DEPARTMENT OF ECOLOGY
State of Washington

Quality Assurance Monitoring Plan

The 2023-2028 Puget Sound Sediment Monitoring Program

March 2023

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COVER PHOTO: Collage of sediment monitoring activities.
PHOTOS BY MARINE SEDIMENT MONITORING TEAM.

Quality Assurance Project Plan

The 2023-2028 Puget Sound Sediment Monitoring Program

by the Marine Sediment Monitoring Team:
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March 2023

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Signatures are not available on the Internet version.
EAP: Environmental Assessment Program
MMU: Marine Monitoring Unit

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2.0 Abstract

The sediments of Puget Sound are a key component of the Puget Sound ecosystem. These sediments provide vital ecosystem services such as: burial and sinks for carbon, nutrients, and chemical contaminants; sources of nutrient remineralization; and critical habitat for sediment-dwelling invertebrates and fish.

Sediment-dwelling invertebrates make ideal sentinels of ecosystem health because of their direct association living in, and sometimes consuming, sediments. Their sedentary lifestyle means they are unable to escape exposure to stressors such as contaminated sediments, changes in nutrient input, ocean acidification, oxygen depletion, and climate change.

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 extent estimates of an area (km^2) with given sediment conditions.
- Document changes in sediment and benthic infaunal conditions over time.
- Provide high-quality data, summary reports, and indices to stakeholders.

This Quality Assurance Monitoring Plan describes the goals, objectives, and study design, and also provides references for all field and laboratory methods for sediment monitoring in Puget Sound.

3.0 Background

3.1 Introduction and problem statement

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), was developed to monitor sediment quality and the condition of the benthic infauna 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; 2009; 2018) and addenda. This document is the recertification of the 2018 Quality Assurance Monitoring Plan (Dutch et al., 2018).

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

The Puget Sound ecosystem is subjected to a multitude of natural forces, or drivers, including inputs from (1) the atmosphere, rivers, groundwater, and the ocean, and (2) point-source and nonpoint-source waste streams related to human activity. These drivers result in changes in climate and weather conditions, nutrients, and toxic chemicals loading to the system. In combination, these pressures bring about changes in the state of the water column, benthic habitat, and ultimately the organisms that live in them. These relationships are depicted in the Driver-Pressure-State-Impact-Response (DPSIR) model in Figure 1 (after Smeets and Wetering, 1999; Niemeijer and de Groot, 2008).

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 ultimately the composition and ecological functioning of the benthic infaunal assemblage.

Key questions

- What is the condition of the benthic habitat, including sediments 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?

