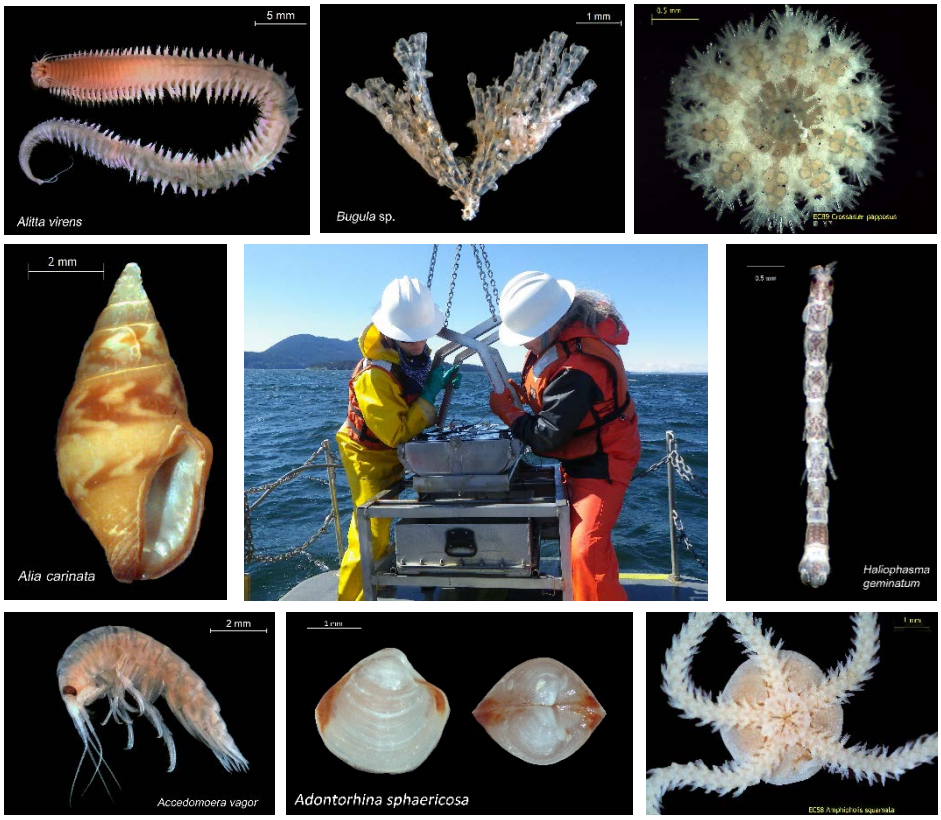
Quality Assurance Monitoring Plan

The Puget Sound Sediment Monitoring Program



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Cover photo: Marine Sediment Monitoring Team staff sampling Puget Sound sediments; benthic invertebrates (microphotography by Dany Burgess and Angela Eagleston).

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March 2018

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2.0 Abstract

This revised Quality Assurance Monitoring Plan (QAMP) has been developed for the Puget Sound Sediment Monitoring Program, updating versions published in 1988, 1998, and 2009. The Washington State Department of Ecology's Marine Sediment Monitoring Team has conducted sediment quality monitoring in Puget Sound since 1989, as part of the Puget Sound Ecosystem Monitoring Program.

Goals for this program are to:

- Document spatial and temporal patterns in sediment quality, including condition of the sediment-dwelling invertebrate assemblages (or benthos).
- Provide high-quality data, summary reports, and indices to stakeholders.

Sediment chemistry, toxicity, and benthos have been monitored annually to determine the effects of contaminated sediments on the benthos, a key indicator of estuarine sediment condition. Recent data reviews from ten long-term stations, eight regions, five strata, and six urban bays, spanning 18 to 28 years, have prompted this program revision.

While findings indicate declining quality of Puget Sound benthos, changes do not appear to correspond with sediment contaminants and/or toxicity values. Based on these findings, the goals of the program have been expanded beyond a focus on toxic pressures alone. Benthos biomass and ecological function – along with a suite of biogeochemical parameters measuring carbon and nitrogen and their stable isotopes, total sulfides, and biogenic silica – have been added to help us better understand the effects of nutrient input and climate change on Puget Sound benthos.

Additionally, the sampling design has been modified. The former *Long-Term/Temporal* monitoring of ten stations has been expanded to new annual *Long-Term* monitoring of 50 stations Puget Sound-wide, while the *Spatial/Temporal (Regional/Stratum)* monitoring has been discontinued. The former *Focus Study (Urban Waters Initiative)* monitoring has been retained as annual *Urban Bays* monitoring in six bays.

This QAMP describes the expanded goals and objectives, revised study design, and all methods for revised sediment monitoring in Puget Sound.

3.0 Background

3.1 Introduction and problem statement

3.1.1 Sediments and benthos: A vital ecosystem component

The sediments of Puget Sound and the invertebrates that live on and within them, known as the benthos, are a vital component of the Puget Sound ecosystem. Sediments provide critical habitat for bottom-dwelling invertebrates and fish, and it is through sediment biogeochemical processes that burial, chemical transformation, and resuspension of carbon, nutrients, and chemical contaminants occurs in this ecosystem.

Benthos play a key role in these biogeochemical processes, changing sediment properties as they move through, feed, and respire within the sands and muds of Puget Sound. They are also a vital food web component, serving as prey for bottom-feeding fish (e.g., English sole), larger epibenthic invertebrates, birds (e.g., surf scoter), marine mammals (e.g., gray whales), and humans. Commercial harvesting of some benthos, including certain species of shellfish (e.g., geoducks, oysters, manila clams) and crabs (e.g., Dungeness), are important to the Puget Sound economy. Washington State is the nation's leading producer of farmed clams, oysters, and mussels, with a total economic contribution of $184 million to Washington's economy in 2010, and annual sales of nearly $150 million in 2014 (Washington Sea Grant, 2015). Benthic species with planktonic larvae also contribute to the pelagic food web, providing food for important forage fish (e.g., Pacific herring, surf smelt, sand lance) (Penttila, 2007) and juvenile salmon (Brennan et al., 2004).

3.1.2 Problem statement and key questions

The Puget Sound ecosystem is subjected to a multitude of natural forces, or drivers, including inputs from the atmosphere, rivers, groundwater, and the ocean, and from point-source and nonpoint-source waste streams related to human activity. These drivers result in changes in climate and weather conditions, carbon and nutrient input, and toxic loading to the system. In combination, these pressures bring about changes in the state of the water column and pelagic assemblages which ultimately influence the state of the sediments, porewater, and the benthos. If habitat alterations are severe enough, benthos will be impacted, and changes in abundance, diversity, biomass, and ecological function will be observed, as depicted in the Driver-Pressure-State-Impact-Response (DPSIR) model in Figure 1 (after Smeets and Wetering, 1999; Niemeijer and de Groot, 2008).

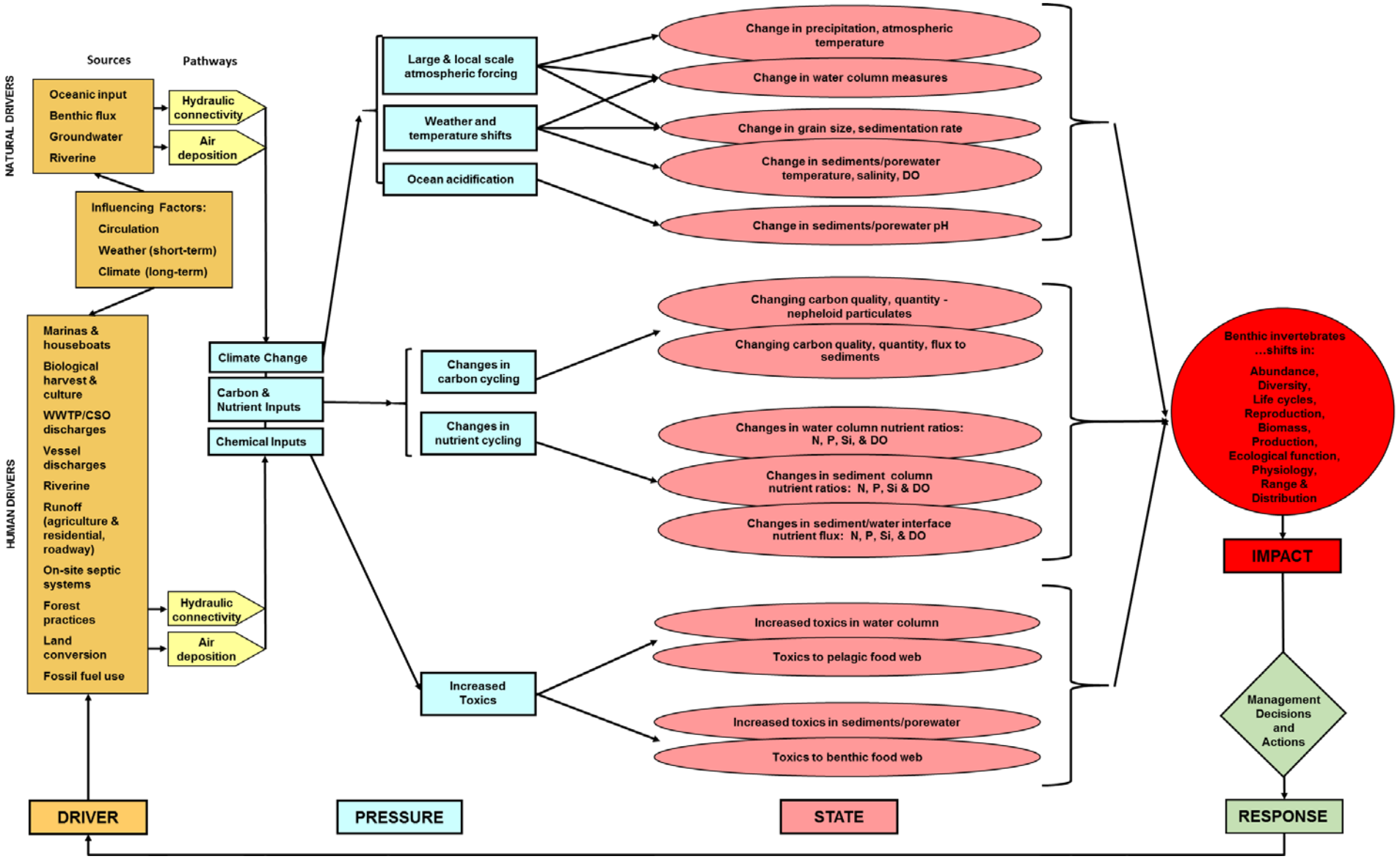

Figure 1. Driver-Pressure-State-Impact-Response (DPSIR) model for water column, sediments, and benthos in Puget Sound.

Based on this model, the problem statement and key questions posed by the *Puget Sound Sediment Monitoring Program* (hereafter referred to as the *Sediment Program*) are:

Problem statement

- Natural and anthropogenic drivers place pressure on Puget Sound's pelagic environment which influence the state of the sediments and porewater and, ultimately the composition and ecological functioning of the benthos.

Key questions

- What is the condition of the benthic habitat, including sediments and porewater and their associated invertebrate assemblages?
- How does benthic condition change over time in response to inputs of carbon, nutrients, and chemicals to the system, and in response to climate-related pressures?

3.1.3 Historical perspective and monitoring enhancements

Long-term sediment monitoring in Puget Sound has been conducted by the Washington State Department of Ecology (Ecology) Marine Sediment Monitoring Team (MSMT) since 1989 as part of the Puget Sound Ecosystem Monitoring Program (PSEMP)[1]. This work, mandated by the Washington State Legislature (Engrossed Substitute Senate Bill 5372) (Appendix A in Dutch et al., 2009), was developed to monitor sediment quality and the condition of the benthos at "ambient" locations throughout Puget Sound. This included areas generally away from municipal and industrial point-source wastewater discharges. Descriptions of the program's origins, the original monitoring design, and modifications made over time are provided in the original PSEMP implementation plan (Puget Sound Water Quality Authority, 1988), the original Sediment Program Quality Assurance Project Plan (QAPP) (Striplin, 1988), and in subsequent QAPP updates (Dutch et al., 1998; Dutch et al., 2009) and addenda.

Stemming from the Federal Water Pollution Control Act of 1948, later known as the Clean Water Act, and major amendments in 1972 (EPA, 2017), the focus of the PSEMP sediment monitoring work, now referred to as the *Puget Sound Sediment Monitoring Program* (or *Sediment Program*) has been on measuring chemical contaminants in sediments and assessing their toxicity and effects on the benthos. Measurements include grain size, total organic carbon, and the Sediment Quality Triad parameters (Long and Chapman, 1985) including concentrations of metal and organic chemical contaminants, laboratory bioassay responses of test organisms to potentially toxic sediments and porewater, and the number of individuals and species of benthic invertebrates at each station. Station locations, sampling frames, and some parameters for the Sediment Program have changed over time.

[1] Formerly known as the Puget Sound Ambient Monitoring Program (1989-2005), then as the Puget Sound Assessment and Monitoring Program (2005-2011), and currently as the Puget Sound Ecosystem Monitoring Program (2011-ongoing)

Data collected for the Sediment Program over 27 years, described in Section 3.2.2, below, suggest that while chemical contamination in sediments is important and of continued concern in Puget Sound's urban bays, other pressures need to be considered. Natural and human-related carbon and nutrient loading, the cycling of nutrients in the system, and changing climate and weather regimes in the Puget Sound region may be altering critical biogeochemical processes in the water column, at the sediment-water interface, and in the sediments themselves, contributing to changes in the state of the benthic habitat and the benthos. Studies of other Puget Sound ecosystem components, discussed in Section 3.2.2, below, provide evidence of and call attention to similar concerns.

Based on these findings, the MSMT is enhancing elements of the Sediment Program described in Dutch, 2009 to better track and understand biogeochemical parameters responding to anthropogenic and natural drivers and pressures of current concern. Suites of chemical analytes from the existing program are being modified and new biogeochemical analytes are being added. Also, the sampling frame is being expanded to assess changes to the sediments and benthos on a Puget Sound-wide scale annually. These changes are summarized in this revision of the Sediment Program QAMP.

3.2 Study area and surroundings

Located in northwestern Washington State, the overall study area extends from the U.S./Canada border to the southern-most bays and inlets of Puget Sound near Olympia **(**Figure 2).

This Puget Sound study area comprises a variety of interconnected shallow estuaries and bays, deep fjords, broad channels, and river mouths. It is bounded by three major mountain ranges: the Olympics to the west, the mountains of Vancouver Island to the north, and the Cascade Range to the east. The northern end of Puget Sound is open to the Strait of Georgia and to the Strait of Juan de Fuca, connecting Puget Sound to the Pacific Ocean. The estuary extends for about 130 km from Admiralty Inlet to Olympia, and ranges in width from 10 to 40 km (Kennish, 1998).

The main basin of Puget Sound was glacially scoured, resulting in depths up to 300 m, and has an area of 2600 km^2 and a volume of 169 km^3 (Kennish, 1998). Circulation in Puget Sound is driven by complex forces of freshwater inputs, tides, and winds. Puget Sound is characterized as a two-layered estuarine system with marine waters entering at the sill in Admiralty Inlet from the Strait of Juan de Fuca at depths of 100 to 200 m and freshwater entering from a number of large streams and rivers.

Major rivers entering Puget Sound include the Skagit, Stillaguamish, and Snohomish, accounting for more than 75% of the freshwater input into the Sound. Another big contributor of freshwater is the Fraser River in British Columbia. The mean residence time for Puget Sound waters is 57 days, ranging from 21 days in South Sound to 81 days in Hood Canal (Sutherland et al., 2011).

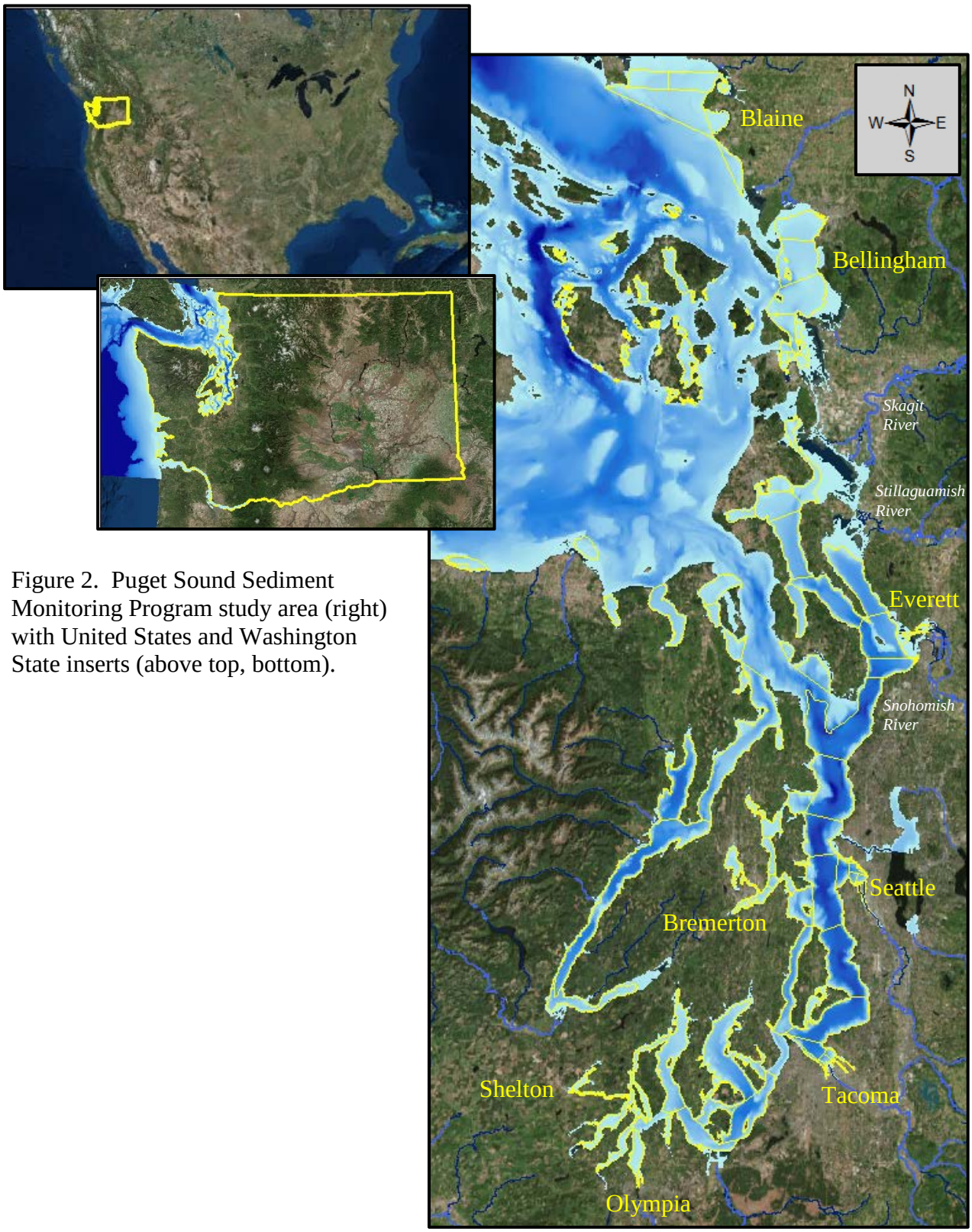

Figure 2. Puget Sound Sediment Monitoring Program study area (right) with United States and Washington State inserts (above top, bottom).

The bottom sediments of Puget Sound are composed primarily of compact, glacially-formed, clay layers and relict glacial tills (Crandell et al., 1965). Sediments measured Puget Sound-wide between 2004 and 2014 were composed of 41% silt/clay (<20% sand), 21% mixed (<60% sand), 12% silty sand (60-80% sand), and 26% sand (>80% sand) particle sizes (Weakland et al., 2018a). Major sources of recent sediments are shoreline erosion and riverine discharges**.**

The Sound is bordered by both relatively undeveloped rural areas and highly developed urban and industrial areas. Major urban centers include the cities of Bellingham, Everett, Seattle, Bremerton, Tacoma, and Olympia, all of which are located at the mouths of large river systems that feed into Puget Sound's largest estuarine embayments.

3.2.1 History of study area

Human population and associated land use in the Puget Sound region has been steadily on the rise throughout the 20th and 21st centuries. Population projections made in 2015 for the Puget Sound region, defined as King, Kitsap, Pierce and Snohomish counties, indicate growth to 4.9 million residents by 2040 (Puget Sound Regional Council, 2015). With population growth comes an increase in urbanization and an intensification of activities that place pressure on and impact the watershed's habitat and biota (USGS, 2006; Villarreal et al., 2017). These activities have resulted in habitat loss (Foley et al., 2017) and/or increased burdens of nutrients (Mohamedali et al., 2011; Roberts et al., 2014) and toxic chemicals (Ecology and King County, 2011; Roberts, 2017) which eventually find their way into Puget Sound through either point-source discharge or stormwater runoff. In combination, the multitude of physical and chemical anthropogenic pressures negatively impact both the pelagic and benthic habitats of the Sound, and the biota that reside there (PSEMP Toxics Work Group, 2017).

Examples of these land use activities and associated pressures to the Puget Sound estuary include, but are not limited to:

- Restriction and alteration of flow of natural waterways (Foley et al., 2017).
- Increases in agriculture and residential application of pesticides to land and water bodies with runoff into the Sound (Bortleson and Davis, 1997; McLain, 2014).
- Commercial and residential deforestation and loss of ground cover resulting in soil erosion and increased loading of sediments and nutrients to nearby rivers and streams (Ecology, 2014).
- Commercial and residential building, and the associated increase in impervious surfaces (roof tops, parking lots) and increased volumes of contaminant-laden stormwater runoff (Winters et al., 2014; Bookter, 2017).
- Shoreline armoring resulting in beach erosion and nearshore habitat loss (Canning and Shipman, 1994; Johannessen and MacLennan, 2007).
- Increased private and commercial motor vehicle and boat use, with associated release of toxic chemicals from leaking engines, brake pads, antifouling paint, and exhaust emissions (Bookter, 2017; Hobbs et al., 2018).

- Discharge of chemicals of emerging concern (e.g., personal care products and pharmaceuticals) via point- and nonpoint-source pathways (Lubliner et al., 2010; Long et. al., 2013; Dutch et al., 2014).

Projected land-use scenarios for the Puget Sound Basin (Villarreal et al., 2017) are under evaluation, and comprehensive growth and environmental management strategies have been developed and adopted by various authorities to address these issues (e.g., Puget Sound Action Agenda – Puget Sound Partnership (PSP), 2016; Vision 2040 - PSRC, 2009; Strategic Climate Action Plan - King County, 2015). Strategies call for continued monitoring of Puget Sound habitats and biota and reporting of the condition of key environmental indicators, including sediments and benthos as Vital Sign Indicators (PSP, 2017a,b) to track, evaluate and address impacts and changes over time.

In addition to these anthropogenic pressures, climate variability and predicted climate change during the 21st century is expected to affect the Puget Sound region by altering key climate-related factors which shape the local environment (Mauger et al., 2015). Expected effects of climate change have been assessed and described for each of the PSP Vital Sign indicators (PSP, 2017a) (Siemann and Binder, 2017).

The combination of these anthropogenic and natural drivers and pressures result in alterations in physical, chemical and biogeochemical properties of the receiving waters of Puget Sound, ultimately resulting in changes in the state of Puget Sound sediments and the benthic habitat, which in turn have an impact on the condition of the benthos. Long-term monitoring in Puget Sound, therefore, needs to address questions about the influence of this wide array of pressures on the condition of the sediment habitat and associated benthos.

3.2.2 Summary of previous studies and existing data

Puget Sound sediment studies have been conducted since the early 1950s, and focused on measuring chemical contaminants in sediments and assessing their toxicity and effects on the benthos. These studies include early baseline surveys, small-scale site assessment for regulatory clean-up activity, and large-scale assessment and monitoring programs, including Ecology's Sediment Program (Long et al., 1999, 2000; Long, 2002).

Findings from early sediment baseline surveys and regulatory assessment work conducted in the 1980s are summarized in Dutch et al., 2009. In general, sediments collected from urban areas had higher contaminant concentrations, higher toxicity, and lower benthic invertebrate assemblage diversity than sediments collected from reference areas. Contaminant levels were also higher in the tissue of bottom-dwelling species of crabs and fish from urban locations, and the occurrence of liver lesions and tumors in these animals was high. These studies prompted the creation of the Sediment Program to determine the extent and impact of chemical contamination on Puget Sound sediments and benthos.

Puget Sound Sediment Monitoring Program findings and relationship to other monitoring

Since 1989, the Sediment Program has accumulated the largest existing set of ambient sediment quality data, with samples collected from 1035 locations throughout Puget Sound. Over time, the

Sediment Program evolved from its original focus and design (Striplin, 1988) into a number of related programs, including the Historical, Long-Term, Spatial, and Urban Waters Initiative monitoring elements as described in Dutch et al., 2009.

Annual Sediment Program findings are published in numerous agency reports and peer-reviewed journal articles. A comprehensive list of publications is provided in Appendix A-1. A summary of major findings in annual reports is provided in Appendix A-2, and in recently published overview summaries including 28 years of findings at ten sentinel stations (Partridge et al., 2018) a summary of 18 years of results at multiple geographic scales (Weakland et al., 2018a), and in two combined summary overviews (Weakland et al., 2017, 2018b). A brief overview is provided below and placed in context with findings from related PSEMP surveys of other Puget Sound ecosystem components.

Puget Sound Sediment Monitoring Program findings – a brief summary

A total of 28 years of chemical contaminant-focused monitoring of individual stations, regions, strata, and urban bays throughout Puget Sound, as described above, indicates that concentrations of chemicals were highest, and sometimes above regulatory values, in urban bays and harbors closest to point source discharges and urban stormwater runoff. Metals and polycyclic aromatic hydrocarbons (PAHs) were usually detected Puget Sound-wide, but, with a few exceptions, at levels generally below regulatory thresholds. Persistent, bioaccumulative, toxic chemicals (PBTs), including polychlorinated biphenyl ethers (PCB), polybrominated diphenyl esters (PBDE), and phthalates, generally were detected only in urban bays and harbors, in various concentrations and combinations based on anthropogenic activities in each bay. Other organic chemicals were generally undetected. In urban bays, levels of some chemicals declined over time, possibly in response to source control and cleanup activities, while others increased, likely in response to resuspension of buried contaminants or new sources or avenues of pollutant discharge.

At 10 long-term monitoring stations sampled annually, benthos assemblages remained relatively stable over time, although for some stations, profound shifts in species composition occurred at specific points in time, possibly in response to cleanup activity in urban locations or to the influence from pressures such as river flow, changes in grain size, or other habitat characteristics at specific points in time. In regional, urban bay, and Puget Sound-wide sampling frames, low-level sediment toxicity increased and the condition of the benthos declined over time in both urban and non-urban areas despite the lack of widespread chemical contamination. In all cases, no strong correlations were found between the suite of Sediment Quality Triad measures of chemistry, toxicity, and benthos assemblage structure.

While the Sediment Program was originally designed to monitor effects of chemical contamination and toxicity of sediments on the benthos, data suggest that pressures other than or in addition to those exerted from chemical contaminants, including increasing nutrients and climate change, may be responsible for declining sediment and benthos quality in Puget Sound.

Other long-term monitoring in the Salish Sea

Biogeochemistry in the sediments and waters of the Strait of Georgia

A five-year project undertaken by scientists in the Strait of Georgia, Haro Strait, and Juan de Fuca Strait, in British Columbia, Canada, with a focus on biogeochemical cycling, reveals the complexity of these processes and underscores the importance of relationships between water column and sediment processes and the benthos (Widdows et al., 2008). Processes of importance include input of particulate and dissolved organic carbon and nutrients from riverine (terrestrial) and pelagic sources and from municipal discharges, and the importance of land use, regional geomorphology, and water circulation patterns in the composition and quality of the water column and, ultimately, in sediment quality and the fate of the benthos.

Water column changes in Puget Sound

Changes in water column parameters such as temperature, salinity, pH, dissolved oxygen, chlorophyll levels, and nutrient ratios measured by Ecology's Marine Waters Monitoring Program (also a PSEMP program) have been measured monthly since the mid-1970s. These data indicate significant physical and biological spatial and temporal changes throughout the Puget Sound water column over this timespan (Newton et al., 2002). Monthly water quality data updates can be found in Ecology's Eyes Over Puget Sound: Surface Conditions Report (https://ecology.wa.gov/Research-Data/Monitoring-assessment/Puget-Sound-and-marine-monitoring/Eyes-over-Puget-Sound) and in the PSEMP Marine Water Monitoring Workgroup's annual monitoring synthesis reports (https://sites.google.com/a/psemp.org/psemp/marine-waters-workgroup).

Long-term water quality data suggest water column changes occurring in response to nutrient loading and climate change pressures in Puget Sound. Since changes in the water column will ultimately influence the benthos, there is a need to consider these data and better understand water column processes when examining changes to the sediments and benthos. A conceptual model integrating water column and sediment process has been put forward by Krembs et al., 2014, to facilitate better understanding and more integrated monitoring of these ecosystem components.

