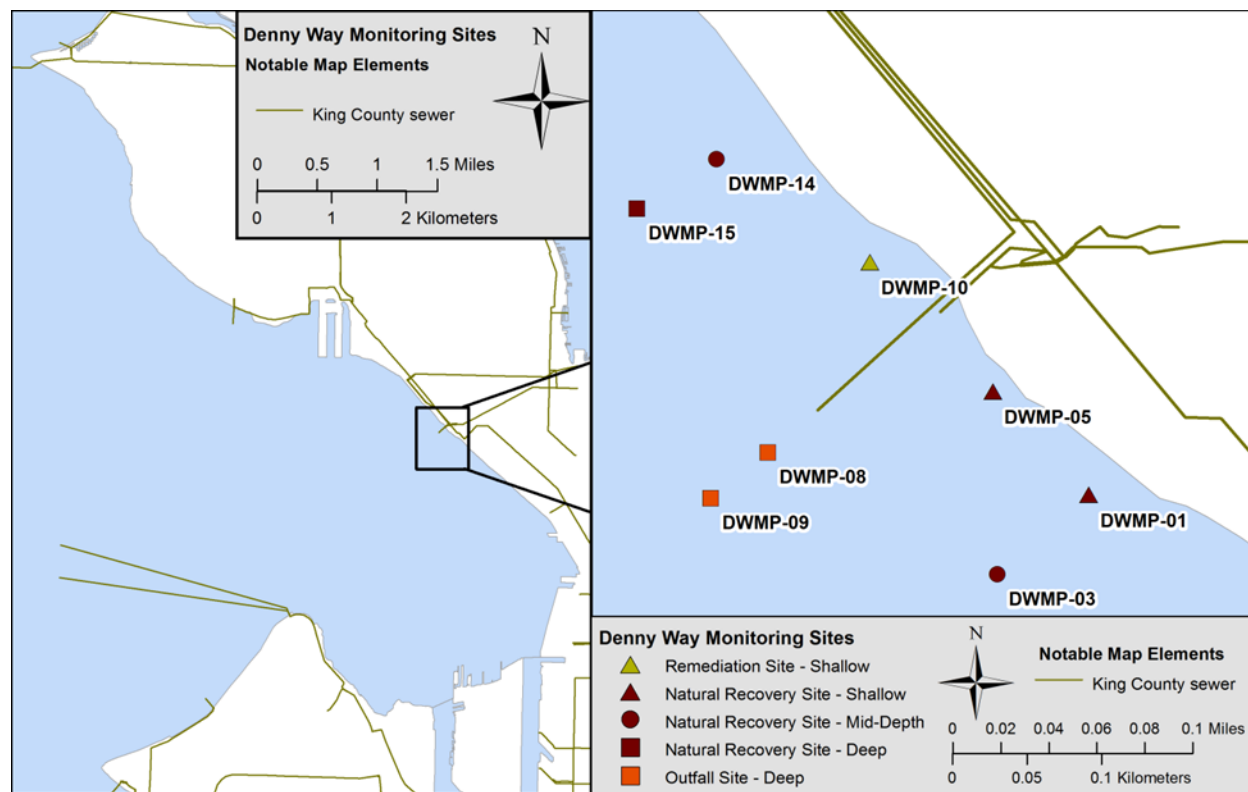


Figure 5-1. Locations of Denny Way marine benthos sampling sites (2010). For site coordinates, see Table 5-1.

Abundance and Richness

Abundance, a measure of the number of individuals per sample, ranged from 489 to 1,309 individuals per 0.1 m² (mean = 888 individuals per 0.1 m²) (Table 5-2). The sites with the highest abundance were in front of the outfall (DWMP-08 and DWMP-09); the site with the lowest abundance (DWMP-10) was located in the remediation area. One-way analysis of variance (ANOVA) and a post hoc Tukey's test of the three types of sites (remediation, outfall, and natural recovery) was conducted on the benthic indices of replicate samples to determine if any types of sites were significantly different from the others (Figure 5-2). The analyses found that abundance was significantly higher at outfall sites than at the other two types of sites.

Richness, a measure of the number of taxa or species per sample, ranged from 54 to 87 taxa per 0.1 m² (mean = 74 taxa per 0.1 m²). Similar to abundance, richness was highest near the outfall sites and lowest at the remediation site, although the two types of sites were not significantly different from each other.

Table 5-2. Summary of benthic indices from area surrounding Denny Way outfall and sediment remediation project (2010).

	Monitoring Site							
	DWMP-01	DWMP-03	DWMP-05	DWMP-08	DWMP-09	DWMP-10	DWMP-14	DWMP-15
Site Type	Natural Recovery	Natural Recovery	Natural Recovery	Outfall	Outfall	Remediation	Natural Recovery	Natural Recovery
Distance and direction from Elliott West Outfall	190 m SE	163 m SE	118 m NE	45 m SW	95 m SW	105 m NE	182 m NW	182 m NW
Distance and direction from Denny Way Outfall	158 m SE	180 m SE	64 m SE	150 m SW	198 m SW	59 m NW	182 m NW	215 m NW
Depth (m)	9	17	5	26	30	6	15	24
% Fines (clay and silt)	51.2	63.9	5.3	43.1	91.7	1.2	45.8	47.5
% Clay	4.7	12.0	1.5	8.6	34.4	0.6	1.9	18.7
% Silt	46.5	51.9	3.8	34.5	57.3	0.6	43.8	28.9
% Sand	34.4	40.8	67.9	45.2	16.4	57.3	42.7	24.4
% Gravel	13.0	4.3	27.4	11.9	1.6	41.1	1.6	19.9
TOC (mg/kg)	65,900	19,700	8,460	20,000	30,800	1,420	22,700	10,100
TOC (% dry weight)	6.59	1.97	0.85	2.00	3.08	0.14	2.27	1.01
Richness (per 0.1 m ²)	57	87	76	87	62	54	87	81
Annelida richness	33	44	33	47	30	29	49	39
Mollusca richness	9	22	18	16	17	11	16	21
Crustacea richness	12	11	22	16	10	10	16	14
Miscellaneous richness	3	10	2	8	5	4	6	8
Abundance (per 0.1 m ²)	730	979	993	1309	1204	489	671	725
Annelida abundance	464	171	549	300	190	307	304	166
Mollusca abundance	143	627	289	906	945	125	301	403
Crustacea abundance	119	148	152	89	60	44	50	135
Miscellaneous abundance	4	31	3	14	10	13	16	21
Shannon Diversity	4.2	3.9	4.8	3.8	2.9	4.6	5.0	4.5
Pielou's Evenness	0.71	0.61	0.76	0.60	0.49	0.80	0.78	0.71
Swartz's Dominance	8	8	15	6	3	13	19	5
% Abund. Tolerant Taxa ^a	74.1	79.9	62.0	84.2	81.7	61.5	65.0	70.6
% Abund. Sensitive Taxa ^a	17.0	5.9	9.9	4.0	2.2	6.6	6.6	7.3

Averages of the three replicates are reported for all metrics. TOC = total organic carbon.

^aTolerant and sensitive determinations were based on a taxa's sensitivity to pollution and/or hypoxia (Ecology, 2015).

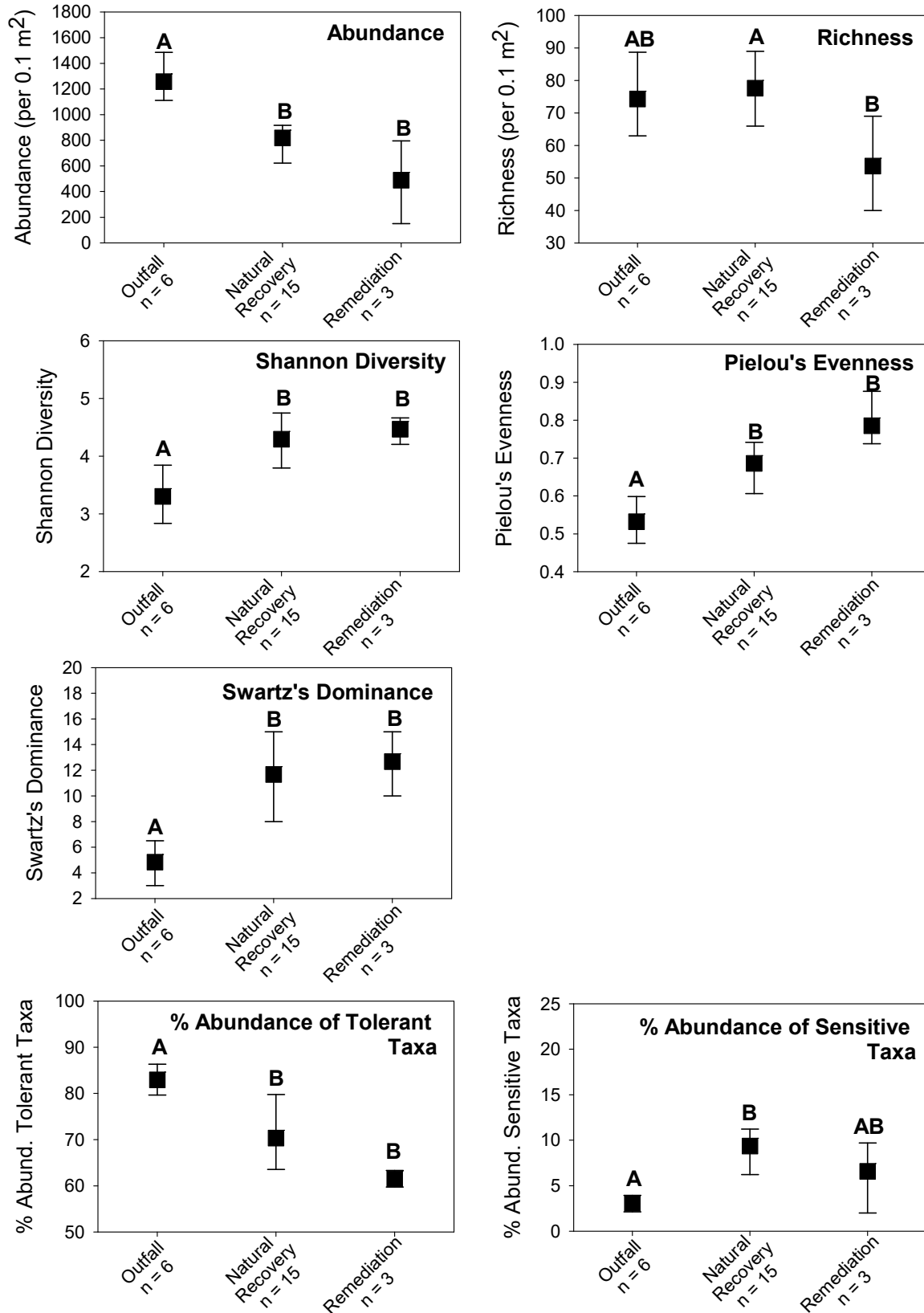


Figure 5-2. Summary of benthic indices (bars = 25th and 75th percentile), including significance, at site types at the Denny Way outfall.

Annelids were the most abundant group at sites ≤ 15 m (DWMP-01, -05, -10, -14). Molluscs were the most abundant group at sites > 15 m (DWMP-03, -08, -09, -15), including the two sites nearest the outfall (Table 5-2 and Figure 5-3). Annelid richness was higher than that of other major taxonomic groups at all sites, with molluscan richness typically being the second highest. It is interesting to note that the only higher taxonomic group that significantly varied between site type was mollusc (abundance only), which was higher at the outfall sites than at all other sites.

Although abundances were higher at the outfall sites, a significantly higher percentage of the individuals collected from outfall sites were pollution and/or anoxia tolerant (Table 5-2, Figure 5-2) than at all other site types. Alternatively, the remediation site (DWMP-10) had the lowest number of tolerant individuals, although it did not significantly differ from the natural recovery sites (Table 5-2; Figure 5-2).

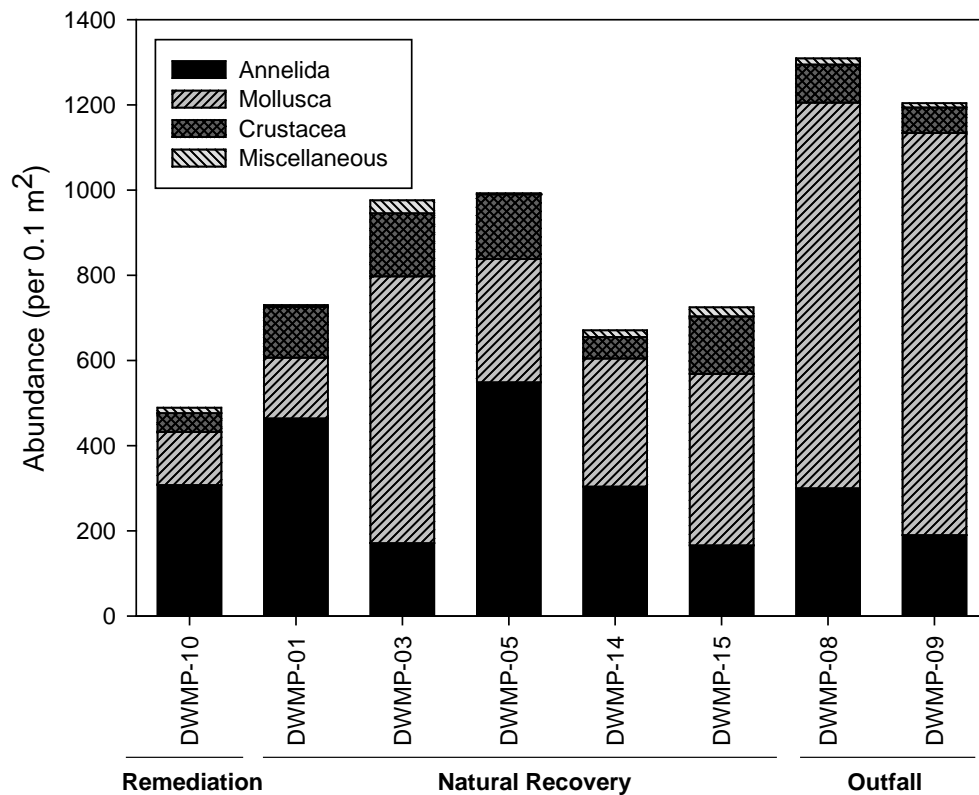


Figure 5-3. Abundance of major benthic taxonomic groups at Denny Way outfall sites (2010).

Species Diversity, Evenness, and Dominance

The indices used to measure species diversity, evenness, and dominance at the Denny Way sites are summarized below:

- Species diversity, a measure of number of species and the distribution/evenness of their abundance, is represented by the Shannon Diversity Index (H') and was calculated using Log_2 . The H' ranged from 2.9 to 5.0 (mean = 4.22).

- Pielou's Evenness Index, which is a measure of the distribution of abundances among taxa (also based on \log_2), ranged from 0.49 to 0.80 (mean = 0.68). For this metric, 0 = all individuals belong to the same taxa and 1 = the same number of individuals represent each taxa.
- Swartz's Dominance Index (minimum number of taxa that account for 75 percent of the total abundance) ranged from 3 to 19 (mean = 10).

The measures near the outfall sites for these three indices were below the mean for the whole monitoring area (Table 5-2) and were significantly lower than at all other types of sites (Figure 5-2), indicating that the benthos may be more stressed near the outfall than at other sites

Spatial Comparison of Benthic Communities

Non-metric multidimensional scaling (MDS) was used to analyze similarities of benthic communities among sites (PRIMER v6). The resulting analysis and plot, which arrange sites based on their rank-ordered similarity scores on a two-dimensional surface, demonstrate that sites are roughly grouped by depth (Figure 5-4). Sites deeper than 10 m group together, including both outfall sites. In contrast, community compositions at sites at shallow depths, although most similar to each other, were much more variable than sites at mid and deep depths.

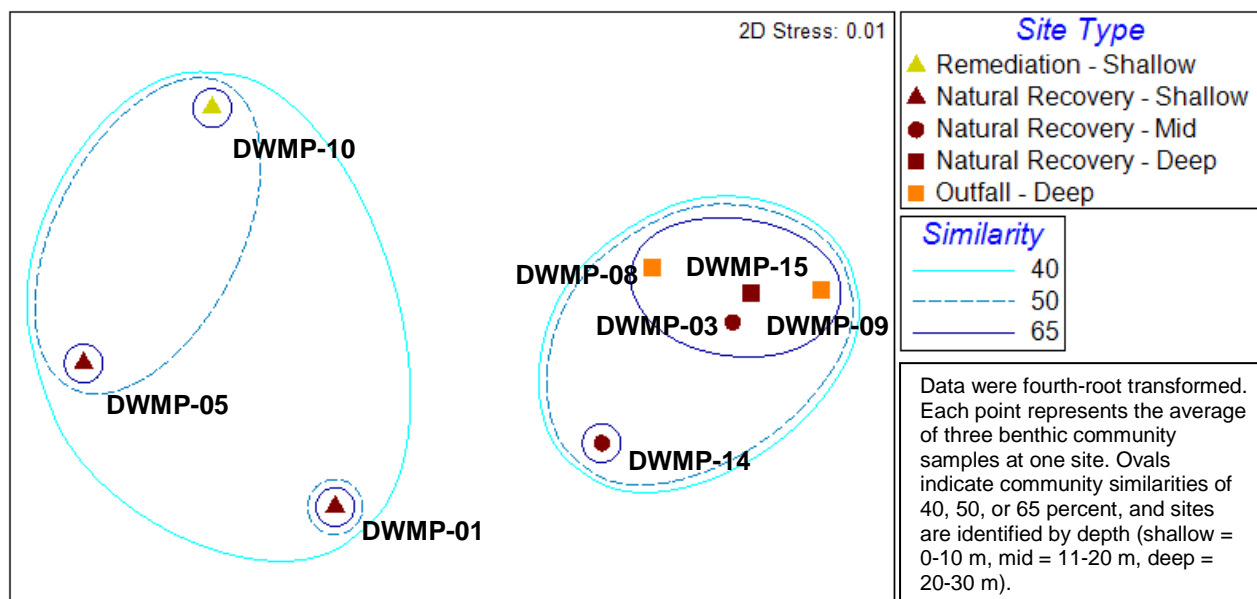


Figure 5-4. Non-metric multidimensional scaling showing similarity of benthic communities near Denny Way outfall (2010).

Sediment Characteristics and Contamination

Physical characteristics of sediment over the monitoring area were heterogeneous with percent fines ranging from 1.2 percent to 91.7 percent (mean = 43.7 percent) and percent total TOC ranging from 0.14 percent to 6.59 percent (mean = 2.24 percent) (Table 5-2).

Environmental parameters were suspected to affect benthic communities at Denny Way. These parameters include percent fines, TOC, depth, ammonia nitrogen, total sulfides, and chemical contamination. To assess this possible effect, the distribution of Denny Way sites across environmental gradients in multivariate space were evaluated through principal components analysis (PCA) using both physical and chemical data (dry weight-normalized) collected with benthos samples. The analysis reduces a large number of likely correlated variables to a smaller number of uncorrelated variables (principal components). The first two principal components explain the most variation and can be used to create a two-dimensional site ordination plot based on both physical and chemical data. For this analysis, the number of variables was reduced by using totals of Aroclors, LPAHs, and HPAHs and by excluding chemicals for which measured concentrations at some sites overlapped with detection limits of non-detects at other sites (for example, dichlorobenzenes and di-n-butyl phthalate). All values (except depth) were log-transformed and normalized prior to analysis.

The PCA analysis of physical and chemical variables showed that variability between sites caused by environmental factors is a good predictor of variability in community composition between sites. Additionally, most of the variability among sites can be explained on only two axes. Principal Component 1 (PC1, x-axis) represents a total of 73.8 percent of the variability between sites, and Principal Component 2 (PC2, y-axis) represents a total of 13.9 percent of the variability (Figure 5-5). Sites tend to separate on both axes based on both physical and contamination data. However, separation on PC1 is highly influenced by the amount of chemical contamination; sites with higher concentrations of chemicals fall farther to the left. Separation on PC2 is dominated by physical characteristics such as depth, grain size, total solids, and total sulfides. The shallow remediation site (DWMP-10) is the least similar to other sites, particularly along PC1. Similarly, shallow sites DWMP-01 and DWMP-05 do not group near other sites. Sites DWMP-03, -08, -09, -14, and -15 were fairly close on PC1 and more dispersed on PC2.

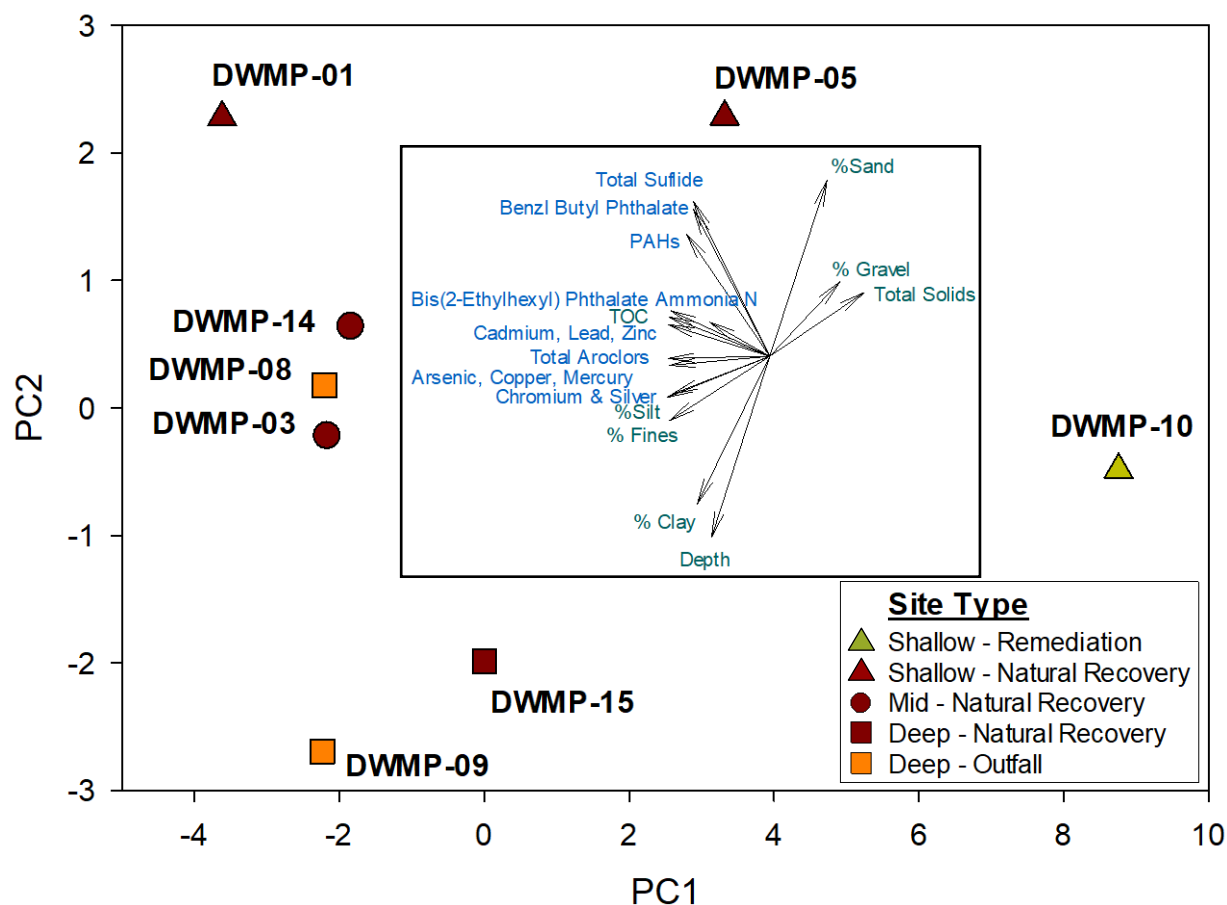


Figure 5-5. Ordination of Denny Way monitoring sites based on physical and chemical sediment characteristics, showing that the two primary principle component axes explain 73.8% (PC1) and 13.9% (PC2) of the variability among sites. The insert depicts vectors of selected variables as estimated from correlation with principal components analysis axes.

Further analysis suggests that depth and grain size have the largest effect on determining benthic community structure at the Denny Way outfall and that concentrations of metals and PAH may also have an effect. The BEST analysis in PRIMER was conducted to relate biological (assemblage) data to environmental data. The analysis found that the two parameters that explained the most variability in the community data were depth and grain size as percent fines (Spearman rank correlation = 0.826). Similar combinations of total LPAHs or HPAHs and a metal (arsenic, chromium, or silver) with depth and percent fines were all highly correlated with assemblage data (Spearman rank correlation > 0.8). This finding is consistent with other studies of the Puget Sound area that indicate that subfaunas are divided by sediment grain size and depth (for example, Ecology, 2013a).

The combination of these variables explains why site DWMP-10 differs so much from the other sites. It is a shallow site with a low percentage of fine sediments and low chemical concentrations. Alternatively, site DWMP-01, while not very different from other sites in depth and grain size, has the highest concentrations of chemical contaminants. The two Denny Way outfall sites, which grouped with other deep sites in the MDS analysis, had

similar chemical concentrations but a slightly higher percentage of TOC than other deep sites. Despite having significantly lower benthic index values, the outfall sites appear to be similar to nearby deep sites both in physical and biological characteristics. To determine with more confidence if benthic communities near the outfall are impacted, the samples should be compared to samples taken at the same time at comparable reference sites.

5.2 Ecology Ambient Sampling

Ecology's Marine Sediment Monitoring Group examines marine sediment chemistry, toxicity, and benthos throughout Puget Sound in three programs that differ in spatial and temporal scales. Elliott Bay is sampled as part of the regional monitoring program in Central Puget Sound (about every 10 years) and as part of a more targeted Urban Waters Initiative (about every 6 years). The most recent sampling events in Elliott Bay occurred in 2008–2009 and 2013. Only six sites in Elliott Bay were sampled in the 2008–2009 Central Puget Sound study, and a report on the 2013 Elliott Bay study has not been released. Therefore, the results of the previous (2007), more comprehensive (30 sites) Urban Waters Initiative study in Elliott Bay are the focus of this discussion. For a complete summary of the Urban Waters Initiative findings, see Ecology (2009) at <https://fortress.wa.gov/ecy/publications/publications/0903014.pdf>.

5.2.1 Methodology

The Urban Waters Initiative uses a stratified random sampling method. The study area is divided into target areas of unequal size based on land use and waterbody characteristics, including depth, sediment grain size, and salinity. As a result, there may be smaller areas where greater variability is expected, such as along industrialized harbors, and larger areas where less variability is expected, such as in deep basins. For each of the designated areas, a set number of random points are generated. This method allows for pseudo-targeted sampling and statistical summaries of the entire study area (Ecology, 2003).

All sampling follows PSEP protocols (PSEP, 1987, 1997). Twenty-three sites were sampled in Elliott Bay, and seven sites were sampled in the Duwamish Estuary and its East and West waterways. One sample was collected at each site, using a 0.1 m² dual-tandem van Veen grab sampler, with no replicates. The natural variability within sites, therefore, is unknown, making it difficult to compare sites.

5.2.2 Results

Abundance and Richness

A total of 385 taxa were identified at the 30 sites, most to the species level. Mean abundance per site was 671 individuals per 0.1 m²; sites with the highest abundances were in shallow waters with larger sediment grain size; deep sites with small grain size had the lowest abundances. Mean richness was 67 individuals per 0.1 m²; the spatial similarities were similar to abundance, but differences between depths were not as extreme as for abundance.

Sites with the highest abundances were typically dominated by polychaetes, which are often indicative of unfavorable conditions. Annelid-dominated sites included sites along the downtown Seattle waterfront, in the Duwamish Estuary, and near the north end of the bay near Pier 90 and Magnolia.

Species Diversity, Evenness, and Dominance

Shannon diversity was not discussed, but used to calculate evenness (Log_{10}). Mean Pielou's Evenness was 0.68. Evenness mostly showed the reverse pattern of abundance and richness and was highest at deep sites that had low abundances and richness. Swartz's dominance ranged from 2 to 25 taxa (mean = 11.5). Dominance was generally lowest in the Duwamish Estuary and at a site west of Pier 48 in Elliott Bay.

Spatial Comparison of Benthic Communities

MDS analysis revealed four assemblages in the study area that appear to be correlated with depth and sediment grain size:

- Sites with shallow (< 25 m) mixed and silty sediments in the Duwamish Estuary and near Pier 90 in Elliott Bay were dominated by a stress-tolerant polychaete.
- A shallow (< 25 m) assemblage included sites along the Seattle waterfront with sandy to silty-sand sediments.
- Another assemblage was made up of deep sites (> 70 m) with mixed silt/clay sediments.
- Sites of medium depth (35–40 m) parallel to the shore of Elliott Bay had mixed and silty-sand.

The distinction of these assemblages demonstrates the importance of depth and grain size in determining benthic community structure. However, another Puget Sound-wide study that excluded sites with poor sediment chemistry found that a single overarching assemblage occurs in the sound; that habitat variables, including depth and grain size, only divide sub-assemblages; and that few abundant species in Puget Sound occur in a single sub-assemblage (SCCWRP, 2013).

Sediment Contamination

Taxonomists used a weight-of-evidence approach and multiple benthic quality indices to determine whether benthos at each site were adversely affected by contamination. Results were as follows:

- 16 of 30 samples were adversely affected.
 - 7 of 7 sites in the Duwamish Estuary were classified as affected.
 - 9 of 23 sites in Elliott Bay that were deemed affected included a mid-depth site at Magnolia Bluff and a shallow site at Pier 90 in the north bay, four mid-depth sites north of Harbor Island, a shallow site north of Duwamish Head, and two deep depositional sites (Figure 5-6).
- Shallow sites along the downtown Seattle waterfront were not affected.

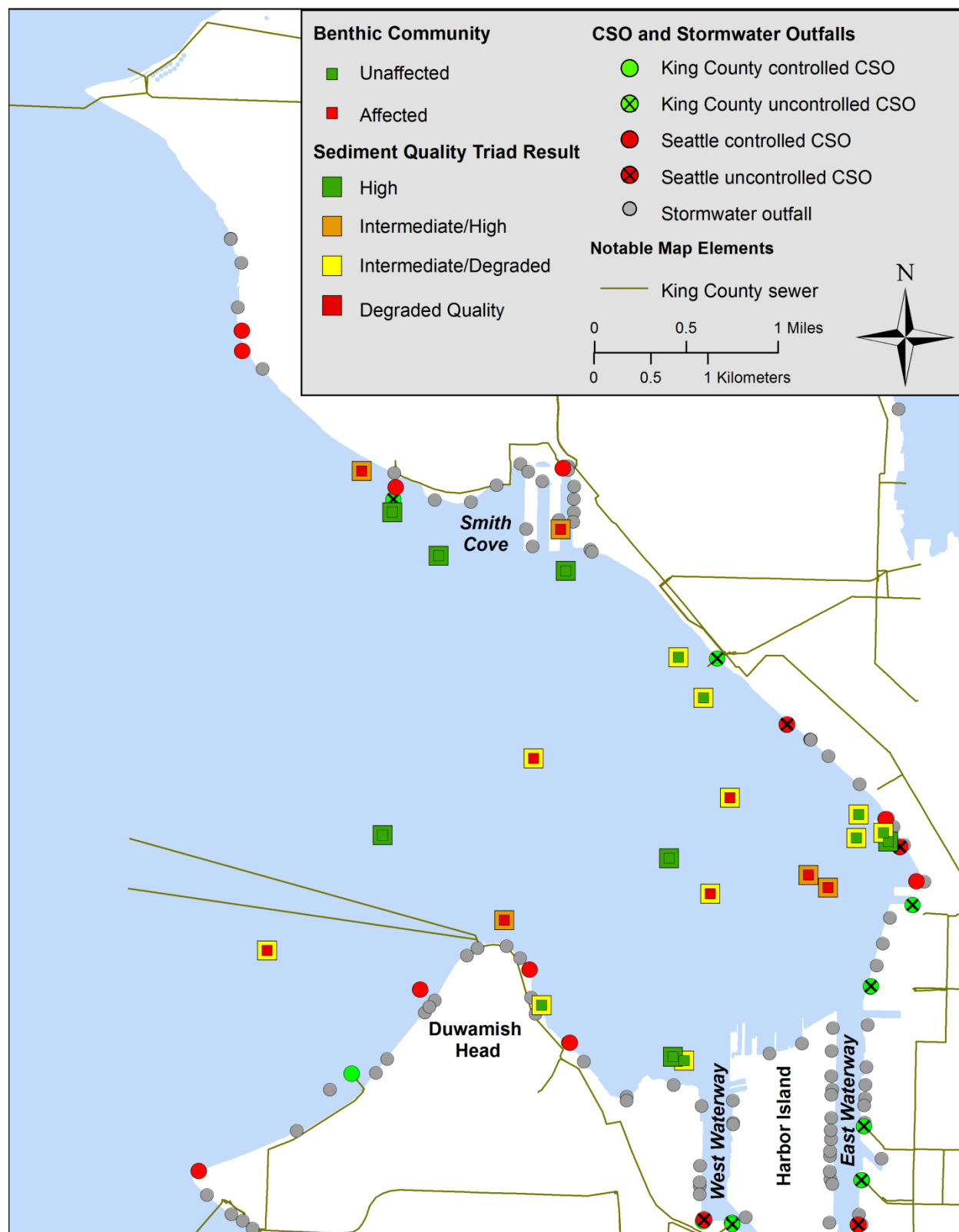


Figure 5-6. Results of Ecology (2009) benthic invertebrate community analysis and sediment quality triad (chemistry, toxicity, benthos) analysis.

Sediment toxicity was determined by the fertilization success of sea urchin gametes (*Strongylocentrotus purpuratus*) in 25, 50, and 100 percent pore water samples over 20 minutes. The results of these tests were compared to controls and significance was identified using ANOVA tests of means. Only one site south of Magnolia Bluff in the northern part of Outer Elliott Bay was determined to have toxic sediments (< 80 percent of reference value).

Results of sediment chemistry analysis, state of the marine benthic communities, and sediment toxicity were used to calculate an index value that describes the sediment quality at each site on a scale of high quality to degraded (Figure 5-5):

- No sediments in Elliott Bay or the Duwamish Estuary were considered degraded.
- Seven sites, all located in Elliott Bay, exhibited no impairments.
- Sites in Elliott Bay considered to be of intermediate/degraded quality are located off Magnolia Bluff, Pier 90, and Duwamish Head, and west of Pier 48 and Yesler (north of the East Waterway) (two sites).
- All but one site (six of seven) in the Duwamish Estuary were considered to be of intermediate/degraded quality (not shown in Figure 5-5).

Between the first survey in 1998 and the 2007 survey, changes in sediment quality varied: some stations improved, others decreased, and others stayed the same.

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6.0 TISSUE CHEMISTRY

Shellfish tissue data for the study area are available from studies conducted by King County and the Washington State Department of Fish and Wildlife (WDFW). These studies are discussed separately in this chapter because of differences in the type and species of organisms, collection and analytical methods, and timescales used. For more information, see Appendix E.

In general, the studies found that PAHs, PCBs, PBDEs, and dichlorodiphenyltrichloroethane (DDT) were the most abundant organic contaminants measured in shellfish tissue from Elliott Bay and Puget Sound. Available data suggest that contaminants in organisms from heavily urbanized areas such as Elliott Bay have higher concentrations of certain chemicals, which can be a human health concern.

6.1 King County's Shellfish Monitoring Program

King County has collected bivalve (butter clam, *Saxidomus gigantea*) tissue samples from a single intertidal location, West Point South in adjacent Puget Sound, from 1970 through 2010 as part of its shellfish monitoring program (Table 6-1 and Figure 6-1). The program was discontinued in 2010.

This section summarizes data collected from 1999 through 2010.

Table 6-1. King County butter clam tissue sampling site at West Point South in adjacent Puget Sound (1970–2010).

Locator	Description	Northing	Easting	Ambient or Outfall	Years Sampled
KSSN05	West Point South	245272	1245980	Outfall	1970–2010

6.1.1 Methodology

Samples were collected annually or biannually and then composited using 5 to 10 clams per composite to provide a suitable mass for analysis. Clam tissue analytes included percent solids, percent lipids, trace metals, and, more recently (2008–2010), PBDEs. Analysis of semivolatile organic compounds was conducted early in the monitoring program but was discontinued because of low detection rates. These compounds therefore are not discussed in this report.