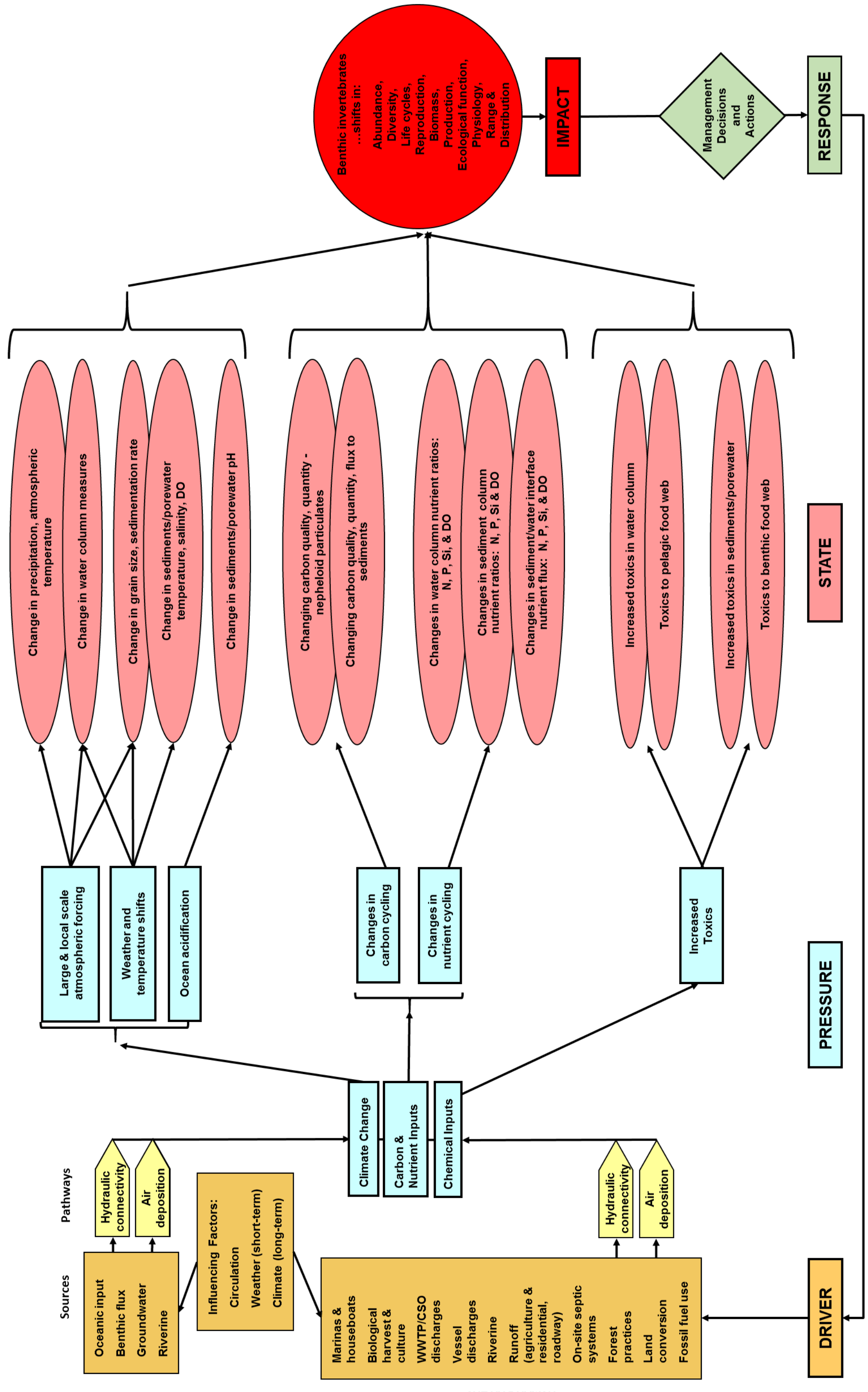

Figure 1. Driver-Pressure-State-Impact-Response (DPSIR) model for water column, sediments, and benthic infaunal assemblage in Puget Sound.

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, Washington (Figure 2).

This Puget Sound study area comprises a variety of interconnected habitat types: shallow estuaries and bays, deep glacially scoured 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. This large, complex estuary extends over 200 miles from Olympia north to the Canadian border and covers an area greater than 2,000 km^2, ranging in width from 10 to 40 km (Kennish, 1998).

Complex circulation patterns in Puget Sound are driven largely by freshwater inputs, tides, and winds. Puget Sound is characterized by a two-layered estuarine system with marine waters entering the Sound through the Strait of Juan de Fuca at depth with net surface outflow.

Freshwater enters the Puget Sound estuary via precipitation, surface runoff, groundwater inflow, and various rivers. Major rivers include the Skagit, Snohomish, Cedar, Duwamish, Puyallup, Stillaguamish, and Nisqually (Figure 2). The Skagit, Stillaguamish, and Snohomish rivers account for most of the freshwater input into the Sound (Kennish, 1998). However, the Fraser River, in British Columbia, contributes substantially to the hydrography of Puget Sound.

Residence and flushing times in Puget Sound have seasonal variability with longer flushing time associated with summer lower tides and lower freshwater inflows (Premathilake and Khangaonkar, 2022). Flushing times vary greatly in the basins and sub-basins of Puget Sound. The major basins, Georgia Basin and Hood Canal, exhibit long flushing times, ranging from 115 to 240 days, while flushing times of Admiralty Inlet and Elliott, Fidalgo, and Commencement bays are much shorter, ranging from 1 to 2 days (Premathilake and Khangaonkar, 2022).