Toxics fate and transport in Puget Sound biota

The Washington Department of Fish and Wildlife (WDFW) has collected data on the levels of PBTs in the tissues of various species of fish and invertebrates for the PSEMP Toxics-focused Biological Observing System (TBiOS), formerly Toxics in Fish, program since 1989. Years of study have yielded varying levels of contamination in English sole, various species of salmon, Pacific herring, mussels, and other benthic and pelagic species in locations of high, medium, and low development (O'Neill et al., 2009; Lanksbury et al., 2014, 2017; West et al., 2008, 2011a,b, 2017). At higher level of the food web, harbor seals and southern resident killer whales in the Salish Sea also show varying levels of accumulation of PBTs (Ross, 2006; Ross et al., 2000, 2004, and 2009). Recent summary work indicates declining levels of PBDEs and DDTs in English sole and herring in some low- and high-development basins, and declining concentrations of PBTs in harbor seals (Ross et al., 2013), suggesting successful source control and mitigation efforts. PCB concentrations in tissue, however, have persisted over time, especially in the pelagic food web. West et al. (2017) recognized the importance of the transfer within the pelagic food web.

Understanding the fate and transport of contaminants through both the benthic and pelagic food webs throughout Puget Sound is critically important. To date, the Sediment Program has measured contaminant levels in the recently-deposited top 2-3 cm of surface sediment but has never measured contaminants in the tissue of the benthos collected from the grab samples or from their reproductive products (e.g., gametes and larvae) which are released into the water column. Such measurements are important and would provide a missing link in understanding the fate and transport of contaminants within and between benthic and pelagic habitat.

An integrated ecosystem approach

Based on the findings of these related, but separate long-term monitoring programs, the Sediment Program is changing to better understand: (1) the influence of water column biogeochemical pressures, nutrient mineralization cycles, and climate change-related pressures on sediments and benthos, and (2) the role of benthic invertebrates and their pelagic reproductive stages in toxics fate and transport in Puget Sound. Changes to the sampling design and parameter lists to address these needs are summarized in this updated QAMP.

Data repositories

All Sediment Program data are found in Ecology's Environmental Information Management (EIM) database (EIM Database) under the following Study IDs: PSAMP_HP (Historical program), PSAMP_LT (Long-Term program), PSAMP_SP (Spatial regions, strata) program), PSEMP_LT (revised Long-Term program covered by this QAMP), and UWI20XX (successive years of the Urban Waters Initiative program, where XX is the two-digit year).

Data for historical and current Puget Sound sediment monitoring conducted for regulatory permit requirements are also housed in EIM. Additionally, sediment and benthos data collected from Puget Sound for the U.S. Environmental Protection Agency (EPA) national monitoring programs are in the EPA data base, including data for EMAP (https://archive.epa.gov/emap/archive-emap/web/html/) and the National Coastal Condition Assessment (NCCA) (https://www.epa.gov/national-aquatic-resource-surveys/ncca).

3.2.3 Parameters of interest

To address the multiple goals and objectives of the revised Sediment Program, a wide variety of environmental parameters will be measured or applied including those characterizing benthos, physical sediment parameters, sediment biogeochemistry related to nutrient loading and climate change pressures, and chemical contaminant loads in both sediments and benthos tissue.

A list including the parameter category and detail, and purpose and/or concerns related to each, is provided in Table 1.

Table 1. Sediment sampling parameters of interest.

Parameter Category (sampling frequency)	Parameter Detail	Purpose/Concern
Benthos (annual)	Count and identify to lowest taxonomic level (to species level if possible)	Characterization of benthos assemblages through calculation of numeric benthic indicators including: total abundance, major taxa abundance, taxa richness, Pielou's evenness, and Swartz's dominance index.
	Size class Biomass estimates	Estimation of biomass of individual organisms and whole benthos samples using biomass measurements taken from a 2016 Puget Sound-wide benthos reference collection. Useful in understanding carbon budget of ecosystem.
	Functional ecology (e.g., feeding guilds, locomotion, etc.)	Application of information on ecological functions (e.g., feeding guilds - Macdonald et al., 2012) to each species to obtain better understanding of benthos population dynamics.
Physical (annual)	Temperature (sediment in grab)	Measurement of physical condition of sediments; for comparison with water column measurements.
	Salinity (overlying water in sediment grab)	Measurement of physical condition of near-bottom water; for comparison with water column measurements.
	Depth	Measurement of water column depth at each station; habitat information.
	Grain size	Measurement of physical structure of substrate; habitat type.
Biogeo-chemistry (bulk sediments - annual) (stable isotopes in benthos tissue - annual)	Total Carbon (TC) Total Organic Carbon (TOC) Total Inorganic Carbon (TIC) Total Nitrogen (TN) C:N ratio	Determination of organic composition and quality in sediments; lability and availability of nutrients to benthos; identification of sources of organic matter; and comparison with similar values measured in water column particulates.
	$\delta^{13}C$ and $\delta^{15}N$ stable isotopes	Determination of relative proportion of terrestrial vs. marine organic input (i.e., nutrient sources); trophic structure.
	Total sulfides	Determination of sediment quality with respect to reduced condition and toxicity to benthos.
	Biogenic silica (BSi)	Proxy for diatom microfossil abundance in sediments; relationship to diatom abundance in water column and food web implications.
Chemistry (bulk sediments, benthos tissue) (5-year rotation)	Metals	Determination of degree of anthropogenic chemical contamination in bulk sediments and benthos tissue. Better understanding of benthic/pelagic food web links and contaminant transfer through the food web.
	Polycyclic Aromatic Hydrocarbons (PAHs)	
	Polychlorinated biphenyls (PCBs)	
	Polybrominated diphenyl ethers (PBDEs)	
	Phthalates	
Toxicity (5-year rotation)	Amphipod 10-day survival in bulk sediments	Determination of the degree of toxicity of bulk sediments to laboratory organisms (the amphipod *Eohaustorius estuarius*), and by proxy to the benthos.

3.2.4 Regulatory criteria or standards

The Sediment Program activities and results are not regulatory in nature. We collect and evaluate surficial sediments based on goals, objectives, and methods appropriate for determining the status and trends of the quality of surficial sediments and benthos at individual long-term stations and for designated large-scale sampling frames.

Some parameters and methods used in the Sediment Program are similar to those used in regulatory work (Ecology, 2017). However, while chemical and toxicological results generated by the Sediment Program are compared to some of the regulatory criteria promulgated in Ecology's Sediment Management Standards rule (WAC 173-204) (Ecology, 2013), interpretation and actions based on these comparisons differs from their use for regulatory purposes. For the Sediment Program, regulatory criteria have been used in the generation of a set of Sediment Quality Triad indicators (Appendix B-1) and PSP Vital Signs that document and track surface sediment conditions over time.

4.0 Project Description

The Puget Sound Sediment Monitoring Program has evolved since its inception in 1989 (see Appendices B-1, B-2 in Dutch, 2009, and Section 3.1.3, above). The current program described in this QAMP is composed of two elements, including:

- **Long-Term monitoring:** Annual characterization and change over time of sediment quality and benthos condition Puget Sound-wide as estimated from samples collected from 50 randomly and non-randomly selected stations.
- **Urban Bays monitoring:** Periodic characterization and change over time of sediment quality and benthos condition bay-wide as estimated from samples collected from six urban bays on an annual rotational basis (i.e., 30-36 randomly-selected stations sampled from one bay per year over a six-year time span).

Specific objectives associated with each goal of the program have been broadened based on findings to include measurement of sediment biogeochemical parameters, benthos biomass, functional ecology of the benthos, and chemical analysis of benthos tissue. Key questions have been developed to address each set of goals and objectives.

Products generated by addressing these goals, objectives, and questions through the Sediment Program serve a number of functions for a variety of stakeholders, including:

- Measuring and predicting sediment and benthos responses to natural and anthropogenic environmental pressures (e.g., point-source and nonpoint-source contaminant discharge, climate change, ocean acidification) in urban bays and Puget Sound-wide.
- Providing a Puget Sound-wide perspective of sediment quality and benthos measures for smaller-scale environmental programs.
- Providing environmental managers with tools to inform their decision-making and to measure the success of environmental remediation programs.
- Providing sampling and analytical support to other related Puget Sound ecosystem monitoring and research programs when appropriate.
- Providing general education about sediments and benthos at multiple levels for multiple audiences.

4.1 Project goals

The revised goals for the Puget Sound Sediment Monitoring Program include the following:

1. Determine the status of and document spatial patterns and variation in Puget Sound sediment quality and benthos condition.
2. Document natural and human-caused changes over time for Puget Sound sediment quality and benthos condition.

3. Provide a Puget Sound-wide baseline of scientifically valid sediment quality and benthos data, summary reports, and indices for environmental managers, scientists, tribes, and the general public, and provide technical support when appropriate.

4.2 Project objectives and questions

Each of the revised project goals (1, 2, 3) includes a set of objectives (a, b, c…) and questions (i, ii, iii…) related to assessment and characterization of the physical, chemical, biogeochemical, and biological condition of the sediments and benthos. They include[2]:

1. Determine the status of and document spatial patterns and variation in Puget Sound sediment quality and benthos condition.

a) Measure and document the geographic distribution of the physical, chemical, and biogeochemical sediment characteristics and the structure and function of benthos assemblages at each monitoring station, and use this information to characterize sediment and benthos condition Puget Sound-wide (i.e., Long-Term monitoring) and for designated embayments (i.e., Urban Bays monitoring).

i) Physical

(1) Temperature: What is the sediment temperature?

(2) Salinity: What is the salinity of the overlying waters?

(3) Depth: What is the depth of the overlying waters?

(4) Grain size: What is the sediment grain size distribution

ii) Chemical

(1) Sediment concentrations: What are the concentrations of anthropogenic chemical contaminants in the sediments?

(2) Tissue concentrations: What are the concentrations of anthropogenic chemical contaminants in benthos tissue?

iii) Biogeochemical

(1) Nutrient composition - quality, quantity: What are the sediment concentrations of organic and/or inorganic carbon, nitrogen, sulfides, and silica?

[2] Questions in *italics* are of high interest to the Sediment Program but will not be addressed immediately. Methods for these are not fully detailed in this QAMP. New projects will be added over time to address these questions, in partnership with interested stakeholders, as time and funding permits. A QAMP addendum will address details for this additional work.

(2) Sources of sediment C, N – marine vs. terrestrial: What are the concentrations and relative proportions of stable carbon and nitrogen isotopes in sediments *and benthos tissue*?

(3) Trophic structure - position in the Puget Sound food web: What are the concentrations and relative proportions of stable carbon and nitrogen isotopes in sediments *and benthos tissue*?

(4) Sedimentation/water column sediment flux: How much particulate material (C, N) is settling over time? Does this input vary seasonally?

(5) Sediment diagenesis[3]: What are the rates of organic-matter mineralization, oxygen consumption, and nutrient cycling?

(6) Dissolved oxygen[3]: What are the DO levels at the sediment/water interface and in sediment porewater?

(7) pH[3]: What are the pH levels at the sediment/water interface and in sediment porewater?

iv) Biological

(1) Numeric characterization of the benthos: What are the spatial patterns and annual and/or seasonal cycles of numeric benthic indices?

(2) Size class and estimated biomass of the benthos: What is the estimated biomass of the benthos and how does biomass fluctuate over time?

(3) Ecological function of the benthos: What are the functional characteristics associated with the benthos (e.g., feeding, reproduction, locomotion) and how do they relate to numeric indices and benthos biomass, and to physical, chemical, and biogeochemical measures of the sediments and benthos tissue?

(4) Benthos activity: What are the rates of bioirrigation?

(5) Contribution to the zooplankton: What percent of the plankton (numeric, biomass) is derived from the benthos?

b) Examine the relationships between measured sediment parameters to determine relationships between natural and human-caused stressors and benthos assemblages.

i) Correlations: Are the measured sediment quality parameters correlated with one another?

ii) Mapping: Are patterns and distributions of these parameters, especially the benthos, associated with natural stressors and/or contaminated sediments?

2. Document natural and human-caused changes over time for Puget Sound sediment quality and benthos condition.

[3] This question is to be addressed as part of a 2018 pilot study conducted as thesis work by a Western Washington University graduate student (see separate QAPP - Rigby, 2018).

a) Document changes over time in physical, chemical, and biogeochemical sediment characteristics and benthos assemblage structure measured for the monitoring stations.

i) Change over time: Are the measured sediment quality parameters changing over time Puget Sound-wide, bay-wide?

b) Evaluate changes over time in physical, chemical, and biogeochemical sediment characteristics and in benthos assemblage structure in relation to changes in natural and human-related environmental drivers and pressures, including carbon, nutrient, and chemical inputs to the system and climate change-related stressors.

i) Relationship to environmental pressures: How do the measured sediment quality parameters and their changes over time relate to and provide evidence about various environmental drivers and pressures including, but not limited to, point-source contamination, stormwater runoff, nutrient loading, climate change, ocean acidification, introduction of invasive species, and oil spills?

3. Provide a Puget Sound-wide baseline of scientifically valid sediment quality data, summary reports, and indices for environmental managers, scientists, tribes, and the general public, and provide technical support when appropriate.

a) Produce high-quality data: Produce high-quality, scientifically-valid sediment data for the network of long-term monitoring stations, and provide them to stakeholders via Ecology's EIM database.

b) Summarize/highlight findings: Summarize and highlight findings in short, easy-to-read glossies, agency reports, detailed web-based appendices, peer-reviewed journal articles, and web-based social media messaging.

c) Provide indicators/benchmarks: Develop appropriate sediment indicators, benchmark, and endpoint values to determine whether sediment quality and condition of the benthos are meeting targets and improving, declining, or remaining unchanged over time for the monitoring stations.

d) Identify problems: Identify sediment measures that do not meet established sediment quality criteria or index benchmarks.

e) Coordinate with stakeholders/other monitoring programs: Coordinate monitoring with regulatory and scientific stakeholders studying related aspects of the Puget Sound ecosystem to develop a more complete, integrated picture ecosystem components and to more effectively leverage monitoring resources. Related stakeholder monitoring elements include, in part: marine waters, toxics in biota, nearshore sediments, eelgrass and kelp forests, sediment cleanup, food web modeling, DO/sediment diagenesis modeling, nutrient cycling, stormwater, climate change, ocean acidification, invasive species, and oil spills.

f) Provide technical support: Provide Puget Sound sediment-related field, lab, and analytical support to other related Puget Sound ecosystem monitoring and research when appropriate.

4.3 Information needed and sources

Existing and new data will be assembled for all parameters listed in Table 1 to address the goals, objectives, and questions set forth for the revised Sediment Program. Existing data include the physical, chemical, and toxicological sediment quality parameters, as well as benthos data collected for the program since 1989. These and additional historical data collected for other Puget Sound monitoring programs, and for regulatory cleanup purposes, are available through Ecology's Environmental Information Management System (EIM) database (EIM Database) and from various stakeholders. These data establish baseline values against which recently collected data are compared to determine change over time.

Environmental modeling data output predicting many sediment quality physical and biogeochemical variables will be obtained from Ecology's Salish Sea Model Ocean Acidification and Sediment Diagenesis Modules (Pelletier et al., 2017a,b). Additionally, information on the functional ecology of the benthos, including feeding guild information developed by Macdonald et al., 2010, and ecological information housed in EPA's Coastal Biodiversity Risk Assessment Tool (CBRAT) database (Lee et al., 2015, 2017; cbrat.org) will be examined for interpretation of benthos community structure data.

4.4 Tasks required

For each Sediment Program element, sediment grab samples are collected from target locations within designated sampling frames. The top 2-3 cm of sediment are collected from each grab, both in April (Long-Term) and June (Urban Bays) annually. These recently deposited sediments are analyzed for the parameters specified in Table 1. Additionally, sediments are collected from the full grab, up to 17 cm depth, to be analyzed for composition of the infaunal invertebrate community.

4.5 Systematic planning process used

Monitoring programs such as this one, conducted over many decades, are extremely rare. They require not only a systematic planning process during their creation, but ongoing planning efforts to ensure their relevance and validity over time.

As described in Section 3, above, the original Sediment Program was developed in the late 1980s (Puget Sound Water Quality Authority, 1988; Striplin, 1988) following an extensive regional planning effort to design a comprehensive monitoring program for Puget Sound. Over time, new data and information has emerged, prompting different questions about drivers and pressures that influence sediment quality and benthos community structure.

To address these questions, monitoring priorities and strategy have been changed. In the past, periodic program reviews were conducted by convening groups of regional and national experts, resulting in major updates to the program (Shen, 1995; Dutch et al., 1998, 2009). For this current major Sediment Program revision, the MSMT conducted both an extensive program data review and an extensive outreach campaign to solicit input from regional stakeholders and national experts. This resulted in a significantly revised sampling design, deletion of old and addition of new monitoring parameters, and generation of this extensively revised QAMP.

In addition to periodic extensive program revisions, the MSMT captures minor changes to the program in annual addenda to the current QAMP. Each year, as recent data are analyzed, team members discuss and agree on changes necessary for the next field season. Sampling frame locations are also changed when part of a rotational design (e.g., Urban Bays monitoring), parameters to be sampled are added or deleted based on need and funding availability, and analytical methods are updated when appropriate.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 2. Organization of project staff and responsibilities.

Environmental Assessment Program Staff	Title	Responsibilities
Margaret Dutch Marine Monitoring Unit Western Operations Section Phone: 360-407-6021	Benthic Ecologist, Project Manager	Marine Sediment Monitoring Team Lead, program outreach and development, QAMP preparation, field sampling preparation and conduct, lab contract oversight, data review, report preparation.
Sandra Weakland Marine Monitoring Unit Western Operations Section Phone: 360-407-6980	Benthic Ecologist	Database management, EIM data entry, data review and analysis, report preparation, field sampling preparation and conduct, Geographic Information System (GIS) lead, lab contract oversight, web steward.
Valerie Partridge Marine Monitoring Unit Western Operations Section Phone: 360-407-7217	Benthic Ecologist	Statistician and lead data analyst, report preparation, field sampling preparation and conduct.
Dany Burgess Marine Monitoring Unit Western Operations Section Phone: 360-407-6685 & 360-407-3970	Lead Taxonomist	Primary and secondary invertebrate taxonomy, voucher sheet generation, voucher collection maintenance, field sampling.
Angela Eagleston Marine Monitoring Unit Western Operations Section Phone: 360-407-6517 & 360-407-3970	Taxonomist	Primary and secondary invertebrate taxonomy, voucher sheet generation, voucher collection maintenance, field sampling.
WCC IP (varies by year) Marine Monitoring Unit Western Operations Section Phone: 360-407-6711	Washington Conservation Corp (WCC) Individual Placement (IP)	Various lab and field work duties for the MSMT.
Carol Maloy Marine Monitoring Unit Western Operations Section Phone: 360-407-6742	Unit Supervisor for the Project Manager	Reviews the project scope and budget, tracks progress, provides internal review of the draft QAMP, and approves the final QAMP.
Dale Norton Western Operations Section Phone: 360-407-6596	Section Manager for the Project Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAMP, and approves the final QAMP.
Alan Rue Manchester Environmental Laboratory Phone: 360-871-8801	Director	Reviews and approves the final QAMP.
Tom Gries Phone: 360-407-6327	Acting Ecology Quality Assurance Officer	Reviews and approves the draft QAMP and the final QAMP.

5.2 Special training and certifications

All personnel who conduct field activities receive training on use of sediment and benthos sample collection equipment, sample handling, program quality assurance/quality control (QA/QC), and safety. Each person is required to be familiar with this QAMP and field procedures described in our standard operating procedures (SOPs). New technicians are given demonstrations of field procedures before they perform field activities. A senior staff member is also designated as lead scientist on each day of field sampling to verify that proper sampling procedures are followed. Periodic field checks are conducted by senior staff to ensure consistent sampling performance among staff. Results from these checks are discussed with the team and appropriate updates or changes are implemented if necessary.

All personnel conducting rescreening, sorting, and/or identification of the benthos samples have a college education in marine and/or environmental sciences and direct experience with sample handling, analysis, QA/QC, and chemical safety. Each person is required to be familiar with this QAMP and lab procedures described in our SOPs. Those conducting identification of the benthos have extensive training and experience in marine invertebrate taxonomy and participate in rigorous taxonomic QC checks as described in our SOPs.

5.3 Organization chart

Not Applicable (NA) - See Table 2.

5.4 Proposed project schedule

This revised Sediment Program QAMP captures program details for annual Long-Term and Urban Bays sediment monitoring. The schedule below is applicable to each year sampled, listing the month of completion of each activity. A QAMP addendum will be developed prior to each year's sampling event to capture details, including scheduling dates that may have changed or are specific for that year.

Long-Term sediment monitoring – April/early May

Key activities for annual Long-Term sediment monitoring are listed in Table 3.

Table 3. Proposed schedule for completing annual field and laboratory work, EIM data entry, and reports for the Long-Term sediment monitoring.

Field and laboratory work	**Due date**	**Lead staff**
Field work completed	April/early May	All MSMT staff
Laboratory analyses completed	Grain Size – July TOC (PSEP, 1986) – June TC/TOC/TIC/TN (EPA 440) – June $\delta^{13}C$ and $\delta^{15}N$ stable isotopes – June Total sulfides – June Biogenic silica – June Sorting – September Taxonomy/Size Class/Biomass – December Chemistry – metals and organics – March, following year	
Environmental Information System (EIM) database		
EIM Study ID	PSEMP_LT	
Product	Due date	Lead staff
EIM data loaded	May, following year	Sandra Weakland
EIM data entry review	May, following year	MSMT staff – will vary
EIM complete	May, following year	Sandra Weakland
Final report		
Author lead / Support staff	MSMT staff – will vary	
Schedule		
Draft due to supervisor	September, following year	
Draft due to client/peer reviewer	October, following year	
Draft due to external reviewer(s)	October, following year	
Final (all reviews done) due to publications coordinator	November, following year	
Final report due on web	December, following year	

Urban Bays sediment monitoring – June

Key activities for the PSEMP Urban Bays sediment monitoring are listed in Table 4.

Table 4. Proposed schedule for completing the field and laboratory work, EIM data entry, and reports for the Urban Bays sediment monitoring.

Field and laboratory work	**Due date**	**Lead staff**
Field work completed	June	All MSMT staff
Laboratory analyses completed	Grain Size – July TOC (PSEP, 1986) – July TC/TOC/TIC/TN (EPA 440) – July $\delta^{13}C$ and $\delta^{15}N$ stable isotopes – July Total sulfides – July Biogenic silica – July Sorting – December Taxonomy/Size Class/Biomass – March, following year Chemistry – metals and organics – March, following year	
Environmental Information System (EIM) database		
EIM Study ID	UWI2018	
Product	Due date	Lead staff
EIM data loaded	May, following year	Sandra Weakland
EIM data entry review	May, following year	MSMT staff – will vary
EIM complete	May, following year	Sandra Weakland
Final report		
Author lead / Support staff	MSMT staff – will vary	
Schedule		
Draft due to supervisor	September, following year	
Draft due to client/peer reviewer	October, following year	
Draft due to external reviewer(s)	October, following year	
Final (all reviews done) due to publications coordinator	November, following year	
Final report due on web	December, following year	

5.5 Budget and funding

Funding sources for the Puget Sound Sediment Monitoring Program include the State Toxics Control Account (50%) and the Environmental Legacy Stewardship Account (50%). The projected budget for the program for the 2017-2019 biennium is provided in Table 5.

Table 5. Budget estimate for the Puget Sound Sediment Monitoring Program, 2017–2019 biennium.

Budget Category/ parameter	Core Monitoring			Pilot Project	Grand Total
	Long-Term	Urban Bays	Taxonomy Contracts	Nutrient Flux pilot study (Rigby, 2018)	
Manchester Environ. Lab	$ 67,010	$ 81,510			$ 148,520
Chemistry QA	$ 6,510	$ -			$ 6,510
Biogeochemistry	$ 15,900	$ 9,900			$ 25,800
Lipids	$ 700	$ -			$ 700
Metals/Organics	$ 43,900	$ 71,610			$ 115,510
Research vessel	$ 6,375	$ 5,100		$ 26,000	$ 37,475
Skookum	$ 6,375	$ 5,100			$ 11,475
Contract vessel				$ 26,000	$ 26,000
Sediment contracts	$ 45,621	$ 29,236	$ 23,140		$ 97,997
Biogeochemistry	$ 18,826	$ 11,616			$ 30,442
Grain Size	$ 9,540	$ 5,940			$ 15,480
QA Taxonomy	$ 17,255	$ 11,680			$ 28,935
Taxonomic Workshops			$ 5,040		$ 5,040
Voucher Sheet review			$ 9,600		$ 9,600
Voucher Specimen review			$ 8,500		$ 8,500
Grand Total	**$ 119,006**	**$ 115,846**	**$ 23,140**	**$ 26,000**	**$ 283,992**

6.0 Quality Objectives

6.1 Data quality objectives

Data quality objectives (DQOs) establish acceptable quantitative criteria on the quality and quantity of the data to be collected, relative to the ultimate use of the data. These criteria are known as performance or acceptance criteria, or DQOs. DQOs represent the overarching quality objectives of the study, including that collected data meet measurement quality objectives (MQOs).

The main DQO for this project is to collect a minimum of 50 sediment and benthos samples annually in April that are representative of Puget Sound and 30 to 36 samples in June from selected urban bays. These samples will be analyzed, using standard methods, to obtain suites of biological, physical, chemical, biogeochemical, and toxicity sediment and benthos data that meet MQOs described below and are comparable to previous study results.

6.2 Measurement quality objectives

MQOs for the Sediment Program include data quality indicators of precision, bias, sensitivity, representativeness, comparability, and completeness. Definitions of these terms are provided in the Quality Assurance Glossary (Appendix I-3). The MQOs for the data to be collected in the program are provided in this section.

6.2.1 Targets for precision, bias, and sensitivity

The MQOs for Sediment Program project results, expressed in terms of acceptable precision, bias, and sensitivity, are described in this section and summarized in Tables 6 through 8, below.

6.2.1.1 Precision

Precision is a measure of variability between results of replicate measurements that is due to random error.

For physical, chemical, and biogeochemical parameters measured from collected sediments and tissue, precision will be assessed by analyzing duplicate samples including field replicate (splits), analytical (laboratory) replicate (splits), and matrix spike duplicates. Targets for acceptable precision between duplicate results, in terms of relative percent difference (RPD), are listed in Tables 6 and 7. Acceptable precision among three or more replicate sample results is expressed as relative standard deviation (RSD).

For toxicity testing, precision will be assessed with the use of negative control samples consisting of clean, non-toxic sediments (Table 8).

Table 6. Measurement Quality Objectives for physical, biogeochemistry, and chemistry analyses – bulk sediment.

All terms are defined in the Quality Assurance Glossary (Appendix I-3).

MQO	Precision			Bias					Sensitivity
Parameter	Field Replicate (Split Sample)	Analytical (Laboratory) Replicate	Matrix Spike Duplicates (MSD)	Laboratory Control Sample (LCS)	Standard or Certified Reference Material (SRM/CRM)	Matrix Spikes (MS)	Surrogate Spike	Method Blank	MDL[3] or Lowest Concentration of Interest
	Relative Percent Difference (RPD) or Relative Standard Deviation (RSD)			Recovery Limits (%)[1]				Comparison of analyte concentration in blank to quantification limit	Concentration Units
Total solids	RPD ≤ 20%	RPD ≤ 20%	NA	NA	NA	NA	NA	Analyte concentration <PQL	0.1% dry wt
Grain size	RPD ≤ 20%	RSD ≤ 20%	NA	NA	NA	NA	NA	NA	1% dry wt
Total carbon Total organic carbon Total inorganic carbon Total nitrogen	RPD ≤ 20%	RSD ≤ 20%	RPD ≤ 20%	Reference material serves as LCS	TOC: 70 – 130%; TC, TIC, TN: 80 – 120% (caffeine check standard)	NA	NA	Analyte concentration <RL	0.1% dry wt
Total sulfides	RPD ≤ 20%	RPD ≤ 20%	RPD ≤ 20%	65 – 135%	NA	75 – 125%	NA	Analyte concentration <PQL	5.0 mg/kg dry wt
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes[4]	<0.4 ‰	<0.3 ‰	NA	<0.2 ‰	< 0.3 ‰	NA	NA	<0.5 MDL	1.4 µnol N
Biogenic silica	RPD ≤ 20%	RPD ≤ 20%	RPD ≤ 20%	Internal lab reference materials	NA	NA	NA	Analyte concentration <DL	1% dry wt
Metals (except mercury)	RPD ≤ 20%	NA – when concentration are low or below Practical Quantitation Limit, MS/MSD serve as analytical duplicate	RPD ≤ 20%	85 – 115%	Based on manufacturers set limits	75 – 125%	NA	Analyte concentration <MDL; if > MDL, lowest analyte concn. must be >10x method blank concn. or qualified as an estimate	0.1 mg/kg dry wt (0.2 for Sn, 0.5 for Cr and Se, 5.0 for Zn)
Total mercury									0.005 mg/kg dry wt

MQO	Precision			Bias					Sensitivity
Parameter	Field Replicate (Split Sample)	Analytical (Laboratory) Replicate	Matrix Spike Duplicates (MSD)	Laboratory Control Sample (LCS)	Standard or Certified Reference Material (SRM/CRM)	Matrix Spikes (MS)	Surrogate Spike	Method Blank	MDL[3] or Lowest Concentration of Interest
	Relative Percent Difference (RPD) or Relative Standard Deviation (RSD)			Recovery Limits (%)[1]				Comparison of analyte concentration in blank to quantification limit	Concentration Units
Phthalate esters	RPD ≤40%	RPD ≤40%	RPD ≤40%	50 – 150%	NA	50 – 150%	50 – 150%	Analyte concentration <MDL; if > MDL, lowest analyte concn. must be >5x method blank concn. or qualified as an estimate.	2.03-5.71 µg/kg dry wt
Polycyclic aromatic hydrocarbons (PAHs)					See detail in Table 6a		20 – 200%		0.07-0.94 µg/kg dry wt
Polychlorinated biphenols (PCBs) - Aroclors					NA		30-150% [2]		0.04-0.73 µg/kg dry wt
Polychlorinated biphenols (PCBs) - Congeners					See detail in Table 6a		30-150% [2]		0.04-0.19 µg/kg dry wt
Polybrominated diphenyl ethers (PBDEs) - Congeners							50 – 150%		0.04-0.18 µg/kg dry wt

NA = not applicable

[1] Recovery limits are based on the low and high confidence limits for each analyte.