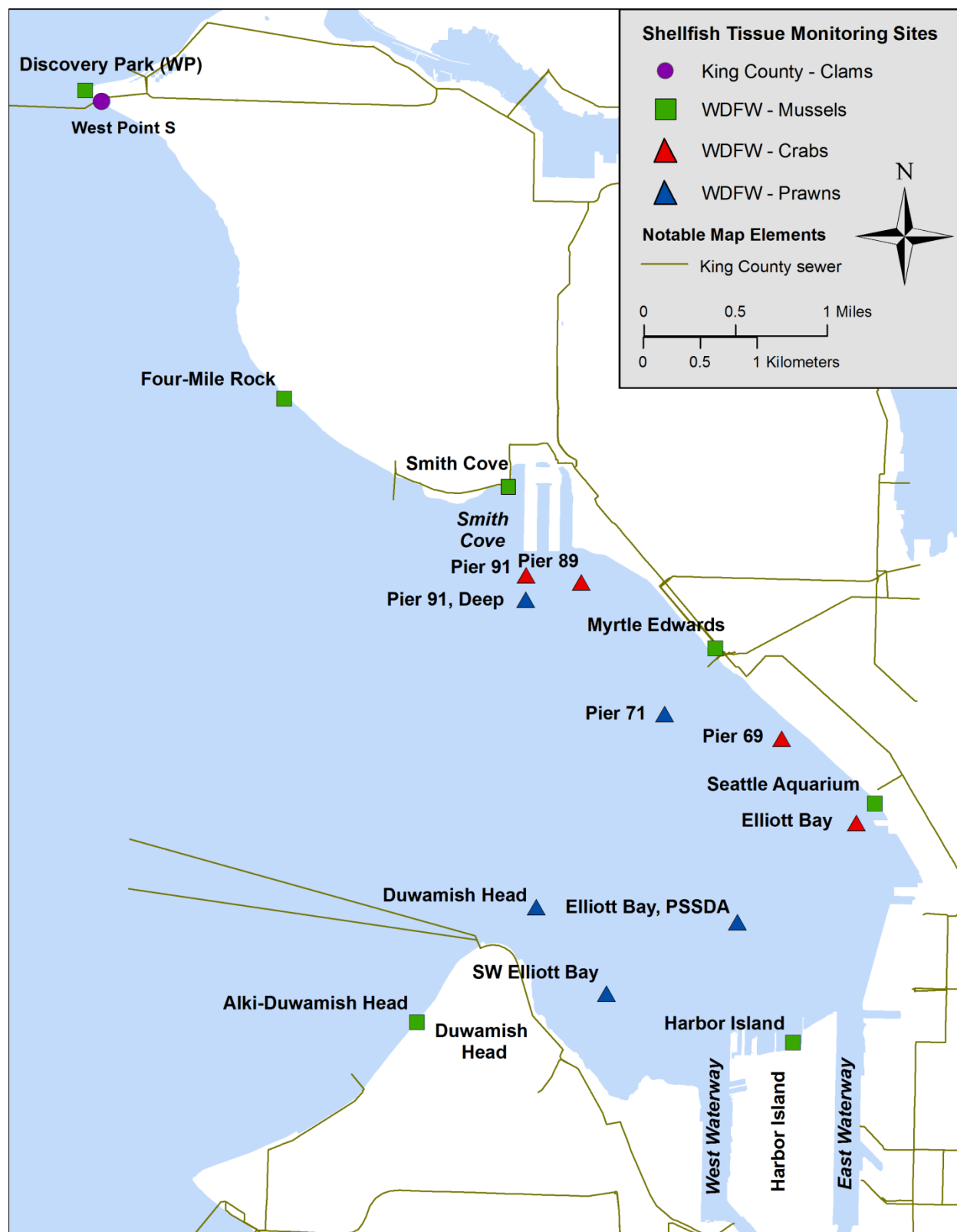


Figure 6-1. King County and Washington State Department of Fish and Wildlife tissue monitoring sites in Elliott Bay and adjacent Puget Sound.

6.1.2 Results

Results of shellfish tissue analysis from 1999 through 2010 are as follows:

- Percent solids and lipids were consistent with very little variation between historical and recent samples, except in August 2010 (lipid concentration = 1.69 percent) (Table 6-2).
- Samples were analyzed for 14 metals. Beryllium was the only metal not consistently detected during the sampling period (Table 6-3).
- Six of the 14 PBDE congeners analyzed were detected. PentaBDE-100 and PentaBDE-99 were detected in all samples. PBDE concentrations were typically higher in samples collected in March than in samples collected in August. TetraBDE-71 was elevated at 6.75 mg/kg wet weight (ww) in March 2008. Five other locations in King County marine waters that were monitored at the same time showed a pattern similar to the March 2008 samples. Lipid normalization of the ww PBDEs did not alter the distribution of these values.

Table 6-2. Percent tissue lipid and total solids concentrations in butter clam tissue samples at West Point South (1999–2010).

Analyte	Percent		
	Minimum	Maximum	Mean
Lipids	0.31	1.69	0.73
Total solids	14.1	23.7	18.44

Table 6-3. Metals concentrations in butter clam tissue samples at West Point South (1999–2010) compared to calculated EPA screening values (mg/kg on a wet weight basis).

Metal	FOD	Minimum	Maximum	Mean	EPA SV Level	Above SV Level?
Aluminum	11/11	10.7	99.5	63.645	1172.5	No
Arsenic	12/12	2.38	4.67	3.08	—	—
Beryllium	0/12	ND	ND	ND	—	—
Cadmium	12/12	0.046	0.0938	0.0578	1.17	No
Chromium	12/12	0.166	0.822	0.42	3.52	No
Copper	12/12	1.67	4.04	2.296	46.9	No
Iron	12/12	25.3	262	110.882	351.8	No
Lead	12/12	0.0666	0.148	0.106	—	—
Manganese	12/12	1.83	71.7	2.565	164.2	No
Mercury	12/12	0.0042	0.00976	0.00586	0.117	No
Nickel	12/12	0.701	1.31	1.024	23.5	No
Selenium	12/12	0.256	0.44	0.339	—	—
Silver	12/12	0.12	0.49	0.25	58.6	No
Zinc	12/12	12.3	18.3	15.7	351.8	No

All values are in mg/kg wet weight.
 FOD = Frequency of detection.
 SV = EPA screening value (EPA, 2000).

6.1.3 Comparison to Criteria

There are no Washington State criteria for metals concentrations in shellfish. The state's department of health (WDOH) uses EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories* (EPA, 2000) to help determine health-based screening values. The values and methodologies used to calculate comparisons to screening values are included in Appendix E. The values are based on a consumption rate of two 8-ounce meals of fish per week. All maximum metals concentrations in butter clams collected at West Point South were well below recommended EPA threshold values (Table 6-3).

6.2 WDFW Shellfish Studies in Elliott Bay

This section describes WDFW shellfish tissue studies in Puget Sound. Contaminant data are presented as summed concentrations (for example, Σ DDTs) for specific analyte groups except in cases where there is only one analyte. Summed analytes are the total of all detected values in each group. If all analytes in a group were not detected, the greatest limit of quantitation (LOQ) for any single analyte in the group was used as the summed concentration, preceded by "<" (less than). An estimated total PCB (eTPCB) concentration was calculated by summing the detected concentrations for 17–18 commonly detected congeners and multiplying the result by two (according to Lauenstein and Cantillo, 1993).

6.2.1 Puget Sound Ecosystem Monitoring Program's Mussel Watch Pilot Expansion

From November 2012 through January 2013, WDFW conducted the first synoptic Puget Sound-wide assessment of toxic contaminants in nearshore biota. The study transplanted uncontaminated native mussels (*Mytilus trossulus*) to 108 locations along the Puget Sound shoreline, including seven locations in Elliott Bay or adjacent Puget Sound (Figure 6-1 and Table 6-4). Caged mussels were deployed for approximately 8 weeks prior to their collection for tissue analysis.

Measurements made following deployment included histopathology and concentrations of several major tissue contaminants including PAHs, PCBs, PBDEs, chlorinated pesticides, arsenic, cadmium, copper, lead, mercury, and zinc (WDFW, 2014a).

Table 6-4. Washington State Department of Fish and Wildlife mussel tissue monitoring sites in Elliott Bay and adjacent Puget Sound (2012–2013).

Locator	Description	Northing	Easting	Years Sampled
15	Discovery Park, West Point	245589	1245513	2012–2013
16	Four Mile Rock	236715	1251246	2012–2013
17	Smith Cove	234032	1257593	2012–2013
18	Myrtle Edwards	229532	1263680	2012–2013
19	Seattle Aquarium (Pier 59)	225063	1268279	2012–2013
20	Harbor Island (Pier 17)	218177	1265922	2012–2013
21	Duwamish Head	218759	1255074	2012–2013

Results were as follows:

- In Elliott Bay, PAHs, PCBs, PBDEs, and DDTs were frequently detected at high concentrations (Table 6-5) compared to other Puget Sound locations. PAHs were detected at the highest concentrations in Elliott Bay and ranged from 394.6 ng/g ww (Σ_{42} PAHs) to 745.6 ng/g ww (Σ_{42} PAHs) at four locations (Myrtle Edwards, Four Mile Rock, Seattle Aquarium, and Smith Cove).
- Concentrations of eTPCBs in Elliott Bay were moderately elevated compared to concentrations detected elsewhere in Puget Sound (2.0–12.0 ng/g ww) (Table 6-5). PBDEs and DDTs similarly had higher concentrations in urbanized areas throughout Elliott Bay than elsewhere in Puget Sound.
- All six metals were detected at low concentrations in mussels from all sites in Elliott Bay (WDFW, 2014a).

Table 6-5. Contaminant concentrations in mussel tissue (ng/g, wet weight) from Elliott Bay and adjacent Puget Sound (2012–2013).

Site Name	Σ_{42} PAHs	Σ_6 DDTs	Σ_{40} PCBs	eTPCBs	Σ_{11} PBDEs
Discovery Park, West Point	118.8	0.38	3.0	4.6	118.8
Four Mile Rock	656.7	1.8	6.5	9.6	656.7
Smith Cove	394.6	1.6	12.0	15.8	394.6
Myrtle Edwards	745.6	2.1	11.0	14.0	745.6
Seattle Aquarium (Pier 59)	478.5	0.96	7.1	10.0	478.5
Harbor Island (Pier 17)	357.7	0.36	9.1	13.0	357.7
Alki-Duwamish Head	57.2	0.28	2.0	3.0	57.2

6.2.2 Crab and Prawn Study

In 2011 and 2012, WDFW conducted a Puget Sound–wide assessment of toxic contaminants in Dungeness crab (*Metacarcinus magister*) and spot prawns (*Pandalus platyceros*) (WDFW, 2014b). Samples were collected from Elliott Bay in 2012 as a part of the assessment. The purpose of the study was to evaluate the extent and magnitude of toxic contaminants in these two crustacean species and to provide data to WDOH to assist in conducting a human health risk assessment and establishing the need for consumption advisories.

Animals typically taken using sport fishery gear were collected from five locations (four in Elliott Bay and one in the Duwamish Estuary) for crab and from six locations for prawns (only five were analyzed) (Figure 6-1; Tables 6-6 and 6-7). Analytes of interest consisted of four major persistent organic pollutants (POPs), including PCBs, PBDEs, PAHs, and organochlorine pesticides, and metals (arsenic, cadmium, copper, lead, mercury, and zinc) (WDFW, 2014b).

Table 6-6. Washington State Department of Fish and Wildlife Dungeness crab tissue monitoring sites in Elliott Bay (2012).

Locator	Site Name	Northing	Easting	Sample Date
30	Elliott Bay	224493	1267740	5/17/2012
31	Pier 69	226918	1265587	6/29/2012
32	Pier 89	231426	1259803	7/12/2012
33	Pier 91	231626	1258214	6/29/2012

Table 6-7. Washington State Department of Fish and Wildlife spot prawn tissue monitoring sites in Elliott Bay (2012).

Locator	Site Name	Northing	Easting	Sample Date
24	SW Elliott Bay	219587	1260525	6/21/2012
25	Elliott Bay	221639	1264308	6/28/2012
26	Duwamish Head	222076	1258505	6/21/2012
27	Pier 71	227635	1262211	7/12/2012
29	Pier 91, deep	230918	1258199	6/29/2012

Results were as follows:

- In Elliott Bay, PCBs were the most frequently detected chemicals in Dungeness crab and spot prawn tissue samples. PCB concentrations were the highest in samples taken from urban areas, including Elliott Bay. A maximum eTPCB concentration of 180 ng/g ww (Elliott Bay site) was measured in crab muscle (Table 6-8). Estimated total PCBs (eTPCBs) in spot prawns had a maximum concentration of 27 ng/g ww (SW Elliott Bay) and were highest in urban areas (Table 6-9).
- DDT and PAHs in both species were detected frequently, with the highest concentrations observed in samples from Elliott Bay. Maximum concentrations of DDTs and total PAHs in crab muscle were 4.8 ng/g ww (Pier 89) and 4.01 ng/g ww (Pier 91), respectively. The maximum total PAH concentration in prawn muscle also occurred in Elliott Bay at Pier 91 (3.72 ng/g ww).
- PBDEs were frequently detected in crab, with the highest concentrations observed in samples from Elliott Bay. PBDEs were detected in only one spot prawn sample (0.32 ng/g ww, SW Elliott Bay).
- Mercury, arsenic, copper, and zinc were the most frequently detected metals in Dungeness crab from Elliott Bay (Table 6-10). These metals, in addition to cadmium, were the most frequently detected in spot prawns (Table 6-11). Unlike the POPs, metals concentrations in Dungeness crab and spot prawn muscle were relatively evenly distributed throughout all marine locations and urban environments in Puget Sound. Mercury was the only metal that occurred in statistically higher concentrations than non-urbanized locations (WDFW, 2014b).

Table 6-8. Concentrations of persistent organic pollutants (ng/g wet weight) in Dungeness crab tissue from Elliott Bay (2012).

Site Name ^{a,b}	Σ_8 CHLDs	Σ_6 DDTs	Σ_3 HCHs	eTPCBs ^c	Σ_{11} PBDEs	Total PAHs
Elliott Bay	0.87	2.6	<0.27	180	1.7	0.96
Pier 69	<0.20	1.1	<0.20	55	1.8	1.44
Pier 89	1.2	4.8	<0.53	160	2.8	3.22
Pier 91	0.82	1.9	<0.17	91	2.5	4.01

^a Summed analytes (for example, Σ_6 DDTs) are the sum of all detected values in each group.

^b Concentrations with a "<" represent non-detected values that are below or equal to the limit of quantitation (LOQ). The maximum LOQ is reported for summed analytes.

^c The sum of 18 congeners multiplied by 2 is used in the estimated total calculation.

Table 6-9. Concentrations of persistent organic pollutants (ng/g wet weight) in spot prawn tissue from Elliott Bay (2012).

Site Name ^{a,b}	Σ_8 CHLDs	Σ_6 DDTs	Σ_3 HCHs	eTPCBs ^c	Σ_{11} PBDEs	Total PAHs
SW Elliott Bay	<0.30	<0.30	<0.30	27	0.32	1.16
Elliott Bay	<0.25	<0.25	<0.25	17	<0.25	1.04
Duwamish Head	<0.31	<0.31	<0.31	16	<0.31	1.2
Pier 71	<0.30	<0.30	<0.30	17	<0.30	1.04
Pier 91, deep	<0.19	<0.19	<0.19	14	<0.19	3.72

^a Summed analytes (for example, Σ_6 DDTs) are the sum of all detected values in each group.

^b Concentrations with a "<" represent non-detected values that are below or equal to the limit of quantitation (LOQ). The maximum LOQ is reported for summed analytes.

^c The sum of 18 congeners multiplied by 2 is used in the estimated total calculation.

Table 6-10. Concentrations of total metals (mg/k wet weight) in Dungeness crab muscle from Elliott Bay (2012).

Site Name	Total Mercury	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Zinc
Elliott Bay	0.0827	4.62	-0.0019 ^a	8.07	0.01	31
Pier 69	0.0659	6.47	0.0031	8.58	0.012	41.6
Pier 89	0.189	14.4	0.0096	8.88	0.0233	52.2
Pier 91	0.1	9.05	0.0038	12.4	0.016	58.5

^a Non-detected values that are below or equal to the method detection limit (MDL).

Table 6-11. Concentrations of total metals (mg/k wet weight) in spot prawn muscle from Elliott Bay (2012).

Site Name	Total Mercury	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Zinc
SW Elliott Bay	0.0638	13.2	0.0245	8.61	-0.0040	13.1
Elliott Bay	0.0563	12	0.0256	7.79	-0.0040	12.9
Duwamish Head	0.0373	12.4	0.0189	10.1	-0.0041	13.5
Pier 71	0.0514	13.9	0.0237	8.35	-0.0040	13.2
Pier 91, deep	0.0442	14.3	0.0162	9.69	0.0045	13.9

6.3 Discussion

The studies found that PAHs, PCBs, PBDEs, and DDT were the most abundant organic contaminants measured in shellfish tissue from Elliott Bay and Puget Sound. Available data suggest that, in general, contaminants in organisms from heavily urbanized areas have higher concentrations of certain chemicals. For example, concentrations of PBDEs in English sole (*Parophrys vetulus*) fillets from Puget Sound urban areas were almost 10 times higher than in sole from the Georgia Basin (WDFW, 2007). Similarly, concentrations of eTPCBs in whole body herring from two south-central Puget Sound urban locations ranged from 125 µg/kg ww to 350 µg/kg ww. These concentrations were statistically higher than concentrations in three nonurban northern locations, where concentrations were all below 125 µg/kg ww (WDFW, 2001a). Elevated PCB tissue concentrations in other urban areas, such as the Duwamish Estuary and the Seattle waterfront, also showed high PCB concentrations consistent with the findings discussed in this chapter (WDFW, 2001b).

King County recently initiated a monitoring program in Elliott Bay and adjacent Puget Sound waters in King County to fill the gap for routine fish tissue monitoring data. English sole was selected as the target species for long-term monitoring based on the historical chemical dataset (data from WDFW), association with bottom sediments, and relatively long lifespan (over 20 years). Additional tissue will be collected and analyzed from brown rockfish (*Sebastes auriculatus*) and crab. These data are not currently available. When available, the data will be used to monitor chemical concentrations (metals, mercury, chlorinated pesticides, PCBs, PBDEs, and some conventional parameters) in fish and shellfish and to evaluate fish and shellfish consumption advisories in the bay.

7.0 CONCLUSIONS

This chapter describes conclusions drawn from the analyses of water and sediment quality, marine benthos, and tissue chemistry data described in previous chapters.

General conclusions are as follows:

- The primary water quality issues in Elliott Bay are high bacteria concentrations, high summer surface water temperatures, and low autumn DO concentrations at depth. More data on the seasonal and spatial variability of metals and organic compound concentrations are needed to fully evaluate their potential impact on overall water quality.
- In sediments, mercury, PAHs, phthalates, and PCBs are the chemicals of highest concern; limited data are available on PBDEs and dioxins/furans, which are also potentially of concern because of their bioaccumulative properties.
- Tissue data indicate that PAHs, PCBs, and PBDEs are chemicals of highest concern for fish and shellfish in Elliott Bay.

Data gaps will be identified and documented based on the information presented in this and the other two area reports (Lake Union/Ship Canal and the Duwamish Estuary). Additional studies will be conducted to fill prioritized gaps.

7.1 Water Quality

Conclusions from the analysis of bacteria, temperature, DO, pH, nutrients, metals, and organics data for Elliott Bay waters are as follows:

- **Bacteria.** From a regulatory and human health standpoint, elevated bacteria concentrations (as measured by fecal coliforms) are a persistent water quality issue in Elliott Bay. Concentrations of fecal coliform are highest nearshore, particularly near the downtown Seattle waterfront. Nearshore bacteria concentrations have declined in the last several decades despite frequent Washington State WQC exceedances. This decline is likely due, in part, to increased CSO control. Nonetheless, bacteria concentrations are still elevated above WQC, especially near the shoreline.
- **Temperature.** State WQC for temperature were set at levels to protect aquatic life, particularly temperature-dependent species such as salmon. Water temperature frequently exceeds WQC in much of Elliott Bay and may be too high to support some aquatic organisms including salmonids, particularly in surface waters during the summer. Temperature in the bay is greatly influenced by large-scale climate patterns such as PDO and ENSO, and no definitive bay-wide trends could be discerned from the available data.
- **Dissolved oxygen.** WQC for DO are commonly exceeded in Elliott Bay, particularly at depth and during fall. Concentrations commonly fall below the state water criterion for DO at several locations in the bay and adjacent Puget Sound. Low DO

environments can be detrimental to aquatic life. Concentrations are lowest in the deep waters of the bay and in the late summer/early fall when low-DO deep waters from the Pacific Ocean upwell into Puget Sound and subsequent de-stratification occurs in Elliott Bay. In contrast, surface waters are typically saturated with DO from May to August when phytoplankton are at their peak abundances. DO concentrations in Elliott Bay have not significantly changed in the last 15–20 years.

- **pH.** pH, a measure of acidity or alkalinity, has not been reliably or consistently monitored in the last several decades in Elliott Bay. Monitoring pH is important because of the increasing concern regarding climate change and ocean acidification in the Puget Sound region. To address the lack of pH data, NOAA's Pacific Marine Environmental Laboratory is installing a pH monitoring station at the Seattle Aquarium, and in 2015, King County installed high-precision pH sensors at continuous monitoring stations in Central Puget Sound.
- **Nutrients.** Nitrogen, phosphorus, and silica in Elliott Bay are largely regulated by inputs from oceanic and freshwater sources and the growth and decay of phytoplankton. Elevated ammonia concentrations at depth near the outfall of the South Treatment Plant, located near the boundary of Elliott Bay and Puget Sound, are the only evidence from routine monitoring data of the presence of treated effluent. Throughout Elliott Bay, including waters surrounding outfalls, nutrients are well below WQC. No definitive trends were identified in nutrient concentrations over the past two decades, suggesting no substantial changes in nutrient loads.
- **Metals.** Recent water column data on metals concentrations are insufficient for assessing current water quality conditions in Elliott Bay. Metals have been analyzed at only one site in Elliott Bay in the last decade, and no data exist for the Seattle waterfront. The available data indicate that metals are well below Washington State WQC and EPA Human Health Criteria. Spatial and temporal patterns of metals in the bay could not be assessed because of data limitations.
- **Organic compounds.** Over the past decade, organic compounds were sampled at only two sites in Elliott Bay. Data indicate that chemical concentrations do not exceed Washington State WQC; however, concentrations of bis(2-ethylhexyl)phthalate and three HPAHs (benzo(a)anthracene, benzo(b)fluoranthene, and benzo(k)fluoranthene) occasionally exceed EPA Human Health Criteria. The mean concentration at any one site never exceeded the criteria. In addition, outdated analytical techniques have yielded samples with frequent blank contamination and detection limits above many of the state chronic WQC and EPA Human Health Criteria. Improved analytical methods would produce more reliable and informative data if future samples were to be collected. In addition, many chemicals currently not monitored are likely to enter the environment through point and nonpoint sources. Little is known about chemicals of emerging concern including pharmaceuticals, pesticides, and flame-retardants still in use. Future studies should consider inclusion of these chemicals.

7.2 Sediments

Pollutant concentrations in Elliott Bay marine sediments are spatially variable. Elevated sediment contaminant concentrations occur in discrete areas (“hot spots”) as the result of historical and/or current sources, including industrial discharges, port/maritime activity, stormwater and wastewater outfalls, surface runoff, combustion, and aerial deposition. Mercury, PAHs, PCBs, and phthalates are the priority pollutants that exceed Washington State SMS most frequently and could, therefore, adversely affect benthos. Although there are no regulatory criteria and few data on PBDE and dioxin/furan concentrations, these chemicals are a concern because of their toxicity and propensity to bioaccumulate.

Overall, this study found that sediments in the nearshore areas of Inner Elliott Bay have the potential to adversely affect benthos because they often exceed the SMS. Sediments along the downtown Seattle waterfront are of particular concern. These sediments exceed criteria for metals (arsenic, copper, lead, mercury, silver, and zinc), PAHs, PCBs, 1,4-dichlorobenzene, dibenzofuran, N-nitrosodiphenylamine, and phthalates. Sediments in northeast Elliott Bay near the Denny Way CSO and in southern Elliott Bay near Harbor Island also exceed the SMS. Nearshore sites in Outer Elliott Bay, including those off of the Magnolia and 53rd Ave SW CSO outfalls, very rarely exceed sediment criteria. In deep offshore sites in the center of the bay, mercury, silver, and PCBs were the only criteria that were exceeded more than once.

Improvements have been seen in concentrations of mercury, HPAHs, and PCBs in sediments. Although some chemical concentrations appear to be declining, sediment contamination remains. In a 1999 study, King County indicted that risks to sediment-dwelling organisms from organic enrichment, and possibly 1,4-dichlorobenzene and bis(2-ethylhexyl)phthalate, in the immediate vicinity of CSOs would be reduced as the result of CSO control (King County, 1999). However, if no other action is taken, threats from other chemicals such as mercury, PAHs, and PCBs will remain after all CSO sites are controlled.

Source control and sediment cleanup projects have been completed in the study area, including in the vicinity of the Denny Way CSO outfall, and others are in progress. Additional projects could speed up these improvements at the many hot spots for sediment contamination in Elliott Bay that are not receiving immediate attention such as the downtown Seattle waterfront.

7.3 Marine Benthos

Marine benthos data are useful for evaluating the impact of point sources, such as CSOs, on biological communities. Because of their close contact with sediment, the abundance and diversity of benthos can be an indicator of stressed biological communities from exposure to sediment-associated contaminants from nearby point sources.

Recent marine benthos data collected by King County are limited to sites in the vicinity of the outfalls for the Elliott West wet weather treatment facility and Denny Way CSO in

northeastern Elliott Bay. Similar to elsewhere in Puget Sound, benthic community composition is highly influenced by depth and sediment grain size but may also be affected to a lesser degree by chemical contaminants including some metals. Benthic communities near the outfalls had significantly lower benthic indices (used to assess community health) than communities at sites with similar depths and grain sizes. These findings indicate that the proximity to outfalls may have an effect on community composition. However, it should be noted that communities at shallow-water sites were more variable than those at deep sites including those near the outfalls. Data from a reference site are needed to make acceptable comparisons to benthic communities elsewhere in Puget Sound.

Ecology routinely evaluates sediment benthos throughout Elliott Bay, but does not target point sources. They have concluded that benthos at mid-depth sites near Magnolia Bluff and Pier 90, mid-depth sites north of Harbor Island, a shallow site north of Duwamish Head, and two deep depositional sites were “affected” or negatively impacted by contaminated sediment. A single site near Magnolia Bluff was determined to be toxic, based on sediment toxicity tests. In contrast, shallow sites along the downtown Seattle waterfront were not affected and not toxic.

Because of differences in sample collection and data analysis methods, Ecology and King County benthos data are not comparable. Moreover, the limited data cannot be used to fully evaluate the effects of point sources, such as at the Denny Way CSO site, on benthic communities. In order to make acceptable comparisons between benthic communities at sites with point sources to communities elsewhere in Elliott Bay and Puget Sound, additional benthic sampling locations are needed.

7.4 Tissue Chemistry

Contaminant accumulation in shellfish tissue in Elliott Bay is influenced by several factors including location, lipid content, and the time of the year that the samples are collected. Contaminants in organisms collected from heavily urbanized areas, such as Elliott Bay, appear to have higher concentrations of some chemicals including DDT, PCBs, PAHs, and PBDEs than elsewhere in Puget Sound. However, chemical concentrations in clams collected from southern Discovery Park, the only King County-monitored site near Elliott Bay, were below recommended EPA screening values for metals.

PAHs, PCBs, PBDEs, and DDT were measured in mussel tissue from Elliott Bay collected during the Puget Sound Ecosystem Monitoring Program effort in winter 2012–2013. The highest PAH concentrations in Puget Sound were detected at four Elliott Bay locations (Myrtle Edwards Park, Four Mile Rock, Pier 59, and Smith Cove). Samples from these same locations had only moderately elevated PCBs and had lower PBDE and DDT concentrations than PAHs and PCBs. In comparison, crab and shrimp tissue samples from deeper water sites had lower PAH, PBDE, and DDT concentrations but higher PCB concentrations at similar locations in Elliott Bay.

7.5 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:

- Two reports describe existing conditions and long-term trends in two other study areas—Lake Union/Ship Canal and the Duwamish Estuary.
- A report documents the process used to assess identified data gaps for the study areas and select studies to fill prioritized gaps.
- 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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9.0 GLOSSARY

Aerobic	Living in the presence of oxygen.
Algae	Mostly aquatic, non-vascular organisms (eukaryotes and cyanobacteria) that float in the water or attach to larger plants, rocks, and other <i>substrates</i> . Also called <i>phytoplankton</i> when floating in the water, these individuals are usually visible only with a microscope. They are a normal and necessary component of aquatic life, but excessive numbers can make the water appear cloudy and colored, which may discourage human use.
algal bloom	Heavy growth of <i>algae</i> or cyanobacteria in and on a body of water, often a result of high nutrient concentrations when occurring frequently but blooms can also be a normal occurrence. Decomposition of algae following blooms can cause reductions in oxygen that may threaten fish and other aquatic animals.
ammonia (NH ₃)	A <i>nitrogen</i> -containing substance which may indicate recently decomposed plant or animal material.
anaerobic	Living in the absence of oxygen.
annelid	Any member of the phylum Annelida, a group of <i>invertebrates</i> . They are also called "segmented worms," and include ragworms, earthworms, and leeches. Various forms specialize in their respective ecosystems. They can be found in marine environments, fresh water, and moist terrestrial environments. The class Polychaete is dominant in marine systems.
anoxic	No oxygen present in the system; see <i>anaerobic</i> .
Aroclors	One of the most commonly known trade names for <i>PCB</i> mixtures.
benthic	Associated with the <i>sediments</i> of a waterbody; often used to describe the community of organisms (<i>benthos</i>) that live in or on the <i>sediment</i> .
benthic invertebrates	See <i>invertebrates</i> .
benthos	The communities of aquatic life that dwell in or on the bottom <i>sediments</i> of a waterbody.
bioaccumulation	Accumulation of chemicals in the tissue of organisms through any route, including respiration, ingestion, and direct contact with contaminated water, <i>sediment</i> , and pore water in the <i>sediment</i> .
blank contamination	Artificially introduced contamination. Blank contamination (chemical demonstrated as present when it should not be) of a sample indicates that other samples analyzed in the same batch may possess false positives.
chlorophyll	A green pigment found in organisms that make their own food, including <i>algae</i> . It plays an important part in the chemical reactions of <i>photosynthesis</i> . A measurement of chlorophyll- <i>a</i> (one form of chlorophyll) is commonly used as a way to estimate the abundance of <i>phytoplankton</i> in water.
combined sewer	Discharges of combined sewage and stormwater into waterbodies as the result of

overflow (CSO)	heavy storms. These discharges are designed to relieve the sewer system as it becomes overloaded with normal sewer flow and increased storm runoff.
concentration	The amount of one substance in a given amount of another substance, such as the mass of a chemical in a liter of water.
conductivity	A measure of water's capacity to convey an electric current. It is related to the total amount of dissolved charged substances (ions) in the water. It can be used as one general indicator of water quality. It is often used as a surrogate for salinity measurements.
congener	Chemical substances (constituents) related to each other by origin, structure, or function.
corrective action site	A hazardous waste site that is being investigated and cleaned up under the Resource Conservation and Recovery Act (RCRA). The site may include risks comparable to <i>Superfund</i> sites.
crustacean	Any member of the subphylum Crustacea (phylum Arthropoda), a group of <i>invertebrate</i> animals. Crabs, lobsters, and shrimps are among the best known marine crustaceans.
diatoms	Golden-brown <i>algae</i> that make intricate siliceous shells, which are found in open water and attached to wood and rocks along shorelines. Diatoms are nutritious food for planktonic animals and are important components of a healthy food chain in aquatic systems.
dinoflagellates	Plankton usually having two flagella, one in a groove around the body and the other extending from its center. They perform <i>photosynthesis</i> , but many ingest <i>phytoplankton</i> as well.
dissolved oxygen (DO)	Oxygen that is dissolved in the water. Certain concentrations are necessary for the life processes of aquatic animals. The oxygen is supplied by the <i>photosynthesis</i> of plants, including <i>algae</i> , and by aeration through contact and mixing of the surface water with the atmosphere. Oxygen is consumed by aerobic organisms during respiration and by the oxidation of chemicals.
eelgrass	A vascular, flowering plant found in shallow muddy or sandy habitats, which spreads by an underground stem.
ecosystem	Any complex of living organisms, along with the non-living factors that affect them and are affected by them. Includes plants, animals, the <i>nutrients</i> that sustain them, and all of the other environmental conditions necessary for successful maturation and reproduction.
effluent	Liquids discharged from sewage treatment plants, septic systems, industrial, or <i>stormwater</i> sources to <i>surface waters</i> .
endocrine disrupting compounds	Chemicals that may interfere with an animal's endocrine system and produce adverse developmental, reproductive, neurological, and immune effects. A wide range of substances, both natural and manmade, are thought to cause endocrine disruption, including pharmaceuticals, dioxins and dioxin-like compounds, <i>PCBs</i> , pesticides, and plasticizers. Endocrine disruptors may be found in many everyday products, including plastic bottles, metal food cans, detergents, flame retardants, food, toys, and cosmetics.

estuary	A partly enclosed coastal body of brackish water with one or more rivers or streams flowing into it and with a free connection to the open sea/ocean.
eutrophic	Waters in which <i>phytoplankton</i> are able to maintain large populations. Generally related to <i>nutrient</i> supply.
eutrophication	The physical, chemical, and biological changes associated with enrichment of a waterbody from increases in <i>nutrients</i> .
fecal coliform bacteria	A group of bacteria from the intestines of warm-blooded animals. Most of the bacteria are not in themselves harmful, but they are measured or counted as indicators of the possible presence of harmful bacteria.
groundwater	Water located and moving beneath the surface of the earth. The water in the ground is supplied by the seepage (percolation) of rainwater, snowmelt, and other <i>surface water</i> into the soil. Some groundwater may be found far beneath the earth's surface; other groundwater may be only a few inches from the surface.
Hydrolab®	A handheld instrument for monitoring multiple water quality parameters.
hypoxic	Low in oxygen; a condition that can be detrimental to aquatic organisms.
imputation	Replacing missing data with estimated values. Discarding observations that has a missing value may introduce bias or affect the representativeness of the data. Imputation preserves the dataset by replacing missing data with probable value based on available information. Once all missing values have been imputed, the dataset can then be analyzed using standard techniques for complete datasets.
intertidal zone	The area between the high tide and low tide marks.
infauna	Aquatic animals living in the <i>sediments</i> of the sea floor.
invertebrates	Animals without internal skeletons including insects, crabs, bivalves, and worms. <i>Benthic invertebrates</i> are an important link in the food chain for fish and can be used as an indicator of <i>sediment</i> quality.
left-censored	A dataset with observations below known values (typically the laboratory detection limit), but the exact values of those observations are unknown.
limiting nutrient	The <i>nutrient</i> that is in lowest supply relative to demand. The limiting nutrient will be the one that is exhausted first by <i>algae</i> /phytoplankton growth. Increasing the amount of the limiting nutrient will result in increased algal production, but once the limiting nutrient is exhausted, growth stops.
lipid	Any of a class of organic compounds that are fatty acids or their derivatives and are insoluble in water but soluble in organic solvents. They include many natural oils, waxes, and steroids.
loading	The total amount of material (<i>sediments</i> , <i>nutrients</i> , chemicals) entering a waterbody via streams, overland flow, precipitation, direct discharge, or other means over time (usually considered annually).
method detection limit (MDL)	The minimum concentration that can be measured and reported with 99 percent confidence that the concentration is greater than zero.
molluscs	A group of <i>invertebrates</i> that includes squids, octopuses, cuttlefishes,

	nudibranchs, snails, slugs, limpets, mussels, clams, and more.
<i>Noctiluca</i>	Also known as sea sparkle, a genus of large <i>dinoflagellates</i> that feeds on other planktonic organisms.
nephelometric turbidity unit (NTU)	A unit measuring the lack of clarity of water.
nitrate, nitrite (NO ₃ , NO ₂)	Two types of <i>nitrogen</i> compounds. These <i>nutrients</i> are forms of nitrogen that <i>algae</i> may use for growth.
nitrogen	One of the elements essential for the growth of organisms. <i>Nitrogen</i> is most abundant on the earth in the form of N ₂ , comprising nearly 80% of the atmosphere, but this inert gas is not bioavailable to most organisms. Nitrogen is usually taken up by plants in the forms NO ₃ , NO ₂ , and NH ₃ (<i>ammonia</i>).
non-ionized/ unionized	Electrically neutral atoms or molecules that have not been converted to electrically charged atoms or molecules (ions).
nonpoint source pollution	Pollution from diverse sources that are difficult to pinpoint as separate entities and thus more complicated to control or manage. Examples include area-wide erosion (as opposed to landslides or mass wasting), widespread failure of septic systems, certain farming practices or forestry practices, and residential/urban land uses (such as fertilizing lawns or landscaping).
nutrients	Any chemical element, ion, or compound required by an organism for growth and reproduction.
oceanographic rosette	A framework with 12 to 36 sampling bottles clustered around a central cylinder, where a CTD (conductivity, temperature, and depth) or other sensor package can be attached.
outfall	A pipe that discharges effluent, CSOs, <i>stormwater</i> , and other substances to a receiving waterbody.
pathogens	Microorganisms that can cause disease in other organisms. Pathogens include bacteria, viruses, fungi, and parasites found in sewage, in runoff from farms or city streets, and in water used for swimming. They can be present in municipal, industrial, and nonpoint source discharges.
pH	The log ₁₀ -transformation of the activity of the hydrogen ion in solution. pH values less than 7 are acidic; values greater than 7 are basic. pH influences the speciation of metals and other constituents. Biota may be negatively impacted at very high and low pH values.
phthalates (plasticizers)	A group of chemicals used to make plastics more flexible and harder to break. They are often called <i>plasticizers</i> . Some phthalates are used as solvents (dissolving agents) for other materials. They are used in hundreds of products, such as vinyl flooring, adhesives, detergents, lubricating oils, automotive plastics, plastic clothes (raincoats), and personal-care products (soaps, shampoos, hair sprays, and nail polishes). Phthalates are used widely in polyvinyl chloride plastics, which are used to make products such as plastic packaging film and sheets, garden hoses, inflatable toys, blood-storage containers, medical tubing, and some children's toys.
phosphorus	One of the essential <i>nutrients</i> for the growth of organisms. Phosphorus occurs

	naturally in soils and in organic material.
photosynthesis	The production of chemical energy using the energy of the sun (light); this energy can be used to fuel the organism's activities. In general, plants and some other organisms are equipped to carry out this process, while animals cannot.
phytoplankton	Free-floating microscopic organisms that <i>photosynthesize</i> (includes both <i>algae</i> and cyanobacteria).
point source pollution	An input of pollutants into a waterbody from discrete sources, such as municipal or industrial <i>outfall</i> pipes.
polybrominated diphenyl ethers (PBDEs)	A class of persistent and <i>bioaccumulative</i> halogenated compounds that have emerged as a major environmental pollutant. PBDEs are used as flame-retardants and are found in consumer goods such as electrical equipment, construction materials, coatings, textiles, and polyurethane foam (furniture padding). Similar in structure to <i>polychlorinated biphenyls</i> (PCBs), PBDEs resist degradation in the environment.
polychlorinated biphenyls (PCBs)	Part of a broad family of manmade organic chemicals known as chlorinated hydrocarbons. PCBs were domestically manufactured from 1929 until their manufacture was banned in 1979. They have a range of toxicity and vary in consistency from thin light-colored liquids to yellow or black waxy solids. Because of their non-flammability, chemical stability, high boiling point, and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications including electrical, heat transfer, and hydraulic equipment; as <i>plasticizers</i> in paints, plastics, and rubber products; in pigments, dyes, and carbonless copy paper; and many other industrial applications.
polycyclic aromatic hydrocarbons (PAHs)	A group of over 100 different chemicals that are formed during the incomplete burning of coal, oil, gas, garbage, and other organic substances like tobacco or charbroiled meat. PAHs are usually found as a mixture containing two or more of these compounds, such as soot. Some PAHs are manufactured. These pure PAHs usually exist as colorless, white, or pale yellow-green solids. PAHs are found in coal tar, crude oil, creosote, and roofing tar, but a few are used in medicines or to make dyes, plastics, and pesticides.
primary treatment	The first stage of <i>wastewater</i> treatment involving removal of debris and solids by screening and settling.
precursor	A chemical compound that participates in the chemical reaction that produces another compound.
riprap	A foundation or sustaining wall of stones or chunks of concrete thrown together without order (as in deep water) or a layer of this or similar material on an embankment slope to prevent erosion.
salmonids	Fish belonging to the taxonomic family Salmonidae, including multiple species of salmon, trout, char, and whitefish.
secondary treatment	Following primary treatment, bacteria are used to consume organic wastes in sewage. The treated sewage is then disinfected and discharged through an <i>outfall</i> . <i>Nutrient</i> concentrations are not decreased with secondary treatment.
sediment	Solid material deposited in the bottom of a waterbody over time, carried in by wind and water or produced by plants and animals.