The bottom sediments of Puget Sound are composed primarily of compact, glacially-formed, clay layers and relict glacial tills (Crandell et al., 1965). On average, Puget Sound sediments are 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., 2018). Major sources of recent sediments are shoreline erosion and riverine discharges.

Puget Sound is bordered by relatively undeveloped rural areas as well as highly developed urban and industrial areas. Major urban centers include the cities of Bellingham, Everett, Seattle, Bremerton, Tacoma, and Olympia. These cities are all located at the mouths of large river systems that feed into Puget Sound's largest estuarine embayments (Figure 2).

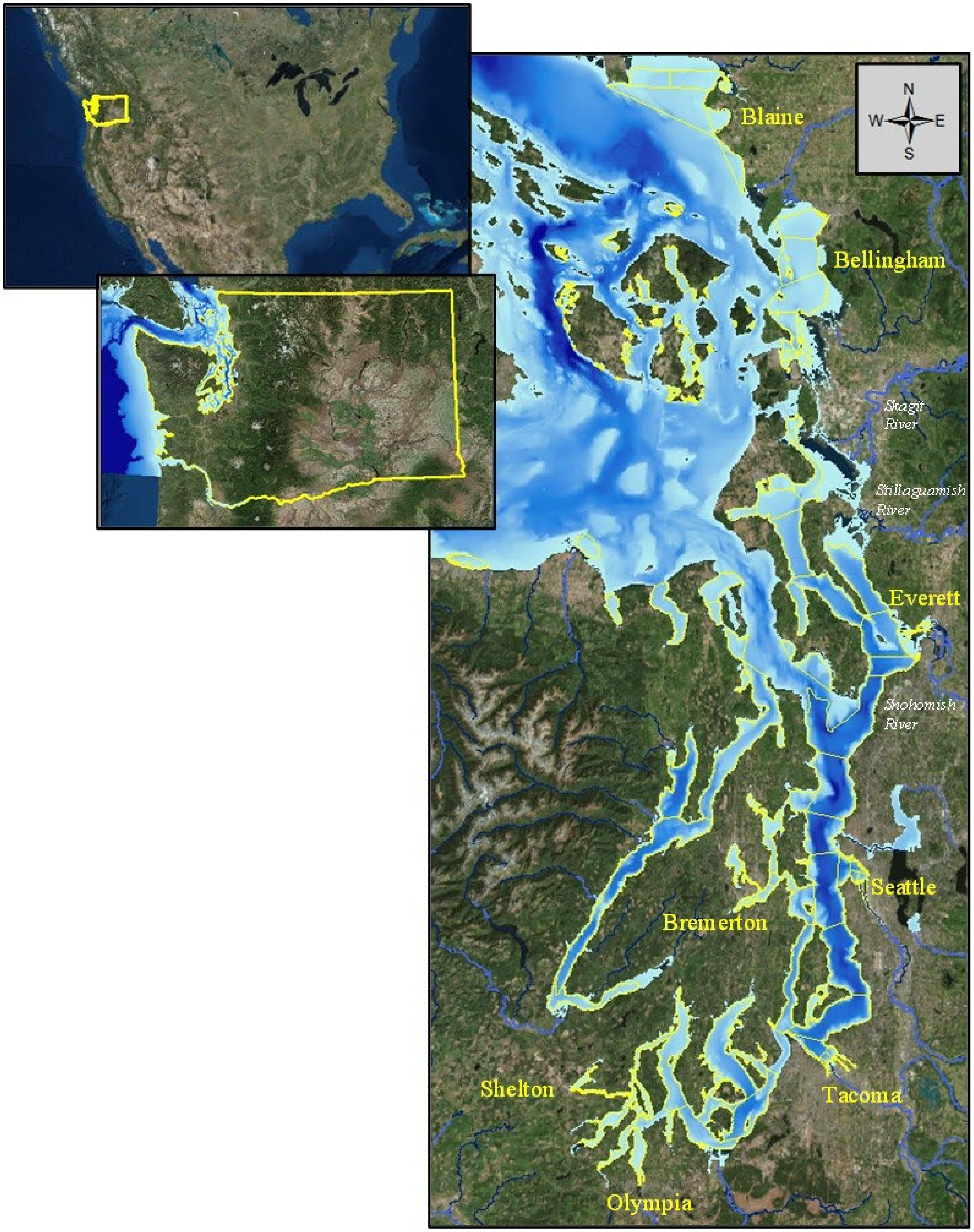

Figure 2. Puget Sound Sediment Monitoring Program study area (right) with United States and Washington State inserts (above top, bottom).

3.2.1 History of study area

A thorough history of the study area is described in the previous Puget Sound Sediment Monitoring Program Quality Assurance Monitoring Plan (Dutch et al., 2018).

3.2.2 Summary of previous studies and existing data

The earliest recorded sediment monitoring data in Ecology's Environmental Information Management (EIM) database were from studies conducted by Richard Roberts in Puget Sound and the Strait of Juan de Fuca in 1950. Since then, many baseline surveys, small-scale site assessments for regulatory clean-up activity, and large-scale assessments and monitoring programs have studied Puget Sound sediments. A summary of these earlier works is given in the 2009 Quality Assurance Project Plan (Dutch et al., 2009).

Since the last inventory of sediment-related studies, presented in the 2018 Sediment QAMP (Dutch et al., 2018), additional site assessments associated with regulatory clean-ups have been conducted. Details of each of these cleanups can be found on Ecology's Sediment Cleanup website.

Recent findings of the Puget Sound Sediment Monitoring Program (Sediment Program)can be found in our interactive story map collection and in reporting collaborations with Puget Sound Ecosystem Monitoring Program (PSEMP) monitoring partners (PSEMP Marine Waters Workgroup, 2018; PSEMP Toxics Work Group, 2019, *in progress*). Some highlights from these publications include:

- In general, most of Puget Sound did not have elevated levels of chemical contaminants. The highest concentrations were found near population and/or industrial centers, including Bellingham, Everett, Seattle, Tacoma, and Bremerton.
- Several of the chemical classes measured are not found at concentrations above the reporting limit of the analytical methods, particularly those in the polybrominated diphenylether (PBDE), polychlorinated biphenyl (PCB), and phthalate chemical classes. Metals and polycyclic aromatic hydrocarbons (PAHs) are most often detected.
- Abundance and biomass of benthic assemblages vary considerably. Seasonal variability is not assessed.
- Benthic community structure corresponded primarily to depth, grain size, and organic matter.
- Significant relationships have been found between carbon and nitrogen in particulates, dissolved fractions, surface sediments, and the benthic community.
- The oceanographic properties, physical characteristics, and benthic community composition vary throughout the Sound.
- A large portion of the variability in the benthic infaunal assemblage remains unexplained with the parameters we have measured.

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 (original Long-Term program), PSAMP_SP (Spatial regions, strata program), PSEMP_LT (revised Long-Term program covered by this QAMP), and UWI (Urban Waters Initiative program, now the Urban Bays program, covered by this QAMP).

Data for historical and current Puget Sound sediment monitoring conducted for regulatory permit requirements are also housed in EIM. Additionally, sediment and benthic infaunal data are available for samples collected from Puget Sound as part of two U.S. Environmental Protection Agency (EPA) national monitoring programs: the Coastal Environmental Monitoring and Assessment Program (EMAP; see https://archive.epa.gov/emap/archive-emap/web/html/) and the National Coastal Condition Assessment (NCCA; see https://www.epa.gov/national-aquatic-resource-surveys/ncca).

3.2.3 Parameters of interest and potential sources

To address the multiple goals and objectives of the Sediment Program, a variety of environmental parameters will be measured, including those characterizing benthic infaunal assemblage, physical sediment parameters, sediment biogeochemistry and chemical contaminants (Table 1).