[2] Surrogate recoveries are compound specific. PCB-050: 50-150%; Tetrachloro-m-xylene, HBBP: 30-130%

[3] Method Detection Limit is compound specific. See Appendix E-1.

[4]Stable isotopic values are quantified as a relative ratio of ratios by normalizing the sample gas ratio of the rare to abundant isotopes to the ratio of a monitoring gas rare to abundant isotope ratio minus 1. As such isotopic values can be negative and terms like RSD or RPD are not analogous. Precision is quantified as a standard deviation (1s) of the isotopic composition of replicates for a calibrated reference material analyzed multiple times during an analytical run. Similarly, the standard deviation of multiple realizations of field control standard can be used to evaluate the instrument performance in addition to external sampling and processing errors.

Table 6a. Standard (Certified) Reference Material (NIST 1944) recovery limits MEL.

Analyte	SRM Limits (%)
PCB- 8	65-153
PCB- 18	62-139
PCB- 28	63-135
PCB- 44	55-131
PCB- 52	57-132
PCB- 66	40-112
PCB-101	70-148
PCB-105	21-128
PCB-118	38-111
PCB-128	34-122
PCB-138	44-115
PCB-153	43-112
PCB-170	36-98
PCB-180	41-105
PCB-187	19-114
PCB-206	35-102
PCB-209	35-119
Benz[a]anthracene	52-96
Benzo(a)pyrene	50-106
Benzo(b)fluoranthene	58-111
Benzo(ghi)perylene	71-127
Benzo(k)fluoranthene	47-220
Benzo[e]pyrene	68-123
Chrysene	61-149
Dibenzo(a,h)anthracene	110-265
Fluoranthene	44-95
Indeno(1,2,3-cd)pyrene	52-140
Perylene	18-127
Phenanthrene	60-122
Pyrene	44-98
PBDE-047	54-107
PBDE-099	47-107
PBDE-100	59-122
PBDE-153	17-206
PBDE-154	45-184
PBDE-183	52-183
PBDE-209	54-166

Table 7. Measurement Quality Objectives for biogeochemistry and chemistry analyses - benthos tissue.

All terms are defined in the Quality Assurance Glossary (Appendix I-3).

MQO →	**Precision**			**Bias**					**Sensitivity**
Parameter	**Field Replicate (Split Sample)**	**Analytical (Laboratory) Replicate**	**Matrix Spike Duplicates (MSD)**	**Laboratory Control Sample (LCS)**	**Standard or Certified Reference Material (SRM/CRM)**	**Matrix Spikes (MS)**	**Surrogate Spike**	**Method Blank**	**MDL[3] or Lowest Concentration of Interest**
	Relative Percent Difference (RPD) or Relative Standard Deviation (RSD)			**Recovery Limits (%)[1]**				**Comparison of analyte concentration in blank to quantification limit**	**Concentration Units**
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes[4]	<0.4 ‰	<0.3 ‰	NA	<0.2 ‰	< 0.3 ‰	NA	NA	<0.5 MDL	1.4 µnol N
Metals (except mercury)	RPD ≤ 20%	NA – when concentration are low or below Practical Quantitation Limit, MS/MSD serve as analytical duplicate	RPD ≤ 20%	85 – 115%	Based on manufacturers set limits	75 – 125%	NA	Analyte concentration <MDL; if > MDL, lowest analyte concn. must be >10x method blank concn. or qualified as an estimate	0.2 mg/kg wet weight (0.4 for Sn, 1.0 for Cr and Se, 10.0 for Zn)
Total mercury									0.01 mg/kg wet weight
Phthalate esters	RPD ≤40%	RPD ≤40%	RPD ≤40%	50 – 150%	NA	50 – 150%	50 – 150%	Analyte concentration <MDL; if > MDL, lowest analyte concn. must be >5x method blank concn. or qualified as an estimate.	4.06-11.42 µg/kg wet weight [3]
Polycyclic aromatic hydrocarbons (PAHs)							20 – 200%		0.14-1.88 µg/kg wet weight [3]
Polychlorinated biphenols (PCBs) - Aroclors							30-150% [2]		0.08-1.46 µg/kg wet weight [3]
Polychlorinated biphenols (PCBs) - Congeners							30-150% [2]		0.08-0.38 µg/kg wet weight [3]
Polybrominated diphenyl ethers (PBDEs) - Congeners							50 – 150%		0.04-0.36 µg/kg wet weight [3]

NA = not applicable

[1] Recovery limits are based on the low and high confidence limits for each analyte.

[2] Surrogate recoveries are compound specific. PCB-050: 50-150%; Tetrachloro-m-xylene, HBBP: 30-130%

[3] Method Detection Limit is compound specific. See Appendix E-1.

[4] Stable isotopic values are quantified as a relative ratio of ratios by normalizing the sample gas ratio of the rare to abundant isotopes to the ratio of a monitoring gas rare to abundant isotope ratio minus 1. As such isotopic values can be negative and terms like RSD or RPD are not analogous. Precision is quantified as a standard deviation (1s) of the isotopic composition of replicates for a calibrated reference material analyzed multiple times during an analytical run. Similarly, the standard deviation of multiple realizations of field control standard can be used to evaluate the instrument performance in addition to external sampling and processing errors.

Table 8. Measurement Quality Objectives for sediment toxicity analysis.

Toxicity Analysis	Precision Negative Controls (clean, nontoxic sediment)	Bias and Sensitivity Positive (Toxic) Controls (Reference Toxicant Dilution Series)
MQO measured	**Test Acceptance Criteria**	**Deviation From Control Chart Mean**
Amphipod (*Eohaustorius estuarius*) 10-day survival in bulk sediments*	mean >90% survival in each batch control and ≥80% in all individual replicates	95% confidence intervals (± 2 standard deviations) around the mean

*minimum of 5 replicates required per test sample

6.2.1.2 Bias

Bias is the difference between the sample mean and the true value.

Bias for chemical and biogeochemical analyses will be assessed by calibrating field and laboratory instruments, and by analyzing lab control samples, standard reference materials, method blanks, and matrix spikes. Targets for bias are listed in terms of acceptable % recovery of a known quantity, listed in Tables 6 and 7.

Bias for toxicity testing will be assessed with the use of positive (toxic) controls applied to a reference toxicant dilution series (Table 8).

If benthos samples for tissue isotope analyses cannot be sorted immediately upon collection and it is necessary to preserve the samples in the field (see section 8.2, Benthos Samples, below), the preservation method will likely introduce a bias into the measurement of $\delta^{13}C$ and possibly $\delta^{15}N$ (e.g., Syväranta et al., 2011). Any reporting of the results must include a statement of the potential bias. Although it may be possible to adjust the results by a numerical factor either from the literature or experimentally determined, users of the data must be cautious in analysis and interpretation.

6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance. It is commonly described as a detection limit. Targets for acceptable sensitivity of all chemistry and biogeochemistry lab measurements, including method detection limits (MDL), for this program are listed in Tables 6 and 7. For toxicity testing, sensitivity is again assessed with the use of positive controls (Table 8).

6.2.2 Targets for comparability, representativeness, and completeness

6.2.2.1 Comparability

One of the goals of the Sediment Program is to provide baseline sediment quality and benthos data on a large geographic scale which can be used for comparison to data collected for smaller-scale studies conducted by regional stakeholders.

Peer-reviewed published methods and SOPs will be followed for sampling, analysis, and data reduction (Appendices C, D, E, F and G). When comparing Sediment Program data to data collected from earlier years and from other projects, the methods and SOPs from those projects will be examined to determine comparability between years and projects. Methods and SOPs, described in detail later in this QAMP and in Appendices C through G, include the following:

Sampling methods (Appendix C)

C-1. Puget Sound Estuary Program (PSEP), 1998. Recommended Guidelines for Station Positioning in Puget Sound.

C-2. PSEP, 1997a. Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissue in Puget Sound.

C-3. PSEP, 1987. Recommended Protocols for Sampling and Analyzing Subtidal Benthic Macroinvertebrate Assemblages in Puget Sound.

C-4. Weakland, 2015. Ecology's Standard Operating Procedures for Obtaining Marine Sediment Samples. EAP039 v1.3.

C-5. Parsons et al., 2016. EAP070 v2.1 SOP – Minimize Spread of Invasive Species.

C-6. EAP Field Operations and Safety Manual – 2017.

Sample analysis

See peer-reviewed, published methods listed for each analytical test in Section 9.0, below, and in the following appendices:

- **Physical, biogeochemical (Appendix D)**

D-1. Physical and Biogeochemistry Analyses Methods Summary.

D-2. PSEP, 1986. Recommended Protocols for Measuring Conventional Sediment Variables in Puget Sound.

D-3. Zimmerman, Keefe, and Bashe, 1997. Method 440.0 – Determination of Carbon and Nitrogen in Sediments and Particulates of Estuarine/Coastal Waters Using Elemental Analysis.

D-4. Plumb, 1981. Procedures for handling and chemical analysis of sediment and water samples. Prepared for US Environmental Protection Agency/Corps of engineers Technical Committee on Criteria for Dredged and Fill Material.

D-5. Mortlock and Froelich, 1989. A simple method for the rapid determination of biogenic opal in pelagic marine sediments.

D-6. Conley and Schelske, 2002. Chapter 14. Biogenic Silica.

D-7. Carter and Barwick, 2011. Good practice guide for isotope ratio mass spectrometry, FIRMS.

- **Metals and organics chemistry (Appendix E)**

  E-1. MEL, 2017. Quality Control and Reporting Limits (PAHs, phthalates, PCBs, PBDEs).

  E-2. Chemical Analyses and EPA methods summary.

  E-3. EPA Chemical Analysis Methods PDFs.

  E-4. PSEP, 1997b. Recommended Guidelines for Measuring Metals in Puget Sound Marine Water, Sediment and Tissue Samples.

  E-5. PSEP, 1997c. Recommended Guidelines for Measuring Organic Compounds in Puget Sound Water, Sediment and Tissue Samples.

  E-6. MEL, 2016. Manchester Environmental Laboratory *Lab Users Manual.*

- **Toxicity (Appendix F)**

  F-1. PSEP, 1995. Recommended Guidelines for Conducting Laboratory Bioassays on Puget Sound Sediments.

  F-2. ASTM E 1367-03. Standard Test Methods for Measuring the Toxicity of Sediment-Associated Contaminants with Estuarine and Marine Invertebrates (10-day amphipod survival in bulk sediment).

- **Benthic infauna analysis (Appendix G)**

  G-1. Weakland, 2016. Standard Operating Procedures for Marine Macrobenthic Sample Analysis. EAP043 v1.2.

  G-2. Burgess, 2017. Standard Operating Procedures for Benthic Macrofaunal Size Classification and Biomass. EAP126 v1.1.

  G-3. Burgess, 2018. Standard Operating Procedure for Taxonomic Standardization of Benthic Invertebrate. Data EAP128.

6.2.2.2 Representativeness

Samples collected for the Sediment Program will be representative of conditions in recently-deposited sediments (i.e., the top 2-3 cm surface layer, and for benthos assemblages residing down to 17 cm). A 0.1-m^2 modified double vanVeen grab sampler will be used to collect an undisturbed bottom sample with minimal disruption to the surface layer. Sampling methods, and criteria for rejecting a non-representative sample, are described in PSEP, 1997a.

6.2.2.3 Completeness

EPA has defined completeness as a measure of the amount of valid data needed to be obtained from a measurement system to meet study objectives. For the Sediment Program, 95% of observations, measurements, and samples must be taken and analyzed acceptably for the study to be a success.

6.3 Acceptance criteria for quality of existing data

Currently there are over 1,878,000 records for marine sediment quality data collected from over 18,500 stations in Puget Sound and along the Washington State coast. These data are available in Ecology's EIM database and from the databases of regional stakeholders. While data from the Puget Sound Sediment Monitoring Program has been collected Sound-wide for ambient monitoring purposes, other studies usually target a small geographic area or region, and are related to sediment cleanup and monitoring activity conducted by waste water discharge permit holders. These data span many decades, and associated metadata are available in EIM for the estimation of data quality. Data quality varies depending on the type of quality assurance (QA) required when the projects were conducted.

All data collected since 1989 for the Sediment Program were collected according to quality standards specified in earlier versions of the program QAMP (Striplin, 1988; Dutch et al., 1998, 2009 and annual addenda (Appendix A-1)). Data collected for sediment regulatory purposes must adhere to quality standards which follow specifications in the Washington State Sediment Management Standards (Ecology, 2013) and the associated Sediment Cleanup User's Manual II (Ecology, 2017). Quality standards may differ between programs based on the goals and objectives of each.

If MSMT staff choose to compare data from EIM and other programs to those collected for the Sediment Program, QA documentation for non-program data will be reviewed to ensure comparability of methods and MQOs.

It is expected that for this revision of the Sediment Program, new data will be generated and analyzed to describe current conditions, will be compared with existing data to examine changes over time, and will also be used to evaluate Salish Sea Model/Sediment Diagenesis Module output and in fine-tuning of the model.

A major data gap that the revised Sediment Program monitoring design will fill is the annual characterization of sediment quality and benthos assemblage condition Puget Sound-wide. Additionally, a suite of sediment biogeochemical parameters, benthos biomass, and benthos tissue chemistry are being added to fill data gaps and assist in interpretation of sediment and benthos data in relation to nutrient loading in Puget Sound and climate change in the Pacific Northwest.

6.4 Model quality objectives

NA

7.0 Study Design

7.1 Study boundaries

The study boundary for Long-Term monitoring lies within the Puget Sound-wide study area described in Section 3.2 and depicted in Figure 2. The Urban Bays study boundaries include defined sampling frames for Elliott Bay, Commencement Bay, the Bainbridge Basin including Sinclair Inlet and Dyes Inlet, Bellingham Bay, Budd Inlet, and Port Gardner including Everett Harbor. These Urban Bays sampling frames are nested within the Puget Sound-wide Long-Term sampling frame. All sampling frames are illustrated in Figure 3. Water Resource Inventory Areas (WRIAs) for the study area can be found at https://fortress.wa.gov/dfw/score/score/maps/map_wria.jsp.

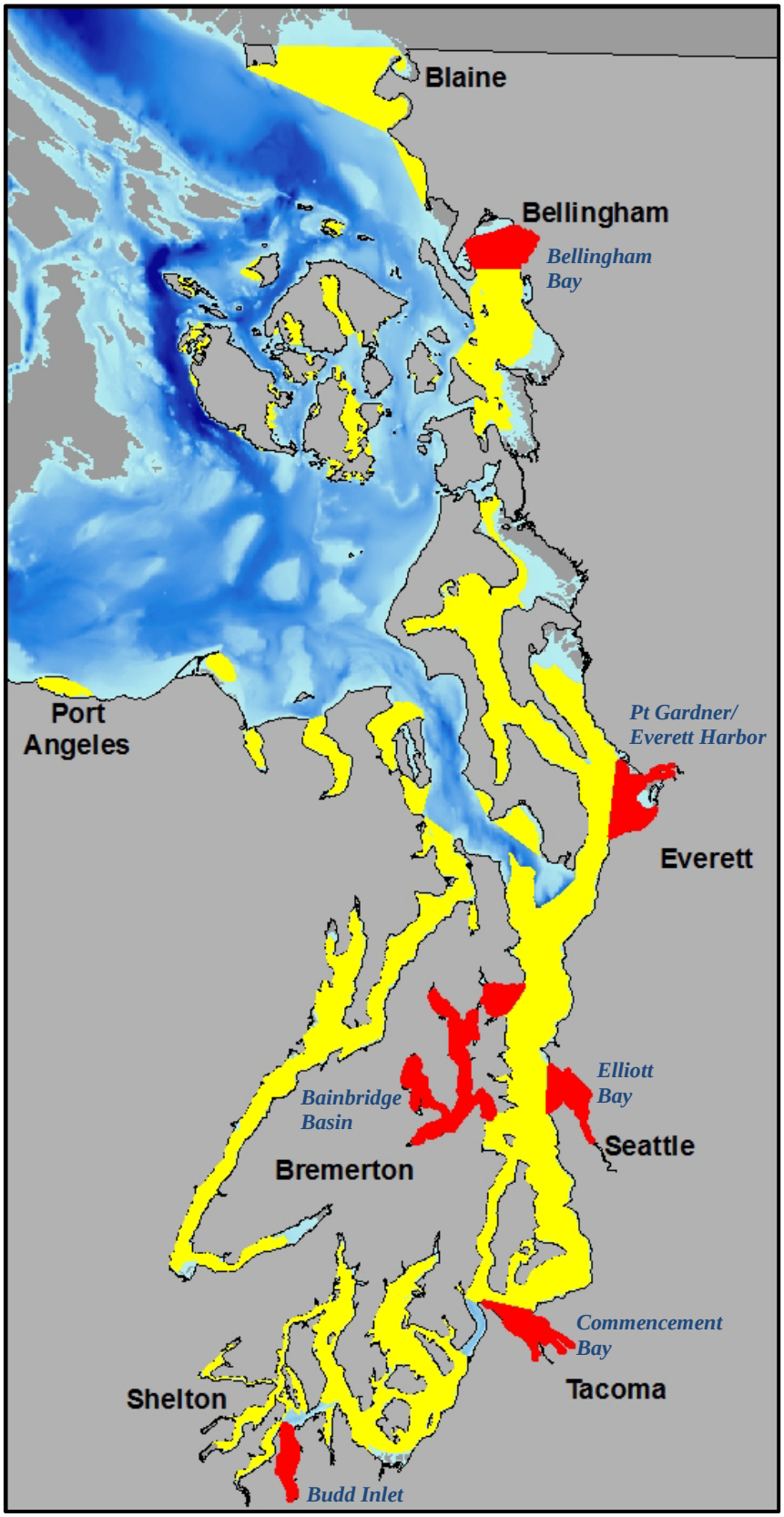

Figure 3. The Puget Sound-wide sampling frame (yellow and red) and six nested Urban Bays sampling frames (red only).

7.2 Field data collection

Sampling strategies are discussed below, and all target and alternate station locations for the Long-Term and Urban Bays monitoring programs are provided.

7.2.1 Sampling locations and frequency

Long-Term monitoring stations

The revised Long-Term monitoring element includes a set of 50 sampling stations. Each station will be resampled annually, beginning in April 2018.

Ten of these stations were drawn from the original suite of non-random monitoring stations selected for the program in 1989 (Striplin, 1988). With few exceptions, each has been monitored annually since the inception of the program. They have been retained because each represents a unique Puget Sound benthos assemblage and habitat type, and because locations for most coincide with stations sampled for Ecology's Marine Waters monitoring and/or the WDFW TBiOS programs (Table 9).

Twelve additional stations, with features similar to the original ten, were added in 2016 to coincide with Marine Waters monitoring and to increase spatial coverage throughout Puget Sound. Each of these stations had been sampled at least once during the history of this program.

The remaining 28 stations were added to the long-term element in 2017. Each is randomly positioned, with locations drawn from the spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004) developed by EPA in 2002 for the Puget Sound-wide sampling frame (Dutch et al., 2009). Addition of these random stations will allow characterization of the spatial extent (unit/km^2) of the measured parameters for the Puget Sound-wide sampling frame for each Long-Term sampling event (Olsen, *pers. comm. with MSMT*, 2017).

The 50 Long-Term stations will be equally weighted, each representing 44.15 km^2 of the total 2207.6 km^2 in the sampling frame for estimates of spatial extent of conditions.

Long-Term monitoring will be conducted from early April through early May each year. This allows spatial and temporal assessment of sediment condition and the benthos in early spring, prior to annual phytoplankton blooms and benthos spawning.

Locations for the 50 Long-Term monitoring stations are depicted in Figure 4. Target station coordinates are listed in Table 9. A total of 21 of the 50 stations are co-located with Ecology Marine Waters stations. Seven are in proximity to WDFW TBiOS monitoring locations sampled biennially to measure toxic contaminants in English sole. Alternate coordinates (Figure 5, Table 10) will be chosen if any of the target stations are rejected.

Urban Bays monitoring stations

The sampling frames and station locations for Urban Bays monitoring remain unchanged from past sampling events. A total of 30 to 36 samples will continue to be collected annually in late spring (early June) from one of six major urban embayments.

Each bay will be sampled once every six years, based on an annual rotational schedule. Additional bays, including ecologically important non-urban bays, may be added to this rotation in the future if there is interest and funding becomes available.

The sampling design for this element is drawn from a combination of a stratified random sampling design employed during the MSMP's joint study with NOAA's National Status and Trends program (Dutch et al., 1998; Long et al., 2005) and the EPA's GRTS design. Data from these randomly located stations allow characterization of the spatial extent (unit/km^2) of the parameters sampled in each bay-scale sampling frame (Olsen, 2002. *pers. comm. with MSMT*).

The Urban Bays monitoring stations and alternate locations are depicted in Figures 6 through 17; coordinates are listed in Tables 11 through 22. Station weights vary within each Urban Bays sampling frame and are also included in these tables. A rotational sampling schedule is provided in Table 23.

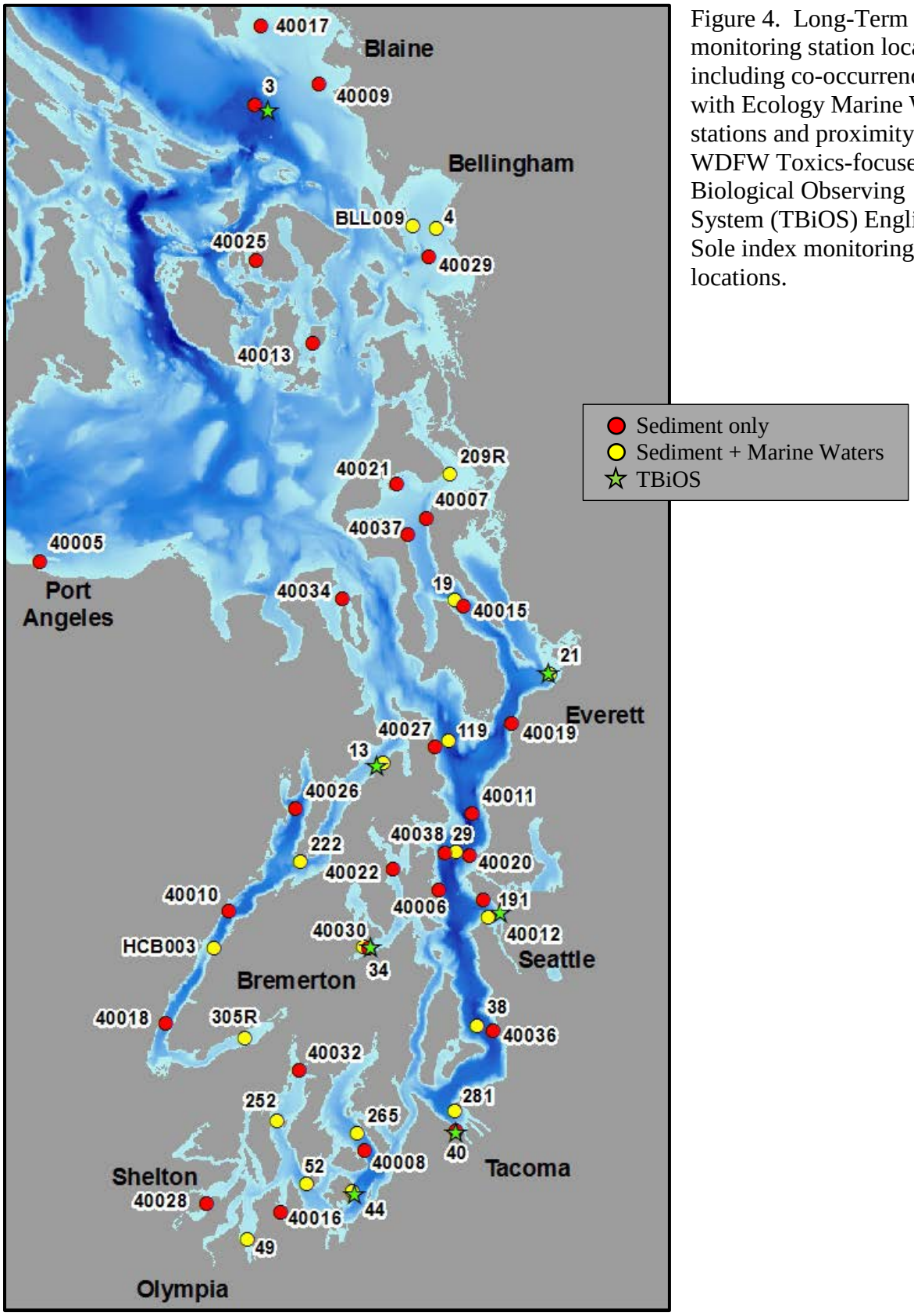

Figure 4. Long-Term monitoring station locations, including co-occurrence with Ecology Marine Waters stations and proximity to WDFW Toxics-focused Biological Observing System (TBiOS) English Sole index monitoring locations.

Table 9. Target coordinates for 50 Long-Term monitoring stations.

"Station Type" includes: LT = 10 original Long-Term stations, MW = 21 co-located sediment and Marine Waters stations, TBiOS = 7 sediment stations in the vicinity of TBiOS English sole index monitoring locations, R = 28 randomly selected stations.