stormwater	Water that is generated by rainfall and is often routed into municipal drain systems in urban environments.
stratification	A layering effect produced by the warming of the surface in many waterbodies during summer. Upper waters are progressively warmed by the sun, and the deeper waters remain cold. Because of the difference in density (warmer water is lighter), the two layers remain separate from each other. Upper waters "float" on deeper waters and wind-induced mixing occurs only in the upper waters. Oxygen in the bottom waters may become depleted.
substrate	A surface on which an organism grows or is attached.
surface water	Water located near the interface of water and air. For this assessment, waters to 1-m depth were considered "surface."
Superfund	The name given to the federal environmental program established to address abandoned hazardous waste sites. It is also the name of the fund established by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended (CERCLA). It allows the U.S. Environmental Protection Agency (EPA) to clean up such sites and to compel responsible parties to perform cleanups or reimburse the government for EPA-lead cleanups.
total suspended solids (TSS)	Particles, both mineral (clay and sand) and organic (<i>algae</i> and small pieces of decomposed plant and animal material), that are suspended in water.
toxic	Causing death, disease, cancer, genetic mutations, or physical deformations in any organism or its offspring upon exposure, ingestion, inhalation, or assimilation.
turbidity	Cloudiness in water caused by the suspension of tiny particles (<i>algae</i> or detritus), commonly measured in <i>NTUs</i> .
van Dorn sampler	A water sampling device that allows collection of a water sample from a desired depth without contaminating the sample with water from other depths.
van Veen sampler	Stainless steel clamshell-like used to extract <i>sediment</i> and/ or <i>benthic invertebrate</i> samples from a 0.1 m ² area.
wastewater	Water from sinks, toilets, and other sources in homes, industries, and businesses that is conveyed to wastewater treatment plants. Also called sewage.
water column	Water between the surface and the bottom <i>sediments</i> . Multiple depths at a given site are often sampled so that the conditions can be described across the vertical distance between the surface and bottom.
zooplankton	A diverse group of small animals that are found in waterbodies of low to moderate flow, such as lakes, river estuaries, and bays. They are free swimming but typically have limited powers of locomotion. They feed on bacteria, <i>algae</i> , smaller animals, and/or organic detritus present in the water.

Appendix A: Concentrations of Metals in the Water Column

Table A-1. Data reporting and qualification in presence of blank contamination.

Blank Result	Sample Result	Action
<MDL	<MDL	Report at MDL and qualify as non-detect ("U")
	≥MDL and <RDL	Report at detected value and qualify as estimated value ("J")
	≥RDL	Report at detected value
≥MDL and <RDL	<MDL	Report at MDL and qualify as non-detect ("U")
	≥MDL and < blank concentration OR ≥MDL and <RDL	Report at RDL and qualify as non-detect ("U")
	≥MDL and >RDL and ≥ blank concentration and < 5x blank concentration	Report at detected value and qualify as non-detect ("U")
	≥MDL and ≥ 5x blank concentration	Report at detected and qualify as estimated value ("J")
≥ RDL	<MDL	Report at MDL and qualify as non-detect ("U")
	≥MDL and < RDL	Report at RDL and qualify as non-detect ("U")
	≥RDL and < 5x blank concentration	Report at detected value and qualify as non-detect ("U")
	≥ 5x blank concentration	Report at detected and qualify as estimated value ("J")

MDL = method detection limit; RDL = reporting detection limit; U = non-detect; J = estimated value.

Table A-2. Concentration (µg/L) of total metals in water samples from Elliott Bay at two offshore sites (LSEP01 and LTED04) from 1999 to 2000. Minimums and maximums are based on detected values.

Parameter	Site	Depth (m)	FOD	Min.	Max.	Mean	Median	Min. MDL of Non-Detects	Max. MDL of Non-Detects
Antimony*	South Plant Outfall	5	13/14	0.0506	0.114	0.0779	0.0737	0.0863	0.0863
		50	13/14	0.058	0.102	0.0756	0.0724	0.0839	0.0839
		130	13/14	0.06	0.104	0.075	0.071	0.0797	0.0797
Arsenic	South Plant Outfall	5	14/14	0.806	1.35	1.09	1.09	NA	NA
		50	14/14	0.996	1.39	1.13	1.12	NA	NA
		130	14/14	0.969	1.44	1.16	1.17	NA	NA
	Central Elliott Bay	5	4/4	1.14	1.33	1.25	1.2	NA	NA
		50	4/4	1.19	1.37	1.3	1.32	NA	NA
		75	4/4	1.22	1.45	1.36	1.38	NA	NA

Parameter	Site	Depth (m)	FOD	Min.	Max.	Mean	Median	Min. MDL of Non-Detects	Max. MDL of Non-Detects
Cadmium	South Plant Outfall	5	14/14	0.0537	0.072	0.0655	0.0668	NA	NA
		50	14/14	0.0591	0.0926	0.0693	0.0681	NA	NA
		130	14/14	0.0636	0.0736	0.0688	0.0678	NA	NA
	Central Elliott Bay	5	4/4	0.0552	0.0745	0.0686	0.0703	NA	NA
		50	4/4	0.0649	0.0795	0.0723	0.0703	NA	NA
		75	4/4	0.0662	0.0799	0.074	0.0727	NA	NA
Chromium	South Plant Outfall	5	14/14	0.14	0.21	0.176	0.18	NA	NA
		50	14/14	0.13	0.21	0.176	0.18	NA	NA
		130	14/14	0.17	0.264	0.214	0.215	NA	NA
	Central Elliott Bay	5	4/4	0.088	0.11	0.101	<MDL	NA	NA
		50	4/4	0.077	0.12	0.097	0.091	NA	NA
		75	4/4	0.088	0.18	0.144	0.14	NA	NA
Copper	South Plant Outfall	5	14/14	0.366	0.663	0.466	0.452	NA	NA
		50	14/14	0.346	0.855	0.431	0.397	NA	NA
		130	14/14	0.341	0.421	0.387	0.379	NA	NA
	Central Elliott Bay	5	4/4	0.507	0.815	0.61	0.516	NA	NA
		50	4/4	0.303	0.707	0.454	0.335	NA	NA
		75	4/4	0.301	0.492	0.39	0.371	NA	NA
Lead*	South Plant Outfall	5	14/14	0.010	0.047	0.023	0.022	NA	NA
		50	14/14	0.012	0.048	0.024	0.021	NA	NA
		130	13/14	0.019	0.074	0.040	0.039	0.025	0.025
	Central Elliott Bay	5	3/4	0.023	0.033	0.026	0.023	0.005	0.005
		50	4/4	0.010	0.045	0.024	0.016	NA	NA
		75	4/4	0.020	0.084	0.059	0.064	NA	NA
Mercury	South Plant Outfall	5	13/13	0.00017	0.00070	0.00037	0.00034	NA	NA
		50	13/13	0.00021	0.00199	0.00045	0.00029	NA	NA
		130	13/13	0.00024	0.00075	0.00040	0.00036	NA	NA
	Central Elliott Bay	5	3/4	0.00021	0.00036	0.00026	0.00021	0.0002	0.0002
		50	3/4	0.00021	0.00028	0.00023	0.00021	0.0002	0.0002
		75	4/4	0.00020	0.00052	0.00036	0.00035	NA	NA
Nickel	South Plant Outfall	5	14/14	0.396	0.511	0.438	0.428	NA	NA
		50	14/14	0.391	0.51	0.441	0.429	NA	NA
		130	14/14	0.401	0.581	0.462	0.458	NA	NA
	Central Elliott Bay	5	4/4	0.393	0.439	0.413	0.409	NA	NA
		50	4/4	0.408	0.426	0.416	0.412	NA	NA
		75	4/4	0.405	0.501	0.447	0.415	NA	NA
Selenium	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.15	0.15
		50	0/14	<MDL	<MDL	NA	<MDL	0.15	0.15
		130	0/13	<MDL	<MDL	NA	<MDL	0.15	0.15
Silver	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.059	0.06
		50	0/14	<MDL	<MDL	NA	<MDL	0.059	0.06
		130	0/14	<MDL	<MDL	NA	<MDL	0.059	0.06
	Central Elliott Bay	5	2/4	0.016	0.031	NA	<MDL	0.01	0.01
		50	2/4	0.017	0.033	NA	<MDL	0.01	0.01
		75	2/4	0.017	0.032	NA	<MDL	0.01	0.01

Parameter	Site	Depth (m)	FOD	Min.	Max.	Mean	Median	Min. MDL of Non-Detects	Max. MDL of Non-Detects
Thallium	South Plant Outfall	5	14/14	0.0095	0.012	0.0105	0.01	NA	NA
		50	14/14	0.0099	0.013	0.0107	0.01	NA	NA
		130	14/14	0.009	0.013	0.011	0.011	NA	NA
Zinc*	South Plant Outfall	5	13/14	0.36	0.984	0.568	0.53	0.739	0.739
		50	13/14	0.35	0.754	0.519	0.5	0.741	0.741
		130	12/14	0.36	0.72	0.522	0.54	0.743	0.744
	Central Elliott Bay	5	4/4	0.847	1.01	0.911	0.88	NA	NA
		50	4/4	0.35	0.734	0.518	0.43	NA	NA
		75	4/4	0.45	0.608	0.526	0.52	NA	NA

Means for parameters with non-detects were calculated using a Kaplan-Meier estimator when $n > 2$.

FOD = frequency of detection; MDL = method detection limit.

* = Blank contamination present in at least some samples analyzed (treated as non-detects and handled according to Table A-1).

Table A-3. Concentration ($\mu\text{g/L}$) of dissolved metals in water samples from Elliott Bay at two offshore sites (LSEP01 and LTED04) from 1999 to 2000. Minimums and maximums are based on detected values.

Parameter	Site	Depth (m)	FOD	Min.	Max.	Mean	Median	Min. MDL of Non-Detects	Max. MDL of Non-Detects
Antimony*	South Plant Outfall	5	13/14	0.068	0.115	0.0852	0.0812	0.0783	0.0783
		50	13/14	0.061	0.0994	0.079	0.0771	0.0681	0.0681
		130	13/14	0.061	0.0877	0.0746	0.0768	0.0713	0.0713
Arsenic	South Plant Outfall	5	14/14	0.895	1.26	1.07	1.08	NA	NA
		50	14/14	0.93	1.22	1.1	1.1	NA	NA
		130	14/14	1.03	1.3	1.14	1.14	NA	NA
	Central Elliott Bay	5	4/4	1.12	1.37	1.26	1.22	NA	NA
		50	4/4	1.23	1.39	1.32	1.33	NA	NA
		75	4/4	1.26	1.39	1.34	1.36	NA	NA
Cadmium	South Plant Outfall	5	14/14	0.0479	0.0689	0.0623	0.0627	NA	NA
		50	14/14	0.0581	0.0725	0.0655	0.0659	NA	NA
		130	14/14	0.0622	0.0742	0.068	0.0678	NA	NA
	Central Elliott Bay	5	4/4	0.061	0.0714	0.0655	0.0624	NA	NA
		50	4/4	0.0627	0.0722	0.0678	0.0647	NA	NA
		75	4/4	0.0679	0.0763	0.0712	0.0689	NA	NA
Chromium*	South Plant Outfall	5	13/14	0.085	0.21	0.13	0.13	0.207	0.207
		50	12/14	0.085	0.19	0.124	0.12	0.207	0.209
		130	12/14	0.077	0.17	0.127	0.13	0.21	0.21
	Central Elliott Bay	5	4/4	0.097	0.14	0.114	0.099	NA	NA
		50	4/4	0.087	0.13	0.104	0.1	NA	NA
		75	4/4	0.085	0.14	0.108	0.099	NA	NA

Parameter	Site	Depth (m)	FOD	Min.	Max.	Mean	Median	Min. MDL of Non-Detects	Max. MDL of Non-Detects
Copper	South Plant Outfall	5	14/14	0.321	0.487	0.388	0.376	NA	NA
		50	14/14	0.317	0.413	0.352	0.344	NA	NA
		130	14/14	0.27	0.397	0.325	0.315	NA	NA
	Central Elliott Bay	5	4/4	0.423	0.635	0.504	0.471	NA	NA
		50	4/4	0.298	0.316	0.308	0.303	NA	NA
		75	4/4	0.277	0.34	0.309	0.303	NA	NA
Lead*	South Plant Outfall	5	3/14	0.0055	0.0071	0.0056	<MDL	0.0049	0.0249
		50	4/14	0.0051	0.0075	0.0055	<MDL	0.0049	0.0247
		130	7/14	0.0051	0.0074	0.0056	0.0051	0.0049	0.0249
	Central Elliott Bay	5	2/4	0.0052	0.0276	NA	<MDL	0.005	0.005
		50	0/4	<MDL	<MDL	NA	<MDL	0.005	0.005
		75	0/4	<MDL	<MDL	NA	<MDL	0.005	0.005
Nickel*	South Plant Outfall	5	13/14	0.386	0.445	0.414	0.415	0.547	0.547
		50	13/14	0.394	0.481	0.419	0.408	0.558	0.558
		130	13/14	0.382	0.51	0.416	0.4	0.572	0.572
	Central Elliott Bay	5	4/4	0.383	0.432	0.41	0.392	NA	NA
		50	4/4	0.395	0.436	0.41	0.401	NA	NA
		75	4/4	0.396	0.427	0.411	0.406	NA	NA
Selenium	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.15	0.15
		50	0/14	<MDL	<MDL	NA	<MDL	0.15	0.15
		130	0/14	<MDL	<MDL	NA	<MDL	0.15	0.15
Silver	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.059	0.06
		50	0/14	<MDL	<MDL	NA	<MDL	0.059	0.06
		130	0/14	<MDL	<MDL	NA	<MDL	0.059	0.06
	Central Elliott Bay	5	2/4	0.019	0.028	NA	<MDL	0.01	0.01
		50	2/4	0.02	0.028	NA	<MDL	0.01	0.01
		75	2/4	0.019	0.028	NA	<MDL	0.01	0.01
Thallium	South Plant Outfall	5	14/14	0.009	0.012	0.0105	0.01	NA	NA
		50	14/14	0.0093	0.012	0.0106	0.01	NA	NA
		130	14/14	0.0094	0.012	0.0106	0.011	NA	NA
Zinc*	South Plant Outfall	5	6/14	0.25	1.04	0.532	0.44	0.745	1.3
		50	6/14	0.36	0.954	0.553	0.56	0.738	1.22
		130	6/14	0.43	1.03	0.552	0.48	0.737	1.25
	Central Elliott Bay	5	4/4	0.61	1.02	0.874	0.858	NA	NA
		50	4/4	0.3	0.644	0.472	0.4	NA	NA
		75	4/4	0.36	0.817	0.487	0.38	NA	NA

Means for parameters with non-detects were calculated using a Kaplan-Meier estimator when $n > 2$.

FOD = frequency of detection.

* = Blank contamination present in at least some samples analyzed (treated as non-detects and handled according to Table A-1).

Table A-4 Concentration (µg/L) of total metals detected in water samples from beach site KSSN05, near the West Point Treatment Plant (1999-2002).

Parameter	Site	FOD	Concentration	Max. MDL for Non-Detects
Antimony	West Point South	1/1	0.032	NA
Arsenic	West Point South	1/1	1.47	NA
Cadmium	West Point South	1/1	0.0776	NA
Chromium	West Point South	1/1	3.54	NA
Copper	West Point South	1/1	3.9	NA
Lead	West Point South	1/1	0.973	NA
Nickel	West Point South	1/1	4.83	NA
Selenium	West Point South	0/1	<MDL	0.15
Silver	West Point South	0/1	<MDL	0.06
Thallium	West Point South	1/1	0.017	NA
Zinc	West Point South	1/1	7.19	NA

FOD = Frequency of detection; MDL = method detection limit.

Table A-5 Concentration (µg/L) of dissolved metals detected in water samples from two beach sites (KSSN05 and KSYV02) in Elliott Bay (1999-2000). Minimums and maximums are based on detected values.

Parameter	Site	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Arsenic	West Point S	3/3	1.07	1.31	1.20	1.23	NA	NA
	Magnolia Outfall	2/2	1.05	1.35	NA	1.20	NA	NA
Cadmium	West Point S	3/3	0.053	0.064	0.060	0.063	NA	NA
	Magnolia Outfall	2/2	0.056	0.061	NA	0.059	NA	NA
Chromium	West Point S	3/3	0.097	0.160	0.126	0.120	NA	NA
	Magnolia Outfall	2/2	0.110	0.140	NA	0.125	NA	NA
Copper	West Point S	3/3	0.37	0.66	0.53	0.57	NA	NA
	Magnolia Outfall	2/2	0.94	1.23	NA	1.08	NA	NA
Lead	West Point S	2/3	0.0084	0.0120	0.0096	0.0084	0.007	0.007
	Magnolia Outfall	1/2	0.013	0.0130	NA	<MDL	0.007	0.007
Nickel	West Point S	3/3	0.44	0.55	0.50	0.51	NA	NA
	Magnolia Outfall	2/2	0.36	0.41	NA	0.39	NA	NA
Selenium	West Point S	0/3	<MDL	<MDL	NA	<MDL	0.15	0.15
	Magnolia Outfall	0/2	<MDL	<MDL	NA	<MDL	0.15	0.15
Silver	West Point S	0/3	<MDL	<MDL	NA	<MDL	0.06	0.06
	Magnolia Outfall	0/2	<MDL	<MDL	NA	<MDL	0.06	0.06
Thallium	West Point S	3/3	0.0086	0.0092	0.0089	0.0089	NA	NA
	Magnolia Outfall	2/2	0.0090	0.0095	NA	0.0093	NA	NA
Zinc*	West Point S	0/3	<MDL	<MDL	NA	<MDL	0.745	0.96
	Magnolia Outfall	1/2	<MDL	2.81	NA	<MDL	1.51	0.15

Means for parameters with non-detects were calculated using a Kaplan-Meier estimator when n > 2.

FOD = frequency of detection; MDL = method detection limit.

* = Blank contamination present in at least some samples analyzed (treated as non-detects and handled according to Table A-1).

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Appendix B: Concentrations of Organics in the Water Column

Table B-1. Detection frequency and maximum concentrations (µg/L) of organic compounds detected in water samples from three sites in Elliott Bay and nearby Puget Sound. Highest mean for a monitoring station/depth also provided.

Analyte	FOD	Max. Detect	Highest Site/Depth Mean	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Endocrine Disrupting Compounds (EDCs)					
Bis(2-ethylhexyl)adipate*	5/19	0.843	<MDL	0.0096	0.134
Total 4-Nonylphenol*	1/19	0.096	<MDL	0.047	0.101
LPAHs					
Acenaphthene	5/56	0.045	0.02	0.0047	0.096
Anthracene	1/56	0.019	<MDL	0.0047	0.14
Fluorene	3/56	0.0336	<MDL	0.0047	0.14
Naphthalene	3/56	0.0813	<MDL	0.012	0.38
Phenanthrene	8/56	0.0847	0.0324	0.0047	0.14
HPAHs					
Benzo(a)anthracene	1/56	0.041	<MDL	0.012	0.14
Benzo(a)pyrene	1/56	0.015	<MDL	0.0047	0.24
Benzo(b)fluoranthene	2/56	0.0734	<MDL	0.0047	0.38
Benzo(k)fluoranthene	1/56	0.0386	<MDL	0.0047	0.38
Chrysene	1/56	0.0616	<MDL	0.012	0.14
Fluoranthene	8/56	0.0813	0.034	0.0047	0.14
Pyrene	4/56	0.0388	0.0187	0.0047	0.14
PCBs					
Total PCBs (congeners)	4/4	0.0000895	0.0000744	--	--
Semivolatile Organic Compounds (SVOCs)					
Benzoic Acid*	3/25	0.567	<MDL	0.12	0.96
Benzyl Alcohol	2/17	0.35	<MDL	0.12	0.24
Benzyl Butyl Phthalate*	3/56	0.0189	<MDL	0.0047	0.14
Bis(2-Ethylhexyl)Phthalate*	10/56	10.5	1.51	0.0723	1.54
Caffeine*	25/56	0.015	0.00827	0.0047	0.048
Di-N-Butyl Phthalate*	2/56	0.0601	<MDL	0.0267	0.24
Di-N-Octyl Phthalate*	2/37	0.0139	<MDL	0.0047	0.14
Dibenzofuran	1/56	0.0271	<MDL	0.0047	0.24
Diethyl Phthalate*	2/56	0.0235	<MDL	0.0119	0.24
Dimethyl Phthalate	3/37	0.013	<MDL	0.0047	0.096
Phenol	11/57	0.092	0.0559	0.047	0.96

Means for parameters with non-detects were calculated using a Kaplan-Meier estimator when n > 2.

FOD = Frequency of detection; MDL = method detection limit.

* = Blank contamination present in at least some samples analyzed (treated as non-detects and handled according to Table A-1 in Appendix A).

Table B-2 Summary of concentrations (µg/L) of organic compounds in water samples at three sites in Elliott Bay and nearby Puget Sound (1999-2004). Only sites that were sampled are listed.

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Chlorinated Herbicides and Pesticides									
2,4,5-T	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.072	0.078
		50	0/2	<MDL	<MDL	NA	<MDL	0.072	0.078
		130	0/3	<MDL	<MDL	NA	<MDL	0.072	0.078
2,4,5-TP (Silvex)	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.076	0.13
		50	0/2	<MDL	<MDL	NA	<MDL	0.076	0.13
		130	0/3	<MDL	<MDL	NA	<MDL	0.076	0.13
2,4-D	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.082	0.086
		50	0/2	<MDL	<MDL	NA	<MDL	0.082	0.086
		130	0/3	<MDL	<MDL	NA	<MDL	0.082	0.086
2,4-DB	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.085	0.1
		50	0/2	<MDL	<MDL	NA	<MDL	0.085	0.1
		130	0/3	<MDL	<MDL	NA	<MDL	0.085	0.1
4,4'-DDD	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
4,4'-DDE	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
4,4'-DDE	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
4,4'-DDT	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Aldrin	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Alpha-BHC	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Alpha-Chlordane	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Beta-BHC	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Chlordane	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.024	0.024
		50	0/9	<MDL	<MDL	NA	<MDL	0.024	0.024
		130	0/10	<MDL	<MDL	NA	<MDL	0.024	0.024
Dalapon	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.087	0.14
		50	0/2	<MDL	<MDL	NA	<MDL	0.087	0.14
		130	0/3	<MDL	<MDL	NA	<MDL	0.087	0.14
Delta-BHC	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Dicamba	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.077	0.14
		50	0/4	<MDL	<MDL	NA	<MDL	0.077	0.14
		130	0/5	<MDL	<MDL	NA	<MDL	0.077	0.14
Dichloroprop	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.11	0.14
		50	0/2	<MDL	<MDL	NA	<MDL	0.11	0.14
		130	0/3	<MDL	<MDL	NA	<MDL	0.11	0.14
Dieldrin	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Dinoseb	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.061	0.062
		50	0/2	<MDL	<MDL	NA	<MDL	0.061	0.062
		130	0/3	<MDL	<MDL	NA	<MDL	0.061	0.062
Endosulfan I	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.028
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.028
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Endosulfan II	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Endosulfan Sulfate	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Endrin	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Endrin Aldehyde	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Gamma-BHC (Lindane)	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Heptachlor	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Heptachlor Epoxide	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/9	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		130	0/10	<MDL	<MDL	NA	<MDL	0.0047	0.0048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Hexachlorocyclopentadiene	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.24	0.24
		50	0/3	<MDL	<MDL	NA	<MDL	0.24	0.24
		130	0/3	<MDL	<MDL	NA	<MDL	0.24	0.24
MCPA	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.08	0.19
		50	0/2	<MDL	<MDL	NA	<MDL	0.08	0.19
		130	0/3	<MDL	<MDL	NA	<MDL	0.08	0.19
MCPP	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.079	0.11
		50	0/2	<MDL	<MDL	NA	<MDL	0.079	0.11
		130	0/3	<MDL	<MDL	NA	<MDL	0.079	0.11
Methoxychlor	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.024	0.024
		50	0/9	<MDL	<MDL	NA	<MDL	0.024	0.024
		130	0/10	<MDL	<MDL	NA	<MDL	0.024	0.024
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.024	0.024
		50	0/4	<MDL	<MDL	NA	<MDL	0.024	0.024
		75	0/5	<MDL	<MDL	NA	<MDL	0.024	0.024
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.024	0.024

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Toxaphene	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/9	<MDL	<MDL	NA	<MDL	0.047	0.048
		130	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
trans-Chlordane	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		50	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
		75	0/5	<MDL	<MDL	NA	<MDL	0.0047	0.0047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0047	0.0048
Organophosphate Pesticides									
Chlorpyrifos	South Plant Outfall	5	0/1	<MDL	<MDL	NA	<MDL	0.032	0.032
		50	0/1	<MDL	<MDL	NA	<MDL	0.032	0.032
		130	0/1	<MDL	<MDL	NA	<MDL	0.032	0.032
Diazinon	South Plant Outfall	5	0/1	<MDL	<MDL	NA	<MDL	0.041	0.041
		50	0/1	<MDL	<MDL	NA	<MDL	0.041	0.041
		130	0/1	<MDL	<MDL	NA	<MDL	0.041	0.041
Disulfoton	South Plant Outfall	5	0/1	<MDL	<MDL	NA	<MDL	0.025	0.025
		50	0/1	<MDL	<MDL	NA	<MDL	0.026	0.026
		130	0/1	<MDL	<MDL	NA	<MDL	0.025	0.025
Malathion	South Plant Outfall	5	0/1	<MDL	<MDL	NA	<MDL	0.45	0.45
		50	0/1	<MDL	<MDL	NA	<MDL	0.46	0.46
		130	0/1	<MDL	<MDL	NA	<MDL	0.45	0.45

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Parathion-Ethyl	South Plant Outfall	5	0/1	<MDL	<MDL	NA	<MDL	0.042	0.042
		50	0/1	<MDL	<MDL	NA	<MDL	0.043	0.043
		130	0/1	<MDL	<MDL	NA	<MDL	0.042	0.042
Parathion-Methyl	South Plant Outfall	5	0/1	<MDL	<MDL	NA	<MDL	0.034	0.034
		50	0/1	<MDL	<MDL	NA	<MDL	0.034	0.034
		130	0/1	<MDL	<MDL	NA	<MDL	0.034	0.034
Phorate	South Plant Outfall	5	0/1	<MDL	<MDL	NA	<MDL	0.031	0.031
		50	0/1	<MDL	<MDL	NA	<MDL	0.031	0.031
		130	0/1	<MDL	<MDL	NA	<MDL	0.031	0.031
Endocrine Disrupting Compounds (EDCs)									
Atrazine	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.047
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.048
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.049
Bis(2-ethylhexyl)adipate*	Central Elliott Bay	1	2/6	0.011	0.535	NA	0.011	0.094	0.134
		50	1/4	0.843	0.843	NA	<MDL	0.094	0.0952
		75	1/5	0.268	0.268	NA	<MDL	0.094	0.0943
	Seattle Waterfront	1	1/4	0.266	0.266	NA	<MDL	0.0096	0.0952
Bisphenol A*	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.094	0.0952
		50	0/4	<MDL	<MDL	NA	<MDL	0.094	0.0952
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0943
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.094	0.0962

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Estradiol	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0094
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0096
Estrone	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0094
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0096
Ethinyl estradiol	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0094
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0096
Methyltestosterone	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0094
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0096
Progesterone	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0094
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0096
Testosterone	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0094
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0096

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Total 4-Nonylphenol	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.101
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.0943
		75	1/5	0.096	0.096	NA	<MDL	0.047	0.0943
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.048	0.0986
Vinclozolin	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0094
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0096
LPAHs									
2-Chloronaphthalene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.14
2-Chloronaphthalene	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0098
2-Methylnaphthalene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.047	0.38
		50	0/12	<MDL	<MDL	NA	<MDL	0.047	0.38
		130	0/11	<MDL	<MDL	NA	<MDL	0.047	0.38
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.094	0.094
		50	0/4	<MDL	<MDL	NA	<MDL	0.094	0.095
		75	0/5	<MDL	<MDL	NA	<MDL	0.094	0.095
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.094	0.098

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Acenaphthene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.094
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.094
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.096
	Central Elliott Bay	1	2/6	0.014	0.018	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	3/4	0.011	0.045	0.02	0.011	0.0098	0.0098
Acenaphthylene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.14
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0098
Anthracene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.14
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	1/4	0.019	0.019	NA	<MDL	0.0094	0.0098

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Fluorene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.14
	Central Elliott Bay	1	2/6	0.0097	0.01	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	1/4	0.0336	0.0336	NA	<MDL	0.0094	0.0098
Naphthalene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.012	0.38
		50	0/12	<MDL	<MDL	NA	<MDL	0.012	0.38
		130	0/11	<MDL	<MDL	NA	<MDL	0.012	0.38
	Central Elliott Bay	1	2/6	0.029	0.031	NA	<MDL	0.024	0.024
		50	0/4	<MDL	<MDL	NA	<MDL	0.024	0.024
		75	0/5	<MDL	<MDL	NA	<MDL	0.024	0.024
	Seattle Waterfront	1	1/4	0.0813	0.0813	NA	<MDL	0.024	0.025
Phenanthrene	South Plant Outfall	5	2/14	0.0052	0.0063	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.14
Phenanthrene	Central Elliott Bay	1	3/6	0.01	0.0249	0.0146	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	3/4	0.014	0.0847	0.0324	0.014	0.0098	0.0098

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
HPAHs									
Benzo(a)anthracene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.012	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.012	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.012	0.14
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.024	0.024
		50	0/4	<MDL	<MDL	NA	<MDL	0.024	0.024
		75	0/5	<MDL	<MDL	NA	<MDL	0.024	0.024
	Seattle Waterfront	1	1/4	0.041	0.041	NA	<MDL	0.024	0.025
Benzo(a)pyrene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.24
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	1/4	0.015	0.015	NA	<MDL	0.0094	0.0098
Benzo(b)fluoranthene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.38
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.38
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.38
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	2/4	0.01	0.0734	NA	<MDL	0.0094	0.0095

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Benzo(g,h,i)perylene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.024	0.24
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.094	0.094
		50	0/4	<MDL	<MDL	NA	<MDL	0.094	0.095
		75	0/5	<MDL	<MDL	NA	<MDL	0.094	0.095
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.094	0.098
Benzo(k)fluoranthene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.38
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.38
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.38
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	1/4	0.0386	0.0386	NA	<MDL	0.0094	0.0098
Chrysene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.012	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.012	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.012	0.14
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.024	0.024
		50	0/4	<MDL	<MDL	NA	<MDL	0.024	0.024
		75	0/5	<MDL	<MDL	NA	<MDL	0.024	0.024
	Seattle Waterfront	1	1/4	0.0616	0.0616	NA	<MDL	0.024	0.025
Dibenzo(a,h)anthracene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.38
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.38
		130	0/11	<MDL	<MDL	NA	<MDL	0.024	0.38

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Dibenzo(a,h)anthracene	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.094	0.094
		50	0/4	<MDL	<MDL	NA	<MDL	0.094	0.095
		75	0/5	<MDL	<MDL	NA	<MDL	0.094	0.095
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.094	0.098
Fluoranthene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.14
	Central Elliott Bay	1	4/6	0.011	0.019	0.0135	0.011	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	4/4	0.012	0.0813	0.034	0.017	NA	NA
Indeno(1,2,3-CD)Pyrene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.024	0.24
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.094	0.094
		50	0/4	<MDL	<MDL	NA	<MDL	0.094	0.095
		75	0/5	<MDL	<MDL	NA	<MDL	0.094	0.095
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.094	0.098
Pyrene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.14
	Central Elliott Bay	1	1/6	0.012	0.012	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	3/4	0.011	0.0388	0.0187	0.011	0.0094	0.0094

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
PCBs									
Aroclor 1016	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/9	<MDL	<MDL	NA	<MDL	0.047	0.048
		130	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
Aroclor 1221	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/9	<MDL	<MDL	NA	<MDL	0.047	0.048
		130	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
Aroclor 1232	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/9	<MDL	<MDL	NA	<MDL	0.047	0.048
		130	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
Aroclor 1242	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/9	<MDL	<MDL	NA	<MDL	0.047	0.048
		130	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Aroclor 1242	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
Aroclor 1248	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/9	<MDL	<MDL	NA	<MDL	0.047	0.048
		130	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
Aroclor 1254	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/9	<MDL	<MDL	NA	<MDL	0.047	0.048
		130	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
Aroclor 1260	South Plant Outfall	5	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/9	<MDL	<MDL	NA	<MDL	0.047	0.048
		130	0/10	<MDL	<MDL	NA	<MDL	0.047	0.048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.048
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.047
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Total PCBs (congeners) [#]	Central Elliott Bay	15	4/4	56.3	89.5	74.4	75.9	NA	NA
Semi-Volatiles Organic Compounds (SVOCs)									
1,2-Dichlorobenzene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.024	0.14
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.047
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.048
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.049
	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.47	0.47
		50	0/3	<MDL	<MDL	NA	<MDL	0.47	0.47
		130	0/3	<MDL	<MDL	NA	<MDL	0.47	0.48
1,2,4-Trichlorobenzene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.14
1,3-Dichlorobenzene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.024	0.14
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.047
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.048
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.049
	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.024	0.14