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 benthic infaunal assemblage 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 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 differ from their use for regulatory purposes. For the Sediment Program, regulatory criteria have been used in the generation of a Sediment Chemistry Index indicator of the Puget Sound Marine Water Vital Sign (Puget Sound Partnership, 2022) that documents surface sediment conditions over time.

Table 1. Sediment sampling parameters of interest.

Parameter Category	Parameter Detail	Purpose/Concern
Benthic infaunal assemblage	Count and identify to lowest taxonomic level (to species level if possible)	Characterization of benthic infaunal assemblages through calculation of numeric benthic indicators including total abundance, major taxa abundance, taxa richness, Pielou's evenness, and Swartz's dominance index.
	Biomass estimates	Estimation of biomass of individual organisms and whole benthic infaunal assemblages using biomass measurements taken from a 2016 Puget Sound-wide benthic infaunal reference collection. Useful in understanding carbon budget of ecosystem.
Habitat characterization	Temperature (sediment in grab)	Measurement of physical condition of sediments.
	Salinity (overlying water in sediment grab)	Measurement of physical condition of near-bottom water.
	Depth	Measurement of water column depth at each station.
	Grain size	Measurement of physical structure of substrate.
	Grab penetration depth	Measurement of degree of compactness of the sediment.
Biogeo-chemistry	Total carbon (TC) Total organic carbon (TOC) Total inorganic carbon (TIC) Total nitrogen (TN)	Determination of organic composition and quality in sediments; lability and availability of nutrients to benthic infaunal assemblage; identification of sources of organic matter.
	$\delta^{13}C$ 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 benthic infaunal assemblages.
	Biogenic silica (BSi)	Proxy for diatom microfossil abundance in sediments; relationship to diatom abundance in water column and food web implications.
Chemistry	Metals	Determination of degree of anthropogenic chemical contamination in bulk sediments.
	Polycyclic aromatic hydrocarbons (PAHs)	
	Polychlorinated biphenyls (PCBs)	
	Polybrominated diphenyl ethers (PBDEs)	
	Phthalates	

4.0 Project Description

Ecology's Marine Sediment Monitoring Team (MSMT) has studied Puget Sound sediments since 1989 as part of the Puget Sound Ecosystem Monitoring Program (PSEMP), with the goal of addressing the following key questions:

- What is the condition of the benthic habitat and associated invertebrate organisms?
- How do the habitats and communities change over time?
- What are the relationships between benthic invertebrates and environmental parameters measured, such as nutrients, and chemical pollutants?

The Puget Sound Sediment Monitoring Program (Sediment Program) uses consistent techniques to monitor Puget Sound sediments for a suite of physical, chemical, and biological variables and environmental indicators. The program uses a monitoring strategy composed of two elements to assess sediment quality for the greater Puget Sound and six urban bays:

- **Long-Term monitoring:** Annual Puget Sound-wide characterization and change over time of sediment quality and benthic infaunal assemblage condition, as estimated from samples collected from 50 stations selected from both random and non-random sample designs.
- **Urban Bays monitoring:** Periodic bay-wide characterization and change over time of sediment quality and benthic infaunal assemblage condition, as estimated from samples collected from 30-36 randomly-selected stations sampled from one of six urban bays on a rotational basis.

The Sediment Program has evolved since its inception in 1989 (see Appendices B-1, B-2 in Dutch, 2009).

4.1 Project goals

The goals for the Sediment Program include the following:

- Determine the status of, and document spatial patterns and variation in, Puget Sound sediment quality and benthic infaunal assemblage condition.
- Document changes over time for Puget Sound sediment quality and benthic infaunal assemblage condition.
- Provide scientifically valid sediment quality and benthic infaunal assemblage data, summary reports, and indices for environmental managers, scientists, tribes, and the general public, and also provide technical support when appropriate.