Station	Location	Target (NAD 83, decimal degrees)		Station Type
		Latitude	Longitude	
3	Strait of Georgia, N of Patos Island	48.87025	-122.97842	LT, TBiOS
4	Bellingham Bay	48.68397	-122.53820	LT, MW
13	North Hood Canal, S of Bridge	47.83758	-122.62895	LT, MW, TBiOS
19	Saratoga Passage	48.09792	-122.47134	MW
21	Port Gardner/Everett Harbor	47.98547	-122.24283	LT, MW, TBiOS
29	Shilshole	47.70075	-122.45403	LT, MW
34	Sinclair Inlet	47.54708	-122.66208	LT, MW, TBiOS
38	Point Pully (3-Tree Point)	47.42833	-122.39363	LT, MW
40	Thea Foss Waterway	47.26130	-122.43730	LT, MW, TBiOS
44	East Anderson Island	47.16133	-122.67358	LT, MW, TBiOS
49	Inner Budd Inlet	47.07997	-122.91347	LT, MW
52	W of Devils Head, E end Nisqually Reach	47.17060	-122.78051	MW
119	Admiralty Inlet, south	47.87616	-122.47816	MW
191	Central Elliott Bay	47.59842	-122.37581	MW, TBiOS
209R	Skagit Bay	48.29533	-122.48850	MW
222	Hood Canal, N of Seabeck	47.67821	-122.81466	MW
252	Case Inlet	47.26957	-122.85101	MW
265	Carr Inlet	47.25240	-122.66572	MW
281	Commencement Bay	47.29229	-122.44193	MW
305R	Lynch Cove	47.39717	-122.93124	MW
BLL009	Bellingham Bay, Pt. Frances (Portage Is.)	48.68593	-122.59420	MW
HCB003	Hood Canal, Central	47.53787	-123.00960	MW
40005	Inner Port Angeles Harbor	48.13872	-123.44985	R
40006	Murden Cove	47.63971	-122.49046	R
40007	Saratoga Passage, north, Camano Island	48.22609	-122.54375	R
40008	Carr Inlet, NE of Gertrude Island	47.22686	-122.64787	R
40009	Strait of Georgia, outer Birch Bay	48.90625	-122.82638	R
40010	Central Hood Canal, S of Triton Cove	47.59743	-122.97830	R
40011	Central Basin, N of Shilshole	47.76108	-122.41759	R
40012	Elliott Bay, Smith Cove	47.62590	-122.38563	R
40013	Reads Bay	48.49626	-122.82139	R
40015	Saratoga Passage, South	48.08877	-122.44853	R
40016	Henderson Inlet	47.12549	-122.83635	R
40017	Boundary Bay	48.99473	-122.96789	R
40018	Hood Canal, Hoodsport	47.41787	-123.11736	R
40019	South Possession Sound	47.90607	-122.33076	R
40020	Shilshole Bay	47.69588	-122.42252	R
40021	Crescent Harbor	48.27948	-122.61517	R
40022	Brownsville	47.67154	-122.59952	R
40025	West Sound	48.62526	-122.96208	R

Station	Location	Target (NAD 83, decimal degrees)		Station Type
		Latitude	Longitude	
40026	Dabob Bay	47.76217	-122.83153	R
40027	Admiralty Inlet, N of Rose Point	47.86624	-122.50820	R
40028	Totten Inlet	47.13600	-123.01006	R
40029	North Samish Bay	48.63718	-122.55226	R
40030	Sinclair Inlet	47.54500	-122.65102	R
40032	Inner Case Inlet, Rocky Bay	47.34949	-122.80550	R
40034	Port Townsend, mouth of Kilisut Harbor	48.09479	-122.73513	R
40036	Des Moines	47.41975	-122.35733	R
40037	Saratoga Passage, Race Lagoon	48.19991	-122.58646	R
40038	North Central Basin	47.69895	-122.47829	R

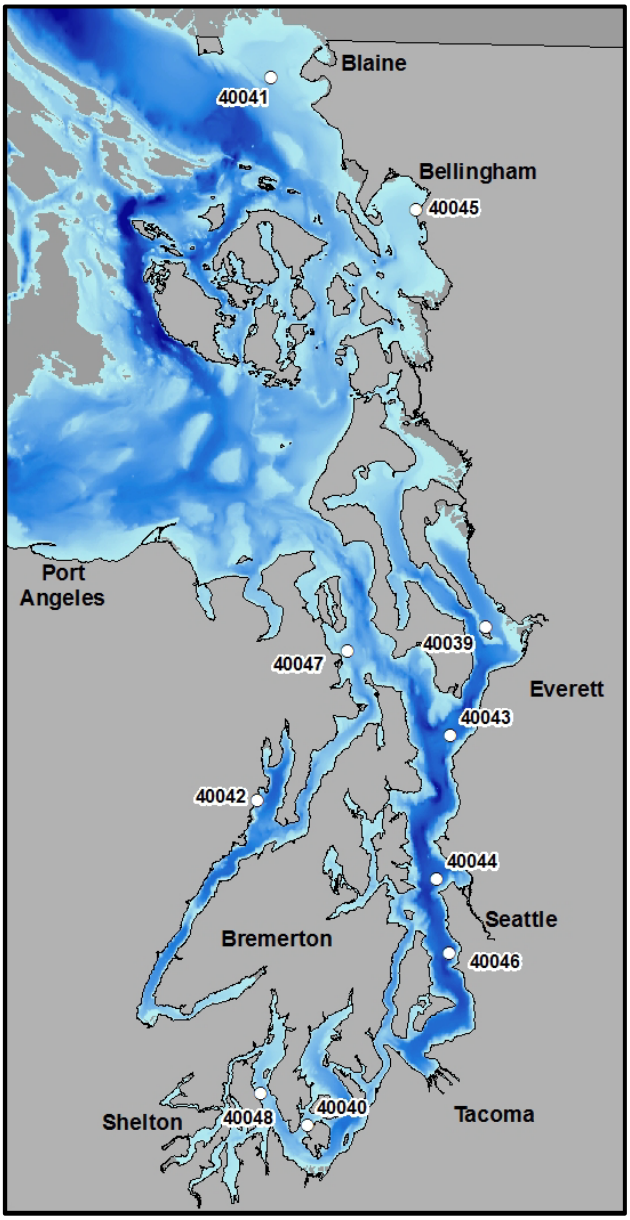

Figure 5. Locations for 10 alternate Long-Term monitoring stations.

Table 10. Target coordinates for 10 alternate Long-Term monitoring stations.

Station	Station location	Target (NAD 83, decimal degrees)	
		Latitude	Longitude
40039	Gedney Island	48.02425	-122.31831
40040	NW Anderson Island, Drayton Passage	47.17831	-122.72910
40041	South Boundary Bay	48.93582	-122.89714
40042	Hood Canal, Right Smart Cove	47.72126	-122.87476
40043	South Possession Sound	47.83918	-122.39813
40044	Central Basin, north of Alki	47.59770	-122.42488
40045	Bellingham Bay, Fairhaven	48.72049	-122.51920
40046	Central Basin, north of Normandy Park	47.47329	-122.38814
40047	Admiralty Inlet, Outer Oak Bay	47.97690	-122.66036
40048	Case Inlet	47.23001	-122.84642

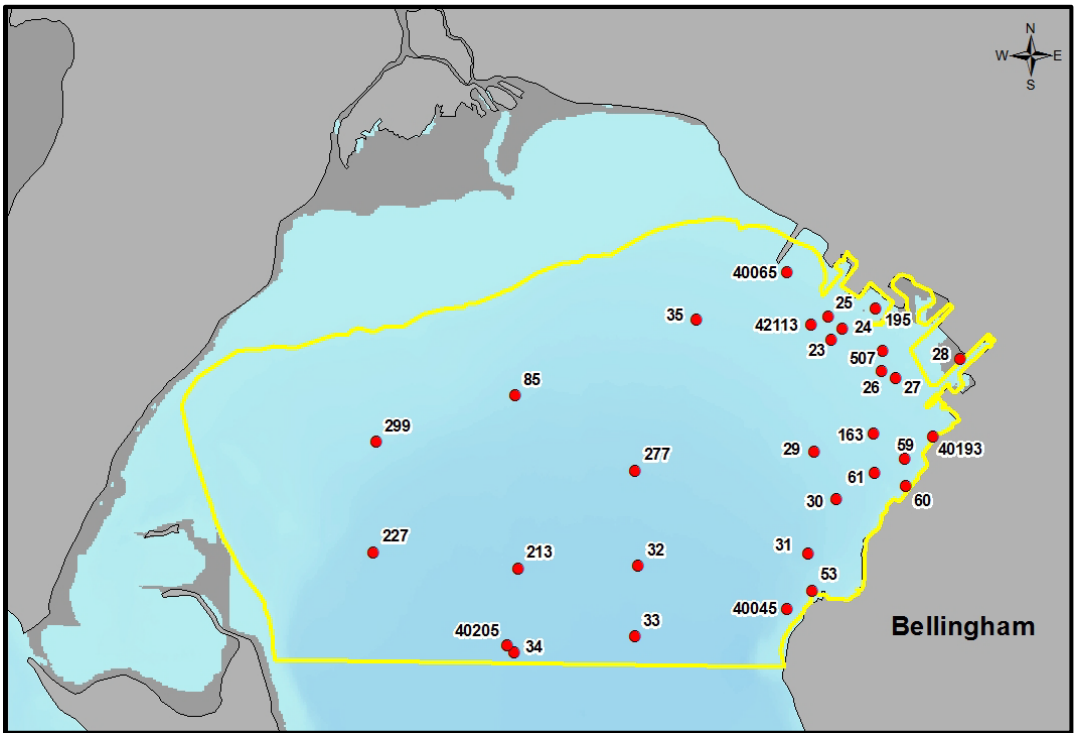

Figure 6. Bellingham Bay sampling frame and 30 monitoring station locations.

Table 11. Target coordinates and station weights for 30 Bellingham Bay monitoring stations.

Station	Weight (km^2)	Target (NAD 83, decimal degrees)	
		Latitude	Longitude
23	0.189	48.75142	-122.51278
24	0.189	48.75280	-122.51083
25	0.189	48.75415	-122.51332
26	0.252	48.74805	-122.50388
27	0.252	48.74723	-122.50138
28	0.252	48.74965	-122.49022
29	1.748	48.73862	-122.51528
30	1.748	48.73328	-122.51113
31	1.748	48.72693	-122.51582
32	1.430	48.72500	-122.54525
33	1.430	48.71693	-122.54548
34	1.430	48.71473	-122.56645
35	1.430	48.75337	-122.53629
53	1.748	48.72268	-122.51494
59	1.398	48.73805	-122.49947

Station	Weight (km^2)	Target (NAD 83, decimal degrees)	
		Latitude	Longitude
60	1.398	48.73498	-122.49922
61	1.398	48.73635	-122.50470
85	1.430	48.74414	-122.56741
163	1.398	48.74085	-122.50506
195	0.189	48.75521	-122.50514
213	1.430	48.72436	-122.56615
227	1.430	48.72574	-122.59123
277	1.430	48.73590	-122.54621
299	1.430	48.73842	-122.59135
507	0.189	48.75032	-122.50374
40045	1.430	48.72049	-122.51920
40065	9.687	48.75903	-122.52072
40193	1.398	48.74072	-122.49463
40205	1.430	48.71553	-122.56759
42113	0.189	48.75312	-122.51627

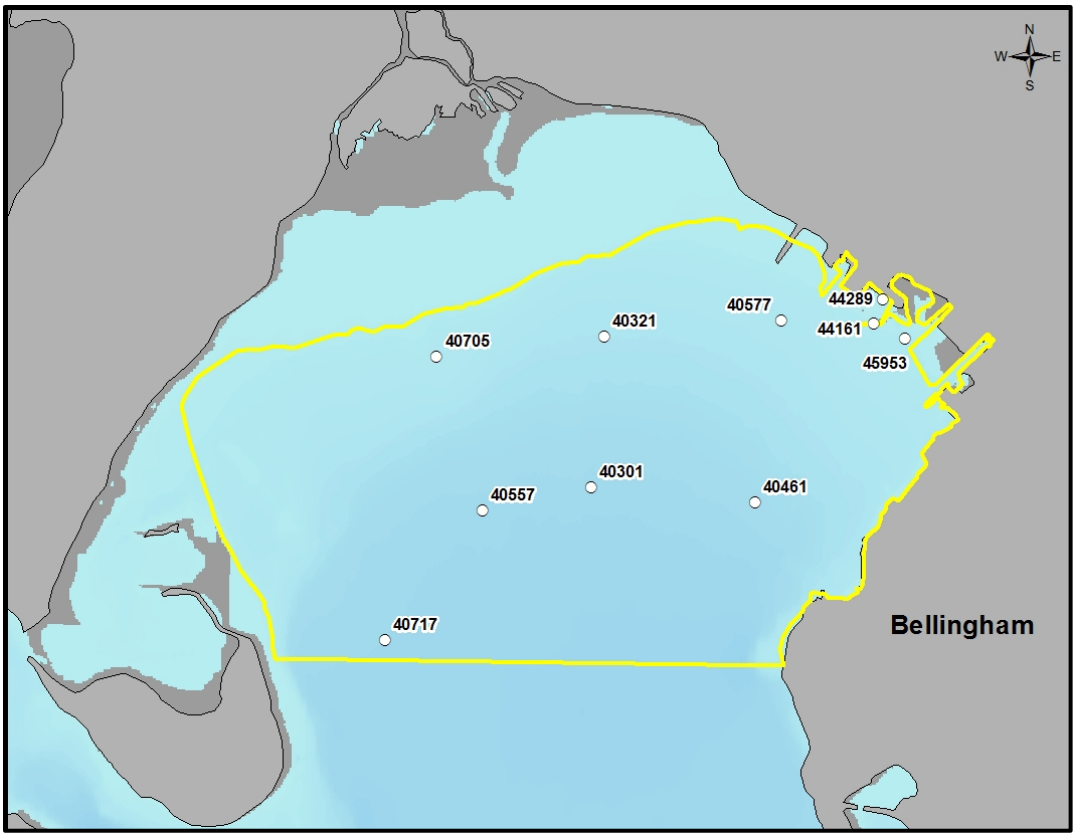

Figure 7. Bellingham Bay sampling frame and 10 alternate monitoring station locations.

Table 12. Target coordinates for 10 Bellingham Bay alternate monitoring stations.

Station	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
40301	48.73378	-122.55376
40321	48.75111	-122.55209
40461	48.73247	-122.52521
40557	48.73075	-122.57251
40577	48.75349	-122.52139
40705	48.74833	-122.58110
40717	48.71558	-122.58879
44161	48.75340	-122.50526
44289	48.75624	-122.50392
45953	48.75175	-122.49979

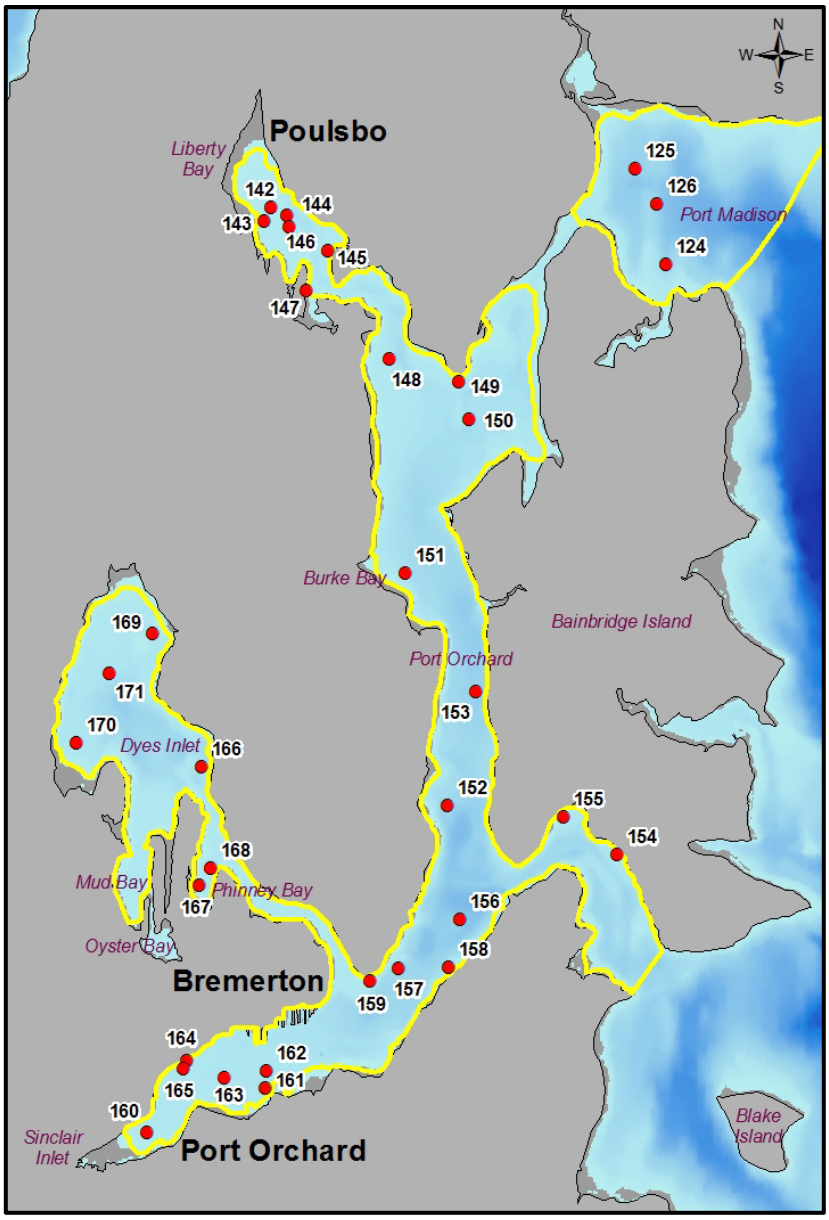

Figure 8. Bainbridge Basin sampling frame and 33 monitoring station locations.

Table 13. Target coordinates and station weights for 33 Bainbridge Basin monitoring stations.

Station	Weight (km^2)	Target (NAD 83, decimal degrees)	
		Latitude	Longitude
124	5.558	47.71381	-122.52732
125	5.558	47.73306	-122.53726
126	5.558	47.72603	-122.53051
142	0.623	47.72316	-122.64702
143	0.623	47.72035	-122.64899
144	0.623	47.72183	-122.64211
145	0.986	47.71468	-122.62932
146	0.986	47.71939	-122.64130
147	0.986	47.70651	-122.63555
148	4.320	47.69294	-122.61013
149	4.320	47.68877	-122.58892
150	4.320	47.68123	-122.58550
151	3.400	47.64943	-122.60349
152	3.400	47.60237	-122.58907
153	3.400	47.62584	-122.58124
154	3.335	47.59342	-122.53736
155	3.335	47.60060	-122.55375
156	3.335	47.57922	-122.58412
157	1.978	47.56905	-122.60235
158	1.978	47.56951	-122.58731
159	1.978	47.56620	-122.61089
160	1.005	47.53423	-122.67688
161	1.005	47.54373	-122.64146
162	1.005	47.54724	-122.64148
163	1.126	47.54572	-122.65406
164	1.126	47.54900	-122.66538
165	1.126	47.54726	-122.66643
166	1.062	47.60889	-122.66347
167	1.062	47.58473	-122.66301
168	1.062	47.58835	-122.65993
169	3.891	47.63572	-122.67908
170	3.891	47.61308	-122.70134
171	3.891	47.62739	-122.69190

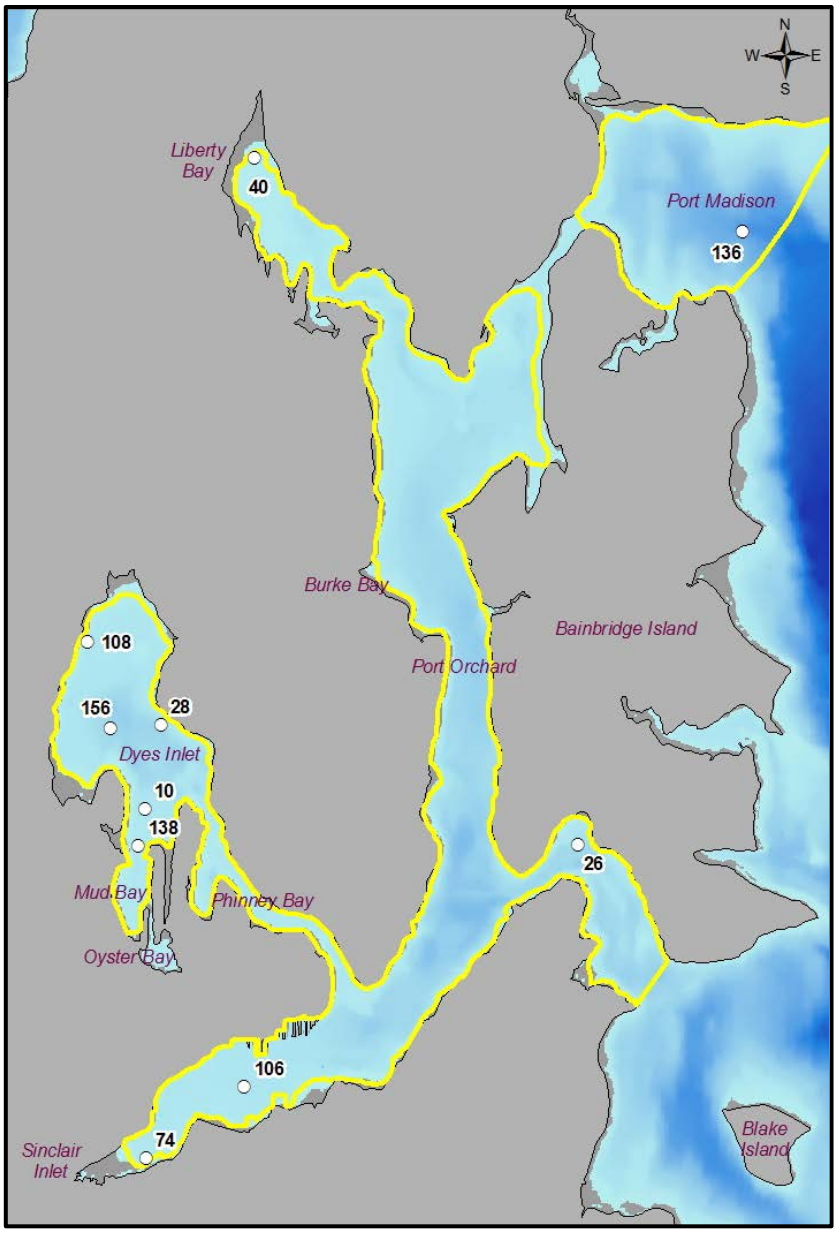

Figure 9. Bainbridge Basin sampling frame and 10 alternate monitoring station locations.

Table 14. Target coordinates for 10 Bainbridge Basin alternate monitoring stations.

Station	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
10	47.60193	-122.67997
26	47.59712	-122.55054
28	47.61891	-122.67585
40	47.73365	-122.65264
74	47.53151	-122.67685
106	47.54641	-122.64810
108	47.63527	-122.69844
136	47.72145	-122.50603
138	47.59444	-122.68152
156	47.61800	-122.69088

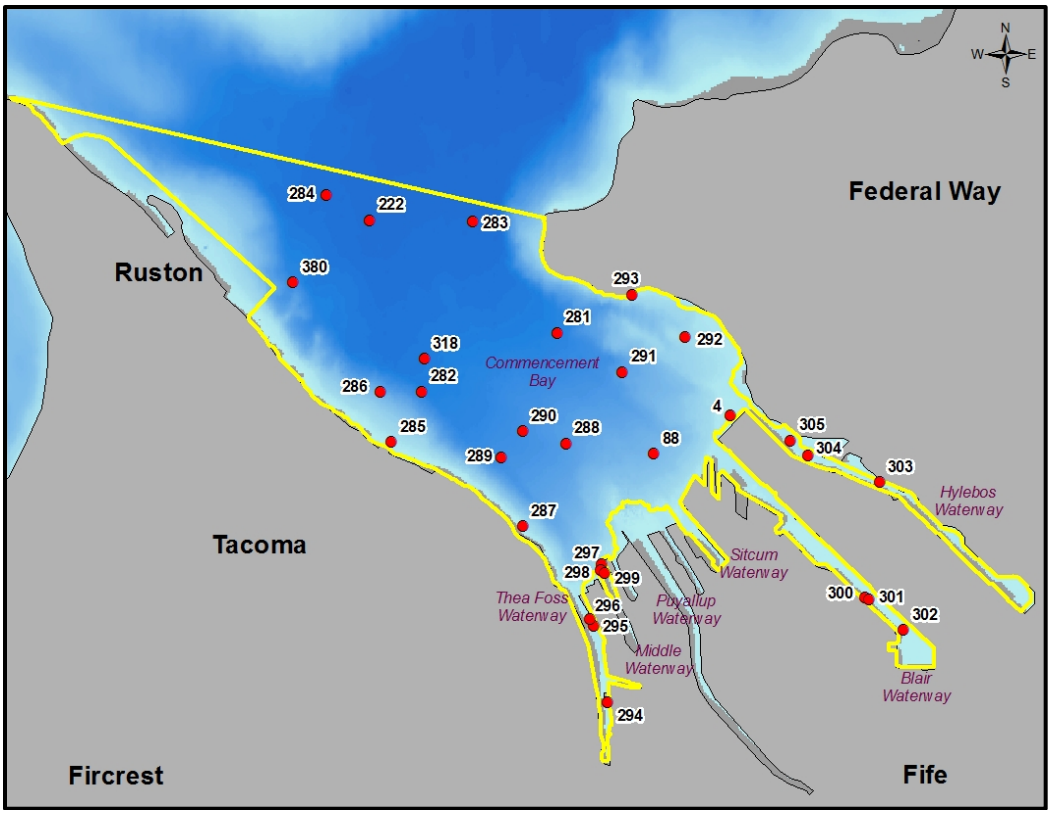

Figure 10. Commencement Bay sampling frame and 30 monitoring station locations.

Table 15. Target coordinates and station weights for 30 Commencement Bay monitoring stations.

Station	Weight (km^2)	Target (NAD 83, decimal degrees)	
		Latitude	Longitude
4	0.831	47.28306	-122.41190
88	0.791	47.27835	-122.42478
222	1.851	47.30494	-122.47454
281	1.851	47.29229	-122.44195
282	1.851	47.28500	-122.46487
283	1.851	47.30511	-122.45689
284	1.851	47.30771	-122.48215
285	0.786	47.27904	-122.46994
286	0.786	47.28487	-122.47207
287	0.786	47.26955	-122.44703
288	0.791	47.27934	-122.43998
289	0.791	47.27746	-122.45096
290	0.791	47.28066	-122.44742
291	0.831	47.28787	-122.43057
292	0.831	47.29214	-122.41988

Station	Weight (km^2)	Target (NAD 83, decimal degrees)	
		Latitude	Longitude
293	0.831	47.29695	-122.42928
294	0.126	47.24917	-122.43166
295	0.126	47.25805	-122.43444
296	0.126	47.25885	-122.43511
297	0.016	47.26528	-122.43334
298	0.016	47.26458	-122.43346
299	0.016	47.26430	-122.43278
300	0.387	47.26217	-122.38805
301	0.387	47.26196	-122.38729
302	0.387	47.25842	-122.38120
303	0.223	47.27573	-122.38602
304	0.223	47.27865	-122.39842
305	0.223	47.28032	-122.40148
318	1.851	47.28889	-122.46461
380	1.851	47.29745	-122.48752

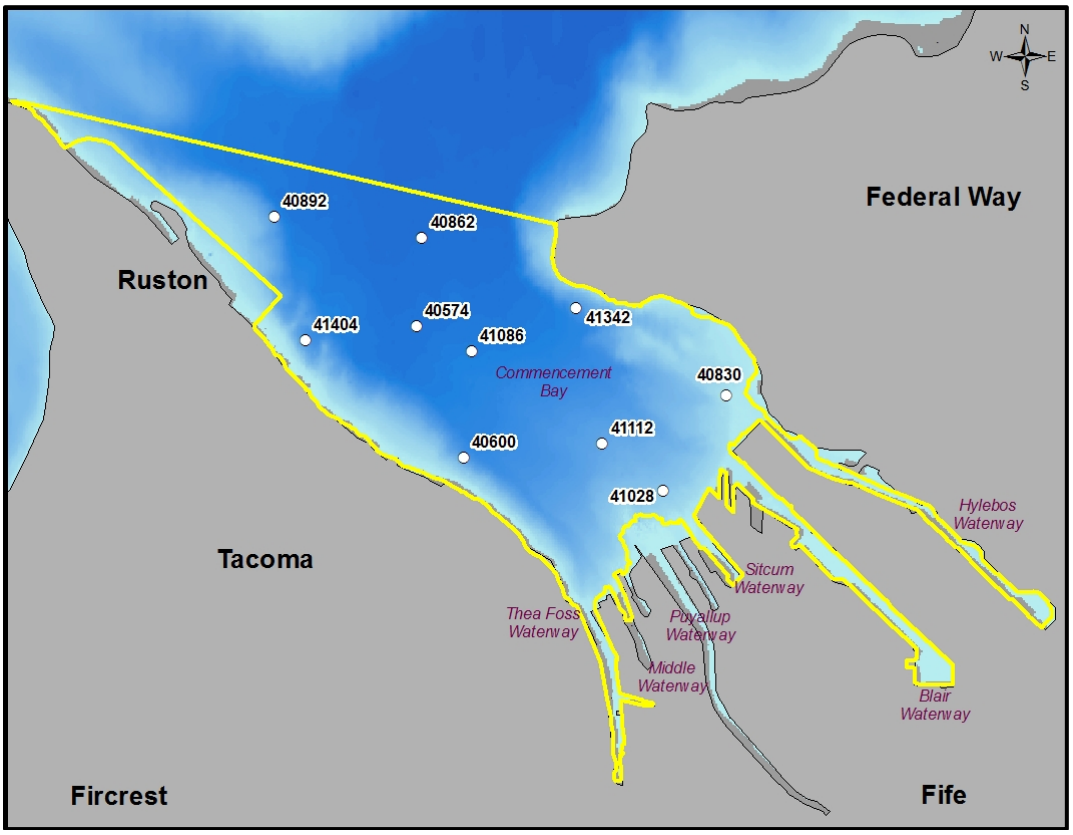

Figure 11. Commencement Bay sampling frame and 10 alternate monitoring station locations.

Table 16. Target coordinates for 10 Commencement Bay alternate monitoring stations.