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
1,4-Dichlorobenzene	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.047	0.047
		50	0/4	<MDL	<MDL	NA	<MDL	0.047	0.048
		75	0/5	<MDL	<MDL	NA	<MDL	0.047	0.048
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.047	0.049
2-Chlorophenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.047	0.47
		50	0/12	<MDL	<MDL	NA	<MDL	0.047	0.47
		130	0/12	<MDL	<MDL	NA	<MDL	0.047	0.48
2-Methylphenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.12	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.12	0.24
		130	0/12	<MDL	<MDL	NA	<MDL	0.12	0.24
2-Nitroaniline	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.047	0.94
		50	0/12	<MDL	<MDL	NA	<MDL	0.047	0.94
		130	0/11	<MDL	<MDL	NA	<MDL	0.047	0.96
2-Nitrophenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.24
		130	0/12	<MDL	<MDL	NA	<MDL	0.024	0.24
2,4-Dichlorophenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.047	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.047	0.24
		130	0/12	<MDL	<MDL	NA	<MDL	0.047	0.24
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.47	0.47
		50	0/4	<MDL	<MDL	NA	<MDL	0.47	0.48
		75	0/5	<MDL	<MDL	NA	<MDL	0.47	0.48
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.47	0.49
2,4-Dimethylphenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.24	0.71
		50	0/12	<MDL	<MDL	NA	<MDL	0.24	0.71
		130	0/12	<MDL	<MDL	NA	<MDL	0.24	0.71

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
2,4-Dinitrophenol	South Plant Outfall	5	0/9	<MDL	<MDL	NA	<MDL	0.47	0.48
		50	0/7	<MDL	<MDL	NA	<MDL	0.47	0.48
		130	0/8	<MDL	<MDL	NA	<MDL	0.47	0.48
2,4-Dinitrotoluene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.094
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.094
		130	0/11	<MDL	<MDL	NA	<MDL	0.024	0.096
2,4,5-Trichlorophenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.059	0.94
		50	0/12	<MDL	<MDL	NA	<MDL	0.059	0.94
		130	0/12	<MDL	<MDL	NA	<MDL	0.059	0.96
2,4,6-Trichlorophenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.94
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.94
		130	0/12	<MDL	<MDL	NA	<MDL	0.024	0.96
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.47	0.47
		50	0/4	<MDL	<MDL	NA	<MDL	0.47	0.48
		75	0/5	<MDL	<MDL	NA	<MDL	0.47	0.48
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.47	0.49
2,6-Dinitrotoluene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.024	0.094
		50	0/12	<MDL	<MDL	NA	<MDL	0.024	0.094
		130	0/11	<MDL	<MDL	NA	<MDL	0.024	0.096
3-Nitroaniline	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.24	0.94
		50	0/12	<MDL	<MDL	NA	<MDL	0.24	0.94
		130	0/11	<MDL	<MDL	NA	<MDL	0.24	0.96
3,3'-Dichlorobenzidine	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.24	0.36
		50	0/12	<MDL	<MDL	NA	<MDL	0.24	0.36
		130	0/11	<MDL	<MDL	NA	<MDL	0.24	0.36

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
4-Bromophenyl Phenyl Ether	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.012	0.094
		50	0/12	<MDL	<MDL	NA	<MDL	0.012	0.094
		130	0/11	<MDL	<MDL	NA	<MDL	0.012	0.096
4-Chloro-3-Methylphenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.12	0.47
		50	0/12	<MDL	<MDL	NA	<MDL	0.12	0.47
		130	0/12	<MDL	<MDL	NA	<MDL	0.12	0.48
4-Chloroaniline	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.12	0.47
		50	0/12	<MDL	<MDL	NA	<MDL	0.12	0.47
		130	0/11	<MDL	<MDL	NA	<MDL	0.12	0.48
4-Chlorophenyl Phenyl Ether	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.012	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.012	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.012	0.14
4-Methylphenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.12	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.12	0.24
		130	0/12	<MDL	<MDL	NA	<MDL	0.12	0.24
4-Nitroaniline	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.24	0.94
		50	0/12	<MDL	<MDL	NA	<MDL	0.24	0.94
		130	0/11	<MDL	<MDL	NA	<MDL	0.24	0.96
4-Nitrophenol	South Plant Outfall	5	0/11	<MDL	<MDL	NA	<MDL	0.24	0.47
		50	0/10	<MDL	<MDL	NA	<MDL	0.24	0.47
		130	0/10	<MDL	<MDL	NA	<MDL	0.24	0.48
4,6-Dinitro-O-Cresol	South Plant Outfall	5	0/9	<MDL	<MDL	NA	<MDL	0.47	0.48
		50	0/8	<MDL	<MDL	NA	<MDL	0.47	0.48
		130	0/9	<MDL	<MDL	NA	<MDL	0.47	0.48
Aniline	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	0.47	0.47
		50	0/3	<MDL	<MDL	NA	<MDL	0.47	0.47
		130	0/3	<MDL	<MDL	NA	<MDL	0.47	0.48

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Benzidine	South Plant Outfall	5	0/3	<MDL	<MDL	NA	<MDL	5.7	5.7
		50	0/3	<MDL	<MDL	NA	<MDL	5.7	5.7
		130	0/3	<MDL	<MDL	NA	<MDL	5.7	5.8
Benzoic Acid*	South Plant Outfall	5	2/9	0.19	0.19	NA	0.19	0.12	0.94
		50	0/8	<MDL	<MDL	NA	<MDL	0.12	0.94
		130	1/8	0.567	0.567	NA	<MDL	0.12	0.96
Benzyl Alcohol	South Plant Outfall	5	1/6	0.35	0.35	NA	<MDL	0.12	0.24
		50	1/6	0.26	0.26	NA	<MDL	0.12	0.24
		130	0/5	<MDL	<MDL	NA	<MDL	0.12	0.24
Benzyl Butyl Phthalate*	South Plant Outfall	5	1/14	0.0179	0.0179	NA	<MDL	0.0047	0.14
		50	1/12	0.0189	0.0189	NA	<MDL	0.0118	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0118	0.14
	Central Elliott Bay	1	1/6	0.01	0.01	NA	0.01	0.0236	0.0897
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0955
		75	0/5	<MDL	<MDL	NA	<MDL	0.0095	0.0525
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0236	0.063
Bis(2-Chloroethoxy)Methane	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.24
Bis(2-Chloroethyl)Ether	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.14
Bis(2-Chloroisopropyl)Ether	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.47
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.47
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.48

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Bis(2-Ethylhexyl)Phthalate*	South Plant Outfall	5	3/14	0.15	10.5	0.966	<MDL	0.101	0.377
		50	2/12	0.2	0.34	NA	<MDL	0.128	0.597
		130	3/11	1.22	3.67	1.51	<MDL	0.101	0.808
	Central Elliott Bay	1	1/6	2.05	2.05	NA	<MDL	0.0804	0.37
		50	0/4	<MDL	<MDL	NA	<MDL	0.0723	0.512
		75	0/5	<MDL	<MDL	NA	<MDL	0.166	1.53
	Seattle Waterfront	1	1/4	1.71	1.71	NA	<MDL	0.183	1.54
Caffeine	South Plant Outfall	5	9/14	0.0057	0.0118	0.0080 7	0.0074	0.0048	0.047
		50	7/12	0.0066	0.012	0.0082 6	0.0082	0.0047	0.047
		130	8/11	0.006	0.011	0.0082 7	0.0084	0.047	0.048
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.024
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.024
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.024
	Seattle Waterfront	1	1/4	0.015	0.015	NA	0.015	0.024	0.025
Carbazole	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.012	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.012	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.012	0.24
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.024	0.024
		50	0/4	<MDL	<MDL	NA	<MDL	0.024	0.024
		75	0/5	<MDL	<MDL	NA	<MDL	0.024	0.024
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.024	0.025
Coprostanol	South Plant Outfall	5	0/7	<MDL	<MDL	NA	<MDL	0.24	2.4
		50	0/7	<MDL	<MDL	NA	<MDL	0.24	2.4
		130	0/8	<MDL	<MDL	NA	<MDL	0.24	2.4

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Di-N-Butyl Phthalate*	South Plant Outfall	5	1/14	0.0529	0.0529	NA	<MDL	0.0267	0.24
		50	1/12	0.0601	0.0601	NA	<MDL	0.033	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.0404	0.24
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0506	0.129
		50	0/4	<MDL	<MDL	NA	<MDL	0.0357	0.108
		75	0/5	<MDL	<MDL	NA	<MDL	0.0296	0.166
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0319	0.104
Di-N-Octyl Phthalate*	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.14
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.14
		130	2/11	0.0081	0.0139	NA	<MDL	0.0047	0.14
Dibenzofuran	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.24
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0094	0.0094
		50	0/4	<MDL	<MDL	NA	<MDL	0.0094	0.0095
		75	0/5	<MDL	<MDL	NA	<MDL	0.0094	0.0095
	Seattle Waterfront	1	1/4	0.0271	0.0271	NA	<MDL	0.0094	0.0098
Diethyl Phthalate*	South Plant Outfall	5	1/14	0.0235	0.0235	NA	<MDL	0.0119	0.24
		50	1/12	0.0201	0.0201	NA	<MDL	0.0124	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.0141	0.24
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.0236	0.0495
		50	0/4	<MDL	<MDL	NA	<MDL	0.0236	0.0383
		75	0/5	<MDL	<MDL	NA	<MDL	0.0236	0.0413
Diethyl Phthalate*	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.0236	0.0344

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
Dimethyl Phthalate	South Plant Outfall	5	1/14	0.0052	0.0052	NA	<MDL	0.0047	0.094
		50	1/12	0.0054	0.0054	NA	<MDL	0.0047	0.094
		130	1/11	0.013	0.013	NA	<MDL	0.0047	0.096
Hexachlorobenzene	South Plant Outfall	5	0/12	<MDL	<MDL	NA	<MDL	0.012	0.14
		50	0/11	<MDL	<MDL	NA	<MDL	0.012	0.14
		130	0/10	<MDL	<MDL	NA	<MDL	0.012	0.14
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.024	0.024
		50	0/4	<MDL	<MDL	NA	<MDL	0.024	0.024
		75	0/5	<MDL	<MDL	NA	<MDL	0.024	0.024
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.024	0.025
Hexachlorobutadiene	South Plant Outfall	5	0/13	<MDL	<MDL	NA	<MDL	0.024	0.24
		50	0/11	<MDL	<MDL	NA	<MDL	0.024	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.024	0.24
Hexachloroethane	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.012	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.012	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.012	0.24
Isophorone	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.24
Nitrobenzene	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.0047	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.0047	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.0047	0.24
N-Nitrosodi-N-Propylamine	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.047	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.047	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.047	0.24

Parameter	Site	Depth	FOD	Min.	Max.	Mean	Median	Min. MDL for Non-Detects	Max. MDL for Non-Detects
N-Nitrosodimethylamine	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.012	0.94
		50	0/12	<MDL	<MDL	NA	<MDL	0.012	0.94
		130	0/11	<MDL	<MDL	NA	<MDL	0.012	0.96
N-Nitrosodiphenylamine	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.12	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.12	0.24
		130	0/11	<MDL	<MDL	NA	<MDL	0.12	0.24
Pentachlorophenol	South Plant Outfall	5	0/14	<MDL	<MDL	NA	<MDL	0.059	0.24
		50	0/12	<MDL	<MDL	NA	<MDL	0.059	0.24
		130	0/12	<MDL	<MDL	NA	<MDL	0.059	0.24
	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.47	0.94
		50	0/4	<MDL	<MDL	NA	<MDL	0.47	0.95
		75	0/5	<MDL	<MDL	NA	<MDL	0.47	0.95
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.47	0.98
	South Plant Outfall	5	4/14	0.047	0.092	0.0555	<MDL	0.047	0.94
		50	3/12	0.05	0.08	0.0559	<MDL	0.047	0.94
		130	4/12	0.05	0.087	0.0553	<MDL	0.047	0.96
Phenol	Central Elliott Bay	1	0/6	<MDL	<MDL	NA	<MDL	0.47	0.47
		50	0/4	<MDL	<MDL	NA	<MDL	0.47	0.48
		75	0/5	<MDL	<MDL	NA	<MDL	0.47	0.48
	Seattle Waterfront	1	0/4	<MDL	<MDL	NA	<MDL	0.47	0.49

Means for parameters with non-detects were calculated using a Kaplan-Meier estimator when $n > 2$.

FOD = Frequency of detection; MDL = method detection limit.

* = Blank contamination present in at least some samples analyzed (treated as non-detects and handled according to Table A-1 in Appendix A).

= Total PCB congeners after blank quantification (King County, 2006. Technical memorandum: Duwamish River/Elliott Bay/Green River water column PCB congener survey transmittal of data and quality assurance documentation. King County, Department of Natural Resources and Parks, Seattle, WA).

Appendix C: Sediment Chemistry

This section summarizes King County data from several recent marine sediment monitoring programs from 2010 to 2013, including a total of 31 samples, and analyzes long-term trends in metals, PAHs, and PCB Aroclors at ambient sites sampled from 1992 to 2013. Conventional parameters (particle size distribution, total organic carbon, and total solids) and the 47 priority pollutants listed as part of Ecology's Sediment Management Standards (SMS) (Ecology, 2013) were measured from 2010 to 2013 for all programs and are analyzed using the same methods at the KCEL. Because all data (excluding trends data) discussed here were collected within four years of each other, detection limits are similar and therefore comparable; however, collection methods differed, as discussed below.

King County's marine ambient subtidal sediment monitoring program includes eight sites in Elliott Bay monitored every two years. All but one of these sites are located within inner Elliott Bay; the other site (Outer Elliott Bay) is located in the center of the border between the inner and outer bay. Four sites were added in 2007, while the original four have been sampled longer (since 1988 for one site). Samples were collected from the top 2 cm of a dual tandem 0.1 m² modified, stainless steel van Veen grab following the Puget Sound Estuary Program's (PSEP) Puget Sound Protocols (PSEP, 1997); for more details on sample collection and analytical methods, see King County, 2011a. In 2010 the county collected intertidal sediment samples throughout Central Puget Sound as part of a routine monitoring program. Two sites in the study area were sampled (Magnolia Outfall and West Point S). Intertidal samples were collected from the top 5 cm of sediment cores. For details on intertidal sediment sampling and analytical methods, see King County, 2010b. In addition to priority pollutants, PBDEs congeners were analyzed at both intertidal and subtidal ambient sites in recent years.

King County also collects targeted samples near CSO outfalls and sediment remediation sites. In 2011, a total of 12 sites located near two King County outfalls (Magnolia and 53rd Ave) in Elliott Bay were sampled as part of the County's Sediment Management Program. The top 10 cm of sediment were collected from a dual tandem 0.1 m² modified van Veen grab sample, which represent the biologically-active zone; details on sediment collection and analytical methods for CSO sediment monitoring can be found in King County, 2011b. Seven sites near the newly extended (2005) Elliott West/Denny Way outfall have been sampled as recently as 2012. Sediments around the outfall have been capped, dredged and filled, or are being monitored for natural recovery. Sampling data presented here were collected from the top 2 cm of sediment from a dual tandem 0.1 m² modified van Veen grab sample. More details on the history of this site and sampling/analytical methods can be found in King County, 2012. A list of all sampling sites, localities, and depth of sediment sampled are available in Table C-1 and localities are displayed in Figure C-1.

Prior to discussion of results of this analysis, it should be noted that differences in sampling depth among data described should be compared with caution. The SMS criteria, which were developed to be protective of aquatic life, were developed using various bioassays using sediments collected from the top 0-10 cm (biologically active zone) and, therefore,

sediments collected from 0-10 cm should be compared to these criteria. Sediments composited from less than 10 cm do not contain the entire biologically active zone and only include more recent deposition. In order to make some conclusions about sediment contamination at various sites within Elliott Bay, all samples were compared to SMS, although this might not be appropriate for all samples.

Table C-1 King County sediment monitoring sites in Elliott Bay sampled between 2010 and 2013.

	Locator	Description	Northing	Easting	Ambient vs Outfall	Depth (m)	Year(s) Sampled	Strata Depth (cm)
Routine Monitoring	KSSN05	West Point S	245272	1245980	Outfall	NA	1994-2010	5
	KSYV02	Magnolia Outfall	234547	1254488	Outfall	NA	2010	5
	KSZY01	Piers 90/91	231983	1258639	Ambient	20	2007-pres.	2
	LSCW02	Outer Elliott Bay	227106	1256271	Ambient	181	1991-pres.	2
	LSHZ08	Seacrest Park	218767	1259170	Ambient	22	2007-pres.	2
	LTAA02	Grain Terminal	231054	1261260	Ambient	24	2007-pres.	2
	LTCA02	Western Elliott Bay	226303	1260915	Ambient	132	1991-pres.	2
	LTDF01	Pier 66	225367	1267270	Ambient	29	1988-pres.	2
	LTED04	Central Elliott Bay	223909	1264675	Ambient	92	1992-pres.	2
	LTGF01	Harbor Island	218854	1265592	Ambient	32	2007-pres.	2
Targeted CSOs	CSO-53-1	53rd Ave.	217294	1253159	Outfall	9	2011	10
	CSO-53-2	53rd Ave.	217246	1253104	Outfall	9	2011	10
	CSO-53-3	53rd Ave.	217328	1253214	Outfall	8	2011	10
	CSO-53-4	53rd Ave.	217315	1253098	Outfall	11	2011	10
	CSO-53-5	53rd Ave.	217358	1253150	Outfall	10	2011	10
	CSO-53-6	53rd Ave.	217386	1253088	Outfall	13	2011	10
	CSO-MG-1	Magnolia	233763	1254386	Outfall	5	2011	10
	CSO-MG-2	Magnolia	233758	1254460	Outfall	4	2011	10
	CSO-MG-3	Magnolia	233766	1254315	Outfall	4	2011	10
	CSO-MG-4	Magnolia	233706	1254417	Outfall	5	2011	10
	CSO-MG-5	Magnolia	233709	1254348	Outfall	5	2011	10
	CSO-MG-6	Magnolia	233645	1254380	Outfall	6	2012	10
	DWMP-01	Denny Way	228813	1264047	Outfall	11	2012	2
	DWMP-02	Denny Way	228770	1263919	Outfall	14	2012	2
	DWMP-03	Denny Way	228638	1263846	Outfall	18	2012	2
	DWMP-08	Denny Way	228907	1263341	Outfall	26	2012	2
	DWMP-10	Denny Way	229326	1263565	Outfall	6	2012	2
	DWMP-14	Denny Way	229553	1263228	Outfall	14	2012	2
	DWMP-15	Denny Way	229444	1263053	Outfall	23	2012	2

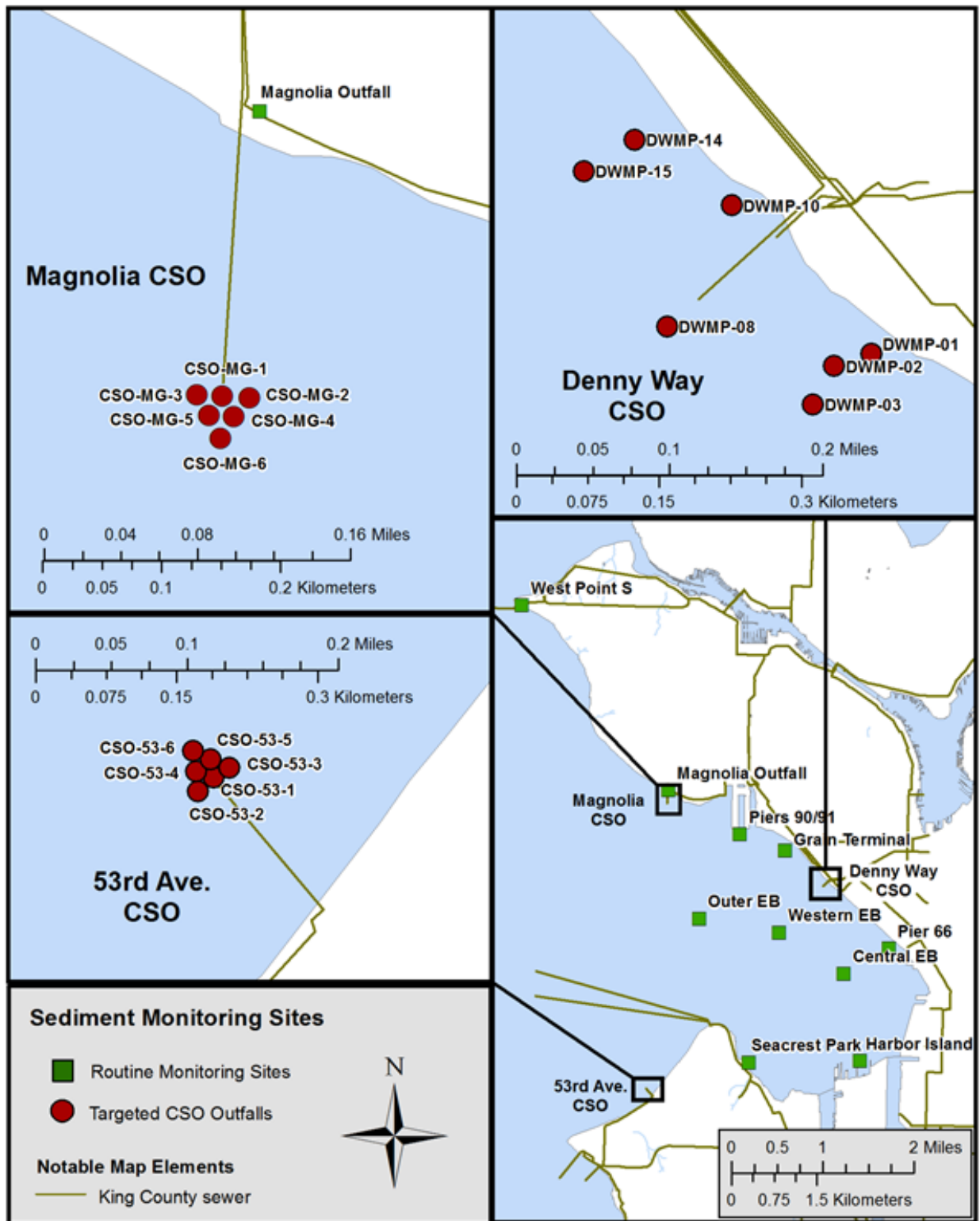


Figure C-1 Routine monitoring and targeted CSO outfall sampling sites in Elliott Bay and adjacent Puget Sound.

Conventionals

All sediment samples were analyzed for grain-size distribution, total organic carbon, and total solids. The physical structure of marine sediments affects the distribution and concentration of metals and organic chemicals. For example, chemical concentrations are often expected to be higher at sites with more fine particles due to the increased surface area for chemicals to bond to; in addition, those with higher concentrations of total organic carbon (TOC) which can increase binding of some organic compounds (Wenning et al., 2005).

Percent fines (silt + clay) ranged from non-detect to 83.1%, while sands ranged from 8.5 to 97.9%, and gravel ranged from non-detect to 57.1% (Table C-2). Overall, sediments at intertidal sites were dominated by gravel. In contrast, deep sites, those located nearest the outlet of the Duwamish River, and sites surrounding the Denny Way CSO (excluding DWMP-10 which had been dredged and refilled), had the highest percentage of fine sediments (Figure C-2). The sites surrounding the Magnolia and 53rd Ave. CSOs had low percentages of fine sediments, which is consistent with Ecology's study in Elliott Bay, which found that sediments collected near the shoreline of Outer Elliott Bay had higher percentages of sand than within most of the inner bay (Ecology, 2009). Total organic carbon concentrations ranged from 0.05 to 4.02% and followed similar patterns as with particle size distributions; sites with higher percentages of fines had higher concentrations of TOC (Figure C-3). The largest outlier was Pier 66 located along the Seattle waterfront, which had 3.56% TOC despite having only 42.3% fines. The high percentage of TOC may be anthropogenically enhanced due to the abundance of aged wood pilings along the waterfront.

Table C-2 Conventional sediment parameters at King County monitoring sites in Elliott Bay and adjacent Puget Sound sampled between 2010 and 2013.

	Site	Depth (m)	% Solids	% Fines	% Sand	% Gravel	% Total Organic Carbon
Routine Monitoring	West Point S	NA	95.1	0.5	42.5	57.1	0.05
	Magnolia Outfall	NA	96.9	< MDL	45.0	53.8	0.08
	Piers 90/91	20	73.1	14.3	74.6	11.4	0.75
	Outer Elliott Bay	181	38.7	66.9	25.0	< MDL	1.84
	Seacrest Park	22	62.8	22.2	48.3	24.5	1.22
	Grain Terminal	24	73.7	10.6	85.6	1.8	0.33
	Western Elliott Bay	132	33.9	83.1	8.5	< MDL	1.97
	Pier 66	29	45.5	42.3	45.1	3.0	3.56
	Central Elliott Bay	92	39	76.3	17.4	< MDL	2.07
	Harbor Island	32	57.6	35.9	55.2	0.4	1.32
Targeted CSOs	CSO-53-1	9	68.2	4.6	65.0	26.5	0.29
	CSO-53-2	9	73.5	3.9	97.1	0.6	0.07
	CSO-53-3	8	72.7	2.6	96.0	< MDL	0.10
	CSO-53-4	11	71.9	4.1	97.9	< MDL	0.21
	CSO-53-5	10	64.4	3.7	96.7	< MDL	0.19
	CSO-53-6	13	60.4	10.4	87.6	0.7	1.23
	CSO-MG-1	5	75.6	3.9	92.0	3.6	0.38
	CSO-MG-2	4	75.3	4.7	52.7	41.7	0.53
	CSO-MG-3	4	75.5	4.5	92.4	2.4	0.20
	CSO-MG-4	5	75.9	4.5	92.8	2.3	0.25
	CSO-MG-5	5	78.8	4.9	92.7	2.0	0.15
	CSO-MG-6	6	75.8	3.8	95.3	< MDL	0.21
	DWMP-01	11	48.3	62.5	26.1	4.3	4.02
	DWMP-02	14	63.3	39.5	48.6	5.2	1.64
	DWMP-03	18	43.9	68.5	31.6	0.6	3.10
	DWMP-08	26	47.7	60.4	30.9	6.5	2.60
	DWMP-10	6	86.8	4.9	60.7	37.0	0.16
	DWMP-14	14	56.3	70.8	29.2	0.3	2.47
	DWMP-15	23	80.7	62.8	28.4	6.3	0.92

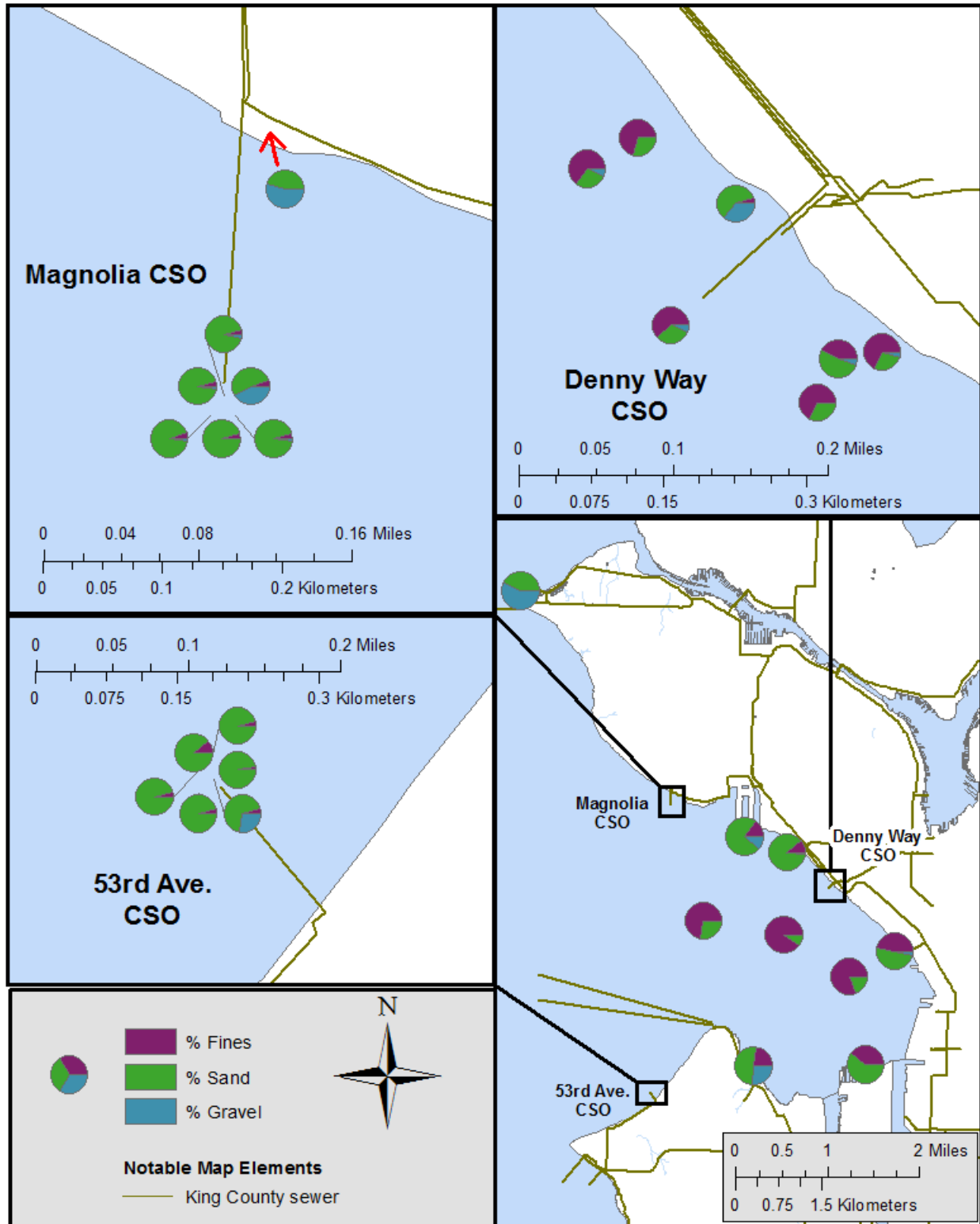


Figure C-2 Sediment grain size distribution in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013).

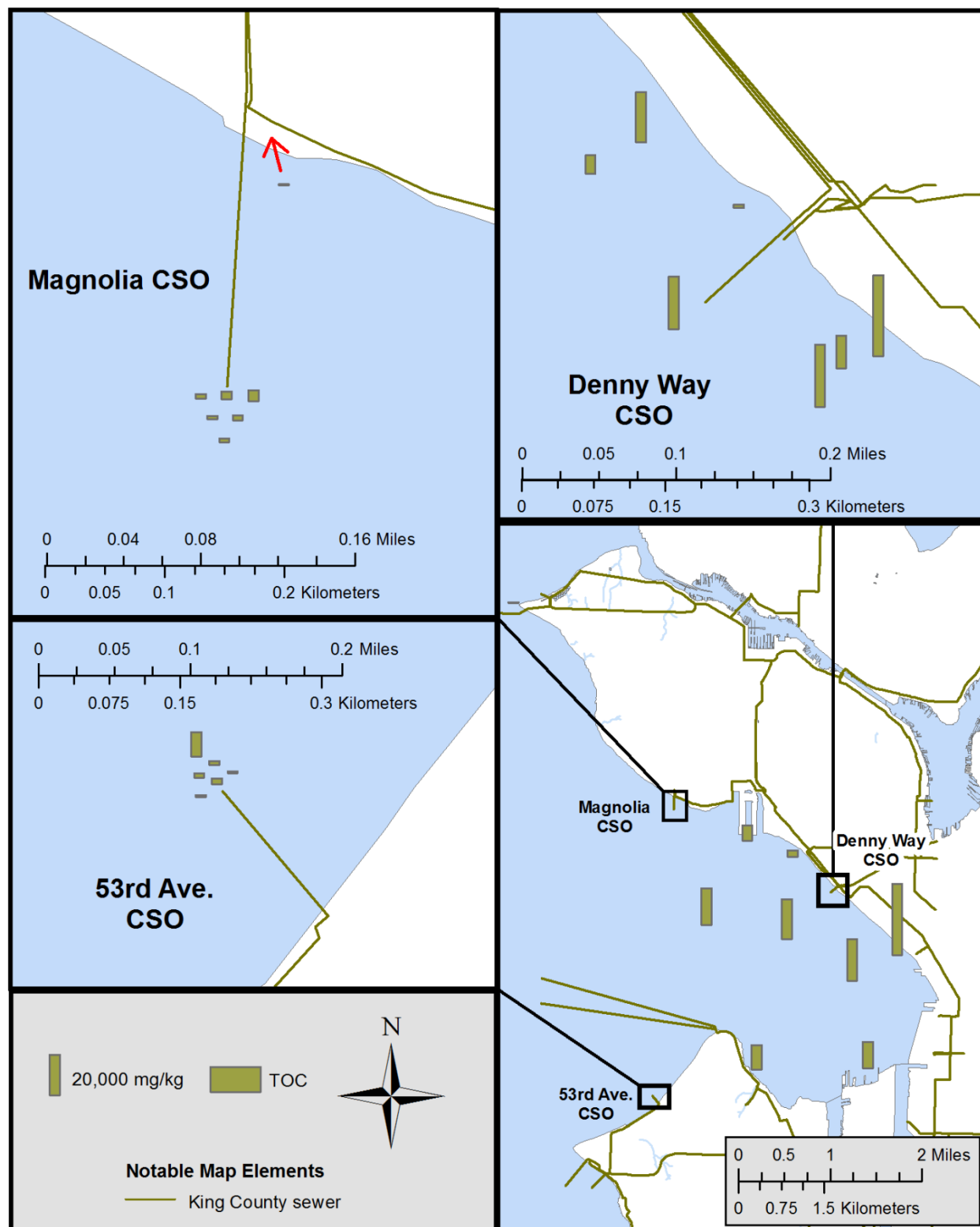


Figure C-3 Dry weight total organic carbon (TOC) in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013).

Metals

Current Conditions

Five metals were detected at all sites: chromium, copper, lead, mercury, and zinc. Additionally, nickel was detected at all sites where it was sampled but was only sampled at ambient monitoring sites. Three metals were not detected at all sites: arsenic, cadmium, and silver. Metals concentrations, including mercury, were highest near the Denny Way outfall (excluding DWMP-10), deep sites in Elliott Bay, and nearest the opening of the Duwamish River where percent fines were elevated (Tables C-3 to C-5 and Figures C-4 to C-6). Among ambient monitoring sites, the Pier 66 site of the waterfront had elevated concentrations of lead as noted in previous studies (e.g., King County, 2006), which may be due to the stations proximity to a Seattle CSO and several stormwater outfalls. Silver, an indicator of wastewater (Martin et al., 1988), had the highest concentrations along the Seattle waterfront and near the Denny Way CSO.

Metals data are dry weight-normalized for comparison to sediment chemical criteria from Tables I and III in the Washington State Sediment Management Standards (SMS) of Chapter 173-204 WAC (Ecology, 2013). Mercury was the only metal that was found at concentrations above the SMS at the sites in Elliott Bay. Three sites including one near the Denny Way outfall (DWMP-14), and the Pier 66 and Harbor Island sites were above the Sediment Quality Standard (SQS) of 0.41 mg/kg-dw. Two sites near Denny Way including one at the new outfall (DWMP-08) and one shallow site had mercury concentrations above the Cleanup Screening Levels (CSLs) (0.631 and 0.638 mg/kg-dw respectively). For a complete comparison of metals concentrations to SMS, see Tables C-3 through C-5.

Long Term Trends

Metals data from 1992 to 2013 were available for four sites within Elliott Bay. Long-term trends in DW-normalized metals concentrations were analyzed at these sites using simple linear regression. For metals with non-detect values, means and slopes were estimated using maximum likelihood estimation with the assumption of Gaussian/normal distribution (cenreg in NADA package for R: Lopaka, 2013). Overall, few changes were detected. Increasing trends were present at two sites for arsenic, two sites for cadmium, and one site for zinc. A decreasing trend in mercury was noted at one site (Pier 66), where recent sample concentrations were above the SQS for mercury; this site also saw a significant decrease in silver concentrations over the time period. A 2007 study in Elliott Bay by Ecology comparing metals concentrations in 1997 to 2007, found similar trends: lead, mercury, and silver concentrations had decreased while zinc concentrations increased (Ecology, 2009). Metals trend data can be found in Table C-6 and are graphically represented in Figure C-7.

Table C-3 Concentration of contaminants in intertidal (2010) and subtidal (2013) sediment collected at routine monitoring sites compared to state sediment quality criteria (5 cm and 2 cm respectively). Note that none of these samples contained the complete 10 cm of the biologically active zone. Sites with > 0.5% total organic carbon (TOC) were compared to sediment management standards (SQS or CSL), while sites with < 0.5% TOC were compared to apparent effects thresholds (SCO AET or CSL AET).