4.2 Project objectives

Each of the 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 benthic infaunal assemblage. They include:

1. **Determine the status of and document spatial patterns and variation in Puget Sound sediment quality and benthic infaunal assemblage condition.**

    a) Measure and document the geographic distribution of the physical, chemical, and biogeochemical sediment characteristics and the structure of benthic infaunal assemblage assemblages at each monitoring station and use this information to characterize sediment and benthic infaunal assemblage condition throughout Puget Sound and for designated urban bays.

    i) Physical

    - Temperature: What is the sediment temperature?
    - Salinity: What is the salinity of the overlying waters?
    - Depth: What is the depth of the overlying waters?
    - Grain size: What is the sediment grain size distribution?
    - Grab penetration depth: How deep is the grab penetrating into the sediment?

    ii) Chemical

    - Sediment concentrations: What are the concentrations of anthropogenic chemical contaminants in the sediments?

    iii) Biogeochemical

    - Nutrient concentrations: What are the sediment concentrations of organic and/or inorganic carbon, nitrogen, sulfides, and biogenic silica?
    - $\delta^{13}C$ and $\delta^{15}N$ values: What are the concentrations and relative proportions of stable carbon and nitrogen isotopes in sediments?

    iv) Biological

    - Numeric characterization of the benthic infaunal assemblage: What are the spatial patterns of numeric benthic indices?
    - Estimated biomass of the benthic infaunal assemblage: What are the spatial patterns of estimated biomass?
    - Ecological function of the benthic infaunal assemblage: What are the functional characteristics associated with the benthic infaunal assemblage (e.g., feeding, reproduction, locomotion) and how do they relate to numeric indices and benthic infaunal assemblage biomass, and to physical, chemical, and biogeochemical measures of the sediments?

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

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

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

2. **Document changes over time for Puget Sound sediment quality and conditions within the benthic infaunal assemblage.**

    a) Document changes over time in physical, chemical, and biogeochemical sediment characteristics and benthic assemblage structure measured for Puget Sound and the urban bays.

    i) Change over time: Are the measured sediment quality parameters changing over time Puget Sound-wide and in the urban bays?

    b) Evaluate changes over time in the relationships between physical, chemical, and biogeochemical sediment characteristics and in benthic assemblage structure and in relation to changes in natural and human-related environmental drivers and pressures.

    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 scientifically valid sediment quality and benthic 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 and provide them to stakeholders via Ecology's EIM database.

    b) Summarize/highlight findings: Summarize and highlight findings in short, easy-to-read products.

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

    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 and to develop a more complete, integrated picture and to leverage monitoring resources more effectively.

    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 Sediment Monitoring Program. Existing data include the physical, chemical, and biogeochemical sediment quality parameters, as well as data for the benthic infaunal assemblage 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 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).

4.4 Tasks required

For each Sediment Program element, sediment grab samples are collected from target locations within designated sampling frames. Samples for the Long-term element are collected annually in April at 50 locations, while the six urban bays are sampled once every six years with 30 to 36 stations in each bay. The most recently deposited sediments (top 2-3 cm) are collected at each location with a van Veen grab sampler. These sediments are analyzed for the parameters specified in Table 1. Additionally, sediments are collected from the full grab, up to 17 cm penetration depth, to be analyzed for composition and biomass of the infaunal invertebrate community (EAP039 v1.4).

4.5 Systematic planning process

As described in the background section of the 2018 Sediment Monitoring Program Quality Assurance Monitoring Plan (Dutch et al., 2018), the 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, as new ecological information has emerged, the monitoring priorities and strategy have changed accordingly.

Each year, as recent data are analyzed, team members discuss and agree on changes necessary for the next field season. Updates to station locations, parameters to be sampled, and analytical methods are updated as information priorities evolve and scientific needs and funding availability change. Any updates to the monitoring plan described in this QAMP will be captured in annual addenda to this QAMP or, if significantly different, will be captured in a new Quality Assurance Monitoring Plan.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 2 shows the responsibilities of those who will be involved in this project.