Station	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
40574	47.29369	-122.46756
40600	47.27879	-122.45912
40830	47.28659	-122.41513
40862	47.30381	-122.46706
40892	47.30574	-122.49204
41028	47.27549	-122.42541
41086	47.29095	-122.45829
41112	47.28075	-122.43588
41342	47.29614	-122.44092
41404	47.29168	-122.48623

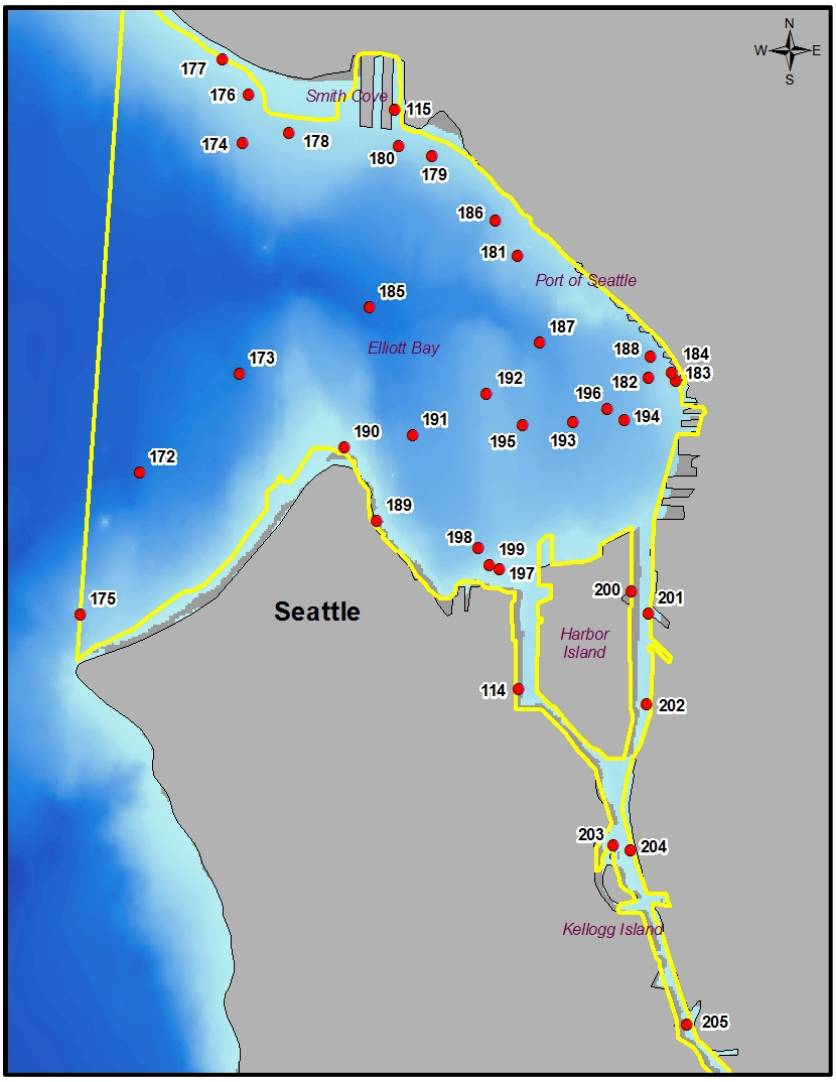

Figure 12. Elliott Bay sampling frame and 36 monitoring station locations.

Table 17. Target coordinates and station weights for 36 Elliott Bay monitoring stations.

Station	Weight (km^2)	Target (NAD 83, decimal degrees)	
		Latitude	Longitude
114	0.270	47.57545	-122.36071
115	0.340	47.62811	-122.37938
172	2.780	47.59440	-122.41267
173	2.780	47.60369	-122.39946
174	2.780	47.62479	-122.39984
175	2.780	47.58127	-122.42014
176	0.340	47.62918	-122.39910
177	0.340	47.63237	-122.40278
178	0.340	47.62581	-122.39357
179	0.340	47.62394	-122.37410
180	0.340	47.62482	-122.37868
181	0.340	47.61504	-122.36230
182	0.120	47.60421	-122.34413
183	0.120	47.60399	-122.34041
184	0.120	47.60466	-122.34099
185	1.060	47.60997	-122.38203
186	1.060	47.61820	-122.36534
187	1.060	47.60719	-122.35899
188	1.060	47.60606	-122.34391
189	0.700	47.59051	-122.38049
190	0.700	47.59716	-122.38506
191	0.700	47.59842	-122.37583
192	0.700	47.60231	-122.36595
193	0.730	47.59998	-122.35420
194	0.730	47.60025	-122.34734
195	0.730	47.59957	-122.36105
196	0.730	47.60120	-122.34965
197	0.270	47.58636	-122.36371
198	0.270	47.58822	-122.36656
199	0.270	47.58666	-122.36504
200	0.180	47.58464	-122.34579
201	0.180	47.58262	-122.34344
202	0.180	47.57433	-122.34334
203	0.220	47.56139	-122.34744
204	0.220	47.56093	-122.34510
205	0.220	47.54511	-122.33688

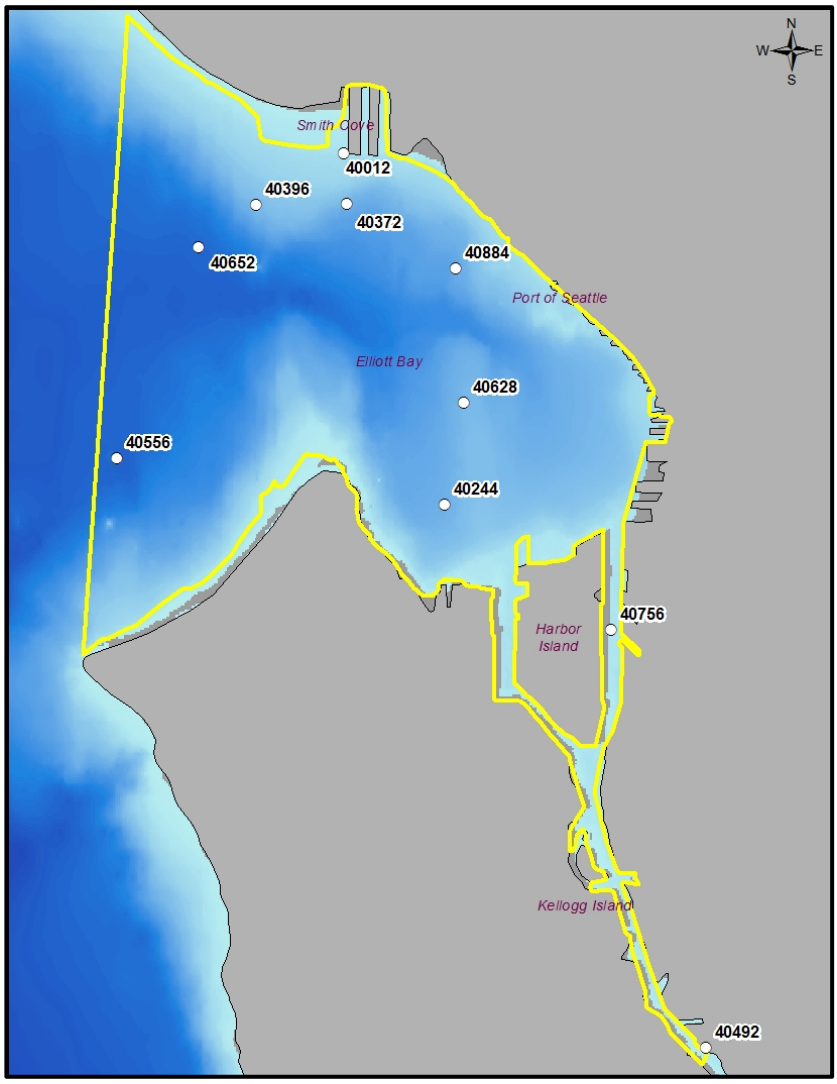

Figure 13. Elliott Bay sampling frame and 10 alternate monitoring station locations.

Table 18. Target coordinates for 10 Elliott Bay alternate monitoring stations.

Station	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
40012	47.626537	-122.38469
40244	47.592447	-122.368936
40372	47.621606	-122.384036
40396	47.621278	-122.397153
40492	47.540085	-122.329387
40556	47.596236	-122.416346
40628	47.60242	-122.366507
40652	47.616982	-122.405276
40756	47.580674	-122.344524
40884	47.61554	-122.368169

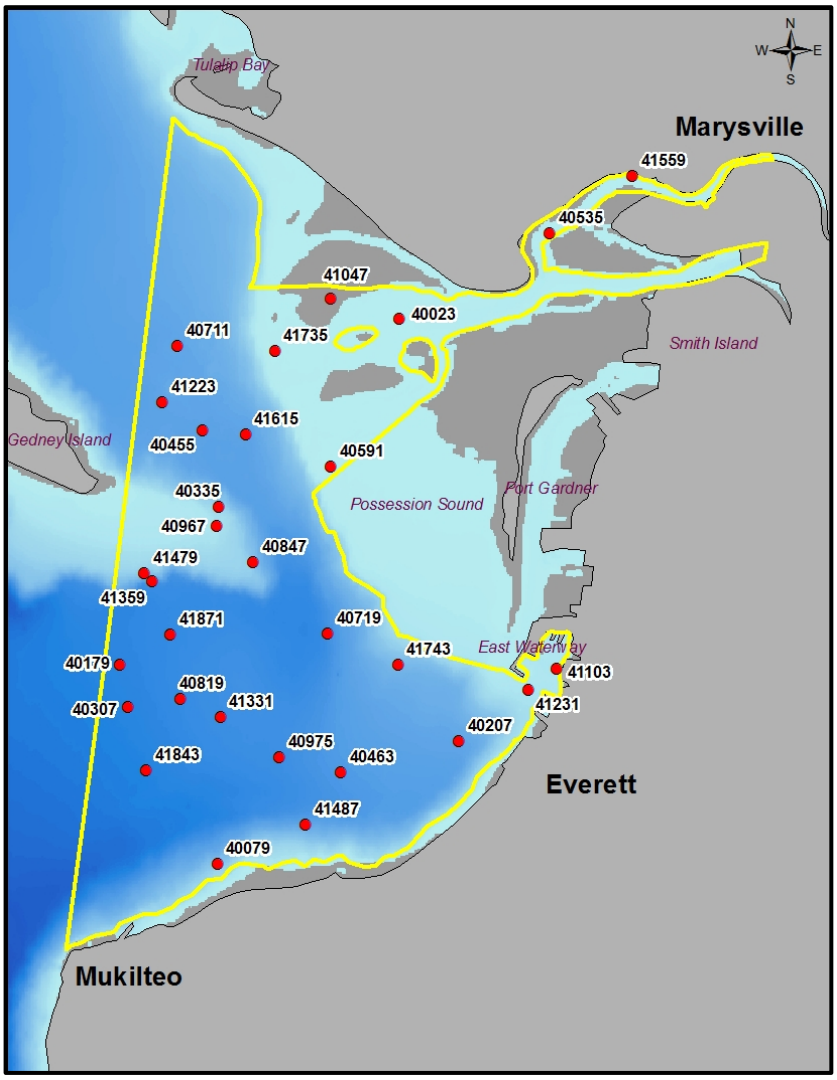

Figure 14. Port Gardner/Everett Harbor sampling frame and 30 monitoring station locations.

Table 19. Target coordinates for 30 Port Gardner/Everett Harbor monitoring stations.

All stations are equally weighted, each representing 1.27 km^2 of the total 38.1 km^2 area.

Station	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
40023	48.02659	-122.24986
40079	47.95991	-122.28059
40179	47.98380	-122.29893
40207	47.97551	-122.23749
40307	47.97868	-122.29727
40335	48.00329	-122.28179
40455	48.01256	-122.28495
40463	47.97142	-122.25867
40535	48.03742	-122.22310
40591	48.00846	-122.26178
40711	48.02266	-122.28990
40719	47.98817	-122.26163
40819	47.97988	-122.28787
40847	47.99670	-122.27528
40967	48.00091	-122.28202
40975	47.97300	-122.26977
41047	48.02892	-122.26236
41103	47.98450	-122.22021
41223	48.01578	-122.29239
41231	47.98299	-122.22734
41331	47.97773	-122.28064
41359	47.99404	-122.29348
41479	47.99496	-122.29489
41487	47.96496	-122.26487
41559	48.04457	-122.20839
41615	48.01214	-122.27724
41735	48.02243	-122.27231
41743	47.98462	-122.24882
41843	47.97108	-122.29379
41871	47.98766	-122.28994

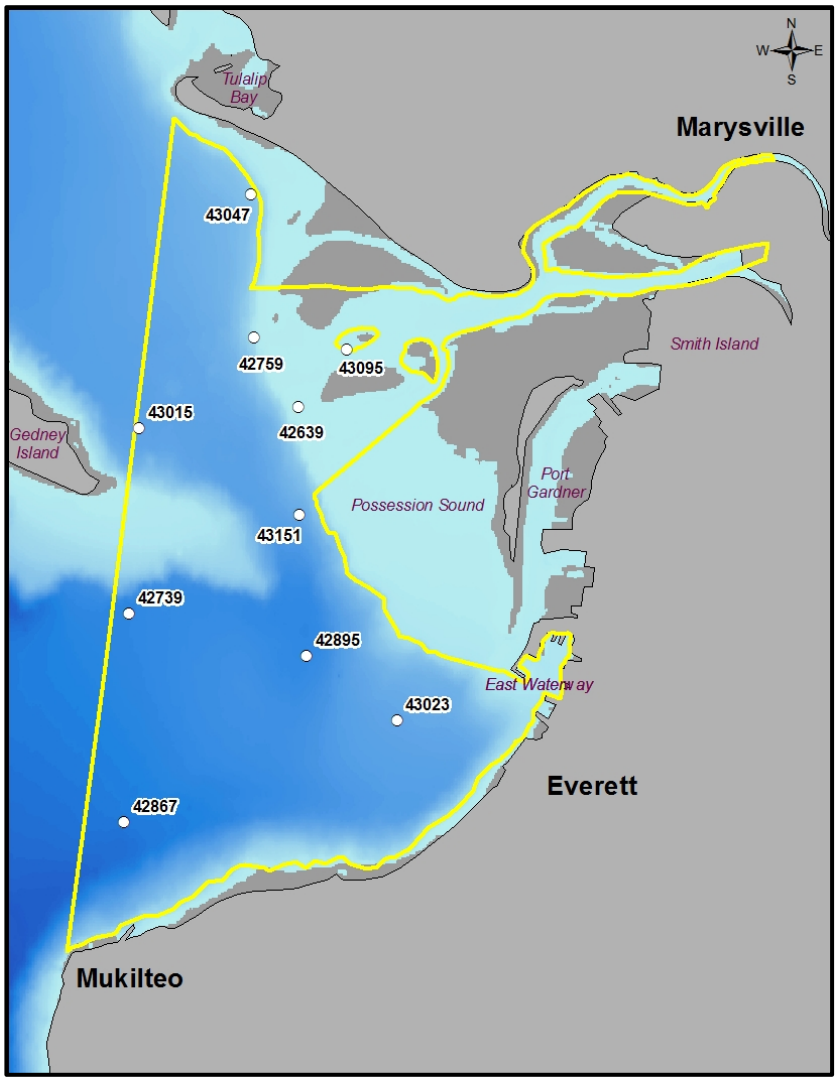

Figure 15. Port Gardner/Everett Harbor sampling frame and 10 alternate monitoring station locations.

Table 20. Target coordinates for 10 Port Gardner/Everett Harbor alternate monitoring stations.

Station	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
42639	48.01573	-122.26804
42739	47.99022	-122.29779
42759	48.02397	-122.27629
42867	47.96486	-122.29770
42895	47.98559	-122.26545
43015	48.01275	-122.29667
43023	47.97801	-122.24897
43047	48.04139	-122.27745
43095	48.02287	-122.25942
43151	48.00260	-122.26734

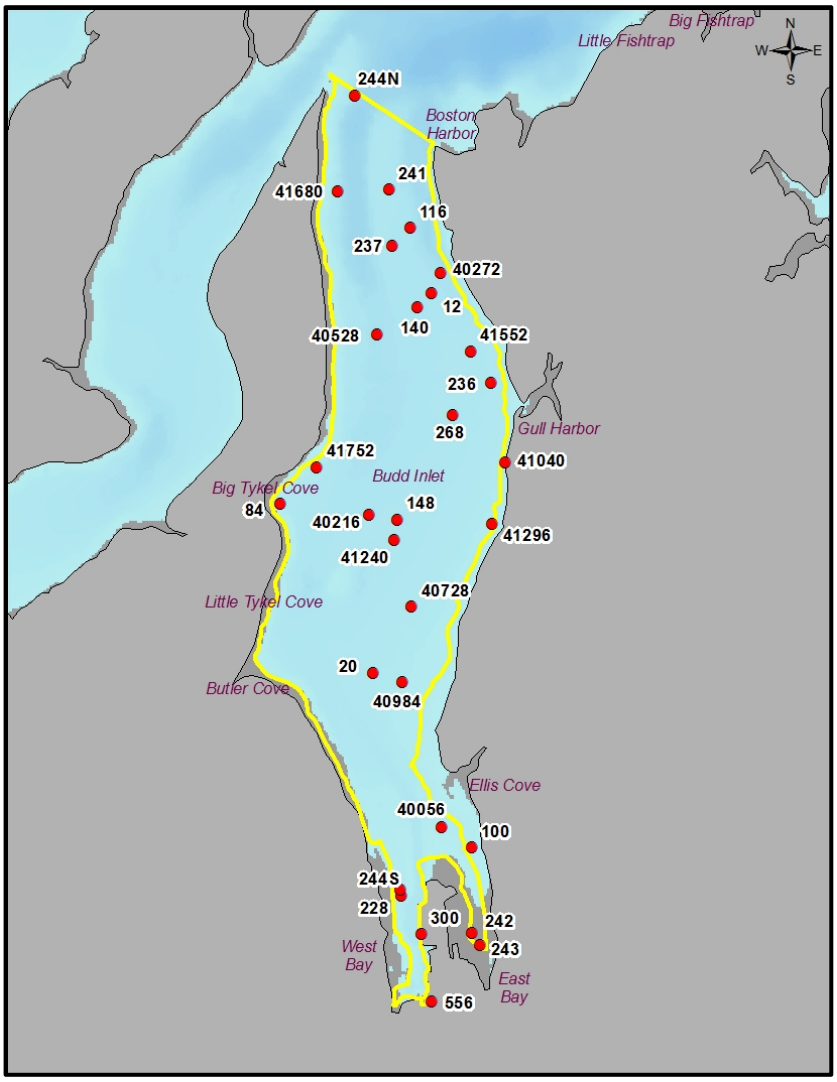

Figure 16. Budd Inlet sampling frame and 30 monitoring station locations.

Table 21. Target coordinates for 30 Budd Inlet monitoring stations.

All stations are equally weighted, each representing 0.578 km^2 of the total 17.35 km^2 area.

Station	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
12	47.12407	-122.90705
20	47.08154	-122.91473
84	47.10008	-122.93065
100	47.06241	-122.89778
116	47.13127	-122.91092
140	47.12242	-122.90933
148	47.09875	-122.91161
228	47.0568	-122.90899
236	47.11424	-122.89695
237	47.12927	-122.91379
241	47.13547	-122.91450
242	47.05286	-122.89736
243	47.05164	-122.89589
244N	47.14588	-122.92064
244S	47.05751	-122.90913
268	47.1106	-122.90308
300	47.05261	-122.90552
556	47.04513	-122.90357
40056	47.06458	-122.90270
40216	47.09917	-122.91611
40272	47.12633	-122.90571
40528	47.11928	-122.91573
40728	47.08906	-122.90877
40984	47.08067	-122.90988
41040	47.10551	-122.89420
41240	47.0964	-122.91197
41296	47.09853	-122.89604
41552	47.11775	-122.90043
41680	47.13508	-122.92285
41752	47.10428	-122.92496

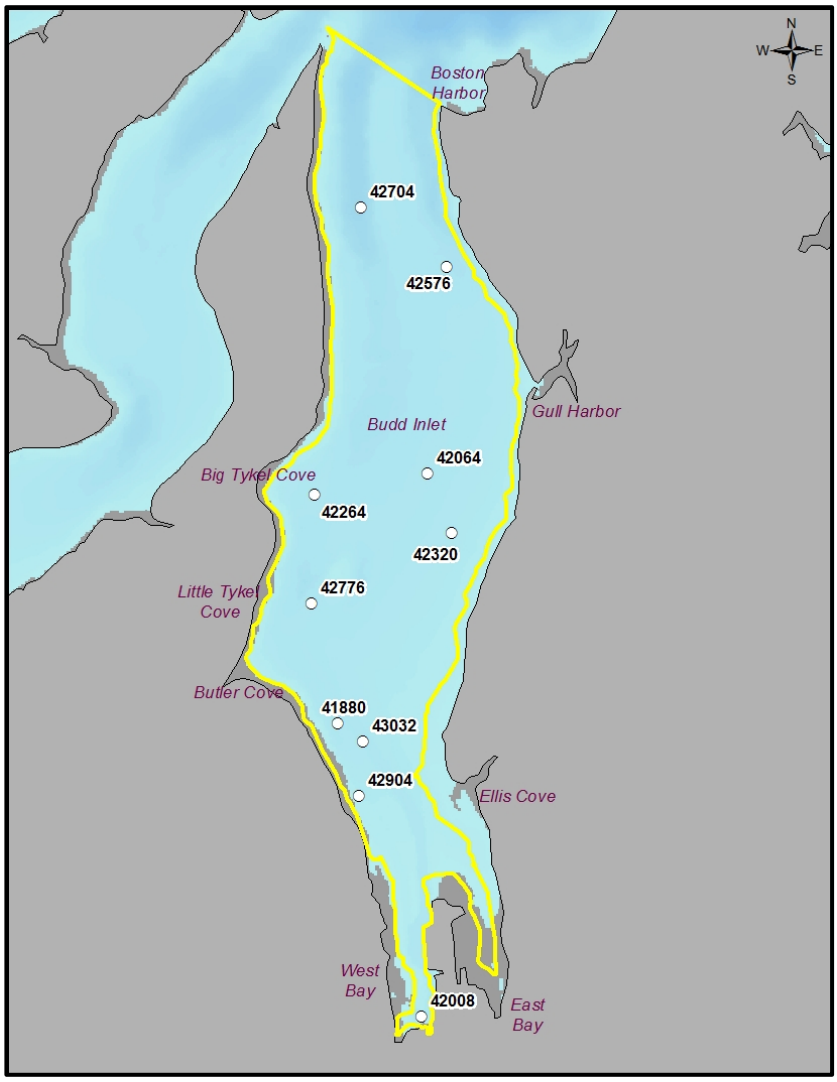

Figure 17. Budd Inlet sampling frame and 10 alternate monitoring station locations.

Table 22. Target coordinates for 10 Budd Inlet alternate monitoring stations.

Station	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
41880	47.07653	-122.92005
42008	47.04648	-122.90604
42064	47.10261	-122.90759
42264	47.10007	-122.92464
42320	47.09653	-122.90369
42576	47.12388	-122.90569
42704	47.12982	-122.91889
42776	47.08882	-122.92458
42904	47.06903	-122.91651
43032	47.07466	-122.91610

Table 23. Puget Sound Sediment Monitoring Program sampling schedule.

Monitoring Program	Sampling Year/Number of stations					
Sampling Frame	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Long-Term						
Puget Sound	50	50	50	50	50	50
Urban Bays rotation						
Budd Inlet	30					
Port Gardner/Everett Harbor		30				
Elliott Bay			36			
Commencement Bay				30		
Bainbridge Basin					33	
Bellingham Bay						30

7.2.2 Field parameters and laboratory analytes to be measured

For Long-Term monitoring, all benthos samples and measurements, and all sediment sample field measurement, physical, and biogeochemical parameters will be collected annually at the 50 stations. Sediment chemistry parameters will be measured at 10 of the 50 stations each year on a five-year station rotation schedule (Figure 18 and Table 24). A complete set of sediment chemistry data for all 50 stations will be available every five years. Additionally, sediment toxicity testing will be conducted for all 50 stations every fifth year as funding permits.

Sampling for benthos tissue is also planned for all 50 stations for stable isotope and chemical analyses, with the chemical analyses on the same five-year station rotation schedule as for bulk sediments. While methods for the stable isotope and chemical analyses for benthos tissue are set forth in this QAMP, this work will not commence immediately. Due to challenges faced in collection of adequate volume of sample tissue and in optimal sample preservation, a pilot study will first be conducted for this work prior to inclusion in the annual sampling. A separate QAMP addendum will be generated for this work.

For Urban Bays monitoring, all parameters except the toxicity test will be conducted on sediments for every station sampled each year. Toxicity testing is not planned for Urban Bays monitoring. Chemical testing of benthos tissue from Urban Bays stations will be conducted in separate studies in partnership with WDFW's TBiOS team as funding permits.

All environmental parameters to be measured or analyzed are listed in Table 25.

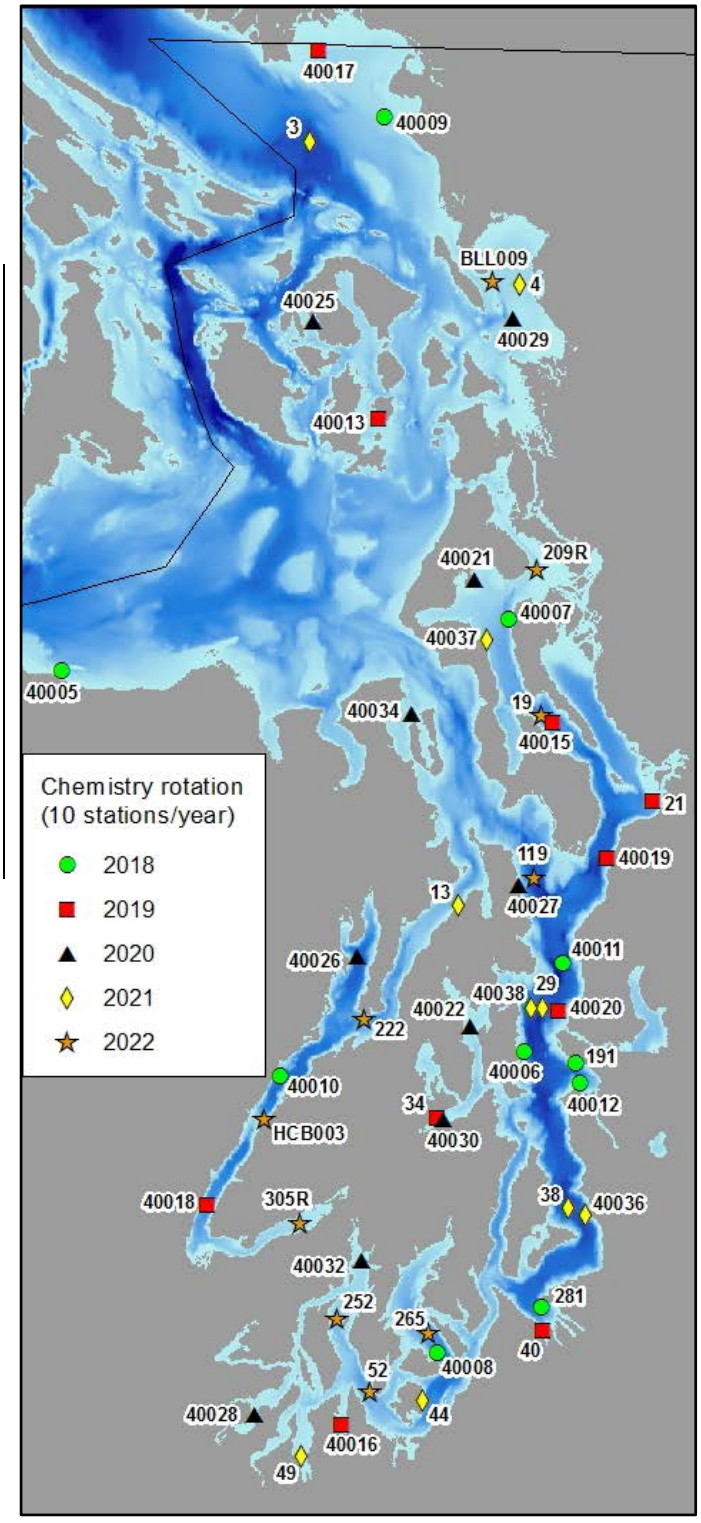

Figure 18. Potential five-year rotation scheme for sediment and tissue chemistry samples.

The numbers on the map are the station identifications.

Table 24. Potential sampling rotation for sediment and tissue chemistry.