				Subtidal									Subtidal	Intertidal	
				Piers 90/91	Outer Elliott Bay	Seacrest Park	Western Elliott Bay	Harbor Island	Central Elliott Bay	Harbor Island			Grain Terminal	West Point S	Magnolia Outfall
	Metals	SQS/SCO mg/kg DW	CSL								SCO AET mg/kg DW	CSL AET			
Metals	Arsenic	57	93	4.2	8	7	10	11	11	6.8	57	93	3.5	1.7 (J)	4.2 (J)
	Cadmium	5.1	6.7	ND	0.28 (J)	ND	ND	0.24 (J)	0.38 (J)	0.23 (J)	5.1	6.7	0.18 (J)	ND	ND
	Chromium	260	270	18.2	37.2	55.4	40.4	37.8	35.4	21.4	260	270	23.3	12.7	9.04
	Copper	390	390	19.4	37.2	47	45.4	65.1	46.2	63.7	390	390	20.4 (J)	10.5	16.7
	Lead	450	530	21.2	25.8	52.5	35.4	60.9	33.6	36.8	450	530	12.8	2.0 (J)	5.0 (J)
	Mercury	0.41	0.59	0.269	0.234	0.147	0.295	0.457	0.264	0.509	0.41	0.59	0.101	0.0072 (J)	0.0072 (J)
	Silver	6.1	6.1	ND	ND	ND	ND	0.51 (J)	ND	ND	6.1	6.1	0.37 (J)	ND	ND
	Zinc	410	960	42	90.2	93	97.3	87.7	95.4	73.1	410	960	38.1	29.8	43.0
LPAHs	Lipophilic Organics	mg/kg OC									ug/kg DW				
	Acenaphthene	16	57	ND	ND	ND	ND	4.14	ND	2.68	500	500	9.1 (J)	ND	ND
	Acenaphthylene	66	66	2.11	ND	0.9 (J)	ND	2.55	ND	1.58	1300	1300	ND	ND	ND
	Anthracene	220	1,200	9.71	1.1 (J)	3.05	1 (J)	13.9	1.1 (J)	7.08	960	960	25.8	3.3 (J)	ND
	Fluorene	23	79	2.12	ND	ND	ND	4.44	ND	2.58	540	540	9.2 (J)	ND	ND
	2-Methylnaphthalene	38	64	ND	ND	ND	ND	2.28	ND	1.1 (J)	670	670	ND	ND	ND
	Naphthalene	99	170	ND	ND	ND	ND	3.7	ND	2	2100	2100	ND	ND	ND
	Phenanthrene	100	480	16.3	3.08	6.89	2.59	35.3	2.79	23.5	1500	1500	86.8	3.0 (J)	ND
HPAHs	Total LPAHs	370	780	30.3	4.17	10.8	3.61	64	3.9	39.5	5200	5200	131.0	6.34	ND
	Benzo(a)anthracene	110	270	20.3	3.17	7.3	2.62	22.8	2.94	18.70	1300	1600	56.2 (J)	2.3 (J)	3.3 (J)
	Benzo(a)pyrene	99	210	32.3	4.86	11.4	3.40	28.8	4.10	25.10	1600	1600	77.1 (J)	ND	3.1 (J)
	Benzo(a)fluoranthenes (Total)	230	450	70.2	9.84	23.8	6.89	58.5	9.0	52.9	3200	3600	157 (J)	ND	7.1 (J)
	Benzo(g,h,i)perylene	31	78	11.5	2.98	6.75	1.89	8.46	1.96	13.20	670	720	40 (J)	ND	ND
	Chrysene	110	460	39.6	4.31	14.9	3.62	39.4	4.89	37.60	1400	2800	83.3 (J)	8.39	3.8 (J)
	Dibenzo(a,h)anthracene	12	33	4.07	ND	2.28	ND	3.23	ND	4.95	230	230	12 (J)	ND	ND
	Fluoranthene	160	1,200	45.0	5.34	14.7	5.17	58.9	6.16	41.00	1,700	2,500	142 (J)	2.3 (J)	6.14
	Indeno(1,2,3-c,d)pyrene	34	88	16.3	3.75	9.15	2.35	12.10	2.60	17.50	600	690	52 (J)	ND	ND
	Pyrene	1,000	1,400	38.5	7.13	15.3	6.05	66.7	7.37	43.40	1,000	1,400	151 (J)	ND	4.85
Total HPAHs	960	5,300	278	41.4	106	32.0	299	39.0	254.0	12,000	17,000	771	13	28.4	
Chloro-benzenes	1,2-Dichlorobenzene	2.3	2.3	ND	ND	ND	ND	ND	ND	ND	35	50	ND	0.457 (B)	0.548
	1,4-Dichlorobenzene	3.1	9	ND	ND	ND	ND	ND	ND	ND	110	110	ND	0.581	0.561
	1,2,4-Trichlorobenzene	0.81	1.8	ND	ND	ND	ND	ND	ND	ND	31	51	ND	ND	ND
	Hexachlorobenzene	0.38	2.3	ND	ND	ND	ND	ND	ND	ND	22	70	ND	ND	0.362
Phthalates	Benzyl Butyl Phthalate	4.9	64	ND	ND	ND	ND	ND	ND	4.640	63	900	ND	ND	ND
	Bis(2-ethylhexyl) Phthalate	47	78	4.85	2 (J)	2.3 (J)	1.6 (J)	2.43	2.73	8.47	1300	1900	218	15.1	7.6
	Di-n-butyl Phthalate	220	1,700	ND	ND	ND	ND	ND	ND	ND	1,400	1,400	ND	6.4 (J,B)	6.6 (J,B)
	Di-n-octyl Phthalate	58	4,500	ND	ND	ND	ND	ND	ND	ND	6,200	6,200	ND	ND	ND
	Diethyl Phthalate	61	110	ND	ND	ND	ND	3.680	ND	ND	200	200	ND	ND	ND
	Dimethyl Phthalate	53	53	ND	ND	ND	ND	ND	ND	ND	71	160	ND	ND	ND
Misc. Organics	Dibenzofuran	15	58	1.1 (J)	ND	ND	ND	2.35	ND	1.96	540	540	7.3 (J)	ND	ND
	Hexachlorobutadiene	3.9	6.2	ND	ND	ND	ND	ND	ND	ND	11	120	ND	ND	ND
	N-Nitrosodiphenylamine	11	11	ND	ND	ND	ND	ND	ND	ND	11	11	ND	ND	ND
	Total PCBs (Aroclors)	12	65	6.53	2.57	5.21	2.47	3.84	3.74	15	130	1000	114	ND	ND
	Total PBDEs (congeners)	NA	NA	0.510	0.154	0.253	0.232	0.226	0.207	0.987	NA	NA	0.800	0.0717 (B)	0.0373 (B)
Hydrophilic Organics	Hydrophilic Organics	ug/kg DW									ug/kg DW				
	Benzoic Acid	650	650	ND	ND	ND	ND	ND	ND	ND	650	650	ND	59.9 (B)	53.0 (B)
	Benzyl Alcohol	57	73	ND	ND	ND	ND	ND	ND	ND	57	73	ND	ND	ND
	2-Methylphenol	63	63	ND	ND	ND	ND	ND	ND	ND	63	63	ND	ND	ND
	4-Methylphenol	670	670	ND	ND	ND	ND	ND	ND	ND	670	670	ND	ND	ND
	2,4-Dimethylphenol	29	29	ND	ND	ND	ND	ND	ND	ND	29	29	ND (J)	ND	ND
	Pentachlorophenol	360	690	ND	ND	ND	ND	ND	ND	ND	360	690	ND	ND	ND
	Phenol	420	1,200	ND	ND	ND	ND	ND	ND	ND	420	1,200	ND	ND	7.2 (J)

Notes

SQS - Sediment Quality Standard (173-204-320(2) WAC).

CSL - Cleanup Screening Level (173-204-520(2) WAC).

SCO AET - Sediment Cleanup Objective Apparent Effects Threshold EPA-910-9-88-246B.

CSL AET - Cleanup Screening Level Apparent Effects Threshold EPA-910-9-88-246B.

DW - normalized to dry weight (based on percent solids).

OC - normalized to organic carbon (based on TOC).

Yellow Cell - Analyte exceeds SQS chemical criterion.

Blue Cell - Analyte exceeds the CSL chemical criterion.

Purple Cells - Analyte exceeds the SCO AET chemical criterion

Green Cell - Analyte exceeds the CSL AET chemical criterion

ND - Analyte not detected.

J - Estimated concentration due to QC, or sample <RDL.

B - Blank contamination (<5x the sample value).

Table C-4 Concentrations of contaminants in sediments collected in 2011 from CSO outfalls compared to state sediment quality criteria (top 10 cm of strata). Sites with > 0.5% total organic carbon (TOC) were compared to sediment management standards (SQS or CSL), while sites with < 0.5% TOC were compared to apparent effects thresholds (SCO AET or CSL AET).

	Metals	SQS/SCO	CSL	CSO-MG-2	CSO053-6	SCO AET	CSL AET	CSO-MG-1	CSO-MG-3	CSO-MG-4	CSO-MG-5	CSO-MG-6	CSO-53-1	CSO-53-2	CSO-53-3	CSO-53-4	CSO-53-5
		mg/kg DW				mg/kg DW											
Metals	Arsenic	57	93	3.2 (J)	2.8 (J)	57	93	2.6	2.6	2.6	3.3	3.0	1.8	ND	ND	ND	2.0
	Cadmium	5.1	6.7	0.24 (J)	0.31 (J)	5.1	6.7	0.19	0.16	ND	ND	0.13	0.16	ND	ND	ND	ND
	Chromium	260	270	16.7	26.8	260	270	16.0	16.6	18.3	17.1	17.5	20.7	19.0	20.1	18.8	21.3
	Copper	390	390	14.5	13.2	390	390	18.3	9.15	8.33	7.30	7.48	23.5	4.83	4.87	5.47	6.10
	Lead	450	530	16.6	7.6 (J)	450	530	10.3	8.53	7.84	6.2	6.79	3.7	3.8	3.4	6.4	5.4
	Mercury	0.41	0.59	0.046 (J)	0.038 (J)	0.41	0.59	0.038 (J)	0.041 (J)	0.026 (J)	0.029 (J)	0.033 (J)	0.016 (J)	0.011 (J)	0.012 (J)	0.014 (J)	0.015 (J)
	Silver	6.1	6.1	ND	ND	6.1	6.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Zinc	410	960	43.7	39.6	410	960	56.0	29.7	28.1	26.6	23.5	30.5	24.8	25.7	26.1	30.1
	Lipophilic Organics	mg/kg OC				ug/kg DW											
LPAHs	Acenaphthene	16	57	ND	ND	500	500	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Acenaphthylene	66	66	ND	ND	1300	1300	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Anthracene	220	1,200	2.34	1.98	960	960	ND	9.7	7.9	8.50	13	16.6	ND	ND	ND	ND
	Fluorene	23	79	ND	ND	540	540	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Methylnaphthalene	38	64	ND	ND	670	670	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Naphthalene	99	170	ND	ND	2100	2100	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Phenanthrene	100	480	5.31	4.85	1500	1500	15.3	25.4	31.0	17.0	35.9	43.1	ND	ND	19.5	19.4
	Total LPAHs	370	780	7.65	6.82	5200	5200	15.3	35.1	38.9	25.5	48.9	59.7	ND	ND	19.5	19.4
HPAHs	Benzo(a)anthracene	110	270	8.62	4.02	1300	1600	28.7	30.6	42.4	24.4	45.4	50.3	ND	ND	17.1	22.5
	Benzo(a)pyrene	99	210	10.6	6.26	1600	1600	39.9	42.5	52.7	36.7	53.3	61.3	ND	ND	26.7	32.6
	Benzofluoranthenes (Total)	230	450	16.8	8.84	3200	3600	59.1	56.6	87.6	48.7	77.2	86.4	ND	ND	25.7	31.2
	Benzo(g,h,i)perylene	31	78	5.46 (J)	2.33 (J)	670	720	17.5	19.3	27.3	13	22.6	18.9	ND	ND	ND	ND
	Chrysene	110	460	8.94	5.22	1400	2800	28.3	27.8	52.0	23.1	40.6	54.7	ND	ND	14	16
	Dibenzo(a,h)anthracene	12	33	2.37	1.33	230	230	9.4	9.1	12	7.9	11	12	ND	ND	ND	8.5
	Fluoranthene	160	1,200	14.2	10.2	1,700	2,500	42.1	42.8	95.1	33.1	71.5	79.5	ND	ND	19.6	25.6
	Indeno(1,2,3-c,d)pyrene	34	88	6.15 (J)	3.00 (J)	600	690	23.5 (J)	24.8 (J)	33.1 (J)	19.0 (J)	29.8 (J)	25.2 (J)	ND	ND	11 (J)	14 (J)
Chloro-benzenes	Pyrene	1,000	1,400	12.6	8.40	1,000	1,400	36.8	37.6	76.9	29.8	62.3	65.4	ND	ND	21.4	23.8
	Total HPAHs	960	5,300	86	49.6	12,000	17,000	285	291	480	235	414	454	ND	ND	135	174
	1,2-Dichlorobenzene	2.3	2.3	ND	ND	35	50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,4-Dichlorobenzene	3.1	9	ND	ND	110	110	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,2,4-Trichlorobenzene	0.81	1.8	ND	ND	31	51	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Hexachlorobenzene	0.38	2.3	ND	ND	22	70	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Benzyl Butyl Phthalate	4.9	64	ND	ND	63	900	ND	ND	54.2 (J)	ND	ND	ND	ND	ND	ND	ND
	Bis(2-ethylhexyl) Phthalate	47	78	187 (B)	54.8 (B)	1300	1900	114 (B)	41.3 (B)	47.4 (B)	39.1 (B)	41.3 (B)	37.0 (B)	32.4 (B)	31.5 (B)	32.8 (B)	41.9 (B)
Phthalates	Di-n-butyl Phthalate	220	1,700	23 (J,B)	ND	1,400	1,400	57.4 (B)	19 (J,B)	20 (J,B)	19 (J,B)	25 (J,B)	16 (J)	16 (J)	15 (J)	17 (J)	17 (J)
	Di-n-octyl Phthalate	58	4,500	ND	ND	6,200	6,200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Diethyl Phthalate	61	110	ND	ND	200	200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Dimethyl Phthalate	53	53	ND	ND	71	160	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Dibenzofuran	15	58	ND	ND	540	540	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Hexachlorobutadiene	3.9	6.2	ND	ND	11	120	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	N-Nitrosodiphenylamine	11	11	ND	ND	11	11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Total PCBs (Aroclors)	12	65	1.37	1.02	130	1000	2.4	5.03	5.27	4.70	7.12	ND	ND	11.2	ND	6.69
Misc. Organics	Total PBDEs (congeners)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hydrophilic Organics	ug/kg DW				ug/kg DW											
	Benzoic Acid	650	650	234	233	650	650	181	159	177	157	158	214	ND	158 (J)	192	174
	Benzyl Alcohol	57	73	ND	ND	57	73	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Methylphenol	63	63	ND	ND	63	63	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4-Methylphenol	670	670	ND	ND	670	670	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,4-Dimethylphenol	29	29	ND	ND	29	29	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Pentachlorophenol	360	690	ND	ND	360	690	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hydrophilic Organics	Phenol	420	1,200	ND	ND	420	1,200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes

SQS - Sediment Quality Standard (173-204-320(2) WAC).

CSL - Cleanup Screening Level (173-204-520(2) WAC).

SCO AET - Sediment Cleanup Objective Apparent Effects Threshold EPA-910-9-88-246B.

CSL AET - Cleanup Screening Level Apparent Effects Threshold EPA-910-9-88-246B.

DW - normalized to dry weight (based on percent solids).

OC - normalized to organic carbon (based on TOC).

Yellow Cell - Analyte exceeds SQS chemical criterion.

Blue Cell - Analyte exceeds the CSL chemical criterion.

Purple Cells - Analyte exceeds the SCO AET chemical criterion

Green Cell - Analyte exceeds the CSL AET chemical criterion

ND - Analyte not detected.

J - Estimated concentration due to QC, or sample <RDL.

B - Blank contamination (<5x the sample value).

Table C-5 2012 sediment concentrations near the Denny Way outfall compared to state sediment quality criteria (top 2 cm of strata). Sites with > 0.5% total organic carbon (TOC) were compared to sediment management standards (SQS or CSL), while sites with < 0.5% TOC were compared to apparent effects thresholds (SCO AET or CSL AET).

	Metals	SQS/SCO	CSL	DWMP-01	DWMP-02	DWMP-03	DWMP-08	DWMP-14	DWMP-15	SCO AET	CSL AET	DWMP-10
		mg/kg DW								mg/kg DW		
Metals	Arsenic	57	93	12	6.6	9.8	9.4	8.2	5.7	57	93	2.2
	Cadmium	5.1	6.7	1.12	0.39	0.71	1.15	0.76	0.45	5.1	6.7	ND
	Chromium	260	270	48.2	40.3	43.3	47.0	44.2	38.0	260	270	13.8
	Copper	390	390	77.2	44.5	54.7	65.2	60.9	40.4	390	390	12.2
	Lead	450	530	134	56.7	69.7	99.4	92.5	44.2	450	530	3.6
	Mercury	0.41	0.59	0.638	0.30	0.41	0.631	0.485	0.284	0.41	0.59	0.028
	Silver	6.1	6.1	4.51	1.3	2.1	4.05	3.14	1.57	6.1	6.1	ND
	Zinc	410	960	142	92.6	106	127	111	75.0	410	960	28.5
	Lipophilic Organics	mg/kg OC								ug/kg DW		
LPAHs	Acenaphthene	16	57	1.96	1.72	6.73	0.943	1.22	1.0	500	500	ND
	Acenaphthylene	66	66	3.31	1.23 (J)	0.963	ND	0.877	ND	1300	1300	ND
	Anthracene	220	1,200	25.6	7.29	12.1	2.70	4.97	4.03	960	960	12 (J)
	Fluorene	23	79	3.24	2.20	5.74	0.984	1.42	1.1	540	540	ND
	2-Methylnaphthalene	38	64	1.14	0.78	2.06	0.911	0.877	ND	670	670	ND
	Naphthalene	99	170	1.71	0.88	2.36	1.09	1.14	0.74	2100	2100	ND
	Phenanthrene	100	480	24.6	23.4	43.9	7.03	15.5	12.5	1500	1500	19.7
	Total LPAHs	370	780	60.4	36.7	71.6	12.7	25.1	19.4	5200	5200	31.2
HPAHs	Benzo(a)anthracene	110	270	73.1	27.1 (J)	22.0	8.39	15.2	15.0	1300	1600	46.3
	Benzo(a)pyrene	99	210	117	34.0 (J)	28.7	13.1	25.0	19.2	1600	1600	50.0
	Benzo(a)fluoranthene (Total)	230	450	266	81.7 (J)	59.0	28.1	59.5	41.3	3200	3600	50.7
	Benzo(g,h,i)perylene	31	78	56.7	17.1 (J)	12.6	5.06	9.92	7.55	670	720	17.4
	Chrysene	110	460	146	41.7 (J)	29.0	12.1	21.9	21.2	1400	2800	51.8
	Dibenzo(a,h)anthracene	12	33	18.0	4.83 (J)	3.21	1.40	2.57	2.07	230	230	ND
	Fluoranthene	160	1,200	49.0	43.3 (J)	46.5	10.7	24.9	26.6	1,700	2,500	46.1
	Indeno(1,2,3-c,d)pyrene	34	88	60.2	17.1 (J)	12.2	4.61	10.0	7.29	600	690	15.2
	Pyrene	1,000	1,400	79.9	45.8	52.3	35.1	30.3	30.3	1,000	1,400	58.8
	Total HPAHs	960	5,300	866	313	265	118	199	171	12,000	17,000	336
Chloro-benzenes	1,2-Dichlorobenzene	2.3	2.3	ND	ND	ND	ND	ND	ND	35	50	ND
	1,4-Dichlorobenzene	3.1	9	ND	ND	ND	ND	ND	ND	110	110	ND
	1,2,4-Trichlorobenzene	0.81	1.8	ND	ND	ND	ND	ND	ND	31	51	ND
	Hexachlorobenzene	0.38	2.3	ND	ND	ND	ND	ND	ND	22	70	ND
Phthalates	Benzyl Butyl Phthalate	4.9	64	5.00	6.30	2.45	3.48	4.01	4.66	63	900	ND
	Bis(2-ethylhexyl) Phthalate	47	78	50.7	25 (J)	25.4	65.8	56.7	49.8	1300	1900	32.9 (B)
	Di-n-butyl Phthalate	220	1,700	1.34	1.5	0.88	1.1	1.5	ND	1,400	1,400	ND
	Di-n-octyl Phthalate	58	4,500	ND	ND	ND	ND	ND	ND	6,200	6,200	ND
	Diethyl Phthalate	61	110	ND	ND	ND	ND	ND	ND	200	200	ND
	Dimethyl Phthalate	53	53	14.5	ND	ND	ND	ND	ND	71	160	ND
Misc. Organics	Dibenzofuran	15	58	1.29	1.1 (J)	2.34	0.67 (J)	0.79 (J)	ND	540	540	ND
	Hexachlorobutadiene	3.9	6.2	ND	ND	ND	ND	ND	ND	11	120	ND
	N-Nitrosodiphenylamine	11	11	ND	ND	ND	ND	ND	ND	11	11	ND
	Total PCBs (Aroclors)	12	65	19.7	11.1	17.1	36.0	27.7	31.5	130	1000	ND
	Total PBDEs (congeners)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hydrophilic Organics	ug/kg DW								ug/kg DW		
Hydrophilic Organics	Benzoic Acid	650	650	793	597	815	761	652	450	650	650	440
	Benzyl Alcohol	57	73	37.7	ND	ND	ND	ND	ND	57	73	ND
	2-Methylphenol	63	63	26.1	ND	ND	ND	ND	ND	63	63	ND
	4-Methylphenol	670	670	ND	ND	ND	ND	ND	ND	670	670	ND
	2,4-Dimethylphenol	29	29	20	ND	ND	ND	ND	ND	29	29	ND
	Pentachlorophenol	360	690	354	ND	ND	ND	ND	ND	360	690	ND
	Phenol	420	1,200	ND	ND	ND	ND	ND	ND	420	1,200	ND

Notes

SQS - Sediment Quality Standard (173-204-320(2) WAC).

CSL - Cleanup Screening Level (173-204-520(2) WAC).

SCO AET - Sediment Cleanup Objective Apparent Effects Threshold EPA-910-9-88-246B.

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Green Cell - Analyte exceeds the CSL AET chemical criterion

ND - Analyte not detected.

J - Estimated concentration due to QC, or sample <RDL.

B - Blank contamination (< 5x the sample value).

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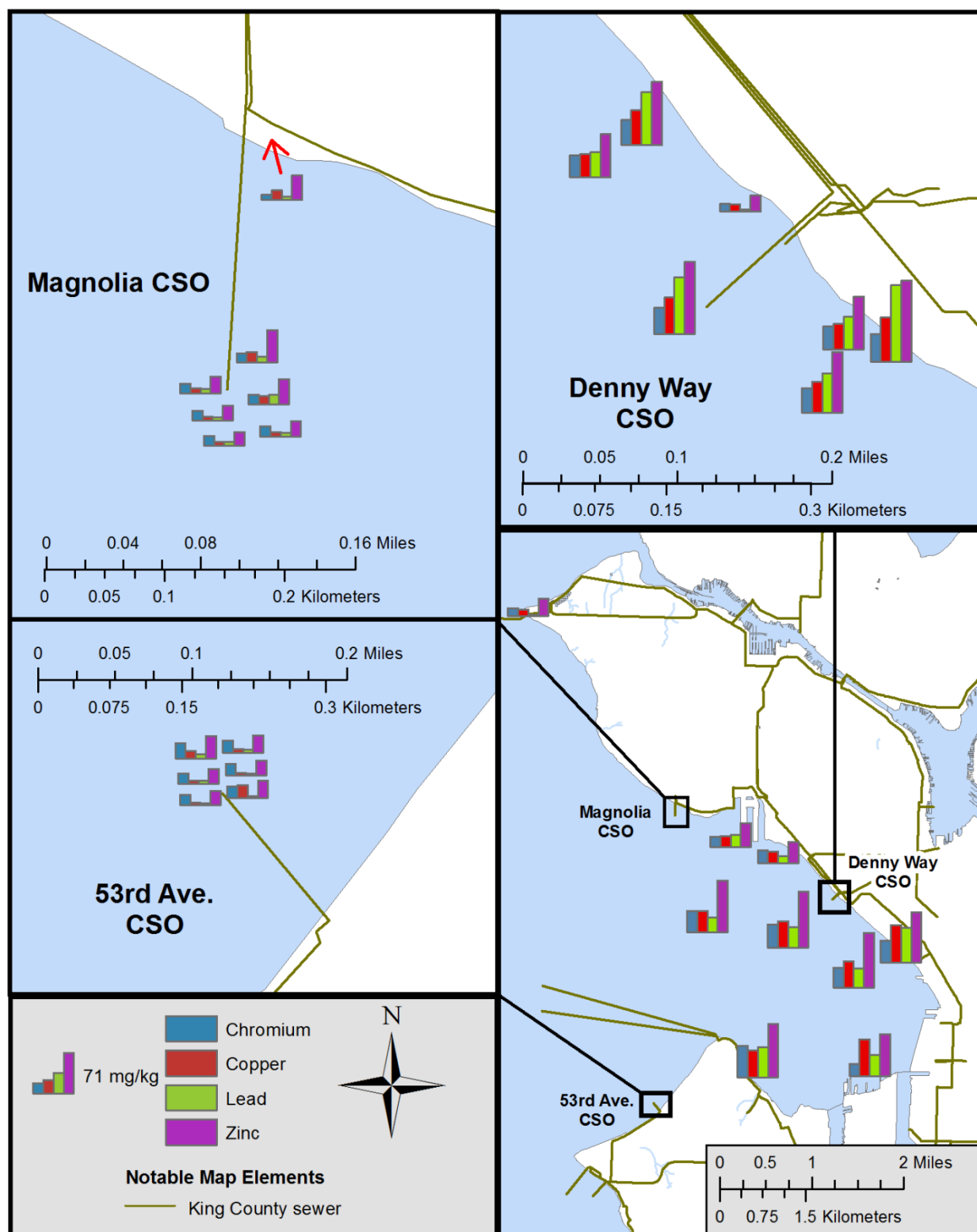


Figure C-4 Dry weight normalized chromium, copper, lead, and zinc concentrations in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013).

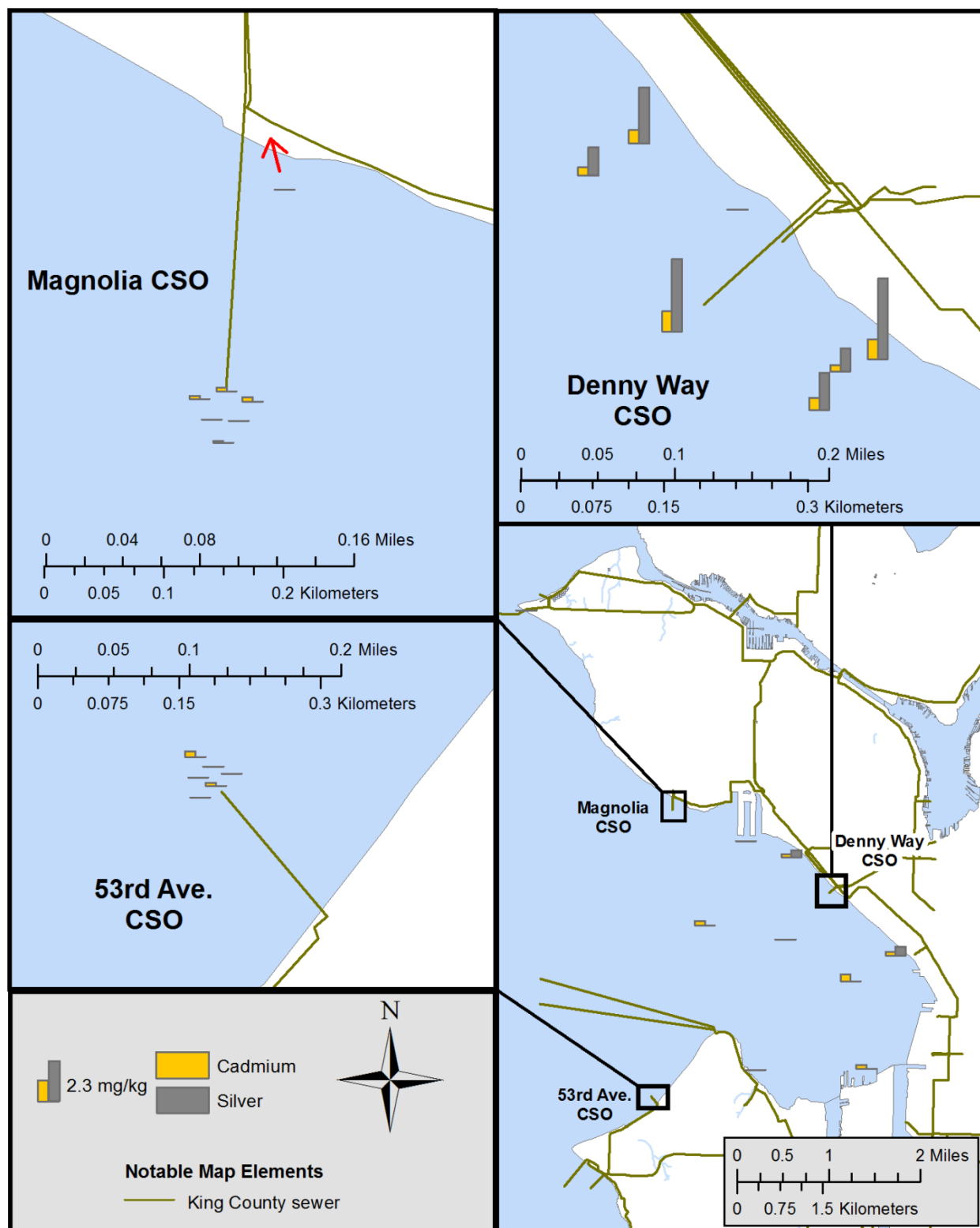


Figure C-5 Dry weight normalized cadmium and silver concentrations in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013).

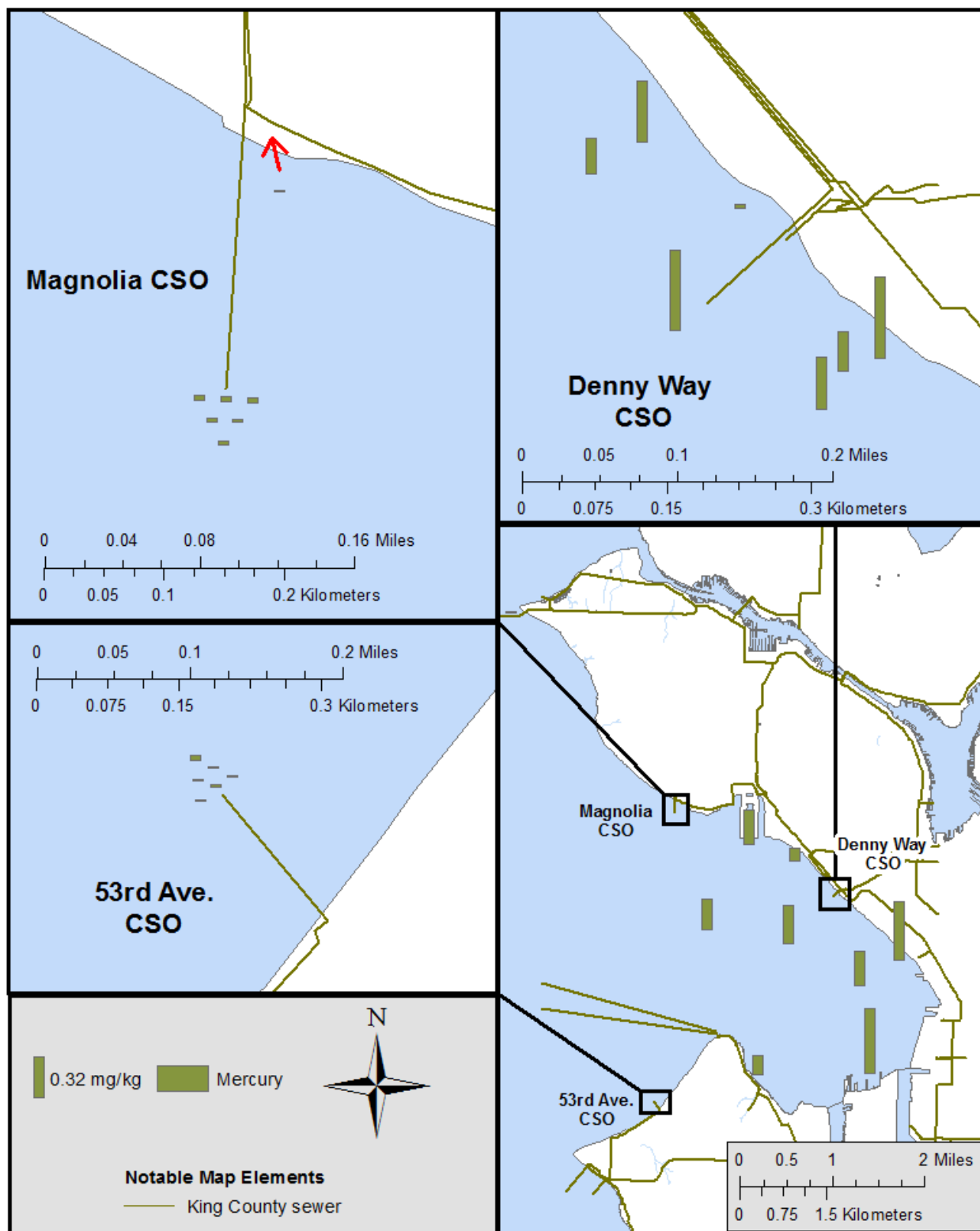


Figure C-6 Dry weight normalized mercury concentration in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013).

Table C-6 Analysis of long-term trends of dry weight-normalized metals concentrations in sediments at four sites in Elliott Bay (1992-2013).

Locator	FOD	Min	Max	Mean	Max MDL	Significance	Trend	p-value	Slope ([mg/kg]/year)
Arsenic									
Outer EB	8/13	<MDL	12.81	9.490	5.0	**	↑	0.0460	0.3870
Western EB	9/13	<MDL	16.72	10.99	5.0	n.s.	--	0.1700	0.2980
Pier 66	10/12	<MDL	12.72	10.36	5.0	*	↑	0.0620	0.3030
Central EB	9/12	<MDL	17.39	12.07	5.0	n.s.	--	0.3400	0.2280
Cadmium									
Outer EB	9/13	<MDL	0.5357	0.3760	0.3	***	↑	0.0081	0.0191
Western EB	4/13	<MDL	0.4938	0.3671	0.4	NA	NA	NA	NA
Pier 66	9/12	<MDL	0.4909	0.3270	0.3	n.s.	--	0.6500	0.0034
Central EB	8/12	<MDL	0.5660	0.4195	0.3	**	↑	0.0400	0.0184
Chromium									
Outer EB	13/13	33.33	52.31	40.14	0.5	n.s.	--	0.7756	0.0578
Western EB	13/13	37.14	45.25	40.29	0.5	n.s.	--	0.9681	0.0043
Pier 66	12/12	27.94	41.86	35.51	0.5	n.s.	--	0.2290	-0.2451
Central EB	12/12	26.67	41.43	35.79	0.5	n.s.	--	0.6844	0.0688
Copper									
Outer EB	13/13	35.56	55.26	41.90	0.4	n.s.	--	0.1309	0.3589
Western EB	13/13	37.14	54.43	47.00	0.4	n.s.	--	0.4474	0.1234
Pier 66	12/12	37.43	65.05	51.11	0.4	n.s.	--	0.5812	-0.2024
Central EB	12/12	33.33	56.03	49.77	0.4	n.s.	--	0.3036	0.2912
Lead									
Outer EB	13/13	22.22	35.53	29.49	3.0	n.s.	--	0.2515	0.1782
Western EB	13/13	28.57	42.62	36.36	3.0	n.s.	--	0.8510	-0.0315
Pier 66	12/12	47.98	69.75	61.66	3.0	n.s.	--	0.2837	-0.2855
Central EB	12/12	20.00	47.41	36.95	3.0	n.s.	--	0.7559	0.1073
Mercury									
Outer EB	13/13	0.1962	0.8518	0.3133	0.021	n.s.	--	0.5855	-0.0043
Western EB	13/13	0.2565	0.3385	0.2888	0.021	n.s.	--	0.7113	-0.0004
Pier 66	12/12	0.3057	0.8478	0.5298	0.021	***	↓	0.0014	-0.0183
Central EB	12/12	0.1111	0.4624	0.3015	0.021	n.s.	--	0.6699	-0.0017
Silver									
Outer EB	3/13	<MDL	1.5179	0.6210	0.4	NA	NA	NA	NA
Western EB	4/13	<MDL	1.5823	0.5311	0.4	NA	NA	NA	NA
Pier 66	12/12	0.5055	1.6763	0.9733	0.4	**	↓	0.0270	-0.0281
Central EB	4/12	<MDL	1.5094	0.6583	0.4	NA	NA	NA	NA
Zinc									
Outer EB	13/13	64.44	99.34	88.52	0.5	**	↑	0.0178	0.8681
Western EB	13/13	80.00	110.82	93.70	0.5	n.s.	--	0.4404	0.2343
Pier 66	12/12	65.93	100.00	83.37	0.5	n.s.	--	0.2094	-0.5664
Central EB	12/12	77.78	108.96	95.42	0.5	n.s.	--	0.4482	0.2663

For metals with non-detect values, means and slopes were estimated using maximum likelihood estimation.