Table 2. Roles and responsibilities of staff involved with the Marine Sediment Monitoring Program.

All are employees of the Washington State Department of Ecology.

Environmental Assessment Program Staff	Title	Responsibilities
Sandra Weakland Marine Monitoring Unit Western Operations Section Phone: 360-668-6420	Benthic Ecologist	Database management lead, EIM data entry lead, data review and analysis, report preparation, field sampling preparation and conduct lead, Geographic Information System (GIS) lead, lab contract oversight, web steward, QAMP preparation, benthic invertebrate sample processing.
Valerie Partridge Marine Monitoring Unit Western Operations Section Phone: 360-407-7217	Statistician/ Benthic Ecologist	Statistician and data analyst lead, report preparation, field sampling preparation and conduct, statistical contract oversight, Benthic Index Principal Investigator.
Dany Burgess Marine Monitoring Unit Western Operations Section Phone: 564-669-1737 & 360-407-3970	Lead Taxonomist	Primary and secondary invertebrate taxonomy, voucher sheet generation, voucher collection maintenance, benthic lab lead, lab contract oversight, field sampling, report preparation.
Creston Wood Marine Monitoring Unit Western Operations Section	Marine Monitoring Technician	Various lab and field work duties for the Marine Monitoring Unit.
Julianne Ruffner Marine Monitoring Unit Western Operations Section Phone: 360-280-4518	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.
Stacy Polkowske Western Operations Section Phone: 360-464-0674	Section Manager for the Project Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAMP, and approves the final QAMP.
Dean Momohara MEL Phone: 360-871-8801	Acting Director	Reviews and approves the final QAMP.
Arati Kaza Phone: 360-480-1960	Ecology Quality Assurance Officer	Reviews and approves the draft QAMP and the final QAMP.

EAP: Environmental Assessment Program
EIM: Environmental Information Management database
MEL: Manchester Environmental Laboratory
QAPP: Quality Assurance Project Plan

5.2 Special training and certifications

All personnel who conduct field activities receive training on use of sediment and benthic infaunal 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) listed in section 6.2.2. New or volunteer staff are given demonstrations of field procedures before they perform field activities. A senior staff member will also be present 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 benthic 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 benthic samples 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 - See Table 2.

5.4 Proposed project schedule

Table 3. Proposed schedule for completing annual field and laboratory work, EIM data entry, and reports for the Marine Sediment Monitoring Program.

Task	Due date	Lead staff
Field work	*Long-term element:* April through early May annually. *Urban Bays element:* early June annually.	All MSMT staff
MEL analyses	February of the following year	Sandra Weakland
Biogeochemistry contract lab analyses	December annually	Sandra Weakland
Grain Size contract lab analyses	December annually	Valerie Partridge
Infaunal sample sorting and QA	6 months post-collection	Creston Wood and Sandra Weakland
Infaunal taxonomy and biomass	9 months post-collection	Dany Burgess
Data analysis report preparation	1 year post-collection	All senior MSMT staff

MEL: Manchester Environmental Laboratory
MSMT: Marine Sediment Monitoring Team

Table 4. Schedule for data entry

Task	Due date	Lead staff
EIM data loaded* [1]	10 months post -collection	Sandra Weakland
EIM QA [2]	11 months post-collection	Creston Wood
EIM complete [3]	1 year post-collection	Sandra Weakland

*EIM Project ID: PSEMP_LT and UWI
EIM: Environmental Information Management database
[1] All data entered into EIM by the lead person for this task.
[2] Data verified to be entered correctly by a different person; any data entry issues identified. Allow one month.
3 All data entry issues identified in the previous step are fixed (usually by the original entry person); EIM Data Entry Review Form signed off and submitted to Melissa Peterson (who then enters the "EIM Completed" date into Activity Tracker). Allow one month for this step. Normally the final EIM completion date is no later than the final report publication date.