*Stations in **bold** are co-located with Marine Waters. Stations in red italics are co-located with WDFW's TBiOS biennial English sole monitoring locations.*

Sampling Year / Station IDs				
2018	**2019**	**2020**	**2021**	**2022**
191	***21***	40021	*3*	**19**
281	***34***	40022	**4**	**52**
40005	***40***	40025	***13***	**119**
40006	40013	40026	**29**	**209R**
40007	40015	40027	**38**	**222**
40008	40016	40028	***44***	**252**
40009	40017	40029	**49**	**265**
40010	40018	40030	40036	**305R**
40011	40019	40032	40037	**BLL009**
40012	40020	40034	40038	**HCB003**

Table 25. Parameters measured in sediments for Long-Term and Urban Bays monitoring. Sampling occurs annually unless otherwise noted. *[+]Denotes calculated values (see Section 14). * Denotes parameters that will also be measured in selected benthos tissue samples each year.*

BENTHOS
Total abundance[+]
Major taxa abundance[+]
Taxa richness[+]
Pielou's evenness[+]
Swartz's dominance index[+]
Size class[+]
Biomass[+]
Ecological function, assigned

FIELD MEASUREMENTS
Station depth
Sediment temperature
Salinity of overlying water

PHYSICAL
Grain size

BIOGEOCHEMISTRY
Total carbon
Total organic carbon
Total inorganic carbon[+]
Total nitrogen
C:N ratio[+]
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes[+]*
Total sulfides
Biogenic silica

CHEMISTRY

METALS*
Arsenic
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Tin
Zinc

ORGANICS*
Phthalate Esters
Bis(2-ethylhexyl)phthalate
Butylbenzylphthalate
Diethylphthalate
Dimethylphthalate
Di-n-butylphthalate
Di-n-octyl phthalate

Polynuclear Aromatic Hydrocarbons
LPAHs
1,6,7-Trimethylnaphthalene
1-Methylnaphthalene
1-Methylphenanthrene
2,6-Dimethylnaphthalene
2-Methylnaphthalene
2-Methylphenanthrene
Acenaphthene
Acenaphthylene
Anthracene
Biphenyl
Dibenzothiophene
Fluorene
Naphthalene
Phenanthrene
Retene
Total LPAHs[+]

HPAHs
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(e)pyrene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Chrysene
Dibenzo(a,h)anthracene
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Perylene
Pyrene
Total HPAH[+]
Total benzofluoranthenes[+]

Polychlorinated Biphenyls
PCB Aroclor 1016
PCB Aroclor 1221
PCB Aroclor 1232
PCB Aroclor 1242
PCB Aroclor 1248
PCB Aroclor 1254
PCB Aroclor 1260
PCB Aroclor 1262
PCB Aroclor 1268
PCB congener 8
PCB congener 18
PCB congener 28
PCB congener 44
PCB congener 52
PCB congener 66
PCB congener 77
PCB congener 101
PCB congener 105
PCB congener 118
PCB congener 126
PCB congener 128
PCB congener 138
PCB congener 153
PCB congener 169
PCB congener 170
PCB congener 180
PCB congener 187
PCB congener 195
PCB congener 206
PCB congener 209

Polybrominated Diphenylethers
PBDE 47
PBDE 49
PBDE 66
PBDE 71
PBDE 99
PBDE 100
PBDE 138
PBDE 153
PBDE 154
PBDE 183
PBDE 184
PBDE 191
PBDE 209

TOXICITY
Amphipod Survival (solid phase) (every 5th year at Long-Term stations only)

7.3 Modeling and analysis design

NA

7.3.1 Analytical framework

NA

7.3.2 Model setup and data needs

NA

7.4 Assumptions in relation to objectives and study area

An inherent design assumption of annual ambient monitoring is that these snapshots are representative of environmental and biotic conditions year-round. However, annual measurements are a snapshot of conditions at one point in time, and may not fully capture the range of conditions nor unique events occurring year-round. Seasonal variability in all parameters may play an important role in shaping sediment and benthos conditions. Although we take steps to assure representativeness, data users must be careful not to overstate these measurements.

7.5 Possible challenges and contingencies

The Sediment Program study design was developed to achieve the goals and objectives of this program and answer the questions posed. Logistical problems, practical constraints, and scheduling limitations do exist, however, presenting challenges. These challenges, and their resolutions, are discussed in this section.

7.5.1 Logistical problems

Potential problems associated with sediment sampling logistics include the following:

- **Research vessel, size, condition, and sea state:** Ecology's 26' R/V Skookum will usually be used for the Sediment Program. It is an efficient, cost-effective research vessel from which to sample Puget Sound sediments. Its speed allows for rapid transit between monitoring stations, allowing more samples to be collected over large geographic areas each day. The smaller size, however, can be restrictive during strong wind and high wave conditions, and no sampling can be conducted during conditions necessitating small craft advisories from the National Weather Service. Under these conditions, the captain and lead crew member work together to alter the sampling schedule.

  The smaller size and deck space may also prohibit the conduct of sampling with multiple types of sampling gear. For example, there is insufficient deck space to deploy and process samples from a vanVeen grab and a sediment coring device during the same cruise.

Larger vessels may occasionally be charted for joint and special projects, allowing more working space on deck and less susceptibility to rough sea conditions.

Additionally, the condition of the research vessel is critical to the success of the sampling mission. The vessel must be kept in an immaculate state of repair. The engines, hydraulic A-frame and winch, and all navigational equipment must be in good working order for the sampling mission to be safe and successful.

- **Sediment type:** The target population for this project is the top 2-3 cm of soft sediment and the benthos that dwell within the sediments up to 17 cm in depth. Samples are collected with a modified vanVeen grab sampler. A representative soft sediment sample cannot be collected successfully from a location with a high proportion of cobble or rocks. If such locations are encountered, they must be rejected and replaced with alternate stations.

- **Sampling permits:** City, county, state, federal, and tribal governments, as well as military bases with boundaries along the Puget Sound shoreline, have regulatory authority regarding sediment sampling within these jurisdictional boundaries. Permits must be obtained from each appropriate agent prior to commencement of sampling. For this long-term ambient monitoring, permission is typically granted for sediment sampling, but it has occasionally been denied. When access is denied, stations must be rejected and replaced with alternates which are outside the restricted areas.

7.5.2 Practical constraints

Practical constraints for the Program may include the following:

- **Field crew capacity:** Sample collection in the field aboard the R/V Skookum typically requires three MSMT members to collect samples and operate the winch, and one of the Environmental Assessment Program's (EAP) trained and certified boat operators to serve as captain. Careful scheduling and preparation of a field itinerary must be conducted at least one month in advance of field work to ensure that there is adequate staffing of a field crew and alternate field crew daily during sampling. There may also be a need for a team member to shuttle field crew and samples to and from marinas during crew changes.

- **Laboratory analysis capacity:** Once samples are collected, they are delivered to and processed in various laboratories. Physical, biogeochemistry, chemistry, and toxicity samples will be processed either by MEL or a contract laboratory. Benthos samples are processed by the MSMT in Ecology's benthic laboratory, with QA performed by contract taxonomists. Careful planning of sample intake and flow must be practiced to ensure timely processing of samples.

- **Budget:** Funding of the Sediment Program is required to conduct collection and analysis of all samples. The MMU supervisor and Sediment Monitoring Team lead must work with EAP's Management Team to ensure adequate funding each year. A full monitoring design is provided in this QAMP. Additions or deletions of monitoring parameters may be made each year based on Sediment Program approved funding levels. Inadequate budget can result in parameters or sampling stations being cut from the program.

7.5.3 Schedule limitations

Logistical problems and practical constraints listed above may impact the proposed study schedule. Issues that may arise to delay sampling, sample analysis, data review and analysis, and data reporting include, in part, the following:

- **Sampling and vessel conditions:** Windy conditions and high seas, encountering hard bottom sediments, and mechanical problems or failures with the research vessel and gear can cause delays in the field sampling schedule.
- **Permits:** Failure to obtaining the proper sampling permits in a timely manner can cause delays in the field sampling schedule.
- **Contracting with outside vendors:** Some laboratory analyses required for the program must be conducted by vendors with specialized expertise. The contracting process is time-consuming and must be started months in advance to be successfully completed before sampling commences.
- **Staff capacity:** There must be an adequate number of trained research vessel captains and sampling crew available and scheduled to participate in field sampling. Heavy workload and higher priority projects can cause lack of a sufficient pool of field crew, delaying sampling.
- **Lab capacity:** Sample processing at the various contract and in-house laboratories can be delayed by existing and unplanned workload or lack of adequate numbers of trained laboratory staff.
- **QAMP generation, review, and approval:** Sample collection may not commence for this program until a parent QAMP or annual QAMP addendum has been generated and approved for the sampling year. Time required for QAMP review and approval can be lengthy, so a draft QAMP should be prepared at least two to three months in advance of planned sampling to allow adequate time for review and approval.

8.0 Field Procedures

8.1 Invasive species evaluation

It is possible that during sampling, invasive species of benthic invertebrates or marine plants could be collected. To avoid the spread of these species to other areas, procedures adapted from Ecology's Standard Operating Procedures to Minimize the Spread of Invasive Species (EAP070; Parsons et al., 2016; Appendix C-5) will be implemented.

During collection of sediments and benthos for the Sediment Program, all sample material not retained for analyses is washed overboard at or near the sampling location. Sieving of sediment samples for benthos will be conducted at or within five nautical miles of the collection site. Additionally, both the vanVeen grab and the sieve boxes will be scrubbed clean of any residual sediment and organisms immediately after completion of sampling at each station.

8.2 Measurement and sampling procedures

All sampling and field measurement methods for the Sediment Program will follow those described in Appendix C. They include the following and are summarized below.

Sampling methods (Appendix C)

C-1. Puget Sound Estuary Program (PSEP), 1998. Recommended Guidelines for Station Positioning in Puget Sound.

C-2. PSEP, 1997a. Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissue in Puget Sound.

C-3. PSEP, 1987. Recommended Protocols for Sampling and Analyzing Subtidal Benthic Macroinvertebrate Assemblages in Puget Sound.

C-4. Weakland, 2015. Ecology's Standard Operating Procedures for Obtaining Marine Sediment Samples. EAP039 v1.3.

Sediment Program sampling procedures, along with the remaining analysis and QA procedures described in this document are generally identical for both Long-Term and Urban Bays monitoring. This allows for comparison of results among stations and sampling frames, and among years. If any variations to the program design described in this QAMP are necessary for a sampling event, they will be documented in a QAMP addendum generated prior to that sampling event.

Sampling platform and station positioning

A marine research vessel of adequate size and speed, and suitably equipped for deployment of sample collection equipment and shipboard sample processing, will be reserved from the Ecology fleet or contracted with an outside vendor for this work. From this platform, station-positioning protocols will follow PSEP, 1998 (Appendix C-1). Positioning will rely on Differential Global Positioning System (DGPS) with expected accuracy of better than 10 meters.

All Long-Term and Urban Bays stations identified in this QAMP have been sampled at least once in previous years, indicating conditions suitable for sediment collection, including station depth of greater than one fathom, sufficient soft sediment for grab closure, and situated outside of sensitive (e.g., eel grass or shellfish beds) or dangerous areas (e.g., communications cables, shipping lanes). Station conditions may change over time, however, making it necessary to move the target coordinates for a station.

If it is necessary to relocate a station, the first course of action will be to move up to 300 m offshore, in a direction perpendicular to shore. If it is not possible to sample successfully after moving up to 300 m seaward, then that station will be rejected and must be replaced. Alternate stations will be selected in order from the GRTS multi-density survey design.

Sample collection and field measurements

Sediment and benthos samples will be collected following procedures outlined in PSEP, 1997a (Appendix C-2); PSEP, 1987 (Appendix C-3); and Weakland, 2015 (Appendix C-4). A double 0.1-m^2 stainless-steel modified van Veen grab sampler will be used, which allows sediment for physical, biogeochemistry, chemistry, and toxicity samples to be collected simultaneously with benthic infaunal samples.

Sediment grab sampling

The grab will be attached to the vessel's cable and winch system and lowered to 2-3 meters above the sediment surface. The vessel will be maneuvered into position above the target location. The grab will then be lowered to the bottom where it will trigger and close upon contact with the sediment surface, and a sample will be collected. The grab will then be raised back up to the vessel and landed on a grab stand.

The collected sediment sample will be visually inspected. Any grab sample lacking fine-grained particles in the sediment (i.e., composed of all cobble, shell hash, or wood, etc.) or for which the jaws of the grab do not close completely will be rejected. Any grab sample that has either a less-than-adequate penetration depth or significant over-penetration will be discarded. If a sample is rejected for any reason, it is dumped overboard after the vessel has been repositioned away from the target location. If a station is rejected, an alternate station with a new station number will be sampled in its place.

Field measurements

For the first acceptable grab sample taken, one side of the double van Veen will be used for determination of various physical/environmental characteristics (Table 26).

Table 26. Field measurements - sediments: Methods and reporting limits for parameters measured at 50 Long-Term and 30-36 Urban Bays stations annually.

Parameter	Expected Range of Results	Technique/ Instrument	Measurement Method	Reporting Limit
Station depth	Up to 230 m	Meter wheel	Reading from ship's meter wheel when grab reaches the sediment surface	1 m
Sediment penetration depth	0-17 cm	Metric ruler	Measure the amount of space between the top of the sample and the top of the grab and subtracting from the maximum grab depth (17 cm).	1 cm
Sediment temperature	7-21 °C	Digital thermometer	Read from thermometer inserted into the sediment sample.	1.0 °C
Overlying salinity	7-34 ppt	Refractometer	Pipet a drop of the water overlying the sample onto the refractometer and read the salinity from the measurement scale.	1.0 ppt
Sediment type	Cobble, gravel, sand, silt-clay	N/A	Visually examine the sediment in the grab.	N/A
Material in sediment	Wood, shell, plant fragments and macroalgae	N/A	Visually examine the sediment in the grab.	N/A
Sediment color	Olive, gray, brown, black	N/A	Visually examine the sediment in the grab.	N/A
Sediment odor	Hydrogen sulfide, petroleum, other	N/A	Smell the sediment in the grab.	N/A

Benthos for enumeration, identification, and size-class/biomass estimates

The sediment from the same side of the grab used for field measurements will be gently rinsed through a 1.0-mm screen for collection of benthos. Organisms retained on the screen will be transferred to high density polyethylene (HDPE) leak-proof jars and preserved in the field with a 10% aqueous solution of borax-buffered formalin. These sample containers will be labeled internally and externally, then sealed in plastic 5-gallon buckets also labeled externally with sample numbers, date, and a hazardous materials (i.e., formaldehyde) warning label.

Additionally, Ecology's Standard Operating Procedure EAP126 for Benthic Macrofaunal Size Classification and Biomass (Appendix G-2) will be followed for field identification and obtaining size and biomass measurements for any megafaunal benthos collected with the grab samples.

Benthos tissue for chemistry and stable isotope analysis

Methods for collection, preservation, and processing of benthos tissue for chemistry and stable isotope analyses will be outlined in an associated QAMP addendum.

Sediment samples

From the other side of the first grab sample, the top 2-3 cm of sediment will be collected with a stainless steel spoon for grain size, biogeochemistry, chemistry, and toxicity analyses. The sediment will be placed in a stainless steel bucket and covered with a lid. On subsequent grabs, the top 2-3 cm of sediment on both sides of the grab will be collected and added to the bucket. Grabs will be taken until enough sediment is collected to fill all necessary sample containers for the station.

The composited sediment in the bucket will be homogenized by stirring with a stainless-steel spoon or paint mixer until a uniform texture and color are achieved. After the sample jars are filled, some (typically the toxicity samples) may be individually sealed with electrical tape to secure the lids. Leftover sediment will be returned to the water column at or near the sites where collected.

Sampling for total sulfides

Before taking sediment to be homogenized into a composite sample, 60-mL subsamples for analysis of total sulfides will be collected from undisturbed sediment. This will eliminate any loss of sulfide gases that may occur during the homogenization process. Subsamples will be collected using a 60-mL plastic syringe with its end removed. The syringe plunger will be placed on the sediment surface, and the syringe body will be gently pushed into the sediment to the 60 mL line. The approximately 60-mL sediment sample will then be extruded from the syringe into a precleaned 2-ounce glass jar. Zinc acetate will be added to the top of the sample as a preservative, and the jar will be sealed to exclude air (zero headspace).

Field replicates

Every year, 5% of the sites with the highest levels of contamination in previous years will be selected for analysis of field replicates. At these stations, double the amount of sediment will be collected and homogenized. Two sets of sample containers for grain size, biogeochemistry, and chemistry analyses will be filled. The second set will be assigned a different sample identification number and submitted to the laboratories as blind field replicates. Field replicates are not collected for benthic infaunal community, benthos tissue analyses, or toxicity due to cost.

Archive samples

A portion of each sediment sample will be jarred and retained as grain size and biogeochemistry/chemistry archive samples. The archive samples will be kept for a minimum of one year in case re-extraction or retrospective analysis is required. Sediment grain size samples will be held at 4 °C. Biogeochemistry/chemistry samples will be frozen at –18 °C (0 °F).

Sample transport and storage

Sediment and benthos samples will be off-loaded from the research vessel every 1-3 days and transported to Ecology's Operations Center (OC) in Lacey, Washington. There, they will be checked in following Chain-of-Custody procedures, Section 8.6 below.

Sediment samples will be stored in either the walk-in refrigerator or the freezer and held at the appropriate temperature (Table 27). From there, they will be transported to Ecology's Manchester Environmental Laboratory (MEL) or shipped to the appropriate contractors by overnight courier. Tissue samples will be processed as indicated above, then shipped to the appropriate contractor. Laboratory staff will be notified that samples have been shipped by either phone call or email message on the day they are shipped.

The formalin-preserved benthos samples collected for infaunal community analyses or for isotope analysis will be transported in sealed 5-gallon buckets to the OC for storage and rescreening. Frozen benthos samples collected for chemical or stable isotope analysis will be stored in the freezer. Unpreserved benthos samples collected for chemical or stable isotope analysis will be refrigerated for immediate sorting (see section 9.2, Tissue Preparation, below).

Archive sediment grain size samples will be stored at 4^{o} C in the walk-in refrigerator and archive biogeochemistry/chemistry samples will be stored at -18^{o} C in the OC freezer.

All appropriate sample holding times (Table 27) will be observed.

8.3 Containers, preservation methods, holding times

Recommended sample sizes, containers, preservation techniques, and holding times for all sediment, tissue, and benthos samples are those listed for the PSEP (1997a), the MEL's *Lab Users Manual* (MEL, 2016), or from published laboratory methods, and are summarized in Table 27.

Table 27. Sample containers, preservation, and holding times.

Parameter	Minimum Quantity Required	Container	Preservative	Maximum Holding Time
Benthos				
Benthic Macrofauna	0.1 m^2	8-, 16-, 32-, or 64-ounce polyethylene wide-mouth jugs	Screen through 1.0-mm mesh, and store in 10% aqueous solution of borax-buffered formalin	48 hours to 14 days
Sediments				
Grain Size/Archive	8 oz.	8-oz wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC	6 months
Total Carbon Total Organic Carbon Total Inorganic Carbon Total Nitrogen	10 grams	2- or 4-oz wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	Refrigerated: 14 days Frozen: 6 months
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes	1 gram	50-mL polyethylene centrifuge tubes	Refrigerate at 4ºC or freeze at -18°C	Indefinite
Total Sulfides (bulk sediments)	2 oz.	2-oz wide-mouth glass jar with Teflon-lined lid	4°C, 5ml of 2 N zinc acetate for a 250 ml sample, sample should not be homogenized in field, no headspace or air pockets should remain, mix sample after sealing container.	7 days
Biogenic Silica	50 mg	50-mL polyethylene centrifuge tubes (no glass)	Freeze at -18°C	1 year
Metals	4 oz.	4-oz wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	All metals except mercury: 6 months at 4ºC or 2 years at -18ºC; Mercury: 28 days at 4ºC

Parameter	Minimum Quantity Required	Container	Preservative	Maximum Holding Time
PAHs, Phthalates	8 oz.	8-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	1 year
PCBs, PBDEs	8 oz.	8-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	1 year
Chemistry Archive Sample	16 oz.	16-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	1 year
Amphipod Survival (Solid Phase)	1 gallon	1-gallon high-density polyethylene, acid-stripped, wide-mouth jugs	Refrigerate at 4ºC	10 days
Benthos Tissue				
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes	2 grams	50-mL polyethylene centrifuge tubes	Freeze at -18°C or freeze-dry	1 year
Metals	10 grams	2- or 4-oz wide-mouth glass jar with Teflon-lined lid	Freeze at -18°C	1 year
PAHs, Phthalates	10 grams	2- or 4-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Freeze at -18°C	1 year
PCBs	10 grams	2- or 4-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Freeze at -18°C	1 year
PBDEs	10 grams	2- or 4-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Freeze at -18°C	1 year

8.4 Equipment decontamination

Prior to sampling, and between sampling stations, the grab, sieves, and all other sampling equipment that comes in contact with the sampled sediment will be scrubbed with a soft brush and Alconox soap and rinsed with *in situ* seawater. This removes any sediment and contaminants from previous stations. The equipment will then be rinsed with acetone, again followed by *in situ* seawater. Residual acetone used for decontamination evaporates quickly, and does not remain in sufficient quantity to collect for disposal.

The spoons, spatulas, and homogenization paddle will be placed in the decontaminated sample collection bucket, and a decontaminated lid will be placed over them until needed for the next sample. Similarly, decontaminated forceps and spoons for benthos for tissue analyses will be placed in a clean, lidded container until needed for the next sample. These precautions are taken to avoid contamination of the samples from engine exhaust, atmospheric particulates, and rain.

8.5 Sample ID

Each sample will be identified with a preprinted vinyl label affixed to the outside of the container, indicating the project, station ID, Manchester Lab ID number (when appropriate), date of collection, and analysis to be performed (Appendix H-1). Barcodes containing this sample information will also be included on the label. The station and replicate numbers will be written on the lid of each sample with a permanent marker.

Each benthos sample will be identified with a label affixed to the outside of the container and a waterproof label placed inside the container with the sample, indicating the project, station ID, date of collection, and sieve mesh size (Appendix H-2).

All labeled grain size, biogeochemistry, chemistry, toxicity, and unpreserved tissue samples will be stored in insulated chests filled with ice. Labeled frozen tissue samples will be stored in a portable freezer or in an insulated chest with dry ice. Labeled preserved benthos sample containers will be sealed in plastic 5-gallon buckets labeled externally with contents, date, and hazardous materials (formaldehyde) warning label.

8.6 Chain-of-custody

Chain-of-custody procedures will follow those recommended by PSEP (1997a), with modifications to include the use of two-dimensional barcodes for sample tracking. These procedures provide an unbroken trail of accountability that ensures the physical security of samples, data, and records.

All samples collected during a field sampling shift will remain in the possession of the field crew during that shift. At the end of each shift, the field crew will transport the samples to the OC. There, biogeochemistry, chemistry, and toxicity samples are removed from each ice chest, and the barcode on each sample label is scanned with a barcode reader connected to a laptop computer. Information read from each barcode populates an electronic chain-of-custody form for each type of analysis with information about each sample (Appendix H-3). The form is

printed and signed by the relinquishing field crew member. Samples are stored in either the receiving freezer or walk-in cooler at the OC until ready for transport to the appropriate analytical laboratory. The signature block on the chain-of-custody form is signed next by the relinquishing and receiving person during each sample transfer. When the sample reaches its destination lab, the completed chain-of-custody form is scanned and e-mailed to MSMT staff.

Benthos samples are not tracked with chain-of-custody forms during the field season as they never leave the custody of the MSMT staff. However, an infaunal sample tracking log is used in-house during sample sorting and identification (Appendix H-4), and a chain-of-custody form is used when samples are sent to a contract lab for Quality Assurance taxonomic identification (Appendix H-5).

8.7 Field log requirements

A *Field Log* will be completed by MSMT crew members during sampling of each station to record information about the station identification, crew, collection gear, collection success, sample description, parameters collected, and who recorded the information (Appendix H-6). A separate field log page, printed on water-resistant paper, will be generated for each station. A *Navigation Log* will also be completed by the ship captain at each station to record information regarding station positioning and depth (Appendix H-7). All logs will be recorded in pencil and stored in a three-ring field notebook when completed. Information from each will be transferred to electronic files and stored as metadata at the end of the field season. Logs may also be recorded electronically in the field if a field computer is available.

8.8 Other activities

Lab notification

Prior to sampling, the MSMT project lead will submit a *Pre-Sampling Notification* and a *Sample Container Request Form* to MEL regarding specifications for all analyses conducted there. For analyses conducted by contract laboratories, laboratory notification procedures will be as specified in the Scope-of-Work prepared for each parameter.

The field collection schedule and sample delivery dates will be included in the laboratory notification. Changes to the schedule may be imposed by inclement weather, which may require suspension of activities or delays in collecting samples at exposed sites. Equipment failures may require delays while repairs are made or replacements located. Changes in the schedule due to these unexpected events will be communicated to MEL and the contract laboratories so they can revise their plans accordingly.

Briefings for field staff

A meeting will be held with all field staff at least two weeks prior to the commencement of field work to review all field sampling and safety protocols.

Safety protocols

Collection of sediment samples aboard a research vessel poses a number of potential safety hazards to the field crew, including falling overboard, being struck by heavy equipment, coming into contact with hazardous materials (formaldehyde and acetone), and exposure to extreme temperatures and sunlight. To ensure their safety, all crew members are required to wear the following safety gear at all times while collecting samples:

- Life vest or flotation suit.
- Hard hat.
- Steel toed boots.
- Rain jacket and pants.
- Protective gloves.
- Protective eyewear (when appropriate).
- Temperature-appropriate clothing.
- Sunscreen.

They are also required to read and follow all appropriate guidelines in EAP039 Standard Operating Procedure for Obtaining Marine Sediment Samples (Weakland, 2015; Appendix C-4) and the EAP Field Operations Safety Manual (Appendix C-6).

Periodic maintenance of field instrumentation

Prior to field sampling, all sampling gear and field instrumentation will be examined to make sure it is in working order. A similar inspection will also happen at the end of each sampling event, prior to placing the equipment in storage. Equipment repairs and replacement will be made as needed.

Excess sample and waste disposal

All in-house and contract labs will be required to dispose of all samples at the end of the tests using acceptable methods. Waste formalin, retained during the benthic sample rescreening process, is considered hazardous waste and is disposed of through Ecology's hazardous waste contractor.

9.0 Laboratory Procedures

Analysis of sediment and benthos samples will be conducted by both Ecology and contract laboratories using analytical methods described in Appendices D, E, F, and G. Methods are summarized in Tables 28-31.

Analytical laboratories to perform these procedures include:

- Grain size – Contract laboratory.
- Total carbon, total organic carbon, total inorganic carbon, total nitrogen – MEL.
- Sediment and benthos tissue chemistry – MEL.
- C and N stable isotopes – Contract laboratory.
- Biogenic silica – Contract laboratory.
- Toxicity – Contract laboratory.
- Benthos sorting and primary taxonomy – MSMT Benthic Lab.
- Benthos sorting QA/QC – MSMT Benthic Lab.
- Benthos taxonomy QA/QC – Contract laboratory.

9.1 Lab procedures table

Table 28. Physical, biogeochemistry, and chemistry parameters – bulk sediments: Laboratory methods and reporting limits for parameters measured at Long-Term (LT) and Urban Bays (UB) stations annually.

Parameter	No. of Stations/ Year	Expected Range Of Results	Extraction Method	Clean-Up Method	Analysis Method	Technique/ Instrument	Reporting Limit
Grain size	50 LT 30-36 UB	<20% - >80% silt+clay	N/A	NA	PSEP 1986	sieve-pipette method	1.0%
Total carbon Total organic carbon Total inorganic carbon* Total nitrogen		0.1-7.2%	70°C drying; Vapor phase acidification (HCL) for organic and inorganic particulate C		EPA method 440.0, Revision 1.4 (after Hedges and Stern, 1984)	CE-440 Elemental Analyzer; Exeter Analytical, Inc.	
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes		1 to 10 ‰ $\delta^{15}N$; -18 to -25 ‰ $\delta^{13}C$	Sample preparation by freeze drying, grinding, acidification (if needed), homogenization, weighing, and encapsulation in tin or silver.	NA	Dumas Combustion. Carter and Barwick, 2011	Delta Plus XP isotope ratio mass spectrometer couples to CE-1108 CHNS-O Elemental Analyzer via a Conflo III interface	0.05 ‰
Total sulfides		1.0 mg/kg	Sediment is acidified under anoxic conditions to release sulfide as H_2S. The released H_2S gas is then trapped in zinc acetate solution to precipitate sulfide (as zinc or sodium sulfide). Finish analysis is conducted on the trapping solution.	NA	Plumb, 1981; Standard Methods, 1995 4500-S^{2-} D-00; PSEP, 1986	Iodometric titration and methylene blue colorimetry	10.0 mg/kg dry weight (to nearest 0.1 unit)

Parameter	No. of Stations/ Year	Expected Range Of Results	Extraction Method	Clean-Up Method	Analysis Method	Technique/ Instrument	Reporting Limit
Biogenic Silica		1 – 8 mM	Sample preparation by freeze drying and grinding, followed by rapid wet-alkaline extraction of biogenic silica.	NA	Mortlock and Froelich, 1989	Measurement of dissolved silicon concentration in extract by molybdate-blue spectrophotometry.	0.1%
Metals (except mercury)	10 LT 30-36 UB	< 0.1 - 500 ppm (up to 1500 for zinc)	EPA 3050B	NA	EPA 6020B	ICP-MS	0.1 mg/kg dry weight (0.2 for Sn, 0.5 for Cr and Se, 5.0 for Zn)
Total mercury		0.001-10 ppm	EPA 245.5		EPA 245.5	CVAA	0.005 mg/kg dry weight
Phthalate esters		0.001-10 ppm	EPA 3541	EPA 3630C	EPA 8270D	MEL modification with capillary GC/MS analysis	0.5-2.0 µg/kg dry weight
Polycyclic aromatic hydrocarbons (PAHs)		0.01 – 50,000 ppb			EPA 8270D with isotopic dilution	MEL modification with capillary GC/MS-SIM isotopic dilution analysis	
PCB Aroclors		1 – 4,000 ppb		EPA 3620 and EPA 3665	EPA 8082A	GC- ECD	2.5 µg/kg dry weight
PCB congeners		< 0.1 – 4,000 ppb					0.5 µg/kg dry weight
PBDE congeners					EPA 8270D	Capillary GC/MS-SIM	0.4-2.0 µg/kg dry weight

NA = not applicable
*Total inorganic carbon is calculated by subtraction
MEL = Manchester Environmental Laboratory

Table 29. Biogeochemistry and chemistry parameters – benthos tissue: Laboratory measurement methods and reporting limits for parameters measured at Long-Term (LT) and Urban Bays (UB) stations annually.