FOD = Frequency of detection

* = Marginally significant (p = 0.05-0.10), ** = Significant (p = 0.01-0.05), *** = Highly significant (p < 0.01), n.s. = Not significant (p > 0.10)

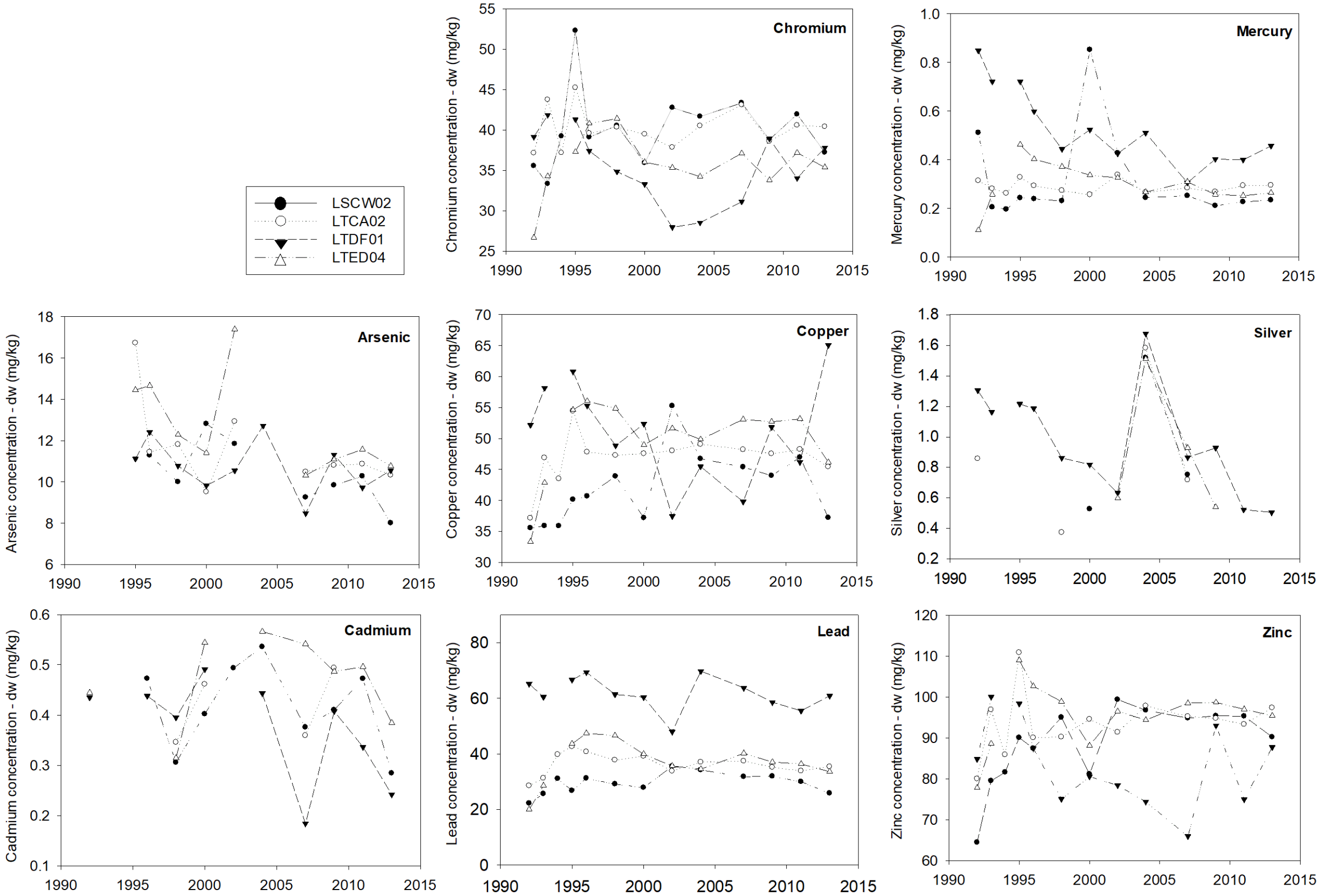


Figure C-7 Dry weight (dw) normalized sediment metals concentrations at four ambient sites in Elliott Bay (1992-2013).

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Organics

Sediments were sampled for a variety of organic compounds that differed between studies. For consistency, only those compounds with marine sediment chemical criteria are discussed with the exception of PBDEs due to their bioaccumulative properties. This list includes 38 semivolatile organics (PAHs, chlorobenzenes, phthalates, and others) and 7 PCB Aroclors. All but five of these compounds (1,2,4-trichlorobenzene, Di-N-octyl phthalate, hexachlorobutadiene, 4-nitrosodiphenylamine, and 4-methylphenol) were detected at one or more sites.

Unlike metals data, sediment data for some organic compounds are normalized to organic carbon content for comparison to SMS criteria. Normalization to organic carbon can produce biased results when the organic carbon content of the sample is very low (Ecology, 1992). When the organic carbon content of a sample is near 0.1 or 0.2% (1,000 to 2,000 milligrams/kilogram (mg/kg) dw), even background concentrations of certain organic compounds can exceed sediment quality criteria. If the organic carbon content at any site was below 0.5% dry weight, then dry weight-normalized results for non-ionizable organic compounds were compared to Lowest Apparent Effects Threshold (LAET) or Second Lowest Apparent Effects Threshold (2LAET) criteria (EPA, 1988), rather than SMS criteria. Concentrations of all organic compounds compared to appropriate criteria can be found in Tables C-3 to C-5 and dry weight concentrations are displayed in Figures C-8 through C-14.

Current Conditions

Base/Neutral/Acids

Benzoic acid was detected at the highest concentration of all BNAs. It was detected above the CSL at four Denny Way sites, with the highest concentration of 815 µg/kg-dw (Figure C-8). This compound can be introduced to the sediment from anthropogenic sources such as food preservatives, dyes, and cigarettes; however, it is also a naturally occurring byproduct of the metabolic processes in shellfish which have high abundances in Denny Way sediments. Benzyl alcohol, 2-methylphenol, 2,4-dimethylphenol, and pentachlorophenol were detected at DWMP-01. Benzoic acid was only detected, without blank contamination, at CSO outfalls (53rd Ave. and Magnolia), while phenol was only detected at an intertidal site (Magnolia Outfall). Contamination by benzyl alcohol, benzoic acid, and phenol has been demonstrated to be highly localized, particularly near outfalls, and can be transient, exceeding SQS criteria one year, but not others (Lower Duwamish Waterway Group, 2011).

Phthalates

Phthalates are plasticizers and ubiquitous in the environment. These analytes, bis(2-ethylhexyl)phthalate in particular, have been a common laboratory contaminant at KCEL. Blank contamination was common for bis(2-ethylhexyl)phthalate and di-n-butyl phthalate in samples from the 53rd Ave and Magnolia CSOs. The highest non-contaminated concentrations of bis(2-ethylhexyl)phthalate were detected near the Denny Way CSO at a maximum of 65.8 mg/kg – OC (Figure C-9). In addition, benzyl butyl phthalate and bis(2-ethylhexyl)phthalate concentrations exceeded SQS criteria at two and four Denny Way

sites respectively. It should be noted that phthalates, particularly bis(2-ethylhexyl)phthalate and butyl benzyl phthalate are known persistent contaminants in the region due to urban inputs such as outfalls (Lower Duwamish Waterway Group, 2013).

Chlorobenzenes

Chlorobenzenes are solvents found in many cleaning products and may enter the marine environment mainly from CSO discharges. Three chlorobenzenes (1,2-dichlorobenzene, 1,4-dichlorobenzene, and hexachlorobenzene) were detected only at intertidal sites in Elliott Bay (Figure C-10). 1,4-dichlorobenzene is used in mothballs, toilet deodorant cakes, and drain cleaners, and was the chlorobenzene detected at the highest concentration (maximum of 0.581 µg/kg-dw); it has been detected at subtidal sites previously in Elliott Bay (King County, 2006) but was not in recent samples.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are byproducts of fossil fuel combustion, constituents in creosote (wood preservative), and asphalt sealants. HPAHs were found at greater concentrations than LPAHs throughout Elliott Bay. Concentrations of PAHs were highest near the Denny Way outfall, near the Seattle waterfront (Pier 66 site), and Harbor Island (Figure C-11). These sites have nearby potential sources of PAHs that include urban runoff, stormwater outfalls, CSOs, and/or creosote pilings. The site with the highest PAH contamination was at the Denny Way outfall (DWMP-01), which exceeded SQS criteria for benzo[a]anthracene, total benzofluoranthenes (benzo(g,h,i)fluoranthene), chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene.

Dibenzofuran

Dibenzofuran is released through combustion and is used as an insecticide. It is found at the highest concentrations near the Denny Way outfall, the Seattle waterfront, and Harbor Island (Figure C-12), with the highest concentration at the Seattle waterfront (Pier 66, 2.35 mg/kg-OC).

Polychlorinated biphenyls

PCBs were widely used for their insulating and fluidity-enhancing properties prior to 1977 when they were banned, but are still present in old building and electrical material. PCBs were measured as Aroclors and detected at all sites throughout Elliott Bay (Figure C-13). Low concentrations were measured at most ambient sites and near the 53rd Ave. and Magnolia outfalls. PCBs were not detected at intertidal sites or at some sites surrounding the 53rd Ave CSO, likely due to the higher sediment particle sizes at these sites. Total PCB Aroclor concentrations were detected above the total PCB SQS criteria at the ambient Harbor Island site (15 mg/kg-OC); the site is located near the northern border of the Harbor Island superfund site where PCBs are a known contaminant of concern. PCB Aroclor concentrations were also elevated surrounding the Denny Way CSO and exceeded SQS criteria at five sites (maximum concentrations of 36.0 mg/kg-OC, at the site of the new outfall). Although, PCB concentrations still exceed sediment criteria at some sites, concentrations are declining throughout Elliott Bay (Ecology, 2009).

Polybrominated diphenyl ethers

PBDEs are flame retardants used in a wide variety of products and are chemicals of emerging concern because of their toxicity and bioaccumulative properties, as they have been found in high concentrations in marine mammals including orca whales and harbor seals (Ross et al., 2004; Ross, 2006). While some of the most common PBDEs have been banned, they are still detected. Currently, the State of Washington has not adopted sediment management standards that regulate the concentration of PBDEs in sediments. Concentrations of PBDEs were only measured at subtidal and intertidal ambient sites in Elliott Bay and were detected at all sites with the highest concentrations near the waterfront (Pier 66) and near Magnolia (Magnolia Outfall) when normalized by TOC (maximum concentration of 0.87 mg/kg OC) the highest dry weight concentrations were detected at the Harbor Island site (13.022 µg/kg dw) (Figure C-14, Table C-7).

Long-term Trends

While data on organics concentrations have been collected since the 1988 at routine ambient sites in Elliott Bay, many organic parameters were detected at too low of a frequency to evaluate for long-term trends or, in the case of phthalates, benzyl alcohol, and benzoic acid, were plagued with persistent blank contamination. PAHs and PCB Aroclors were the exception due to their frequency of detection at ambient monitoring stations. Data from 1992 to 2013 were evaluated from four monitoring sites in Elliott Bay (data from 1988-1992 were not used due to a lack of confidence in data quality). It should be noted that detection limits did change (were reduced) for all parameters during this time period; therefore, earlier data may be low-biased compared to more recent data.

Similar to metals data, long-term trends in dry weight-normalized, rather than TOC-normalized, sediment concentrations were analyzed for total LPAHs, total HPAHs, and total PCB Aroclors using simple linear regression. PCB Aroclor datasets at three sites contained non-detects; for these sites means and slopes were estimated using maximum likelihood estimation with the assumption of Gaussian/normal distribution (cenreg in NADA package for R: Lopaka, 2013). Overall, total HPAHs have declined at ambient monitoring sites over the past two decades despite the decrease in detection limits. Three sites (Central, Western, and Outer Elliott Bay) had significantly decreasing trends with rates ranging from -28.71 to -93.96 µg/kg per year (Table C-8). The only site without decreasing HPAH trends was at Pier 66 along the Seattle Waterfront. Conversely, LPAHs only decreased at a marginally significant rate at one site (Western Elliott Bay), and significantly increased at the Central Elliott Bay site at a rate of 0.1762 µg/kg per year (Table C-8).

In general, the concentrations of total PCB Aroclors did not change during the study period. There was no significant change at three of four sites. At one site (Pier 66) there was a marginally significant decreasing trend of -6.778 µg/kg per year (Table C-8). Overall, it did not appear that there were long-term changes in PCB Aroclor concentrations in Elliott Bay. However, detection limit changes make it difficult to make true comparisons between years.

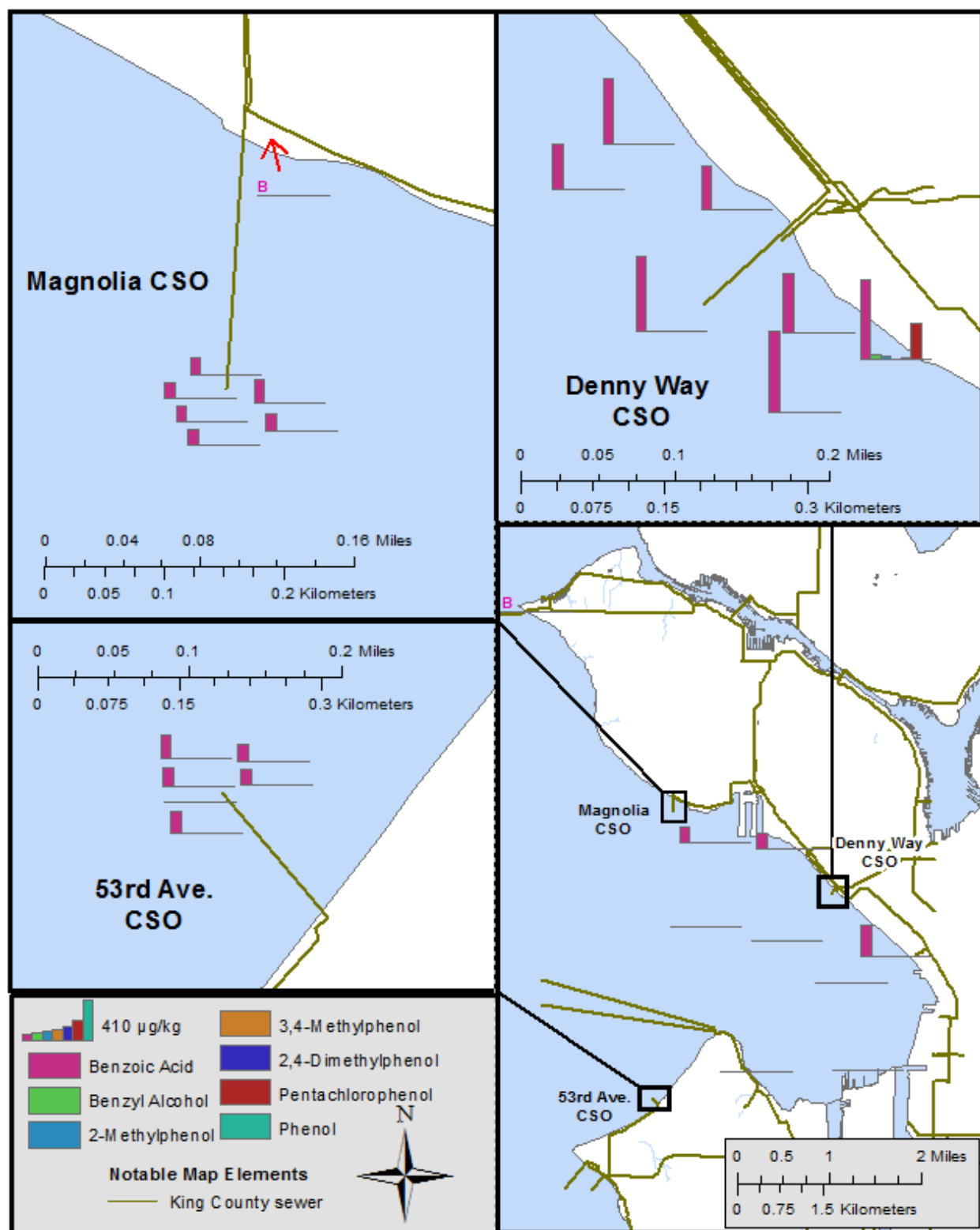


Figure C-8 Dry weight normalized base/neutral/acid semi-volatile compound concentrations in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013). B = blank contamination.

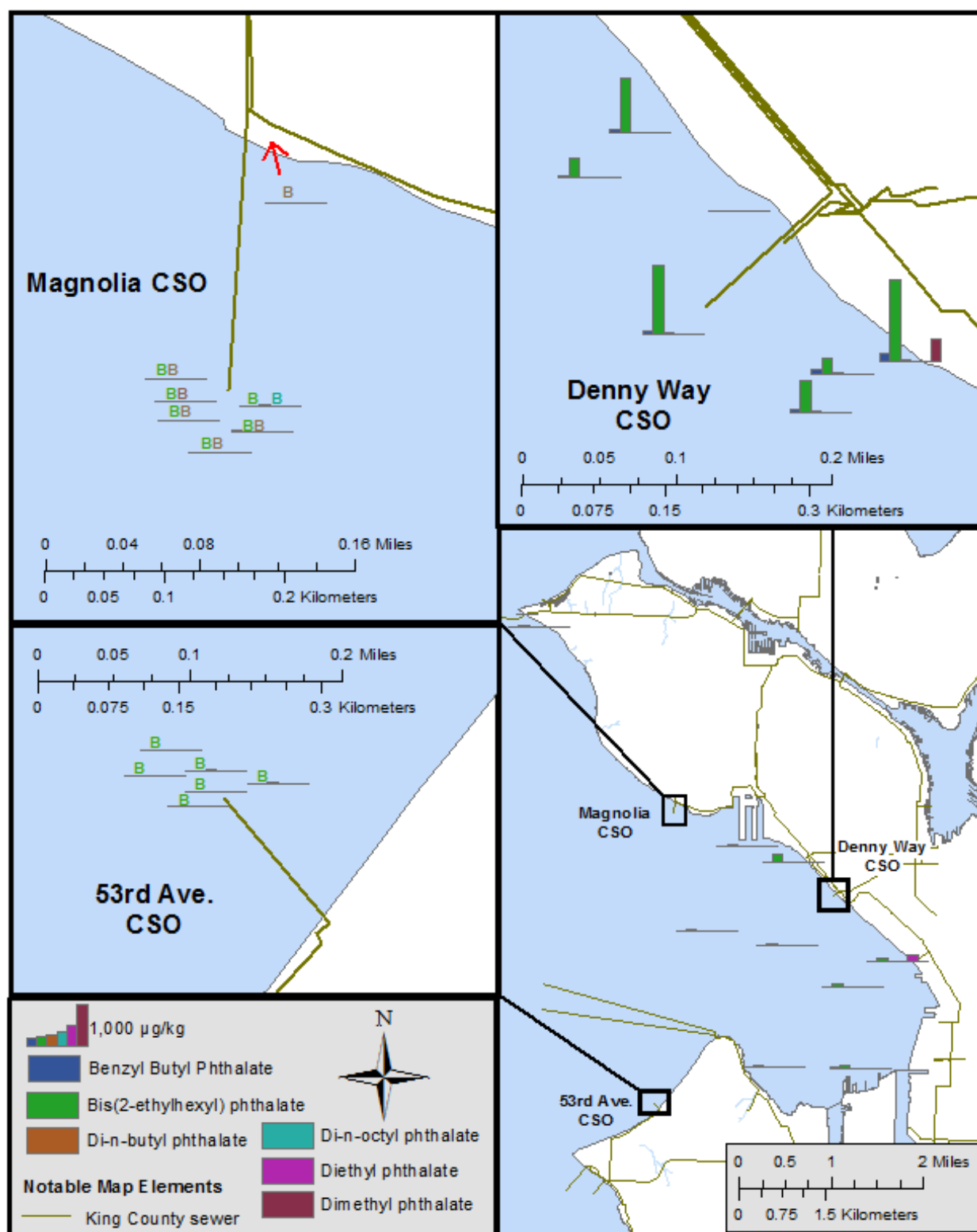


Figure C-9 Dry weight normalized phthalates concentrations in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013). B = blank contamination.

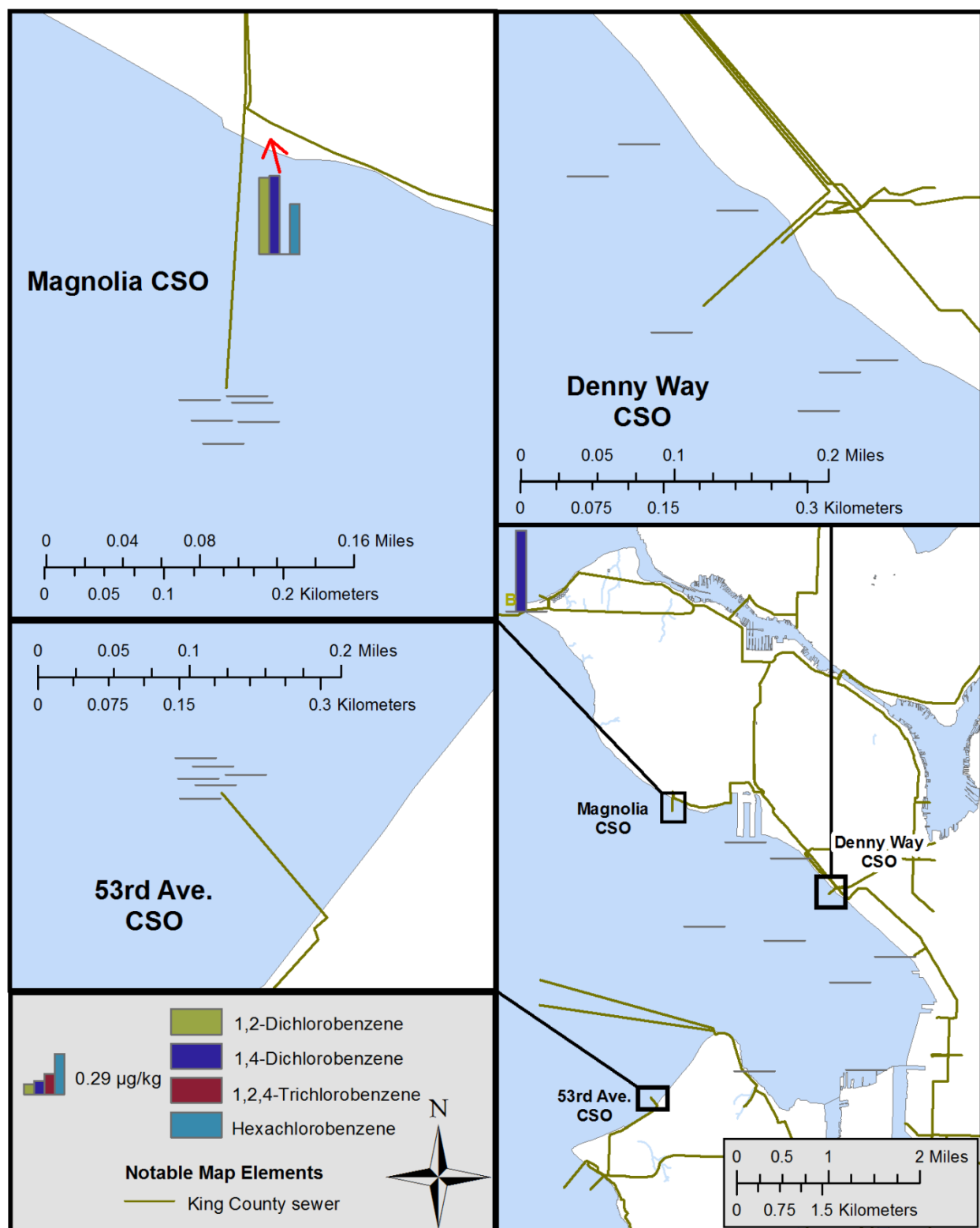


Figure C-10 Dry weight normalized chlorobenzene concentrations in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013). B = blank contamination.

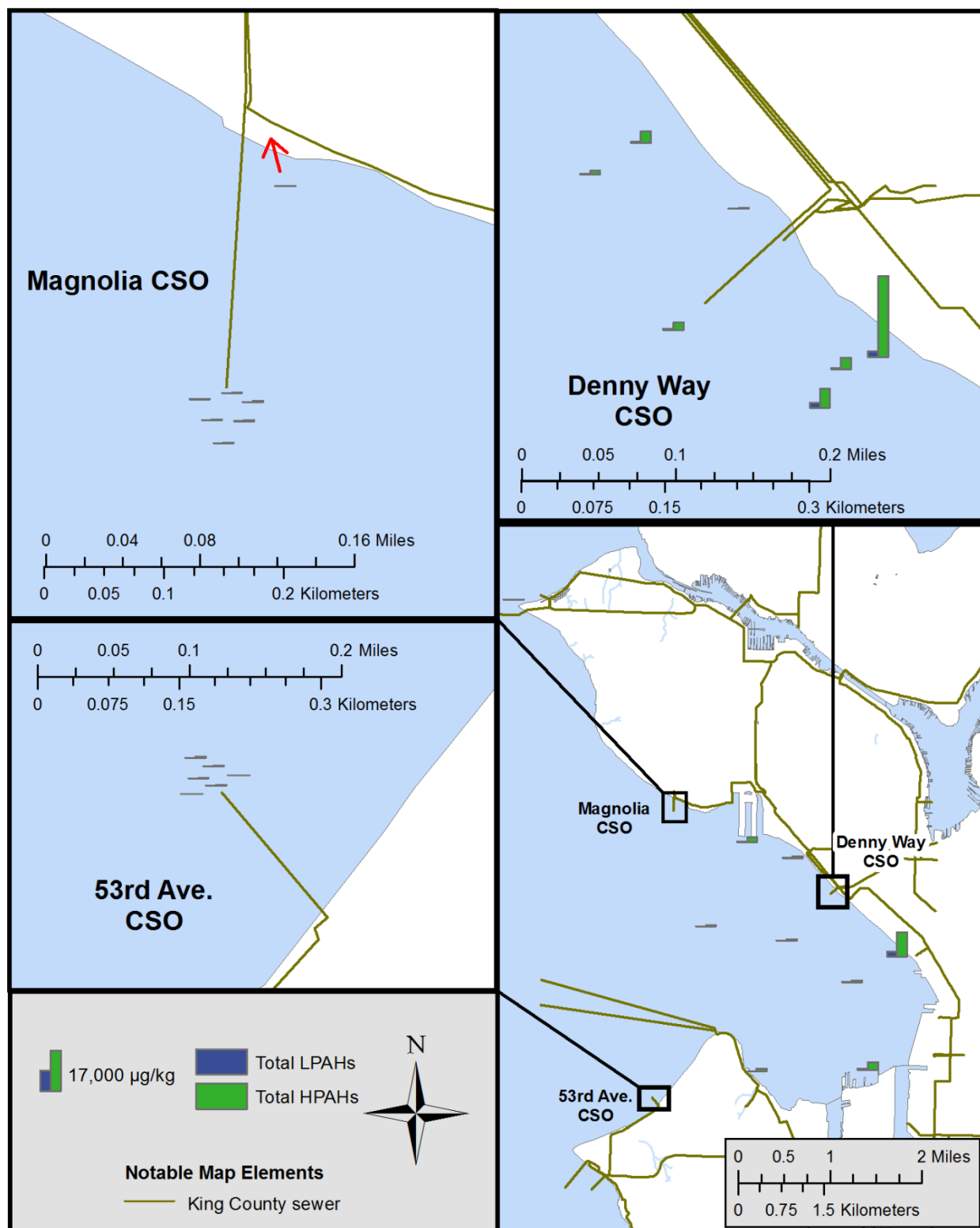


Figure C-11 Dry weight normalized PAH concentrations in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013).

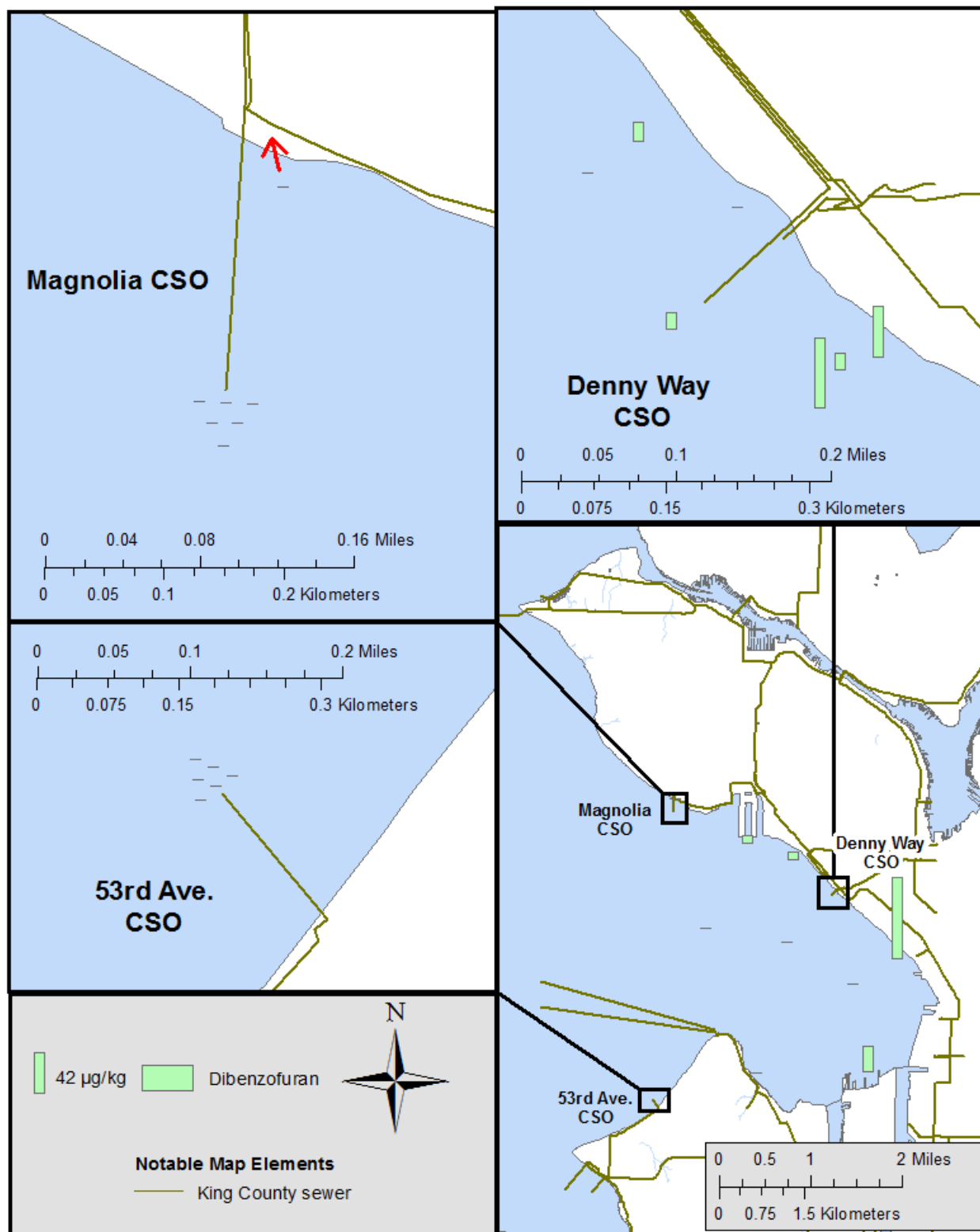


Figure C-12 Dry weight normalized dibenzofuran concentrations in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013).

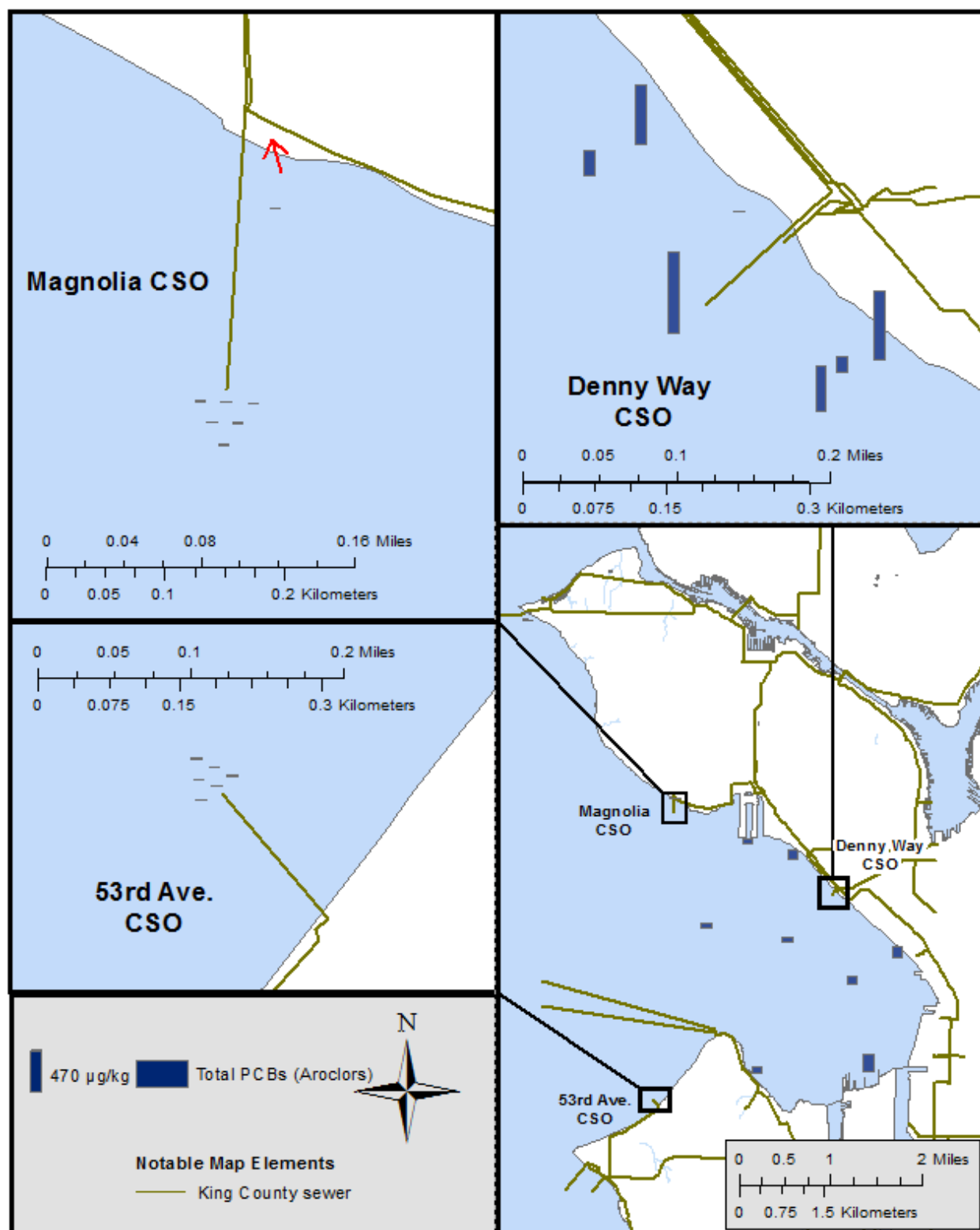


Figure C-13 Dry weight normalized total PCB Aroclor concentrations in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013).