Parameter	No. of Samples/ Year	Expected Range Of Results	Extraction Method	Clean-Up Method	Analysis Method	Technique/ Instrument	Reporting Limit
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes	50 LT 30-36 UB	1 to 10 ‰ $\delta^{15}N$; -18 to -25 ‰ $\delta^{13}C$	Sample preparation by freeze drying, grinding, acidification (if needed), homogenization, weighing, and encapsulation in tin or silver.	NA	Dumas Combustion. Carter and Barwick, 2011	Delta Plus XP isotope ratio mass spectrometer couples to CE-1108 CHNS-O Elemental Analyzer via a Conflo III interface	0.05 ‰
Metals (except mercury)	10 LT	< 0.1 - 500 ppm (up to 1500 for zinc)	EPA 3050B	NA	EPA 6020B	ICP-MS	0.1 mg/kg wet weight (0.2 for Sn, 0.5 for Cr and Se, 5.0 for Zn)
Total mercury	10 LT	0.001-10 ppm	EPA 245.6	NA	EPA 245.6	CVAA	0.005 mg/kg wet weight
Phthalate esters	10 LT	0.001-10 ppm	EPA 3541	EPA 3630C	EPA 8270D	MEL modification with capillary GC/MS analysis	0.5-2.0 µg/kg wet weight
Polycyclic aromatic hydrocarbons (PAHs)	10 LT	0.01 – 50,000 ppb			EPA 8270D with isotopic dilution	MEL modification with capillary GC/MS-SIM isotopic dilution analysis	
PCB Aroclors	10 LT	1 – 4,000 ppb		EPA 3620 and EPA 3665	EPA 8082A	GC- ECD	5 µg/kg wet weight
PCB congeners	10 LT	< 0.1 – 4,000 ppb				GC- ECD	1 µg/kg wet weight
PBDE congeners	10 LT				EPA 8270D	Capillary GC/MS-SIM	0.8-4.0 µg/kg wet weight

"NA" = not applicable. MEL = Manchester Environmental Laboratory

Table 30. Sediment toxicity: Test method and endpoint for toxicity measured at Long-Term (LT) monitoring stations.

Toxicity Test	No. of Samples/ Year	Test Method	Sediment Matrix	Test Organism	Life History Stage	Endpoint	Expected Range of Results
Amphipod 10-day	50 LT/every 5th year	PSEP, 1995; ASTM, 2004a	bulk sediment	*Eohaustorius estuarius*	adult	survival as % of control	90 – 100% survival

Table 31. Benthos parameters: Laboratory measurement methods and resolution for parameters measured at Long-Term (LT) and Urban Bays (UB) stations annually.

Parameter	No. of Samples/ Year	Method	Resolution
Infaunal Sorting	50 LT 30 – 36 UB	All benthic macroinfaunal invertebrates are removed from sample with use of a dissection microscope.	• Macroinfauna: Sorted into Annelida, Arthropoda, Mollusca, Echinodermata, and Miscellaneous Taxa. • Meiofauna: Presence and relative abundance of recorded. • Colonial organisms: Representative samples collected and relative abundance noted.
Taxonomic Identification	50 LT 30 – 36 UB	Identification with dissection and compound microscopes, taxonomic literature, and voucher specimens.	Lowest taxonomic level possible, preferably species.
Taxonomic Enumeration	50 LT 30 – 36 UB	Count	Count all whole organisms.

9.2 Sample preparation method(s)

Standard preparation, extraction, and cleanup techniques for laboratory analyses of sediments and benthos tissue are summarized in Section 9.1, Tables 28 and 29, and in Appendices D, E, and F. Any additional preparation for tissue chemistry and stable isotope analyses will be presented in an associated QAMP addendum developed prior to tissue sampling.

9.3 Special method requirements

NA

9.4 Laboratories accredited for methods

All laboratories performing grain size, biogeochemistry, chemistry, and toxicity analyses must be accredited by the State of Washington for the parameters and methods used to ensure generation of accurate and defensible analytical data (MEL, 2016). Currently, Ecology does not accredit laboratories for analysis of sediment for biogenic silica or analysis of sediment and tissue for C and N stable isotopes. For these parameters, the accreditation requirement has been waived based on laboratory experience and demonstration of method performance. Neither does Ecology accredit benthic taxonomic analysis or benthic community assessment. The sediment monitoring program instead relies on regional taxonomic experts to conduct this work following established QC protocols.

10.0 Quality Control Procedures

Implementing quality control (QC) procedures provides the information needed to assess the quality of the data that is collected. These procedures also help identify problems or issues associated with data collection and data analysis while the project is underway. The following QC procedures are performed while collecting field measurements and samples, and during conduct of the various laboratory analyses associated with this monitoring program. A brief outline for each is given, below, followed by summary tables in Section 10.1.

Field Measurements

Field personnel will be trained to follow measurement and QC procedures specified in Table 32 to obtain consistent field measurements of the various sediment sample characteristics.

Field Sampling

Field personnel will be trained in the sampling methods specified in this QAMP.

All completed sample labels, chain-of-custody forms, and field logs will be double-checked by members of the field crew after sample collection.

Field QC sampling will include collection of field-split samples for grain size, biogeochemistry, and chemistry analyses at 5% of all stations sampled. The field-split samples will be submitted to the laboratories as blind replicates in order to measure the amount of variability within the compositing of sediment in the field and within the analytical procedures in the laboratories. (The two sources of variability cannot be separated unless analytical lab duplicates are run on the same samples.)

Laboratory Analyses

Grain size

All grain-size analyses conducted by contractors shall adhere to general QC procedures for grain-size analyses as outlined in PSEP, 1986. One sample per batch of 20 shall be analyzed in triplicate (Table 33**)**. QC sample results must be within ± 5% of the original sample results or the sample must be re-analyzed. All fractions within a sample must total 100% ± 1% or the sample must be reanalyzed. Additional QC procedures instituted as part of a contract laboratory's in-house SOPs will also be followed. The contract laboratory will provide case narratives documenting any sample or analysis anomalies, raw data, and QC summaries.

Biogeochemistry and chemistry

All biogeochemistry and chemistry analyses conducted by contract laboratories or at Ecology's Manchester Environmental Laboratory (MEL) will adhere to analytical QC methods outlined in published protocols (Tables 28 and 29) and in each laboratory's in-house standard operating procedures. The frequency and type of each biogeochemistry and chemistry QC test in sediments and tissue is specified in Tables 33 and 34, respectively.

Toxicity

Amphipod bioassay QC procedures should be applied as outlined in published protocols (PSEP, 1995; ASTM, 2004a). These include use of both a non-toxic (negative) control using clean, nontoxic sediments; toxic (positive) controls using a reference toxicant in a dilution series (Table 35); use of healthy test organisms; observance of sediment holding times, proper equipment-cleaning procedures, and standard laboratory procedures; measurement and maintenance of water quality (Table 36); and blind testing.

For the toxicity test, it will be the responsibility of the testing laboratory to identify, collect, and test a non-toxic control sediment. These sediments must be un-contaminated, collected outside the study area, and shown from previous tests to be not toxic to sensitive organisms. For example, they can be the "home" sediments from the location where amphipods are collected for toxicity tests.

The negative controls must be tested with each batch of samples from the field using the same methods applied to the test samples and at least the same number of replicates. The results from tests of the negative controls are highly important, because they will be used in statistical analyses to classify samples as either toxic or non-toxic.

In all cases, the maximum holding time for the samples shall be no more than 10 days from the date of collection.

Benthos

Sorting of benthos samples

To determine sorting efficiency and ensure that all organisms are removed from the sediment, a QC check will be completed for every sample sorted. A total of 25% to 100% of each sample will be re-examined by an independent sorter to determine whether a sorting accuracy of 95% removal of organisms is achieved. Using best professional judgment, the QC technician has the option to completely resort small or difficult-to-divide samples, while large samples can be subdivided, with no less than one-quarter of the sample being reexamined.

All organisms found in the sample during the QC check are counted, identified to major taxa group, and placed in the appropriate major taxa vial for that sample. The sample will have passed the QC check if the number (or estimated number) of organisms found during the resort does not differ from the original count (conducted by the sorter) by greater than 5%. If the sample fails, then the entire sample must be resorted. The QC technician will also check all major taxa vials for mis-sorted organisms (i.e., organisms placed in the incorrect vials).

Taxonomic identification and standardization of benthos samples

Taxonomic identification QC for both Ecology and contract taxonomists will include re-identification of 5% of all samples identified by one taxonomist, and review and verification of all voucher specimens generated by another qualified taxonomist. Taxonomists are also generating a series of taxonomic voucher sheets describing all Puget Sound species and provisional species designations to ensure standardized identifications among different taxonomists and across the years.

Ecology's Marine Sediment Monitoring Unit houses a large collection of marine infaunal invertebrate organisms from Puget Sound. The collection contains over 14,239 specimens from 2,035 taxa, and includes all reference and voucher specimens collected from sediment monitoring work conducted since 1989, as well as some earlier Puget Sound studies. The collection is an extremely valuable tool that may be used by taxonomists to help ensure consistency in taxonomic identifications in future monitoring work.

In addition to specimen re-identification, Ecology personnel have developed a nomenclature standardization process. This process will be applied to all taxonomic data to ensure consistency among different taxonomists both within and between years.

The process attempts to minimize the unavoidable inconsistencies in taxonomic nomenclature due to changing taxonomic nomenclature in the published literature, to damaged physical condition or immaturity of organisms making identification difficult, and to assignment of taxonomic names by taxonomists with varying backgrounds and skill levels. A continuously-updated list of previous taxonomic discrepancies has been maintained over the years of developing this process, which is helpful in checking for and avoiding common discrepancies in future taxonomic work.

Taxonomic standardization will be applied at regular intervals as data are generated so that inconsistencies can be resolved and data can be standardized while the taxonomic identification of samples is still being conducted. Protocols for taxonomic standardization are outlined in the SOP EAP128 (Appendix G-3).

Benthos biomass estimates

The Puget Sound Benthos Size Class Reference Collection compiled during the first round of macrofaunal sample processing (2016 PSEMP Long-Term samples) will serve as QC for biomass estimates, and will be updated as necessary to reflect any changes in the observed size ranges of benthic organisms (Appendix G-2).

10.1 Table of field and laboratory quality control

QC procedures will be implemented for all field measurements taken and for all physical, chemistry, biogeochemistry, and toxicity laboratory methods employed. The types of QC measurements, along with their measurement method and frequency are given in Tables 32 through 36.

Table 32. Quality Control procedures for collection of field measurements – one measurement collected per sediment grab.

Parameter	Quality Control
Station depth	Reset meter wheel to 0 while grab is at water surface
Sediment penetration depth	Careful measurement with metric ruler
Sediment temperature	Calibration of thermometer
Overlying salinity	Calibrate refractometer by setting to 0 ppt with DI water daily
Sediment type	Training from experienced personnel
Material in sediment	Training from experienced personnel
Sediment color	Training from experienced personnel
Sediment odor	Training from experienced personnel

Table 33. Quality Control sample types and frequency for physical, biogeochemistry, and chemistry parameters – bulk sediments.

Quality Control Sample Type	Field	Laboratory						
	Field Replicate (Split Sample)	Analytical (Laboratory) Replicate	Matrix Spike Duplicates (MSD)	Laboratory Control Sample (LCS)	Certified Reference Material (CRM)	Matrix Spikes (MS)	Surrogate Spike*	Method Blank
Measurement Frequency	Duplicate analysis for 5% of samples	Triplicate analysis/batch of 20 samples for grain size and TOC, TC/TOC/ TIC/TN. Duplicate analysis/batch of 20 for total sulfides, biogenic silica, stable isotopes, metals and organics samples	NA	1/batch of 20	1/batch of 20	NA	Every organics sample, blank, and QC sample	1/batch of 20

Table 34. Quality Control sample types and frequency for biogeochemistry and chemistry parameters – tissue.

(Note: As similar material is not available, no CRMs recommended for tissue analysis.)

Quality Control Sample Type	Field	Laboratory						
	Field Replicate (Split Sample)	Analytical (Laboratory) Replicate	Matrix Spike Duplicates (MSD)	Laboratory Control Sample (LCS)	Certified Reference Material (CRM)	Matrix Spikes (MS)	Surrogate Spike*	Method Blank
Measurement Frequency	NA	Duplicate analysis/batch of 10 for metals and organics samples	1/batch of 10	1/batch of 10	NA	1/batch of 10	Every organics sample, blank, and QC sample	1/batch of 10

Table 35. Quality Control tests and frequency for Amphipod 10-day toxicity test.

Quality Control Test Type	Laboratory	
	Negative Controls (clean, nontoxic sediment or porewater)	**Positive (Toxic) Controls (**Reference Toxicant Dilution Series)
Measurement Frequency	1/batch	1/batch; 1/test

Table 36. Quality Control sediment and water laboratory sample types, frequency, and measurement ranges – toxicity analyses.

Quality Control Measurement Type	Sediment	Water Quality						
	Grain Size	Salinity (ppt)	Dissolved Oxygen (% saturation)	pH	Temper-ature (°C)	Sulfide	Total Ammonia	Unionized ammonia
Measurement Frequency	1/sample	Daily				Day 0 and at test termination		Calculated for Day 0 and test termination
Measurement Range	<70% fines	26 ppt or less in overlying water or can be acceptable with overlying water salinity ranging from 1-32 ppt or pore water: 1-34ppt for *E. estuarius*	>90% (SOP requires continuous aeration)	7.7	15°C	NA	<60 total mg/L	<0.8 mg/L

10.2 Corrective action processes

If activities and analyses are found to be inconsistent with the QAMP, and do not meet MQOs or performance expectations, or if some other unforeseen problem arises, corrective actions may be taken, including:

- Reanalysis of samples that do not meet QC criteria.
- Convening project personnel and technical experts to decide on the next steps that need to be taken to improve performance.

11.0 Management Procedures

11.1 Data recording and reporting requirements

Field data and observations recorded on field logs (Appendix H-6) and station positioning information recoded in the navigation log (Appendix H-7) are kept in a three-ring binder aboard the research vessel during sampling. A new entry will be completed at every station, including those that are rejected. All logs will be reviewed after each station is sampled to ensure they are complete and correct. This information will be entered into the MSMT database upon completion of annual sampling. All entries will be independently verified for accuracy by another individual on the project team, and necessary corrections will be made. The data will then be uploaded to Ecology's EIM database.

If available, a weather-resistant laptop computer may also be used aboard the vessel to enter the field data directly onto spreadsheets. Data entries for each station would be entered by one team member, then verified for accuracy by another individual on the project team during field operations. Any entry errors would be corrected immediately. Electronic files would be regularly backed up during sampling onto a flash drive (i.e., memory stick). At the end of the sampling event, the data would then be uploaded to Ecology's EIM database.

11.2 Laboratory data package requirements

Grain size, biogeochemistry, and chemistry

Data packages from contract laboratories for grain size, biogeochemical parameters, toxicity testing, and from MEL for carbon, nitrogen, and chemical contaminant analyses will include:

- Printed values for all parameters measured at each station.
- A case narrative or report detailing methods used, any problems with the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers.
- All associated QC results. This information is needed to evaluate the accuracy of the data and to determine whether the MQOs have been met. This will include results for all required field and analytical (laboratory) control replicates, laboratory control samples, reference materials, method blanks, matrix spike, matrix spike duplicates, and surrogate spikes.
- An electronic version of the data and report in Ecology's EIM or other specified format. Output from MEL's Laboratory Information Management System will be submitted electronically for upload into EIM. Data entered into EIM follow a formal data review procedure in which data are reviewed by the project manager of the study, the person entering the data, and an independent reviewer.

All deliverables expected from contract laboratories for grain size, biogeochemistry, and toxicity testing are specified in a scope-of-work sent to contractors.

Toxicity

The data packages from the contract toxicology labs will include:

- Printed values for all parameters measured at each station.
- Measures of within sample variability, sample and test organism holding time, and test organism lengths.
- A report detailing methods used, any problems with the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers.
- All associated QC results. This information is needed to evaluate the accuracy of the data and to determine whether the MQOs have been met. This will include results for all negative and positive controls, and all water quality measurements.
- An electronic version of the data and report in Ecology's EIM or other specified format. Data entered into EIM follow a formal procedure where data are reviewed by the project manager of the study, the person entering the data, and an independent reviewer.

All deliverables expected from the contract toxicity labs for the currently used toxicity tests are specified in a scope-of-work sent to contractors.

Benthos

The data packages generated both in the MSMT benthic lab and from the benthos taxonomy contractors will include:

Sorting

- A spreadsheet (Ecology format) filled out with sample number, date collected (from the sample label), number of vials, and estimated counts of sorted specimens in each sample for each of the five major taxonomic groups.

Sorting QA

- A spreadsheet (Ecology format) filled out with sample number, date collected, percent of the sample resorted, count of organisms removed during the resorting process, percent of sorting success, and whether the sample passed or failed the sort QA.

Taxonomy

- An electronic copy of identifications and counts (data report) and the bibliography of taxonomic literature used to identify specimens found in the samples.
- A voucher collection and voucher list for QC purposes.

Taxonomic QA

- A spreadsheet with a list of the original identifications (provided by Ecology), any changes to the identifications proposed by the QA taxonomist, and, where appropriate, comments about the suggested changes.

Taxonomic voucher sheet generation and/or review

- A draft voucher sheet (if generating), or an edited version of a draft voucher sheet (if reviewing), including appropriate taxonomic references when necessary.

Biomass

- Size category information for every organism identified in each sample (i.e., small, medium, large, megafauna).
- Dimensions and mass (g) for each megafaunal organism.
- All deliverables expected from the contract benthic labs for taxonomy and taxonomic QA are specified in a scope-of-work sent to contractors.

Data storage – MSMT Access and Ecology's EIM database

All sediment quality data generated for this project will be evaluated through the data verification process outlined in Section 13, below. Acceptable results will be entered into the MSMT sediment database, uploaded to Ecology's EIM database, and made available to the public via Ecology's web site (EIM Database). These data will be used by the MSMT to prepare the final report for each survey.

11.3 Electronic transfer requirements

All contract laboratories will be required to submit data electronically in Ecology's EIM templates. These are preformatted Excel spreadsheets with specific data-entry requirements. They are used to minimize data entry problems and facilitate data analysis. Current EIM templates and guidance on populating them are provided on the EIM Help Center web page (https://fortress.wa.gov/ecy/eimhelp/).

Data will be received from contract laboratories in EIM comma-separated values (CSV) templates. All data generated by Ecology's Manchester Environmental Laboratory (MEL) will be accessed and downloaded from its Laboratory Information Management System (LIMS) into Excel spreadsheets. MEL will provide an electronic data deliverable (EDD) in the EIM template.

11.4 EIM/STORET data upload procedures

All data submitted to Ecology must be formatted for entry into Ecology's EIM data system. EPA-funded projects usually require data entry in the STORET data system. Data upload procedures for STORET will be determined at the time of data entry according to current EPA instruction.

All completed project data will be entered into Ecology's Environmental Information Management (EIM) database and receive a formal review process following the internal protocols and business rules detailed in Ecology's Environmental Assessment Program's (EAP) EIM Data Entry Review Procedure (http://ecyeim/eimhelp/helpdocuments/opendocument/57). This internal data QC includes a review by the project manager, the person entering the data, and an independent reviewer of the uploaded data.

EIM can be accessed on Ecology's Internet homepage at EIM Database.

The data for Long-Term and Urban Bays programs are stored under the Study IDs PSEMP_LT and UWI20XX (20XX indicates the sampling year), respectively.

11.5 Model information management

NA

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

12.1.1 Field audits

Field staff may be audited at any time by the appropriate project manager or supervisor to ensure that field work is being completed according to this QAMP, any published QAMP amendment, and any published Ecology SOPs. This would consist of observing and correcting any sampling technique inconsistent with those provided in this QAMP. Experienced MSMT staff will conduct field training sessions and consistency reviews before and/or during each field season. Field consistency reviews are not true audits, but instead serve to improve field work consistency, improve adherence to SOPs, provide a forum for sharing innovations, and strengthen Ecology's data QA program.

12.1.1 Laboratory audits

All laboratories conducting analytical work for this project, including MEL, must be accredited in Washington State in accordance with the State Legislature's WAC-173-50, Accreditation of Environmental Laboratories (Washington State Legislature, 2010) (http://apps.leg.wa.gov/WAC/default.aspx?cite=173-50). Ecology's Laboratory Accreditation Unit (LAU) (Laboratory Accreditation Unit) implements the accreditation process, which includes routine performance and system audits of analytical procedures. If a lab is not accredited, a waiver must be received from Ecology's QA officer.

12.2 Responsible personnel

Personnel responsible for audits are:

- Field audits: experienced MSMT staff.
- Lab audits: MEL's LAU.

MSMT staff will track the status of samples being analyzed by MEL and the other contract laboratories, being particularly alert to any significant QC problems as they arise. Team members may visit the contract labs to observe conduct of any of the contracted analyses. MSMT taxonomists may also visit with contracted benthic sorters and taxonomists to verify that standardized procedures are being followed. MEL and the contract labs will each provide a data report to the MSMT principal investigator.

12.3 Frequency and distribution of reports

MSMT staff will be responsible for analyzing annual sediment and benthos data and determining how the results will be summarized and documented for all Long-Term and Urban Bays reports, and for reporting of taxonomic work. A variety of traditional formal and informal reporting formats will be used, along with social media publications, depending on the information being reported and the audience it is intended for.

Reports, social media, and public presentation products will include:

Reports

- **MSMT expanded executive summaries** – High-level overview summary of work and conclusions, with detailed data summary figures and tables attached as appendices.
- **Ecology technical reports** – Standard scientific reporting format following EAP template, ≥12 pages.
- **Ecology short reports** – Standard scientific reporting format following EAP template, ≤12 pages.
- **Ecology technical memos** – Document detailing technical methods.
- **Ecology focus sheets** – 1-2 page high-level summary of specific findings.
- **Peer-reviewed journal publications** – Standard scientific reporting format following journal specifications.

Long-Term and Urban Bays data will be summarized and reported annually as MSMT expanded executive summary reports (see reporting schedules in Tables 3, 4). Examples of this reporting style are provided in recent MSMT reports (e.g., Weakland et al., 2016 a,b). Other reports, in various reporting formats, will be planned annually. As indicated in Section 3.2, a list of previous publications is provided in Appendix A-1.

All final reports will be published on Ecology's website. Report announcements will be sent as e-mail to selected stakeholder distribution lists. Public access to electronic versions of the data and reports generated from this project will be available via Ecology's web site (https://www.ecology.wa.gov/), EIM home page (https://www.ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database), and MSMT home page (https://www.ecology.wa.gov/Research-Data/Monitoring-assessment/Puget-Sound-and-marine-monitoring).

Social media – Eyes Under Puget Sound

- **Critter of the Month** – Monthly blog from MSMT taxonomists with photos and information about one or a group of benthic invertebrates. http://ecologywa.blogspot.com/search/label/Critter%20of%20the%20Month
- **Flickr Collection** - Photomicrographs of Puget Sound benthos – Updated periodically. https://www.flickr.com/photos/ecologywa/collections/72157636917218284/
- **Encyclopedia of Puget Sound** – Master Species List, Critter of the month link, and periodic articles. http://www.eopugetsound.org/species/custom-lists/306
- **ECOconnect** – Eyes Under Puget Sound – Periodic blogs about Ecology's Puget Sound Sediment Monitoring Program. http://ecologywa.blogspot.com/search?q=Eyes+Under+Puget+Sound
- **Ecology's Facebook, Twitter, YouTube accounts** – Periodic postings about the Puget Sound Sediment Monitoring Program findings.

A list of previous social media releases is provided in Appendix A-3.

Presentations at scientific conferences and other meetings

- **Oral presentations –** Typically consists of PowerPoint presentations of current work related to the conference theme.
- **Poster presentations –** All posters will be published as Ecology publications and posted to Ecology's website (see Appendix A-1).

Information will also be summarized and presented at annual regional and national meetings, and to stakeholder audiences as requested.

12.4 Responsibility for reports

Report authors will vary for different reports generated for this program and will be identified annual for each report.

13.0 Data Verification

Data verification will be conducted by MSMT, MEL, and contract lab staff to ensure:

- Specified field and laboratory methods and protocols were followed.
- All data quality objectives (Section 6.1) were met.
- All measurement quality objectives (Section 6.2) were met.
- All QC procedures (Section 10.0) were followed.
- Established criteria for QC results were met.
- Data qualifiers are properly assigned where necessary.

13.1 Field data verification, requirements, and responsibilities

Throughout the duration of the field sampling, the cruise leader and all crew members will have responsibilities for implementation of the specified station-positioning and sample-collection procedures. Additionally, there will be systematic review of all field documentation generated (e.g., field logs, chain-of-custody sheets, sample labels) to ensure data entries are consistent, correct, and complete, with no errors or omissions. This review should be completed prior to leaving the site where the measurements were made.

Upon completion of field sampling, MSMT personnel will complete a post-cruise report consisting of both target and actual sample positioning (e.g., station coordinates, depths), charts depicting actual sampling locations of all stations, field logs for all stations, and notes which describe any unusual events or alterations of the original sampling plan. This information will be included as an appendix in the final report for each sampling event.

13.2 Laboratory data verification

Upon completion of grain size, biogeochemical, chemical, toxicity, and benthos analyses, laboratories and contractors shall submit an interim data report to the MSMT project lead.

The report should include:

- Sample chain-of-custody.
- Description of analytical methods.
- Raw data in electronic format.
- QA sample results.
- Data evaluation results.
- Any problems encountered and corrective actions which were taken.
- Any qualification of the results.

MSMT personnel will check all data received against the verification criteria listed above. Any discrepancies will be reported back to the laboratories or contractors for amendment in the final data report. Once data have been reviewed and verified, MSMT personnel will enter the data into the MSMT and EIM databases.

13.3 Validation requirements, if necessary

NA

13.4 Model quality assessment

NA

13.4.1 Calibration and validation

13.4.1.1 Precision

NA

13.4.1.2 Bias

NA

13.4.1.3 Representativeness

NA

13.4.1.4 Qualitative assessment

NA

13.4.2 Analysis of sensitivity and uncertainty

NA

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

Upon completion of the data verification process, Data Quality (Usability) Assessment will be conducted (Lombard and Kirchmer, 2004). Data from all field and laboratory procedures will be examined to determine whether they were measured with the proper procedures, fall into the expected range of results, and meet reporting limits as described in Sections 8 and 9, above. They will also be examined to determine whether all MQOs and QC procedures described in Sections 6 and 10, respectively, have been met.

If all specifications are met, the quality of the data should be usable for meeting project objectives. If the MQOs have not all been met, MSMT staff will examine the data to determine whether they are still usable and whether the data quantity and quality are sufficient to meet project objectives. Data that do not meet the criteria detailed in this QAMP will be qualified appropriately for each parameter type. MSMT staff will be responsible for analyzing the data and determining how the results will be summarized and documented in each report.

14.2 Treatment of nondetects

Nondetects in sediment chemistry will be censored at the reporting limits (quantitation limits) specific to those samples. Data will be graphed with censored boxplots or other appropriate graphical methods for visual representation. Summary statistics will be estimated using accepted state-of-the-science techniques, such as robust regression on order statistics (ROS) or, if detection rates are > 50% and sample size is large enough, Kaplan-Meier censoring techniques (Helsel, 2012).

Data preparation for comparison to WA Sediment Management Standards (Ecology, 2013) is prescribed by statute to use only detected results. For sums of contaminant concentrations (e.g., Total HPAH), if all constituent compounds are nondetect, the highest reporting limit is to be used as the total value (Ecology, 2013). Contaminant sums consisting of only a single reporting limit will be treated as nondetect for further analyses, for the Sediment Program.

The weighted-analysis techniques developed by EPA specifically for GRTS designs such as used by the Sediment Program (Stevens and Olsen, 1999, 2003, 2004) currently are not designed to handle nondetects; however, methods are being developed for handling censored data (Olsen, 2017. *pers. comm. with V. Partridge*). In the interim, because metals and PAHs are almost always detected, the weighted-mean and CDF-comparison analyses (Kincaid, 2000; Kincaid et al., 2016) will be conducted on detected values only, only when the detection rate is ≥ 90%. CDFs will be drawn, but confidence intervals not calculated, when the nondetect rate is < 90% and ≥ 50%.

The detection rate for other organic compounds has typically been far lower than 90%, and usually lower than 50%; hence these weighted analyses would not be performed.
Zeros in grain size proportions, although sometimes stored in the database as nondetect with a reporting limit of 0.1%, are not true nondetects and will be treated as zeros (detected or estimated) in data analyses.

14.3 Data analysis and presentation methods

The statistical descriptive and inferential techniques used are determined by the questions to be answered (i.e., the research hypotheses). The choice of methods is updated to use best available, appropriate practices according to statistical research in peer-reviewed literature. Examples of methods currently used are mentioned in the subsections below.

At any stage of the analysis, particularly in graphical displays, data anomalies may be found which previously escaped detection. Such anomalies are examined carefully. Data found to be in error are removed or corrected, and analyses re-executed.

Data summaries and displays

For chemical contaminant data with field or lab replicates, or both, the first field or lab replicate result is used as the value for that parameter at that station, for consistency and to preserve the statistical variability of the data. Nondetects in sediment chemistry are censored at the reporting limits (quantitation limits) specific to those samples.

Data are graphed with boxplots (censored boxplots, in the event of nondetects), bar graphs, scatterplots, or other appropriate graphical methods for visual representation. Possible and probable outliers (as indicated by the boxplots or appropriate statistical tests) are researched individually to determine whether the outlier is an error or represents a real, though less probable, member of the population. Data which are in error are corrected or removed before further analysis.

For these probability-based GRTS sample designs, cumulative distribution functions (CDF) of a given variable are computed using EPA's spsurvey analysis routines (Kincaid et al., 2016) and graphed, to describe spatial extent. The calculation of the CDFs includes the weighting of each sample result by the amount of area (within the study area) that that sample represents.

Summary statistics are computed for all variables. When nondetects are present in sediment chemistry data, summary statistics are estimated using accepted state-of-the-science techniques such as robust regression on order statistics (ROS) or Kaplan-Meier estimation techniques, as appropriate (Helsel, 2012).

Similarities of multiple multivariate samples, especially of benthic invertebrate assemblages, but also of physical or chemical variables, are graphically displayed with nonmetric multidimensional scaling (nMDS) or other graphical descriptive procedures. Appropriate measures of similarity are calculated, depending on the type of data (currently, the Bray-Curtis similarity measure for benthos and Euclidean distance for environmental variables). Species abundances and environmental variables are first transformed or normalized as appropriate (Clarke et al., 2014).

Derived variables

Measures of benthic community diversity (taxa richness, Pielou’s evenness, Swartz’ dominance, total and major taxa abundance) are calculated from species richness and abundances (Table 37).

Summed concentrations of specific chemicals (Total Aroclors, Total Benzofluoranthenes, Total HPAH, Total LPAH) are calculated from the individual chemicals measured as specified in the Washington State Sediment Management Standards (Ecology, 2013) TOC-normalized concentrations are calculated for organic compounds and compound totals, per Ecology, 2013.

For those contaminants for which there are Washington State Sediment Management Standards, SQS quotients (ratio of measured chemical contamination to the respective SQS) are calculated (Appendix B-1). The mean SQS quotients are calculated to account for not only the presence of the chemicals that exceed the respective values but also the degree by which they exceed the values as mixtures. The SQS quotients also are used in calculation of MSMT's Sediment Chemistry Index (see Sediment Quality Indicators subsection, below); details are provided in Appendix B-1.

Table 37. Calculated parameters for Long-Term and Urban Bays monitoring.

Calculated parameter	Definition	Calculation
Benthos indicators		
Total Abundance	A measure of density equal to the total number of organisms per sample area	Sum of all organisms counted in each sample
Major Taxa Abundance	A measure of density equal to the total number of organisms in each major taxa group (Annelida, Mollusca, Echinodermata, Arthropoda, Miscellaneous Taxa) per sample area	Sum of all organisms counted in each major taxa group per sample
Taxa Richness	Total number of taxa (taxa = lowest level of identification for each organism) per sample area	Sum of all taxa identified in each sample
Pielou's Evenness (J') (Pielou, 1966, 1974)	Relates the observed diversity in benthic assemblages as a proportion of the maximum possible diversity for the data set (the equitability (evenness) of the distribution of individuals among species)	$J' = H'/\log S$, where $H' = -\sum_{i=1}^{S} p_i \log p_i$, where p_i = the proportion of the assemblage that belongs to the i^{th} species (p_i=n_i/N, where n_i=the number of individuals in the i^{th} species and N= total number of individuals) and S = the total number of species (H' is the Shannon-Wiener diversity index)
Swartz's Dominance Index (SDI) (Swartz et al., 1985)	The minimum number of taxa whose combined abundance accounted for 75% of the total abundance in each sample	Sum of the minimum number of taxa whose combined abundance accounted for 75% of the total abundance in each sample
Size class	See Appendix G-2	
Biomass		

Calculated parameter	Definition	Calculation
Biogeochemical values		
C:N ratio	Ratio of total carbon to total nitrogen in the sample	This may be calculated several ways: %C/%N, weight C/weight N, or moles C/moles N. The data analyst and reader need to be aware of which calculation method is used and appropriate.
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes	The delta ratio of $_{15}N$ to $_{14}N$ is expressed as $\delta_{15}N$ ‰ = $[(R_{sample}-R_{reference})/ R_{reference}] \times 1{,}000$, where R is $_{15}N$ /$_{14}N$ in parts per thousand (‰), and the reference is atmospheric N_2 (Peterson and Fry, 1987). A similar ratio is used to describe the relation of stable isotopes delta $_{13}C/_{12}C$, denoted here as $\delta_{13}C$ in parts per thousand. The reference for $\delta_{13}C$ was a standard representing the Cretaceous fossil *Belemnitella americana* from the PeeDee formation in South Carolina.	
Chemical values (Ecology, 2013)		
Total LPAH	Combined acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene	Sum of detected concentrations. When all constituents are nondetect, the highest reporting limit will be used as the Total LPAH value.
Total HPAH	Combined benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-c,d)pyrene, pyrene, total benzofluoranthenes	Sum of detected concentrations. When all constituents are nondetect, the highest reporting limit will be used as the Total HPAH value.
Total benzofluoranthenes	Combined benzo(b)fluoranthene, benzo(j)fluoranthene, and benzo(k)fluoranthene	Sum of detected concentrations. When all constituents are nondetect, the highest reporting limit will be used as the Total Benzofluoranthenes value.
Total Aroclors	Combined PCB Aroclors	Sum of detected concentrations. When all constituents are nondetect, the highest reporting limit will be used as the Total Aroclors value.
TOC-normalized concentrations	Concentration of contaminant standardized by organic carbon content; result is in units of ppm organic carbon	$100 \times \left\{ \frac{concentration\ (ppb)/1000}{\%TOC/100} \right\}$

Relationships among variables

The Sediment Program surveys do not include determinations of cause/effect relationships among the variables that are measured. However, it is useful to determine whether variables co-vary with each other throughout the study area. Co-varying variables may lead to future experiments to determine and verify cause/effect relationships.

Due to the multivariate nature of the data, multivariate correlation procedures are appropriate. Nonparametric multivariate correlation procedures, such as the BioEnv/BEST procedure in PRIMER v.7 (Clarke et al., 2014), are used.

If bivariate correlations are appropriate, the two variables are plotted against each other first, to determine visually whether the data are appropriate. The data are tested for normality by one of several methods. If the data are normally distributed, the Pearson correlation coefficient is calculated. If not, or if the plot of the two variables indicates strong non-linearity, a nonparametric measure of association (usually Spearman's rho) is calculated.

Semi-metric distance-based analogs of analyses such as ANOVA, ANCOVA, multivariate multiple regression and discriminant analysis in PERMANOVA+ may be used to model and test relationships between the benthos and habitat variables (Anderson et al., 2008).

Comparisons

Because the Sediment Program uses probability-based sampling designs with unequal weighting, temporal or spatial comparisons of population estimates are conducted by comparing CDFs or comparing weighted means using EPA's spsurvey analysis routines (Kincaid, 2000; Kincaid et al., 2016). Unweighted (or equally-weighted) comparisons of populations are made with appropriate nonparametric procedures. The CDFs being compared, along with their confidence bands, are graphed.

Since all stations are fixed and have been sampled at least once, except for new parameters, temporal comparisons involving repeat sampling of stations may be made using appropriate paired-comparison tests.

- For unweighted or equally-weighted samples: the Wilcoxon signed ranks test or, when nondetects are present, the paired Prentice-Wilcoxon test (Helsel, 2012).
- For unequally weighted samples, repeat-sampled stations are identified in the weighted-mean or weighted categories analyses (Kincaid et al., 2016).

Comparisons of proportions (e.g., percent of study area exceeding mercury SQS) are done with appropriate statistical tests (e.g., two-proportion test). Area proportions (spatial extent) are calculated using the amounts of area represented by the samples.

Analogous to ANOVA (analysis of variance), the analysis of similarities (ANOSIM) is used to perform multivariate comparisons of results from two or more sets of samples (e.g., benthic assemblages from the same urban bay in two different years), based on their similarities (Clarke et al., 2014). Similarity measures are calculated as described above for data summaries and displays. The ANOSIM procedure uses a permutation test to determine whether samples are more dissimilar between vs. within sets.

Sediment quality indicators

Data collected for the Sediment Program are summarized as a set of sediment quality indicators meant to inform environmental managers about the current condition of sediments collected from stations and sampling frames for this program. Existing Sediment Quality Triad Indicators (Appendix B-1) will be calculated for parameters that have been monitored in the past, including chemical contaminants in bulk sediments, toxicity, and numeric benthic indices. While some of these indicators are based on sediment criteria set forth by the Washington State Sediment Management Standards (WAC 173-204) (Ecology, 2013), they are not used for regulatory

purposes. In addition, new indicators will be developed over time for parameters that have been, or will be, added to the program, including benthos biomass, zooplankton, biogeochemistry, and chemical contaminants in benthos tissue.

As with previously conducted Sediment Program work, the Sediment Quality Triad of chemistry, toxicity, and benthos data generated in this revised program will be compared with a combination of regulatory and non-regulatory criteria and standards developed for various audiences and purposes. They are described below; derivations and calculations are detailed in Appendix B-1.

There are no existing regulatory criteria or standards for the new parameters added to the program, including benthos biomass, contribution to the zooplankton, and tissue chemistry (other than human consumption limits for edible crustaceans and molluscs), or for the new biogeochemical parameters that have been added. Baseline data will be collected for these new parameters during their initial years of collection, followed by evaluation to determine (1) their relationships to each other, (2) numeric ranges associated with poor to high quality condition, and (3) target values for environmental management associated with desired environmental condition.

Chemistry

Chemical concentrations measured in sediments collected for the Sediment Program will continue to be compared to Chemical Criteria that have been developed for Marine Sediment Quality Standards/Sediment Cleanup Objectives and Cleanup Screening Levels set forth in the Washington State Sediment Management Standards (SMS) (WAC 173-204) (Ecology, 2013). Chemical concentrations measured at or below these criteria values are expected to correspond to a level of sediment quality that will result in no acute or chronic adverse effects to the benthic community and no significant health risk to humans.

While use of the Chemical Criteria is carefully specified in the SMS for water quality permits and regulated sediment cleanup work, the Sediment Program uses the Chemical Criteria for 32 chemicals or chemical groups in several ways to characterize ambient sediment quality, including:

- Stations where sediment chemical measurements exceed these criteria are mapped, to visualize spatial patterns.
- The spatial extent (km^2 and percent of total area) of the sampling frame with values exceeding criteria is calculated.
- Criteria values for 30 chemicals or chemical groups are used to calculate individual and mean Sediment Chemistry Index (SCI) values for stations and sampling frames, respectively (Appendix B-1).

  Four quality categories, characterizing sediment exposure to toxic contaminants from *minimum* to *maximum* have been developed, and the SCI value of 93.3, the lowest value of the minimum exposure category, was selected as the threshold above which sediment quality is not expected to cause benthos impairment Appendix B-1; Long et al., 2012; http://www.psp.wa.gov/vitalsigns/in-sediment-chemistry-index.php. SCI categories are mapped and spatial extent values are calculated to visualize spatial and temporal patterns in sediment quality.

- The percent of chemicals exceeding SMS Chemical Criteria is also calculated for each sampling frame as an estimate of sediment quality in specified geographic areas. A target of 0 has been adopted for this indicator (PSP, 2017a; http://www.psp.wa.gov/vitalsigns/in-chemical-measurements-sqs.php).

Toxicity

While the sea urchin fertilization test used in Sediment Program work through 2015 has been dropped from the revised program described here, evaluation of sediment toxicity for the 10-day test of amphipod survival in bulk sediment samples will continue, to be sampled Puget Sound-wide once every five years.

Four categories of toxicity have been defined for a Sediment Toxicity Index (STI), ranging from *non-toxic* to *high toxicity*, as described in Appendix B-1. STI categories are mapped and spatial extent values are calculated to visualize spatial and temporal patterns in sediment quality.

Benthos

Widely accepted multi-metric benthic infaunal indices equivalent to those developed elsewhere (e.g., Weisberg et al., 1997; Van Dolah et al., 1999; Smith et al., 2001) have not yet been adopted for sediment regulatory or ambient monitoring work in Puget Sound.

The Washington State SMS considers benthos to be adversely affected when assemblages in test sediments have less than fifty percent of the reference sediment mean abundance of Crustacea, Mollusca, or Polychaeta and the test sediment abundance is statistically different from that in the reference sediment (Ecology, 2013). Reference value ranges for selected benthic indices have also been developed to represent reference area conditions (Striplin Environmental Associates, Inc., 1996; Striplin and Weston, 1999).

Both methods have limitations and are not widely accepted procedures for classifying benthos in Puget Sound (Long et al., 2005). More recently, five multi-metric benthic indices were calibrated for use in Puget Sound (Ranasinghe et al., 2013), but further validation of this work is required prior to adopting any of them for use.

In the absence of a widely accepted multi-metric benthic index for Puget Sound, the MSMT calculates nine numeric indices for each benthos sample, including total abundance, total taxa richness, evenness, dominance, and abundances of annelids, molluscs, arthropods, echinoderms and miscellaneous taxa. These values are compared to median values calculated for Puget Sound, along with the presence/absence and abundance of pollution-tolerant and -sensitive species. Best professional judgement is used to classify the invertebrate assemblages as either *adversely affected* or *unaffected* by natural and/or human-caused stressors in a binary Sediment Benthic Index (SBI) for Puget Sound (Appendix B-1). SBI categories are mapped and spatial extent values are calculated to look for spatial and temporal patterns in sediment quality.

Sediment Quality Triad Index

A Sediment Quality Triad Index (SQTI) was developed which combines the Sediment Chemistry, Toxicity, and Benthic Indicators for Puget Sound into an overall index of sediment condition (Appendix B-1). Six categories describing impact from environmental stressors,

ranging from *unimpacted* to *clearly impacted*, and *inconclusive*, have been developed. A target value of 81, representing the lowest value in the *unimpacted* category, has been selected as the threshold above which sediment quality is not expected to cause benthos impairment (Appendix B-1).

SQTI categories are mapped and spatial extent values are calculated to visualize spatial and temporal patterns in sediment quality. Since toxicity testing and calculation of the STI will occur only every fifth year for the revised sediment monitoring program, the SQTI will be calculated only every five years when the SCI, STI, and SBI are all available.

Puget Sound Vital Sign Indicators

The SCI, percent of chemicals exceeding SMS, and the SQTI, as well as their associated target values, were adopted by the Puget Sound Partnership in 2011 as Puget Sound Vital Sign Indicators (O'Neill, 2014; PSP, 2017a). They are used by stakeholders and environmental managers to assess sediment quality in Puget Sound and establish target management goals in the Puget Sound Action Agenda (PSP, 2016; 2017a).

Recommendations have been made to elevate a revised multi-category, multi-metric SBI as a new Vital Sign Indicator. The MSMT has begun literature research and data analysis to develop a new benthic index. Also, when enough baseline data have been obtained, the MSMT will develop and propose new Vital Sign Indicators based on some of the other new parameters in the sediment monitoring program.

14.4 Sampling design evaluation

In application, survey design must balance desired theoretical statistical performance with practical limitations. Given budgetary constraints on the numbers of stations sampled, the type of design employed affects the precision of estimates and the power to make comparisons or detect trends.

In spatially-restricted survey designs (such as GRTS), precision is expected to be better than that for simple random designs (Stoddard et al., 2005). Furthermore, the inherent correlation between resamplings of the same sites improves the ability to detect change beyond that of designs without resamples.

14.5 Documentation of assessment

If all specifications are met, the quality of the data should be usable for meeting project objectives. If the MQOs have not all been met, MSMT staff will examine the data to determine whether they are still usable and whether the data quantity and quality are sufficient to meet project objectives. Data that do not meet the criteria detailed in this QAMP will be qualified appropriately for each parameter type. MSMT staff will be responsible for analyzing the data and determining how the results will be summarized and documented in each report.

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16.0 Appendices

Appendices A–H are available only online as a zip file linked to this Quality Assurance Monitoring Plan at:
https://fortress.wa.gov/ecy/publications/SummaryPages/1803109.html

Appendix A. Previous Studies

A-1. Puget Sound Sediment Monitoring Program publications list.

A-2. Puget Sound Sediment Monitoring Program findings summary.

A-3. Eyes Under Puget Sound social media links.

Appendix B. Sediment Quality Indices

B-1. Sediment Quality Indicators - Definitions, Derivations, Evolution.

Appendix C. Sampling Methods

C-1. Puget Sound Estuary Program (PSEP), 1998. Recommended Guidelines for Station Positioning in Puget Sound.

C-2. PSEP, 1997. Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissue in Puget Sound.

C-3. PSEP, 1987. Recommended Protocols for Sampling and Analyzing Subtidal Benthic Macroinvertebrate Assemblages in Puget Sound.

C-4. Weakland, 2015. Ecology's Standard Operating Procedures for Obtaining Marine Sediment Samples EAP039 v1.3.

C-5. Parsons et al., 2016. EAP070 v2.1 SOP – Minimize Spread of Invasive Species.

C-6. EAP Field Operations and Safety Manual – 2017.

Appendix D. Physical, Biogeochemistry Analyses – Published methods, Scope-of-Work for Contract Laboratories

D-1. Physical and biogeochemistry analyses methods summary.

D-2. PSEP, 1986. Recommended Protocols for Measuring Conventional Sediment Variables in Puget Sound.

D-3. Zimmerman, Keefe, and Bashe, 1997. Method 440.0 – Determination of Carbon and Nitrogen in Sediments and Particulates of Estuarine/Coastal Waters Using Elemental Analysis.

D-4. Plumb, 1981. Procedures for handling and chemical analysis of sediment and water samples. Prepared for US Environmental Protection Agency/Corps of engineers Technical Committee on Criteria for Dredged and Fill Material.

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D-6. Conley and Schelske, 2002. Chapter 14. Biogenic Silica.

D-7. Carter and Barwick, 2011. Good practice guide for isotope ratio mass spectrometry, FIRMS.

Appendix E. Metals and Organic Chemistry Analyses – Published methods, Scope-of-Work for Contract Laboratories

E-1. MEL, 2017. Quality Control and Reporting Limits (PCBCongNOAA).

E-2. Chemical Analyses Performed for the Puget Sound Sediment Monitoring Program.

E-3. EPA Chemical Analysis Methods (.pdf files) – 245.5, 3050B, 3541, 3620C, 3660B, 3665A, 6020B, 8082A, 8270DSIM/SCAN.

E-4. PSEP, 1997b. Recommended Guidelines for Measuring Metals in Puget Sound Marine Water, Sediment, and Tissue Samples.

E-5. PSEP, 1997c. Recommended Guidelines for Measuring Organic Compounds in Puget Sound Water, Sediment, and Tissue Samples.

E-6. MEL, 2016. Manchester Environmental Laboratory *Lab Users Manual.*

Appendix F. Toxicity Analyses – Published methods, Example Solicitation and Specifications for Contract Laboratory

F-1. PSEP, 1995. Recommended Guidelines for Conducting Laboratory Bioassays on Puget Sound Sediments.

F-2. ASTM E 1367-03. Standard Test Methods for Measuring the Toxicity of Sediment-Associated Contaminants with Estuarine and Marine Invertebrates (10-day amphipod survival in bulk sediment).

Appendix G. Benthic Infauna Analysis – Published methods, SOPs, SOWs for Contract Laboratories

G-1. Weakland, 2016. Standard Operating Procedures for Marine Macrobenthic Sample Analysis. EAP043 v1.2.

G-2. Burgess, 2017. Standard Operating Procedures for Benthic Macrofaunal Size Classification and Biomass. EAP126 v1.1.

G-3. Burgess, 2018. Standard Operating Procedure for Taxonomic Standardization of Benthic Invertebrate Data. EAP128.

Appendix H. Labels, Logs, and Chain-of-Custody Forms

H-1. Example of preprinted external sample container labels for Puget Sound Sediment Monitoring Program sediment, tissue, and benthos samples.

H-2. Example of preprinted internal sample container labels for Puget Sound Sediment Monitoring Program benthos samples.

H-3. Example of a completed Puget Sound Sediment Monitoring Program chain-of-custody form.

H-4. Example of a Benthic Laboratory Tracking Excel spreadsheet used for sorting, taxonomy, and Quality Assurance/Quality Control.

H-5. Example of a Puget Sound Sediment Monitoring Program chain-of-custody form for Quality Assurance taxonomic identification.

H-6. Example of Puget Sound Sediment Monitoring Program field log.

H-7. Example of Puget Sound Sediment Monitoring Program Navigation Log.

Appendix I. Glossaries, Acronyms, and Abbreviations

I-1. Glossary of General Terms

Ambient: Background or away from point sources of contamination. Surrounding environmental condition.

Anthropogenic: Human-caused.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Effluent: An outflowing of water from a natural body of water or from a human-made structure. For example, the treated outflow from a wastewater treatment plant.

Eutrophic: Nutrient rich and high in productivity resulting from human activities such as fertilizer runoff and leaky septic systems.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Source of pollution that discharges at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Sediment: Soil and organic matter that is covered with water (for example, river or lake bottom).

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Synoptic survey: Data collected simultaneously or over a short period of time.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

90^{th} percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90^{th} percentile value is a statistically derived estimate of the division between 90% of samples, which should be less than the value, and 10% of samples, which are expected to exceed the value.

I-2. Acronyms and Abbreviations

DO	(see Glossary above)
DOC	Dissolved organic carbon
e.g.	For example
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
GIS	Geographic Information System software
GPS	Global Positioning System
GRTS	Generalized Random Tessellation Stratified multi-density survey design
i.e.	In other words
MEL	Manchester Environmental Laboratory

MQO	Measurement quality objective
MSMT	Marine Sediment Monitoring Team (Dept of Ecology)
NPDES	(See Glossary above)
PBDE	polybrominated diphenyl ethers
PBT	persistent, bioaccumulative, toxic chemical
PCB	polychlorinated biphenyls
QA	Quality assurance
QAMP	Quality assurance monitoring plan
QC	Quality control
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedure
SRM	Standard reference materials
TBiOS	Toxics-focused Biological Observing System
TOC	Total organic carbon
TSS	Total suspended solids
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
dw	dry weight
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mm	millimeter
mg	milligram
mg/d	milligrams per day
mg/Kg	milligrams per kilogram (parts per million)
mL	milliliter
ng/g	nanograms per gram (parts per billion)
psu	practical salinity units
ug/g	micrograms per gram (parts per million)
ug/Kg	micrograms per kilogram (parts per billion)
ww	wet weight

I-3. Quality Assurance Glossary

Accreditation: A certification process for laboratories, designed to evaluate and document a lab's ability to perform analytical methods and produce acceptable data. For Ecology, it is "Formal recognition by (Ecology)…that an environmental laboratory is capable of producing accurate analytical data." [WAC 173-50-040] (Kammin, 2010)

Accuracy: The degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms precision and bias be used to convey the information associated with the term accuracy. (USGS, 1998)

Analyte: An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e.g., fecal coliform, Klebsiella. (Kammin, 2010)

Bias: The difference between the sample mean and the true value. Bias usually describes a systematic difference reproducible over time, and is characteristic of both the measurement system, and the analyte(s) being measured. Bias is a commonly used data quality indicator (DQI). (Kammin, 2010; Ecology, 2004)

Blank: A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process. (USGS, 1998)

Calibration: The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured. (Ecology, 2004)

Check standard: A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards, but should be referred to by their actual designator, e.g., CRM, LCS. (Kammin, 2010; Ecology, 2004)

Comparability: The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator. (USEPA, 1997)

Completeness: The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator. (USEPA, 1997)

Continuing Calibration Verification Standard (CCV): A QC sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run. (Kammin, 2010)

Control chart: A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system. (Kammin, 2010; Ecology 2004)

Control limits: Statistical warning and action limits calculated based on control charts. Warning limits are generally set at +/- 2 standard deviations from the mean, action limits at +/- 3 standard deviations from the mean. (Kammin, 2010)

Data integrity: A qualitative DQI that evaluates the extent to which a data set contains data that is misrepresented, falsified, or deliberately misleading. (Kammin, 2010)

Data Quality Indicators (DQI): Commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity. (USEPA, 2006)

Data Quality Objectives (DQO): Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.
(USEPA, 2006)

Data set: A grouping of samples organized by date, time, analyte, etc. (Kammin, 2010)

Data validation: An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment, and objective criteria, to determine whether the MQOs for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability and integrity, as these criteria relate to the usability of the data set. Ecology considers four key criteria to determine if data validation has actually occurred. These are:

- Use of raw or instrument data for evaluation.
- Use of third-party assessors.
- Data set is complex.
- Use of EPA Functional Guidelines or equivalent for review.

Examples of data types commonly validated would be:

- Gas Chromatography (GC).
- Gas Chromatography-Mass Spectrometry (GC-MS).
- Inductively Coupled Plasma (ICP).

The end result of a formal validation process is a determination of usability that assigns qualifiers to indicate usability status for every measurement result. These qualifiers include:

- No qualifier, data is usable for intended purposes.
- J (or a J variant), data is estimated, may be usable, may be biased high or low.
- REJ, data is rejected, cannot be used for intended purposes (Kammin, 2010; Ecology, 2004).

Data verification: Examination of a data set for errors or omissions, and assessment of the Data Quality Indicators related to that data set for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a data set. (Ecology, 2004)

Detection limit (limit of detection)**:** The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero. (Ecology, 2004)

Duplicate samples: Two samples taken from and representative of the same population, and carried through and steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis. (USEPA, 1997)

Field blank: A blank used to obtain information on contamination introduced during sample collection, storage, and transport. (Ecology, 2004)

Initial Calibration Verification Standard (ICV): A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples. (Kammin, 2010)

Laboratory Control Sample (LCS): A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples. (USEPA, 1997)

Matrix spike: A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias due to interference or matrix effects. (Ecology, 2004)

Measurement Quality Objectives (MQOs)**:** Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness. (USEPA, 2006)

Measurement result: A value obtained by performing the procedure described in a method. (Ecology, 2004)

Method: A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed. (EPA, 1997)

Method blank: A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples. (Ecology, 2004; Kammin, 2010)

Method Detection Limit (MDL): This definition for detection was first formally advanced in 40CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero. (Federal Register, October 26, 1984)

Percent Relative Standard Deviation (%RSD): A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$\%RSD = (100 * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples. (Kammin, 2010)

Parameter: A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all "parameters." (Kammin, 2010; Ecology, 2004)

Population: The hypothetical set of all possible observations of the type being investigated. (Ecology, 2004)

Precision: The extent of random variability among replicate measurements of the same property; a data quality indicator. (USGS, 1998)

Quality assurance (QA): A set of activities designed to establish and document the reliability and usability of measurement data. (Kammin, 2010)

Quality Assurance Project Plan (QAPP)/Quality Assurance Monitoring Plan (QAMP): A document that describes the objectives of a project or monitoring program, and the processes and activities necessary to develop data that will support those objectives. (Kammin, 2010; Ecology, 2004)

Quality control (QC): The routine application of measurement and statistical procedures to assess the accuracy of measurement data. (Ecology, 2004)

Relative Percent Difference (RPD): RPD is commonly used to evaluate precision. The following formula is used:

$$[Abs(a-b)/((a + b)/2)] * 100$$

where "Abs()" is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples. (Ecology, 2004)

Replicate samples: Two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled. (USGS, 1998)

Representativeness: The degree to which a sample reflects the population from which it is taken; a data quality indicator. (USGS, 1998)

Sample (field): A portion of a population (environmental entity) that is measured and assumed to represent the entire population. (USGS, 1998)

Sample (statistical): A finite part or subset of a statistical population. (USEPA, 1997)

Sensitivity: In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit. (Ecology, 2004)

Spiked blank: A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method. (USEPA, 1997)

Spiked sample: A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method's recovery efficiency. (USEPA, 1997)

Split sample: A discrete sample subdivided into portions, usually duplicates. (Kammin, 2010)

Standard Operating Procedure (SOP): A document which describes in detail a reproducible and repeatable organized activity. (Kammin, 2010)

Surrogate: For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis. (Kammin, 2010)

Systematic planning: A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning. (USEPA, 2006)

References for QA Glossary

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