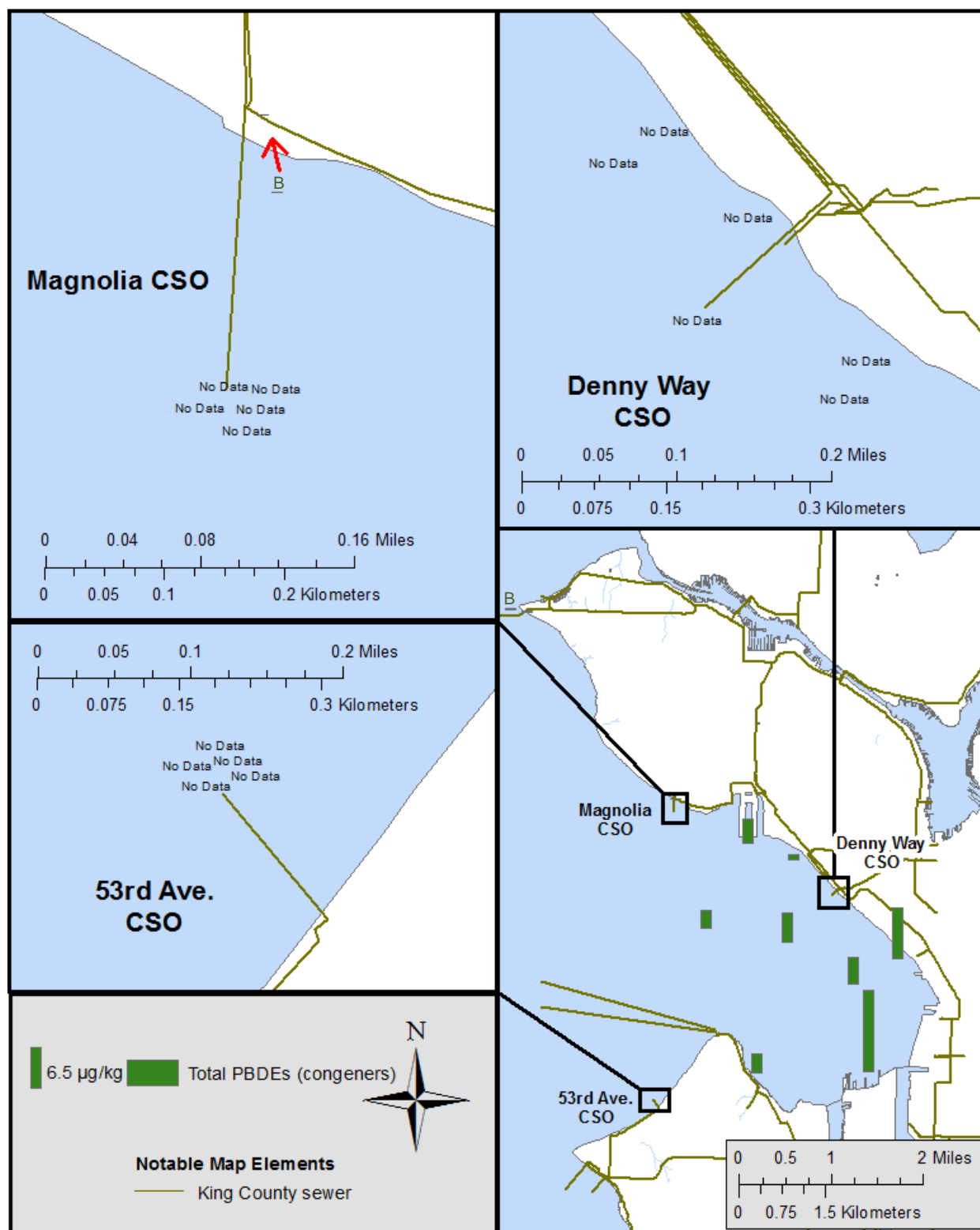


Figure C-14 Dry weight normalized PBDE concentrations in sediments at sites in Elliott Bay and adjacent Puget Sound (2010-2013). B = blank contamination.

Table C-7 Concentration of PBDEs in sediments sampled from Elliott Bay in 2013. All values are in ug/kg dw (not TOC normalized).

	Piers 90/91			Grain Terminal			Outer Elliott Bay			Western Elliott Bay			Pier 66			Central Elliott Bay			Harbor Island			Seacrest Park			West Point S			Magnolia Outfall		
	Locator: KSZY01			Locator: LTAA02			Locator: LSCW02			Locator: LTCA02			Locator: LTDF01			Locator: LTED04			Locator: LTGF01			Locator: LSHZ08			Locator: LSHZ08			Locator: KSYV02		
	Date: 06/03/13			Date: 06/03/13			Date: 06/03/13			Date: 06/03/13			Date: 06/03/13			Date: 06/03/13			Date: 06/03/13			Date: 06/03/13			Date: 06/03/13					
	% Solids: 73.1			% Solids: 73.7			% Solids: 38.7			% Solids: 33.9			% Solids: 45.5			% Solids: 39.0			% Solids: 57.6			% Solids: 62.8			% Solids: 95.1			% Solids: 96.9		
	Depth (m): 20			Depth (m): 24			Depth (m): 181			Depth (m): 132			Depth (m): 29			Depth (m): 92			Depth (m): 32			Depth (m): 22			Depth (m): intertidal			Depth (m): intertidal		
Parameters	Value	Qual	MDL	Value	Qual	MDL	Value	Qual	MDL	Value	Qual	MDL	Value	Qual	MDL	Value	Qual	MDL	Value	Qual	MDL	Value	Qual	MDL	Value	Qual	MDL	Value	Qual	MDL
DecaBDE-209	3.49	J	0.27	0.771		0.27	2.04		0.52	3.48		0.59	7.43		0.44	3.28		0.51	4.15		0.35	2.87		0.32	--	<MDL	0.042	--	<MDL	0.041
HeptaBDE-183	--	<MDL	0.022	--	<MDL	0.022	--	<MDL	0.041	--	<MDL	0.047	--	<MDL	0.035	--	<MDL	0.041	--	<MDL	0.028	--	<MDL	0.025	--	<MDL	0.0084	--	<MDL	0.0083
HeptaBDE-190	--	<MDL	0.022	0.026	<RDL	0.022	0.139		0.041	0.105		0.047	0.051	<RDL	0.035	--	<MDL	0.041	0.033	<RDL	0.028	0.045	<RDL	0.025	--	<MDL	0.0084	--	<MDL	0.0083
HexaBDE-138	--	<MDL	0.022	--	<MDL	0.022	--	<MDL	0.041	--	<MDL	0.047	--	<MDL	0.035	--	<MDL	0.041	0.047	<RDL	0.028	--	<MDL	0.025	--	<MDL	0.0084	--	<MDL	0.0083
HexaBDE-153	--	<MDL	0.022	--	<MDL	0.022	0.049	<RDL	0.041	0.071	<RDL	0.047	--	<MDL	0.035	0.044	<RDL	0.041	0.304		0.028	--	<MDL	0.025	--	<MDL	0.0084	--	<MDL	0.0083
HexaBDE-154	0.022	<RDL	0.022	--	<MDL	0.022	--	<MDL	0.041	0.05	<RDL	0.047	0.101		0.035	--	<MDL	0.041	0.278		0.028	0.033	<RDL	0.025	--	<MDL	0.0084	--	<MDL	0.0083
PentaBDE-100	0.031	<RDL	0.027	--	<MDL	0.027	0.093	<RDL	0.052	0.126		0.059	0.064	<RDL	0.044	0.087	<RDL	0.051	0.675		0.035	0.037	<RDL	0.032	--	<MDL	0.0084	--	<MDL	0.0083
PentaBDE-85	--	<MDL	0.022	--	<MDL	0.022	--	<MDL	0.041	--	<MDL	0.047	--	<MDL	0.035	--	<MDL	0.041	0.184		0.028	--	<MDL	0.025	--	<MDL	0.0084	--	<MDL	0.0083
PentaBDE-99	0.13	<RDL	0.11	--	<MDL	0.11	0.28	<RDL	0.21	0.35	<RDL	0.24	0.22	<RDL	0.18	0.28	<RDL	0.21	4.84		0.14	--	<MDL	0.13	0.0331	B	0.0084	0.0144	<RDL,B	0.0083
TetraBDE-47	--	<MDL	0.19	--	<MDL	0.19	--	<MDL	0.36	--	<MDL	0.41	--	<MDL	0.31	0.38	<RDL	0.36	2.29		0.24	--	<MDL	0.22	0.0386	B	0.0084	0.0233	B	0.0083
TetraBDE-66	0.038	<RDL,JG	0.031	--	<MDL,JG	0.031	--	<MDL,JG	0.059	--	<MDL,JG	0.068	--	<MDL,JG	0.051	--	<MDL,JG	0.059	0.059	<RDL,JG	0.04	--	<MDL,JG	0.037	--	<MDL	0.0084	--	<MDL	0.0083
TetraBDE-71	0.034	<RDL	0.022	--	<MDL	0.022	0.133		0.041	0.187		0.047	0.103		0.035	0.144		0.041	0.0917		0.028	--	<MDL	0.025	--	<MDL	0.0084	--	<MDL	0.0083
TriBDE-17	0.038	<RDL	0.022	--	<MDL	0.022	0.0997		0.041	0.074	<RDL	0.047	--	<MDL	0.035	0.072	<RDL	0.041	--	<MDL	0.028	0.049	<RDL	0.025	--	<MDL	0.0084	--	<MDL	0.0083
TriBDE-28	0.0594	TA	0.022	--	<MDL	0.022	--	<MDL	0.041	0.124		0.047	0.082		0.035	--	<MDL	0.041	0.0698		0.028	0.0599		0.025	--	<MDL	0.0084	--	<MDL	0.0083
Total PBDEs	3.842		--	0.797		--	2.834		--	4.567		--	8.051		--	4.287		--	13.022		--	3.094		--	0.072			0.038		

Total PBDEs were calculated summing only detected congeners.
B = blank contamination.
J = estimate.
JG = estimate, probable low bias.

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Table C-8 Analysis of long-term trends of dry weight-normalized total PAHs and total PCB Aroclor concentrations in sediments at four sites in Elliott Bay (1992-2013).

Locator	FOD	Min	Max	Mean	Max MDL	Significance	Trend	p-value	Slope ([μ g/kg]/year)
Total HPAHs									
Outer EB	13/13	6.358	5,051	1,136	119.4	*	↓	0.0686	-93.96
Western EB	13/13	9.581	1,247	831.2	141.0	***	↓	0.0026	-28.71
Pier 66	12/12	79.00	10,640	5,299	90.15	n.s.	--	0.2776	105.4
Central EB	12/12	20.05	2,343	1,192	124.3	***	↓	0.0085	-47.94
Total LPAHs									
Outer EB	12/12	<MDL	1,556	227.3	119.4	n.s.	--	0.1611	-24.42
Western EB	12/12	<MDL	209.4	92.11	141.0	*	↓	0.0981	-2.701
Pier 66	11/11	<MDL	2,211	955.8	90.15	n.s.	--	0.2920	22.00
Central EB	11/11	<MDL	282.8	147.9	124.3	**	↑	0.0162	0.1762
Total PCB Aroclors									
Outer EB	10/13	<MDL	161.8	51.67	36.11	n.s.	--	0.3600	1.470
Western EB	8/13	<MDL	70	37.38	42.62	n.s.	--	0.1800	1.240
Pier 66	12/12	82.88	409.8	169.4	27.25	*	↓	0.0999	-6.778
Central EB	10/12	<MDL	498.5	133.5	37.57	n.s.	--	0.4100	4.380

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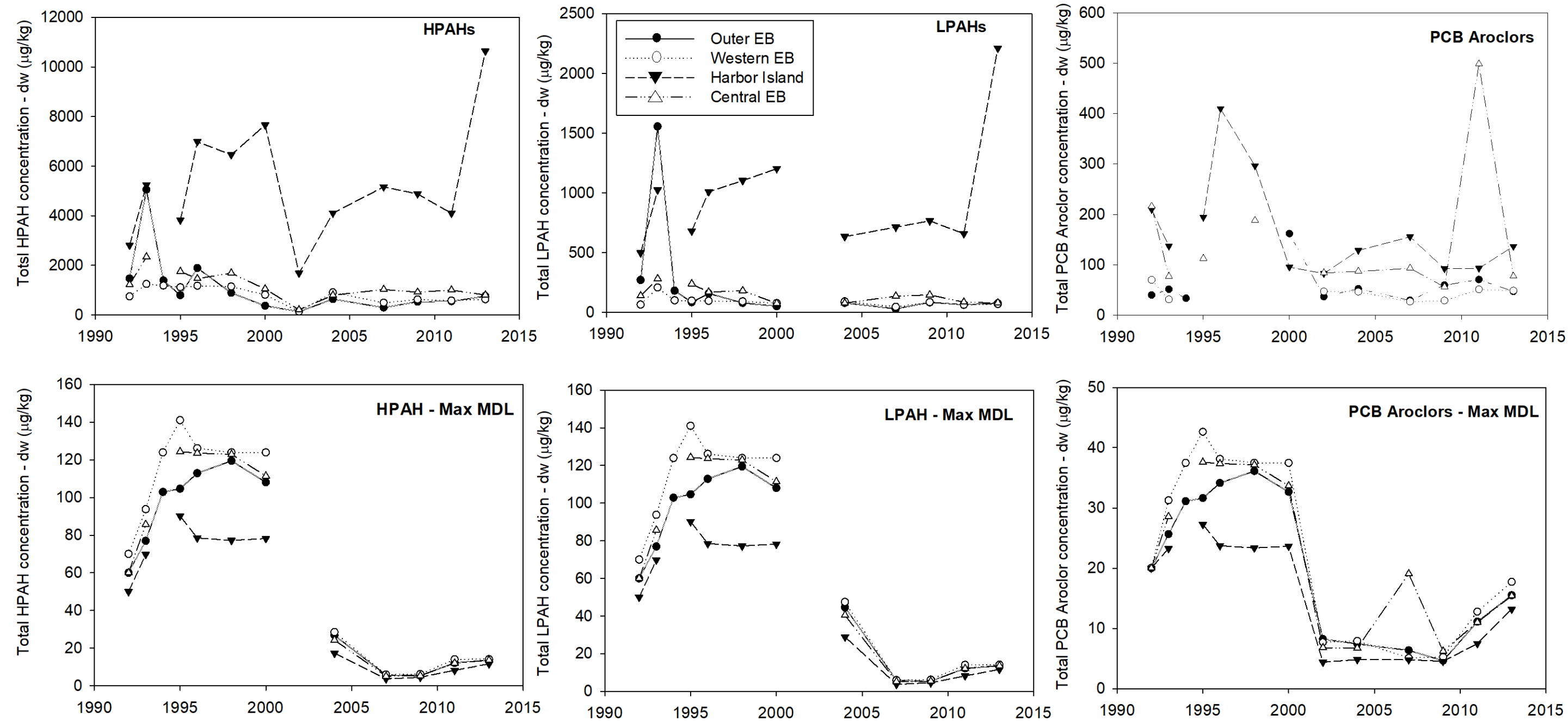


Figure C-15 Dry weight (dw) normalized sediment total PAHs and PCB Aroclor concentrations at four ambient sites in Elliott Bay (1992-2013).

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Summary

Concentrations of pollutants in sediments at ambient monitoring sites in Elliott Bay rarely exceeded state marine sediment criteria; the only parameters that were above the SQS at these sites was mercury at two sites (Pier 66 and Harbor Island) and total PCBs (Aroclors) at one site (Harbor Island). Although mercury and PCBs were the only chemicals detected above marine sediment criteria at Pier 66 and Harbor Island, concentrations of several other chemicals included dibenzofuran, PAHs, and PBDEs were elevated at those sites compared to other ambient sites within Elliott Bay. Sediment criteria were exceeded most frequently at non-ambient sites near the Denny Way CSO (Figure C-16). The exception was site DWMP-10, which was dredged and backfilled with clean sediment in 2008. By comparison, the nearshore site DWMP-01 exceeded SQS or CSL criteria for 10 parameters including mercury, HPAHs, phthalates, PCB Aroclors, and benzoic acid. Sediments at the Magnolia and 53rd Ave. CSOs did not exceed any sediment quality criteria, likely impart due to the low concentration of fine sediments and total organic carbon at those sites.

Overall, sediment data analyzed here were similar to other studies in Elliott Bay. Ecology's 2007 study of the bay determined that bis(2-ethyhexyl)phthalate, mercury, total PCB Aroclors, and PAHs were the most common chemicals to exceed SQS (Ecology, 2009). The same study by Ecology, which compared chemical concentrations to those a decade earlier, found that concentrations of PCBs and most PAHs had declined while phthalate concentrations, particularly bis(2-ethyhexyl)phthalate increased (Ecology, 2009). Trends in organics from King County's ambient monitoring data were only calculated for total PAHs and total PCB Aroclors due to method and detection limit changes. Similar to Ecology's studies, HPAH concentrations decreased at King County's ambient monitoring sites in Elliott Bay during the period of 1992-2013. Trends in LPAHs and PCBs were less obvious. Sediment cores can be dated and then analyzed for chemical concentrations over different time frames; this method could be used in the future to determine concentrations changes over time using the same methods and detection limits.

The trend in sediment PAHs is mirrored in fish tissue from Elliott Bay, which has declined since the 1990; however, PCB concentrations in tissue have not declined since the 1980s likely due to recycling of contaminants through the food web (WDFW, 2007; WDFW, 2011). Despite the current lack of criteria, PBDE concentrations should continue to be monitored in the future due to their toxicity and propensity to bioaccumulate (Ross et al., 2004; Ross, 2006).

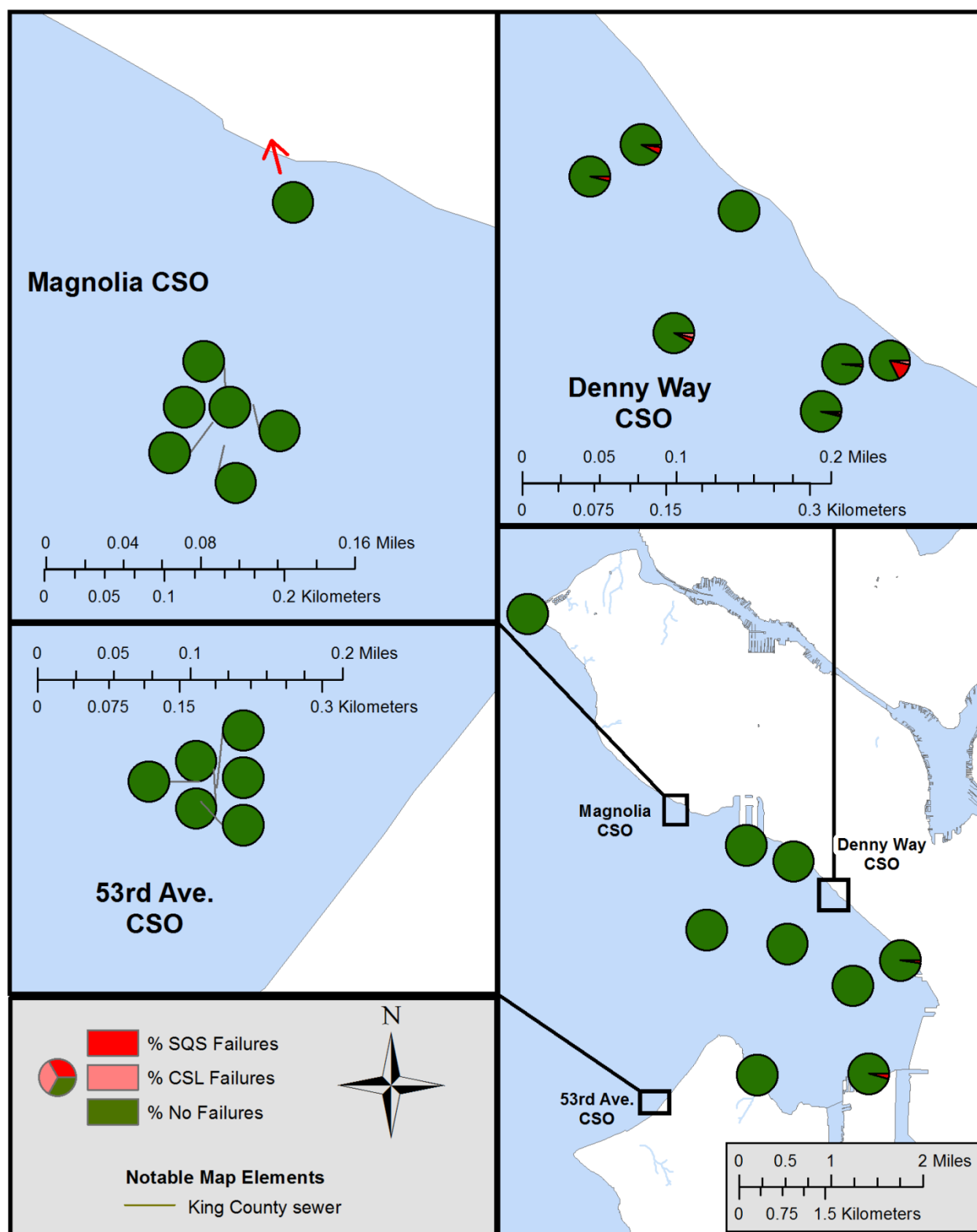


Figure C-16 % of sediment management standards criteria failures for 47 regulated chemicals at sites in Elliott Bay and adjacent Puget Sound (2010-2013).

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Appendix D: Site-Specific Chemical Exceedances in Sediments

Table D-1. Elliott Bay sediment sampling locations and summary data (1990-present). Chemical concentrations were compared to SMS criteria. Those samples with < 0.5% or > 4% total organic carbon (TOC) were compared to AETs. -- = no data. * = samples taken from 3 cm depth or less.

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
0	CSO62_S1	1249899	238160	2013	0.14	3.30										
0	CSO62_S2	1249846	238234	2013	0.12	2.60										
0	CSO62_S3	1249839	238301	2013	0.09	2.60										
0	CSO62_S4	1249870	238224	2013	0.17	2.50										
0	CSO62_S5	1249831	238169	2013	0.09	3.85										
0	KSUR01	1249675	241311	1996	0.20	2.50										
0	KSXS02	1251031	237125	1998	0.38	2.60										
0	LSCW02*	1256271	227106	2013	1.84	66.90										
0	LSDS02	1249953	224635	1995	2.39	95.30										
0	LSDZ01	1259060	225936	1998	2.54	57.50										
0	LSEZ01	1259158	224109	1998	2.84	59.00										
0	LTAA02*	1261260	231054	2013	0.33	10.60										
0	LTBC41	1261487	230719	2002	0.71	31.50										
0	LTCA02*	1260915	226303	2013	1.97	83.10										
0	LTED04*	1264675	223909	2013	2.07	76.30										
0	PSAMP/NOAA-175*	1248813	216067	1998	0.32	6.02										
0	PSAMP/NOAA-179*	1260486	231398	1998	0.69	47.47								SQS		
0	PSAMP/NOAA-191*	1259873	222099	1998	1.83	74.96	CSL									
0	PSAMP/NOAA-193*	1265219	222562	1998	1.55	33.37										
0	PSAMP_HP-32*	1252064	234480	1995	0.15	6.00				--		--	--		--	--
0	PSDAM92PMONT01A	1261776	226129	1992	NA	NA										

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
0	PSDAM92PMONT01B	1261782	226055	1992	NA	NA										
0	PSDAM92PMONT01C	1261821	226097	1992	NA	NA										
0	PSDAM92PMONT03A	1260932	226298	1992	1.90	NA	CSL									
0	PSDAM92PMONT03B	1260924	226274	1992	1.83	NA	CSL									
0	PSDAM92PMONT03C	1260957	226297	1992	2.07	NA	SQS									
0	PSDAM92PMONT05A	1260031	226474	1992	1.90	NA										
0	PSDAM92PMONT05B	1260057	226474	1992	2.10	NA										
0	PSDAM92PMONT05C	1260044	226492	1992	1.50	NA										
0	PSDDA_02EBB03	1263218	227205	2002	1.77	69.97		--	--		--	--	--	--	--	--
0	PSDDA_02EBB04	1254315	223442	2002	1.90	75.83		--	--	--	--	--	--	--	--	--
0	PSDDA_02EBP01	1262235	226008	2002	1.63	71.23										
0	PSDDA_02EBP03	1264718	226111	2002	1.33	20.30										
0	PSDDA_02EBP11	1261762	222217	2002	1.37	41.20										
0	PSDDA_02EBS02	1264474	220704	2002	1.90	70.10										
0	PSDDA_02EBS04	1265959	223026	2002	1.90	85.70	SQS									
0	PSDDA_02EBZ01	1264395	222038	2002	2.40	21.40										
0	UWI2007-172*	1250755	220818	2007	2.26	84.67						--	--			
0	UWI2007-173*	1254083	224139	2007	1.66	53.90						--	--			
0	UWI2007-178*	1255699	232176	2007	0.19	8.00										
0	UWI2007-185*	1258428	226342	2007	2.26	83.30										
0	UWI2007-187*	1264090	225215	2007	2.00	82.23						--	--	SQS		
0	UWI2007-190*	1257586	221686	2007	0.14	3.20						--	--			

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
0	UWI2007-192*	1262338	223469	2007	0.82	22.10			SQS		SQS	--	--	SQS		
0	UWI2007-195*	1263527	222446	2007	1.84	58.00						--	--	SQS		
0	UWI2007-196*	1266350	222985	2007	2.19	81.30						--	--	SQS		
1	CSO-MG-1	1254386	233763	2011	0.38	3.90										
1	CSO-MG-2	1254460	233758	2011	0.53	4.70										
1	CSO-MG-3	1254315	233766	2011	0.20	4.50										
1	CSO-MG-4	1254417	233706	2011	0.25	4.50										
1	CSO-MG-5	1254348	233709	2011	0.15	4.90										
1	CSO-MG-6	1254380	233645	2011	0.21	3.80										
1	CSO-MG-7	1254360	233806	2013	0.89	7.60										
1	MG1000E	1254832	232879	1996	0.18	5.30										
1	MG114E	1254247	233217	1996	0.16	4.70										
1	MG114W	1254091	233312	1996	0.12	7.20										
1	MG228E	1254319	233171	1996	0.13	5.00										
1	MG228W	1253997	233374	1996	0.14	4.70										
1	MG28P	1254163	233262	1996	0.15	3.10										
1	PSAMP/NOAA-174*	1254146	231836	1998	0.13	7.52										
1	UWI2007-176*	1254361	233433	2007	0.35	9.30						--	--			
1	UWI2007-177*	1253477	234615	2007	0.17	3.60										
2	KSZY01*	1258639	231983	2013	0.75	14.30										
2	LDWRRUN0EB-SS2A	1259293	234706	2005	6.63	NA	--	--	--	--	--	--	--		--	--
2	LDWRRUN0EB-SS2B	1259243	234651	2005	4.64	NA	--	--	--	--	--	--	--		--	--

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
2	TERNL91T91_01XX	1258122	232550	1991	2.50	NA	CSL		CSL		SQS					
2	TERNL91T91_02XX	1258130	232945	1991	2.33	NA	CSL		CSL		SQS					
2	TERNL91T91_03XX	1258136	233275	1991	1.47	NA	CSL		CSL		CSL					
2	UWI2007-115	1259214	232945	2007	1.83	36.20			SQS							
2	UWI2007-180	1259363	231741	2007	0.69	25.20										
3	DW-01	1263143	229703	2008	2.01	54.70	CSL							SQS		
3	DW-03	1263359	229529	2008	0.10	2.30										
3	DW-13	1263343	229363	2008	NA	1.70										
3	DW-19	1263268	229150	2008	1.95	45.40	SQS							SQS		
3	DW-33	1263747	229130	2008	NA	1.20										
3	DW-34	1263903	228952	2008	2.38	27.00										
3	DW-AE-SAM-1	1263982	228713	2006	2.10	59.40	SQS							SQS		
3	DW-AE-SAM-2	1264037	228776	2006	1.83	61.70	SQS							SQS	SQS	
3	DWMP-01	1264047	228813	2012	4.02	62.50	CSL	CSL	CSL					SQS	CSL	CSL
3	DWMP-02	1263919	228770	2012	1.64	39.50									SQS	CSL
3	DWMP-03	1263846	228638	2012	3.10	68.50	SQS							SQS		CSL
3	DWMP-04	1263631	228546	2010	1.20	37.90										
3	DWMP-05	1263836	229041	2010	0.85	5.30									SQS	
3	DWMP-06	1263542	228839	2010	2.31	29.80										
3	DWMP-07	1263350	228660	2010	1.04	32.00										
3	DWMP-08	1263341	228907	2012	2.60	60.40	CSL							SQS	SQS	CSL
3	DWMP-09	1263215	228806	2010	3.08	91.70	SQS							SQS		

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
3	DWMP-10	1263565	229326	2012	0.16	4.90										
3	DWMP-11	1263272	229156	2010	1.64	26.00										
3	DWMP-12	1263055	228963	2010	4.33	79.00								SQS		
3	DWMP-13	1263317	229640	2010	0.75	10.40										
3	DWMP-14	1263228	229553	2012	2.47	70.80	SQS							SQS	SQS	CSL
3	DWMP-15	1263053	229444	2012	0.92	62.80								SQS	SQS	
3	DWMP-16	1262966	229353	2010	1.88	68.80								SQS		
3	DWPD-03	1263420	229578	2008	0.48	7.30										
3	LTBC20	1263455	229241	2000	1.10	10.89										
3	LTBC21	1263562	229181	2000	1.91	28.10										
3	LTBC22	1263517	229098	2000	0.48	10.60										
3	LTBC34	1263502	229191	2000	0.66	4.30										
3	LTBC35	1263582	229241	2000	0.25	5.10										
3	LTBC36	1263627	229202	1994	1.74	7.40									CSL	
3	LTBC37	1263322	228921	1994	1.67	48.70	CSL							SQS	CSL	
3	LTBD23	1263692	228961	2000	0.51	5.20									SQS	
3	LTBD24	1263650	229031	2000	0.46	3.70										
3	LTBD26	1263853	228711	1994	2.51	52.80										
3	UWI2007-181*	1263330	228094	2007	1.38	42.35			SQS			--	--	CSL		
3	UWI2007-186*	1262604	229261	2007	0.91	33.48			CSL		SQS	--	--	SQS		
4	COLMAN94CDOCK-1	1269169	223088	1993	6.80	NA		CSL	CSL							
4	COLMAN94CDOCK-2	1269131	222971	1993	6.30	NA		CSL	CSL							

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
4	COLMAN94EB-8	1269065	222866	1993	NA	NA	CSL	--	--	--	--	--	--	--	--	--
4	COLMAN94VG-1	1268915	223768	1994	0.40	0.80				--	--	--	--	--	--	--
4	COLMAN94VG-10	1268776	223700	1994	4.30	10.70	CSL	CSL	CSL	--	--	--	--	--	--	--
4	COLMAN94VG-11	1268690	223727	1994	2.20	11.30	CSL	CSL	SQS	--	--	--	--	--	--	--
4	COLMAN94VG-3	1268375	224153	1994	1.70	10.70		CSL	CSL	--	--	--	--	--	--	--
4	COLMAN94VG-5	1268567	223805	1994	1.60	14.00		SQS	SQS	--	--	--	--	--	--	--
4	COLMAN94VG-6	1268522	223958	1994	2.20	20.00			SQS	--	--	--	--	--	--	--
4	COLMAN94VG-8	1268529	223585	1994	0.46	18.60				--	--	--	--	--	--	--
4	COLMAN94WSF-1	1268663	223893	1994	2.00	15.70		SQS	SQS	--	--	--	--	--	--	--
4	COLMAN94WSF-10	1268959	223014	1994	4.15	42.05	CSL	CSL	CSL	--	--	--	--	--	--	--
4	COLMAN94WSF-11	1269207	222810	1994	1.80	64.90			SQS	--	--	--	--	--	--	--
4	COLMAN94WSF-12	1268689	223017	1994	3.20	45.60	CSL			--	--	--	--	--	--	--
4	COLMAN94WSF-13	1268755	222698	1994	3.10	47.00	CSL			--	--	--	--	--	--	--
4	COLMAN94WSF-2	1268810	223792	1994	1.10	9.20		SQS	CSL	--	--	--	--	--	--	--
4	COLMAN94WSF-3	1268859	223612	1994	1.10	6.60		CSL	CSL	--	--	--	--	--	--	--
4	COLMAN94WSF-4	1268742	223586	1994	1.20	11.50		CSL	CSL	--	--	--	--	--	--	--
4	COLMAN94WSF-5	1268459	223639	1994	2.40	18.00			SQS	--	--	--	--	--	--	--
4	COLMAN94WSF-6	1268428	223708	1994	0.56	3.80		CSL	SQS	--	--	--	--	--	--	--
4	COLMAN94WSF-7	1268696	223816	1994	1.80	14.60		SQS	SQS	--	--	--	--	--	--	--
4	COLMAN94WSF-8	1269411	223030	1994	7.90	31.50	CSL	CSL	CSL	--	--	--	--	--	--	--
4	COLMAN94WSF-9	1269222	223032	1994	3.90	23.70	CSL		SQS	--	--	--	--	--	--	--
4	COLMAN94WSF-A	1268724	223741	1994	1.70	12.70		CSL	SQS	--	--	--	--	--	--	--

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
4	COLMAN94WSF-B	1268577	223708	1994	5.70	25.60	CSL	CSL	CSL	--	--	--	--	--	--	--
4	COLMAN94WSF-C	1269300	222940	1994	5.20	32.70	CSL	CSL	CSL	--	--	--	--	--	--	--
4	COLMAN94WSF-D	1269081	223112	1994	1.30	16.90	CSL			--	--	--	--	--	--	--
4	COLMAN94WSF-E	1268919	222920	1994	5.50	40.20	CSL	CSL	CSL	--	--	--	--	--	--	--
4	ELLIOTB1	1267823	225455	1994	7.70	73.00	SQS	CSL	CSL		CSL	--	--	SQS		
4	ELLIOTB2	1268559	224631	1994	11.00	81.00	CSL	CSL	CSL	CSL	CSL	--	--	SQS		
4	ELLIOTB3	1268216	224637	1994	8.40	87.00	CSL	CSL	CSL		CSL	--	--	SQS		
4	ELLIOTB7	1268886	223814	1994	7.00	82.00	CSL	CSL	CSL		CSL	--	--	SQS		
4	ELLIOTB8	1269071	222796	1994	4.50	77.00	CSL	CSL	CSL		CSL	--	--	SQS		
4	ELLIOTB9	1268720	222398	1994	7.70	90.00	CSL	CSL	CSL		CSL	--	--	SQS		
4	ELLIOTC2	1268423	224633	1994	7.00	90.00	CSL	--	--	--	--	--	--	CSL	--	--
4	ELLIOTC3	1269071	222796	1994	7.30	66.00	CSL	--	--	--	--	--	--	SQS	--	--
4	LTDF01*	1267270	225367	2013	3.56	42.30	SQS									
4	P53C1	1268656	223829	2002	0.70	NA										
4	P53C2	1268497	223886	2002	0.36	2.90										
4	P53C3	1268422	224002	2002	0.56	8.70										
4	P53C4	1268450	224131	2002	0.67	4.28										
4	P53C5	1268387	224215	2002	0.38	3.50										
4	P53VG1	1268451	223878	2002	0.71	9.40										
4	P53VG10	1268786	223751	1994	4.15	14.70	CSL	CSL	CSL							
4	P53VG11	1268718	223753	1994	1.65	15.80	CSL	CSL	CSL		CSL					
4	P53VG2	1268461	224026	2002	2.27	13.80										

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
4	P53VG3	1268430	224175	2002	0.95	13.05										
4	P53VG4	1268346	224277	2002	0.96	16.20										
4	P53VG5	1268620	223874	2002	2.00	26.35										
4	P53VG6	1268560	223996	2002	1.40	17.70										
4	P53VG7	1268267	223836	2002	0.33	4.95										
4	P53VG8	1268544	223692	1994	0.40	22.00										
4	P66CAPBH10	1267127	225025	2004	3.80	13.80				--		--	--		--	--
4	P66CAPBH11	1267084	224965	2004	2.20	17.00				--		--	--		--	--
4	P66CAPBH12	1267268	225934	2004	5.90	37.30	CSL	CSL	CSL	--		--	--	CSL	--	--
4	P66CAPBH13	1267389	225810	2004	4.90	53.40	CSL	CSL	CSL	--		--	--	SQS	--	--
4	P66CAPBH2	1266578	226373	2004	0.12	3.80				--		--	--		--	--
4	P66CAPBH3	1266659	226311	2004	2.90	19.80				--		--	--	SQS	--	--
4	P66CAPBH4	1266601	223393	2004	2.40	9.30				--		--	--		--	--
4	P66CAPBH5	1266782	226309	2004	3.00	28.70				--		--	--		--	--
4	P66CAPBH6	1266904	226245	2004	2.10	13.40				--		--	--		--	--
4	P66CAPBH7	1266985	226183	2004	3.30	17.20				--		--	--		--	--
4	P66CAPBH8	1266983	226061	2004	2.50	26.50				--		--	--		--	--
4	P66CAPBH9	1267066	226120	2004	2.95	16.47				--		--	--		--	--
4	P66CAPCS1	1266617	226312	2004	4.10	32.10	CSL	CSL	CSL	--		--	--	SQS	--	--
4	P66CAPCS2	1266902	226124	2004	2.90	22.00				--		--	--		--	--
4	P66CAPCS3	1267186	225936	2004	2.40	9.35				--		--	--		--	--
4	P66CAPSS5B	1266693	225945	2004	2.00	72.70	CSL			--		--	--	SQS	--	--

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
4	PSDDA_02EBB02	1267992	222530	2002	1.80	60.13	CSL	--	--		--	--	--	--	--	--
4	UWI2007-182*	1267734	224056	2007	4.04	59.30	CSL				CSL			SQS		
4	UWI2007-183*	1268650	223958	2007	1.00	17.10			CSL		SQS	--	--	SQS		SQS
4	UWI2007-184*	1268511	224205	2007	3.31	19.60			CSL		SQS					
4	UWI2007-188*	1267801	224729	2007	2.66	69.50			SQS			--	--	SQS		
4	UWI2007-194*	1266913	222627	2007	2.13	81.30										
4	WF-01	1268120	225017	1996	8.48	54.20	CSL		CSL					CSL	SQS	
4	WF-02	1267944	225031	1996	4.24	37.80	CSL		CSL					SQS		
4	WF-03	1268309	224881	1996	9.00	55.40	CSL		CSL					CSL	SQS	
4	WF-05	1268048	224721	1996	4.50	55.90	CSL		CSL					CSL		
4	WF-08	1268293	224604	1996	7.55	43.20	CSL		CSL					CSL	CSL	
4	WF-09	1268569	224599	1996	7.59	53.80	CSL		CSL	CSL				SQS	CSL	
4	WF-10	1268210	224455	1996	2.96	32.90	CSL							SQS	SQS	
4	WF-15	1268512	224328	1996	4.96	31.20	CSL		CSL					SQS		
4	WF-16	1268584	224151	1996	2.02	26.50									CSL	
4	WF-17	1268861	224135	1996	9.82	49.50	CSL		CSL		CSL			CSL	CSL	
4	WF-19	1268824	223869	1996	4.55	45.30	CSL		CSL					CSL	SQS	
5	CN5C	1267645	219872	1995	1.10	10.90										
5	EW09-SS-217	1267301	219270	2009	0.81	21.70										
5	EW09-SS-218	1267468	219325	2009	0.80	38.00										
5	EW09-SS-220	1267783	219553	2009	0.87	24.20		SQS	SQS							
5	EW09-SS-221	1267685	219343	2009	1.96	12.90										

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
5	EW09-SS-222	1267923	219524	2009	0.78	10.40										
5	EW09-SS-223	1267907	219714	2009	0.19	42.70										
5	LTGF01*	1265592	218854	2013	1.32	35.90	SQS							SQS		
5	N-01*	1266020	218135	1991	0.52	53.00	SQS	SQS	SQS							
5	N-03*	1265679	218116	1991	2.44	35.00		CSL	SQS		CSL					
5	N-09*	1263646	217593	1991	0.49	43.00		CSL	CSL							
5	N-10*	1263387	217287	1991	1.54	42.00	CSL							CSL		
5	N-11*	1263034	217295	1991	0.74	55.00	CSL	SQS	SQS					SQS		
5	N-12*	1262658	217287	1991	0.71	44.00	SQS									
5	N-13*	1265716	218331	1991	1.60	51.00		CSL	SQS		CSL					
5	N-14*	1265326	218254	1991	0.90	35.00		CSL	SQS		CSL				CSL	
5	N-19*	1263372	217919	1991	1.98	44.00	CSL									
5	N-20*	1263042	217815	1991	1.11	35.00	SQS					CSL				
5	N-21*	1262628	217828	1991	1.07	44.00										
5	N-22*	1265704	218669	1991	2.73	56.00	CSL									
5	N-23*	1265300	218581	1991	2.02	45.00	CSL									
5	N-27*	1263882	218560	1991	1.31	42.00	CSL							SQS	SQS	
5	N-28*	1263496	218568	1991	0.55	43.00								CSL	SQS	
5	N-29*	1265756	219571	1991	2.24	64.00	SQS									
5	N-30*	1264399	219390	1991	0.63	25.00	CSL	SQS	SQS					SQS		
5	PDM-11	1267730	219120	2000	0.79	NA		SQS		--		--	--		--	--
5	POLARISSTA001*	1265736	218339	2001	NA	NA										

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
5	POLARISSTA002*	1265901	218288	2001	NA	NA								SQS		
5	PSDDA_02EBB01	1263026	218564	2002	1.43	18.73		--	--		--	--	--	--	--	--
5	PSDDA_02EBP07	1266736	220021	2002	1.70	48.90										
5	PSR07-OSA-1-S	1260538	217159	2007	1.21	37.45			SQS							
5	PSR07-OSA-2-S	1260636	217746	2007	3.05	21.50										
5	PSR07-OSA-3-S	1260653	218347	2007	1.31	32.22										
5	PSR07-OSA-4-S	1261056	219251	2007	1.16	36.30										
5	PSR07-OSA-5-S	1262571	218456	2007	6.55	18.82										
5	PSR07-OSA-6-S	1262544	218047	2007	0.40	21.07										
5	PSR07-OSA-7-S	1262462	217452	2007	1.16	33.92	CSL		SQS					SQS		
5	PSR07-RA2B-1-S	1262173	217437	2007	0.28	86.30										
5	PSR07-RA4-10-S	1262348	218152	2007	0.68	12.75										
5	PSR07-RA4-2-S	1260965	217465	2007	0.52	14.34										
5	PSR07-RA4-3-S	1261254	217447	2007	1.51	14.00										
5	PSR07-RA4-6-S	1261552	217747	2007	0.76	13.21										
5	PSR07-RA4-9-S	1262142	218024	2007	1.14	11.70										
5	PSR07-RA5-10-S	1261844	218346	2007	0.95	24.90										
5	PSR07-RA5-11-S	1262154	218350	2007	2.16	23.39										
5	PSR07-RA5-12-S	1261566	218651	2007	1.26	25.61										
5	PSR07-RA5-13-S	1262249	218647	2007	1.08	30.07										
5	PSR07-RA5-14A-S	1260977	218946	2007	1.35	30.00								SQS		
5	PSR07-RA5-14A-S-D	1260977	218946	2007	1.76	NA								SQS		

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
5	PSR07-RA5-15-S	1261361	218956	2007	1.11	27.94								SQS		
5	PSR07-RA5-1-S	1261043	217740	2007	1.88	32.29										
5	PSR07-RA5-20-S	1261240	218552	2007	1.39	25.88										
5	PSR07-RA5-21-S	1261889	218664	2007	0.98	24.64										
5	PSR07-RA5-2-S	1261266	217738	2007	1.45	14.87										
5	PSR07-RA5-3-S	1261051	218033	2007	1.50	38.89										
5	PSR07-RA5-4-S	1261263	218039	2007	1.19	12.42										
5	PSR07-RA5-5-S	1261528	218048	2007	0.85	21.70										
5	PSR07-RA5-6-S	1261847	218044	2007	1.26	15.79										
5	PSR07-RA5-7-S	1260944	218341	2007	1.45	34.27										
5	PSR07-RA5-8-S	1261244	218354	2007	1.93	22.55										
5	PSR07-RA5-8-S-D	1261243	218355	2007	1.90	25.56										
5	PSR07-RA5-9-S	1261551	218358	2007	1.69	27.55										
5	UWI2007-197*	1262775	217641	2007	0.45	13.40	CSL									
5	UWI2007-199*	1262449	217757	2007	5.76	32.70										
5	W-55*	1263641	217291	1991	1.25	43.00	SQS							SQS		
6	DWMP-BREF1	1259459	218630	2004	0.59	14.70										
6	LSHZ03	1259382	218241	1990	0.76	8.84									SQS	CSL
6	LSHZ03-97	1259659	218323	2000	0.70	20.50										
6	LSHZ04	1259142	218526	1990	1.80	20.37	CSL							SQS		CSL
6	LSHZ05	1259322	218441	1990	2.09	28.06	CSL							--		
6	LSHZ06	1259382	218511	1990	2.11	27.70	CSL							--		

Area (Figure 6-4)	Locator	X	Y	Year	% TOC	% Fines	Metals	LPAHs	HPAHs	Chlorobenzenes	Dibenzofuran	Hexachlorobutadiene	N-Nitrosodiphenylamine	Total PCBs (Aroclors)	Phthalates	Hydrophilic Organics
6	LSHZ07	1259172	218431	1990	0.97	13.33								--		
6	LSHZ08	1259170	218767	2013	1.22	22.20										
6	PSAMP_HP-33	1259790	217997	1995	0.90	32.00	SQS			--		--	--	SQS	--	--
6	SEACRE9710537-1*	1259277	218366	1997	0.89	31.60								--		
6	SEACRE9710537-2*	1259350	218260	1997	0.74	32.20								--		
6	SEACRE9710537-3*	1259151	218570	1997	1.84	27.80								--		
6	SEACRE9710537-4*	1259356	218466	1997	0.94	33.60								--		
6	UWI2007-189*	1258665	219238	2007	0.65	25.20			SQS		SQS					
7	CSO-53-1	1253159	217294	2011	0.29	4.60										
7	CSO-53-2	1253104	217246	2011	0.07	3.90										
7	CSO-53-3	1253214	217328	2011	0.10	2.60										
7	CSO-53-4	1253098	217315	2011	0.21	4.10										
7	CSO-53-5	1253150	217358	2011	0.19	3.70										
7	CSO-53-6	1253088	217386	2011	1.23	10.40										
7	DH1000S	1252437	216841	1996	0.32	5.70								SQS	SQS	
7	DH107N	1253239	217317	1996	0.09	1.80										
7	DH107S	1253114	217207	1996	0.13	0.90										
7	DH14P	1253203	217257	1996	0.13	0.10										
7	DH214N	1253315	217404	1996	0.12	1.60										
7	DH214S	1253059	217142	1996	0.13	1.40										

Appendix E: Tissue Chemistry

Tissue Chemistry Data Summary

The uptake of contaminants by marine organisms occurs through ingestion of food and detrital particles, water exchange at feeding and respiratory surfaces, and adsorption of chemicals onto body surfaces. These contaminants may be stored in skeletal material, shells, and soft tissues. Biological monitoring has been a component of the County's routine monitoring programs for many years, with the objective to monitor contaminants that may bio-accumulate in shellfish and could pose a potential risk to human health and the environment.

King County Shellfish Tissue Data

Prior to 1996, shellfish samples were collected from a number of clam species, whichever species were present at the time of collection. Since interpreting mixed species tissue analysis is problematic, a single species was chosen for the monitoring program. From 1996 to 2010, shellfish samples were comprised of a single species of butter clam, *Saxidomus giganteus*. Shellfish samples were collected once a year between mid-July and late August until 2006. After that time, the shellfish monitoring program increased its sampling of clams to twice-yearly (March and July/August). This was done to help assess potential seasonal variability in clam tissue chemical concentrations. Up until that time, shellfish tissue samples were analyzed for metals and trace organic compounds only. These measurements provided a good indication of potential health risks to shellfish and the public that consumes them. Because of the low frequency of detection of organic compounds in clam tissue over the years, they were not monitored after 2006. In 2008, the analysis of 14 PBDEs congeners was added to the program due to their high detection rate in local sediments, their status as an emerging chemical of concern, and their potential to bioaccumulate.

Shellfish tissue samples were collected from nine intertidal monitoring stations throughout King County. Five outfall-vicinity monitoring sites were located at West Point (North and South), Vashon Treatment Plant, and the Alki and Carkeek Treatment Plant outfalls. Four ambient monitoring sites were located at Edwards Point, Point Wells, Golden Gardens Park, and Normandy Park. The West Point South intertidal location is the only site that fell within the boundaries of the current Elliott Bay WQA study area and will be assessed in the following sections (see Table E-1 and Figure E-1 for locality information). Specific analytes in clam tissue that are included in this section are: percent solids, percent lipids, trace metals and PBDEs. Algae samples were also collected during all of the tissue sampling events, but because the data are sparse they will not be part of the current Elliott Bay WQA.

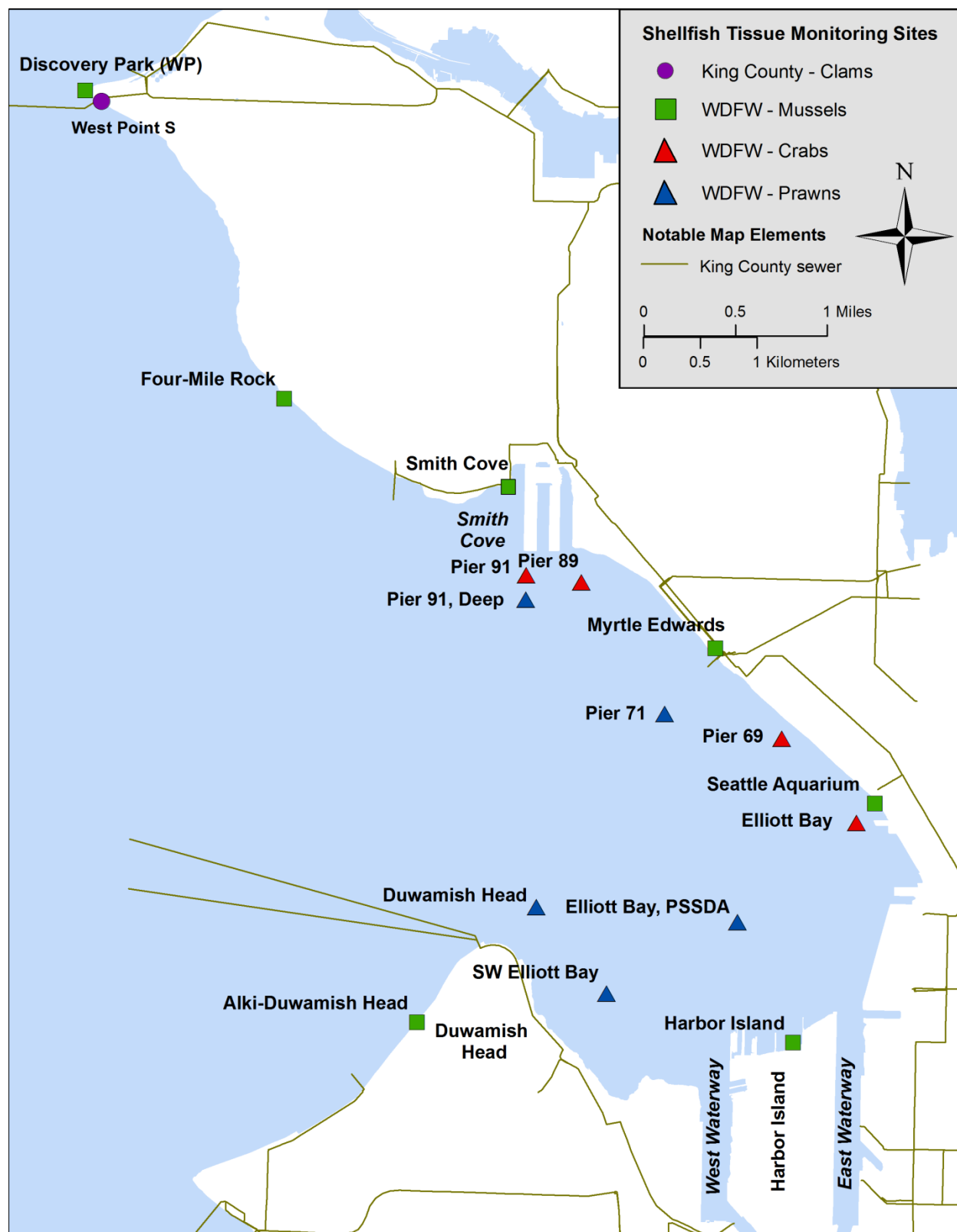


Figure E-1 Tissue monitoring sites in Elliott Bay and adjacent Puget Sound by King County and Washington Department of Fish and Wildlife (WDFW).

Table E-1 Shellfish tissue monitoring sites in Elliott Bay and adjacent Puget Sound.

Locator	Description	Northing	Easting	Monitoring Agency	Ambient vs. Outfall	Years Sampled
KSSN05	West Point South	245272	1245980	KC	Outfall	1970-pres.
15	Discovery Park, West Point	245589	1245513	WDFW	Outfall	2012/2013
16	Four Mile Rock	236715	1251246	WDFW	Ambient	2012/2013
17	Smith Cove	234032	1257593	WDFW	Ambient	2012/2013
18	Myrtle Edwards	229532	1263680	WDFW	Ambient	2012/2013
19	Seattle Aquarium	225063	1268279	WDFW	Ambient	2012/2013
20	Harbor Island	218177	1265922	WDFW	Ambient	2012/2013
21	Duwamish Head	218759	1255074	WDFW	Ambient	2012/2013

King County collected butter clams from sediment, for tissue analysis. WDFW used shellfish tissue from mussel bags.

Field Methods

Shellfish samples were collected by KCEL. For each site, butter clams were collected by hand digging with shovels in the approximate vicinity of siphon holes. Care was taken during the sampling process to minimize disturbance to other organisms in the area. After completion of sampling, all sediment was replaced at the dig site. Clams were then placed into four-liter glass jars and stored on ice until being delivered to the laboratory. Because organic compounds were no longer analyzed after 2005, clams were placed into plastic bags from 2006 through 2010 and stored on ice for delivery to the laboratory.

Laboratory Methods

Shellfish samples were processed at KCEL in accordance with established PSEP recommended protocols (PSEP, 1997). Each tissue sample consists of the soft body parts of a minimum of five clams between 60 to 120 mm in size. Prior to opening the clams in the lab, the shells were rinsed with deionized water to remove sand and adhering material. Each clam was measured and the length recorded. Tissues from the clams were extracted from the shell with ceramic knives and composited with their liquor. The tissues and liquor were homogenized in a blender with stainless steel blades and then frozen until analysis.

KCEL analyzed all shellfish parameters. Table E-2 lists methods and detection limits. Metals (except mercury) were analyzed using either ICP and/or ICP-MS depending on detection limits. Mercury was analyzed using cold-vapor atomic absorption spectroscopy (CVAA). PBDEs were extracted using an ultra-sonic solvent analyzed using Gas Chromatograph Inductively Coupled Plasma Mass Spectrometry (GC-ICP-MS) instrumentation.

Table E-2 Laboratory methods and detection limits for shellfish.

Parameter	Unit	MDL	Method
Total Solids	%	0.005	SM2540-G
Total Lipids	%	0.1	KCEL or 07-01-001
Metals, Total, ICP	mg/kg	Variable ¹	PSEP (1997)
Metals, Total, ICP-MS	mg/kg	Variable ¹	PSEP (1997)
Mercury, Total, CVAA	mg/kg	0.004	PSEP (1997)
Polybrominated Diphenyl Ether (PBDEs)	µg/kg	Variable ¹	EPA 3550C/1614

¹Detection limits vary with parameter analyzed

Data Analysis

The analytical results presented in this section represent the precision of the analytical laboratory for measuring specific analytes in tissue samples. Total metal recoveries are reported in units of milligrams per kilogram (mg/kg), and PBDE congener data are in micrograms per kilogram (µg/kg). All results are expressed on a wet weight basis.

The tissue sample results include various data qualifiers. Samples qualified as (“R”-rejected), or (“U”-non-detect) were not analyzed in this section. When a sample was qualified with a “B”- (blank contamination), it was assessed on a case-by-case basis. If the affected sample was confirmed to have a concentration of less than 5 times the sample blank, then that individual sample was considered non-detected. Non-detected results were used for frequency of detection analysis only. All “J”- (estimated) qualified data were considered to be usable for purposes of this analysis. For total PBDEs, only detected concentrations of individual congeners were included in the resulting total calculations.

Human Health Standards for Clam Tissue

Several contaminants found in surface water and sediment have the potential to bioaccumulate in the tissues of a variety of aquatic organisms, such as fish and shellfish. Bioaccumulation in biota may affect not only the organism directly accumulating the contaminants, but also consumers of those organisms, such as humans or a variety of other wildlife species. Currently, WDOH uses EPA’s Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories to determine health-based screening values (EPA, 2000).

Screening values (SVs) for metals in clam tissue were based on a consumption rate equal to two, eight ounce meals per week or 59.7 g/day for non-carcinogenic end points. SVs were calculated using chronic EPA’s oral reference doses (RfDs) (Table E-3). RfDs represent an estimate of daily human exposure to a contaminant below which non-cancer adverse health effects are unlikely and would not trigger a potential consumption advisory by WDOH. Screening values were calculated for non-cancer endpoints associated with consumption of shellfish with the following equation:

$$\text{SV non-cancer} = \frac{\text{RfD} * \text{BW}}{\text{CR} * \text{CF}}$$

Where:

RfD = oral reference dose (mg/kg-day).

BW = mean body weight of the general population or subpopulation of concern (70 kg).

CR = daily consumption rate based on two meals per week, eight ounces per meal (59.7 g/d).

CF = conversion factor (0.001 kg/g).

Table E-3 Oral reference doses (RfDs) used in calculating the screening values for metals in clam tissue.

Metal	Oral RfD (mg/kg-day)	RfD Source	Notes
Aluminum	1.0	NCEA, 2001	--
Cadmium	0.001	IRIS, 2014	Cadmium RfD for food was used
Chromium	0.003	IRIS, 2014	--
Copper	0.04	HEAST, 1997	--
Iron	0.3	NCEA, 2001	--
Manganese	0.14	IRIS, 2014	RfD selected is applicable to exposures via ingestion of food
Mercury	0.0001	IRIS, 2014	--
Nickel	0.02	IRIS, 2014	--
Silver	0.005	IRIS, 2014	--
Zinc	0.3	IRIS, 2014	--

Summary of Tissue Results

The following sections summarizes King counties shellfish monitoring program's butter clam data collected from 1999 through 2010 from a single intertidal location KSSN05. Samples were composited from 5 to 10 clams, to provide the proper volume matrix for analysis. Analytes in clam tissue that were included in this assessment are: percent solids, percent lipids, trace metals, and PBDEs.

Total solids and percent lipid concentrations in shellfish tissue samples collected from KSSN05 between 1999 until 2010 are shown in Table E-4. Overall, percent solids and lipids stayed consistent throughout the years with very little variation between historic and current conditions, with one exception in August of 2010 (lipid concentration = 1.69 percent) (Table E-4).

Table E-4. Shellfish tissue lipid and total solids concentrations (percent) at station KSSN05 (1999 to 2010).

Analyte	Min	Max	Mean
Lipids	0.31	1.69	0.73
Total Solids	14.1	23.7	18.44

Metals

Clam tissue from KSSN05 was analyzed for 14 metals between 1999 and 2010. All metals except beryllium were detected during all the sampling events. All metals results are presented in Table E-5. To evaluate seasonal variation, only samples collected in late July through early August were used for the analysis. All wet weight metal concentrations in butter clams collected by King County at site KSSN05 were well below recommended EPA SVs (Table E-5).

Table E-5. Historical clam tissue data 1999 to 2010 summary and comparisons to EPA screening values for site KSSN05. All values in mg/kg on a wet weight basis.

Metal	FOD	Min	Max	Mean	EPA SV Level	Above SV?
Aluminum	11/11	10.7	99.5	63.645	1172.5	No
Arsenic	12/12	2.38	4.67	3.08	—	—
Beryllium	0/12	ND	ND	ND	—	—
Cadmium	12/12	0.046	0.0938	0.0578	1.17	No
Chromium	12/12	0.166	0.822	0.42	3.52	No
Copper	12/12	1.67	4.04	2.296	46.9	No
Iron	12/12	25.3	262	110.882	351.8	No
Lead	12/12	0.0666	0.148	0.106	—	—
Manganese	12/12	1.83	71.7	2.565	164.2	No
Mercury	12/12	0.0042	0.00976	0.00586	0.117	No
Nickel	12/12	0.701	1.31	1.024	23.5	No
Selenium	12/12	0.256	0.44	0.339	—	—
Silver	12/12	0.12	0.49	0.25	58.6	No
Zinc	12/12	12.3	18.3	15.7	351.8	No

**ND= non-detect

PBDEs

Six of the 14 PBDE congeners analyzed were detected in butter clam tissue samples (Figure E-2). TriBDE-17, TriBDE-28, TetraBDE-66, HexaBDE-138, PentaBDE-153, PentaBDE-154, HeptaBDE-183, and HeptaBDE-190 were not detected in any of the 14 samples analyzed, while PentaBDE-100 and PentaBDE-99 were detected in all samples. PBDE concentrations were typically higher in samples collected in March than in those collected in August. TetraBDE-71 was elevated at 6.75 mg/kg-ww during March 2008. Five other locations monitored at by King County had similarly elevated TetraBDE-71 concentrations in March 2008 (Figure E-2). Additionally, lipid normalization of the wet weight PBDEs did not alter the distribution of these values.

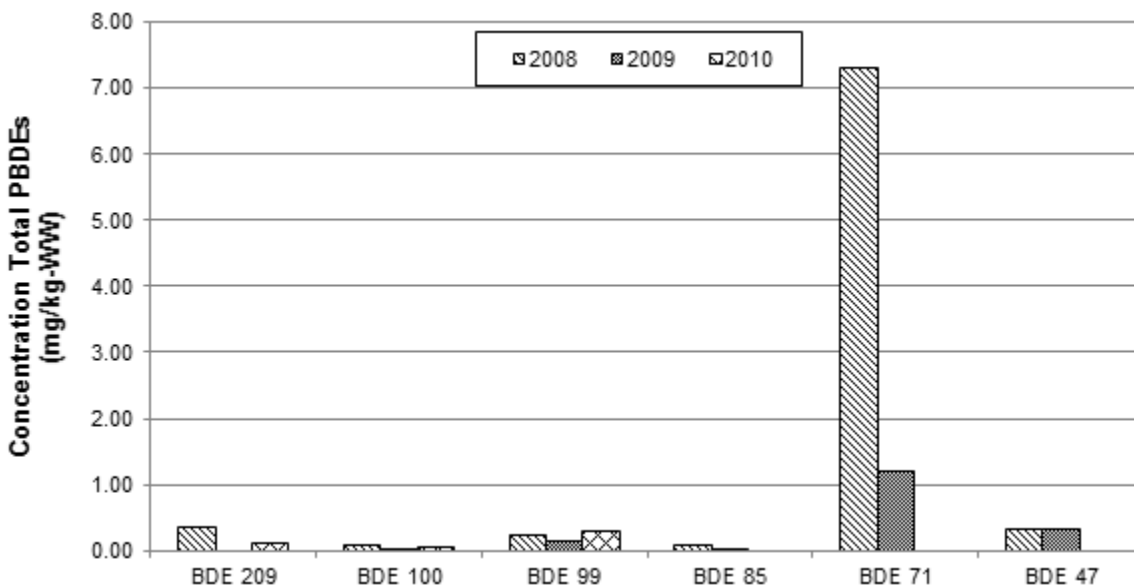


Figure E-2 Distribution of detected PBDE congeners between 2008 and 2010 at site KSSN05.

Other Shellfish Studies within Elliott Bay

The purpose of this section is to provide additional information on the extent of chemical contamination in shellfish tissue for Elliott Bay. The following are summaries from various studies conducted around Puget Sound. Contaminant data are presented as summed concentrations (e.g., Σ DDTs) for specific analyte groups except in cases with fewer than two analytes per group. Summed analytes are the sum of all detected values, within each analyte group. In cases where all analytes in a group were not detected, the greatest limit of quantitation (LOQ) for any single analyte in the group was used as the summation concentration, and the value was preceded by a "<" (less than) qualifier. An estimated total PCB (eTPCB) concentration was calculated by summing the detected concentrations for 17-18 commonly detected congeners and multiplying the result by two, according to Lauenstein and Cantillo (1993).

Puget Sound Ecosystem Monitoring Program (PSEMP) Mussel Watch

In the winter of 2012-13 the Washington Department of Fish and Wildlife (WDFW) coordinated the first synoptic Puget Sound-wide assessment of toxic contaminants in nearshore biota (WDFW, 2014a). The study used native mussels (*Mytilus trossulus*) as indicators of the degree of contamination for local nearshore habitats. Uncontaminated mussels were transplanted at 108 locations along the Puget Sound shoreline. Six locations were chosen for mussel deployment within Elliott Bay (Figure E-1; Table E-1). Measurements made at the end of the study included histopathology and concentrations of tissue contaminants including: PAHs, PCBs, PBDEs, chlorinated pesticides, arsenic, cadmium, copper, lead, mercury, and zinc (WDFW, 2014a).

Within Elliott Bay, PAHs, PCBs, PBDEs, and DDT were the most abundant organic contaminants measured. PAHs were detected in the highest concentrations (394.6 to 745.6

ng/g ww) at four Elliott Bay locations (Myrtle Edwards, Four Mile Rock, Pier 59, and Smith Cove). Total PCBs concentrations in Elliott Bay were moderately elevated (between 2.0 and 12.0 ng/g ww). PBDEs and DDTs were similarly found in higher concentrations in urbanized locations compared to non-urbanized areas throughout Puget Sound and Elliott Bay (Table E-6). All six metals were detected in mussels from all sites in Elliott Bay, with relatively low concentrations similar to locations in Puget Sound (WDFW, 2014a).

Table E-6. Contaminant concentration in mussel tissue November 2012 through January 2013. Concentrations in ng/g, dry weight. ¹

Locator	Site Name ^{1,2}	Σ_{42} PAHs	Σ_6 DDTs	Σ_{40} PCBs	eTPCBs ³	Σ_{11} PBDEs
15	Discovery Park (WP)	118.8	0.38	3.0	4.6	118.8
16	Four-Mile Rock	656.7	1.84	6.5	9.6	656.7
17	Smith Cove	394.6	1.6	12.0	15.8	394.6
18	Myrtle Edwards	745.6	2.1	11.0	14.0	745.6
19	Seattle Aquarium-	478.5	0.96	7.1	10.0	478.5
20	Harbor Island-	357.7	0.36	9.1	13.0	357.7
21	Alki-Duwamish Head	57.2	0.28	2.0	3.0	57.2

¹Summed analytes (e.g., Σ_6 DDTs) are the sum of all detected values within each group.

²Concentrations with a "<" represent non-detected values that are below or equal to the limit of quantitation (LOQ). The maximum LOQ is reported for summed analytes.

³The sum of 17 congeners used.

WDFW Crab/Prawn Study

In 2011 and 2012 WDFW conducted a Puget Sound-wide assessment of toxic contaminants in Dungeness crab (*Metacarcinus magister*) and spot prawns (*Pandalus platyceros*) (WDFW, 2014b). The purpose of the study was to evaluate the extent and magnitude of toxic contaminants in these two crustacean species in Puget Sound and to provide data to WDOH to assist in conducting a human health risk assessment. This study was designed to sample animals typically taken in fisheries using sport-fishery gear. Five locations were chosen for crab, four within the bay one in the Duwamish River (Table E-7, Figure E-1) and six for prawn collection sites (Table E-8, Figure E-1) within Elliott Bay (only five were analyzed). Analytes of interests for this study consisted of 4 major POPs including PCBs, PBDEs, PAHs, organochlorine pesticides, and metals (arsenic, cadmium, copper, lead, mercury, and zinc) (WDFW, 2014b).

Table E-7. WDFW Dungeness crab (*Metacarcinus magister*) Elliott Bay sampling sites 2012.

Locator	Description	Northing	Easting	Monitoring Agency	Ambient vs Outfall	Sample Date
30	Elliott Bay	224493	1267740	WDFW	Outfall	5/17/2012
31	Pier 69	226918	1265587	WDFW	Outfall	6/29/2012
32	Pier 89	231426	1259803	WDFW	Ambient	7/12/2012
33	Pier 91	231626	1258214	WDFW	Ambient	6/29/2012

Table E-8. WDFW spot prawns (*Pandalus platyceros*) Elliott Bay sampling sites 2012.

Locator	Description	Northing	Easting	Monitoring Agency	Ambient vs Outfall	Sample Date
24	SW Elliott Bay	219587	1260525	WDFW	Outfall	6/21/2012
25	Elliott Bay	221639	1264308	WDFW	Outfall	6/28/2012
26	Duwamish Head	222076	1258505	WDFW	Ambient	6/21/2012
27	Pier 71	227635	1262211	WDFW	Ambient	7/12/2012
29	Pier 91, Deep	230918	1258199	WDFW	Ambient	6/29/2012

Within Elliott Bay, PCBs were the most frequently detected contaminant in Dungeness crab and spot prawn tissue samples. Total PCBs in Elliott Bay were the highest in all samples taken from urban areas with a maximum concentration of 180 ng/g ww for crab (Table E-9) and a maximum in spot prawns of 27 ng/g ww (Table E-10). DDT and PAHs in both species, and PBDEs in crab, were frequently detected, with the highest concentrations in Puget Sound found in samples from Elliott Bay. Observed maximums for DDTs in Elliott Bay were 4.8 ng/g ww, total PAHs were 4.01 ng/g ww, and PBDEs were 2.8 ng/g ww in crab muscle. Similarly, the maximum total PAHs concentration in Puget Sound prawn muscle also occurred in Elliott Bay at the Pier 91 (3.72 ng/g ww) (Table E-10). PBDEs were rarely detected in spot prawns from Elliott Bay (Table E-10).

Arsenic, copper, mercury and zinc were the most frequently detected metals in Dungeness crab from Elliott Bay (Table E-11), while those metals plus cadmium were most frequently detected in spot prawn (Table E-12). Unlike the POPs, metal concentrations in Dungeness crab and spot prawn muscle were relatively similar throughout all marine locations in Puget Sound including urban environments. Mercury was the only metal that occurred in significantly greater concentrations in urban than non-urban environments (Tables E-11 and E-12).

PAHs, PCBs, PBDEs, and DDT were the most abundant organic contaminants measured in shellfish tissue from Elliott Bay as well as the Puget Sound. Studies on contamination in fish tissue in Elliott Bay have been inconsistent in species tested and location. Data available, suggest that contaminants in organisms from heavily urbanized areas have higher concentrations of certain chemicals. For example, PBDEs in English sole (*Parophrys vetulus*) from Puget Sound urban areas were almost 10 times higher compared to levels measured in sole from the Georgia Basin (WDFW, 2007). Similarly, total PCBs in whole herring bodies from two Central/South Puget Sound urban locations had concentrations ranging from 125 to 350 µg/kg, significantly higher than concentrations in three northern non-urban locations, which were all below 125 µg/kg (WDFW, 2001a). Other urban areas, such as the Duwamish River and the Seattle waterfront, also showed high PCB tissue residues (WDFW, 2001b) that were consistent with the findings above.

Table E-9. Persistent organic pollutants (ng/g wet weight) in Dungeness crab tissue from Elliott Bay.

Site Name ^{1,2}	Σ_8 CHLDs	Σ_6 DDTs	Σ_3 HCHs	eTPCBs ³	Σ_{11} PBDEs	Total PAHs
Elliott Bay	0.87	2.6	<0.27	180	1.7	0.96
Pier 69	<0.20	1.1	<0.20	55	1.8	1.44
Pier 89	1.2	4.8	<0.53	160	2.8	3.22
Pier 91	0.82	1.9	<0.17	91	2.5	4.01

¹Summed analytes (e.g., Σ_6 DDTs) are the sum of all detected values within each group.

²Concentrations with a "<" represent non-detected values that are below or equal to the limit of quantitation (LOQ). The maximum LOQ is reported for summed analytes.

³The sum of 18 congeners used in the total calculation.

Table E-10. Persistent organic pollutants (ng/g wet weight) in spot prawn tissue from Elliott Bay.

Site Name ^{1,2}	Σ_8 CHLDs	Σ_6 DDTs	Σ_3 HCHs	eTPCBs ¹	Σ_{11} PBDEs	Total PAHs
SW Elliott Bay	<0.30	<0.30	<0.30	27	0.32	1.16
Elliott Bay	<0.25	<0.25	<0.25	17	<0.25	1.04
Duwamish Head	<0.31	<0.31	<0.31	16	<0.31	1.2
Pier 71	<0.30	<0.30	<0.30	17	<0.30	1.04
Pier 91, Deep	<0.19	<0.19	<0.19	14	<0.19	3.72

¹Summed analytes (e.g., Σ_6 DDTs) are the sum of all detected values within each group.

²Concentrations with a "<" represent non-detected values that are below or equal to the limit of quantitation (LOQ). The maximum LOQ is reported for summed analytes.

³The sum of 18 congeners used in the total calculation.

Table E-11. Metal concentrations (mg/k-ww) in Dungeness crab muscle from Elliott Bay.

Site Name	Total Mercury	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Zinc
Elliott Bay	0.0827	4.62	-0.0019	8.07	0.01	31
Pier 69	0.0659	6.47	0.0031	8.58	0.012	41.6
Pier 89	0.189	14.4	0.0096	8.88	0.0233	52.2
Pier 91	0.1	9.05	0.0038	12.4	0.016	58.5

**Concentrations with a "-" represent non-detected values that are below or equal to the method detection limit (MDL).

Table E-12. Metal concentrations (mg/kg-ww) in spot prawn muscle from Elliott Bay.

Site Name	Total Mercury	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Zinc
SW Elliott Bay	0.0638	13.2	0.0245	8.61	-0.0040	13.1
Elliott Bay	0.0563	12	0.0256	7.79	-0.0040	12.9
Duwamish Head	0.0373	12.4	0.0189	10.1	-0.0041	13.5
Pier 71	0.0514	13.9	0.0237	8.35	-0.0040	13.2
Pier 91, Deep	0.0442	14.3	0.0162	9.69	0.0045	13.9

**Concentrations with a "-" represent non-detected values that are below or equal to the method detection limit (MDL).

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Appendix F: Literature Review

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