Table 5. Schedule for final report

Task	Due date	Lead staff
Draft to supervisor	13 months post-collection	all senior MSMT staff
Draft to client/ peer reviewer	14 months post-collection	all senior MSMT staff
Draft to external reviewers	14 months post-collection	all senior MSMT staff
Final draft to publications team	15 months post-collection	all senior MSMT staff
Final report due on web	17 months post-collection	all senior MSMT staff

5.5 Budget and funding

The Puget Sound Sediment Monitoring Program (Sediment Program) is funded by the Model Toxics Control Account. The projected budget for the program for the 2023-2025 biennium is provided in Table 6. The Manchester Environmental Laboratory (MEL) budget is detailed in Table 7.

Table 6. Project budget estimate for the Puget Sound Sediment Monitoring Program 2023-2025 biennium.

This is not the cost of the whole program, excludes staffing, internal lab samples, administrative costs, etc.

Item	Cost ($)
Equipment	$3,000.00
Field Travel	$18,688.00
Boating Operations support (ECY owned research vessels)	$8000.00
Biogeochemistry Contracts	$16,630.54
Grain Size Contracts	$14,430.00
Taxonomic Contracts	$32,810.00
MEL (See Table 7 for details.)	$131,775.00
Total	$225,333.54

Table 7. MEL budget details for the Marine Sediment Monitoring Program 2023-2025 biennium.

Prices are subject to change at the end of the fiscal year.

Parameter	Number of Samples	Number of Field QA Samples	Total Number of Samples	Cost Per Sample ($)	Lab Subtotal ($)
Total carbon, total organic carbon, total inorganic carbon, and total nitrogen	163	12	175	$95.00	$16,625.00
Total sulfides	163	12	175	$60.00	$10,500.00
Metals	83	8	91	$230.00	$20,930.00
PAH and phthalates	83	8	91	$500.00	$45,500.00
PCB Congeners and Aroclors	83	8	91	$190.00	$17,290.00
13 PBDEs	83	8	91	$230.00	$20,930.00

6.0 Quality Objectives

6.1 Data quality objectives [2]

The main data quality objective (DQO) for this project is to collect a minimum of 50 sediment and benthic infaunal 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 physical, chemical, biogeochemical sediment and benthic infaunal data that meet measurement quality objectives (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 (see Appendix). 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 8 and 9, below.

[2] DQO can also refer to ***Decision*** Quality Objectives. The need to identify Decision Quality Objectives during the planning phase of a project is less common. For projects that do lead to important decisions, DQOs are often expressed as tolerable limits on the probability or chance (risk) of the collected data leading to an erroneous decision. And for projects that intend to estimate present or future conditions, DQOs are often expressed in terms of acceptable uncertainty (e.g., width of an uncertainty band or interval) associated with a point estimate at a desired level of statistical confidence.

Table 8. Measurement quality objectives for physical, biogeochemistry, and chemistry analyses of sediment.

All terms are defined in the Quality Assurance Glossary (see Appendix).

Parameter	Blind Field Duplicate	Laboratory Duplicate	Lab Control Standard (LCS) %Recovery	Standard or Certified Reference Material (SRM/CRM) % Recovery	Matrix Spike (MS) % Recovery	Matrix Spike Duplicate (MSD)	Surrogate Spike % Recovery	Method Blank	Lowest Concentration of Interest
Percent Solids	RPD ≤ 20%	RPD < 20%	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	< PQL	0.1% dry wt
Grain Size	CV<3% at D50 and <5% at D10 and D90 for particles ≥ 10um; CV<6% at D50 and <10% at D10 and D90 for particles < 10um†	CV<3% at D50 and <5% at D10 and D90 for particles ≥ 10um; CV<6% at D50 and <10% at D10 and D90 for particles < 10um†	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	0.01% dry wt
Total carbon	RPD ≤ 20%	RPD ≤ 20%	Not applicable	70 – 130%	Not applicable	Not applicable	Not applicable	< RL	0.1% dry wt
Total organic carbon	RPD ≤ 20%	RPD ≤ 20%	Not applicable	70 – 130%	Not applicable	Not applicable	Not applicable	< RL	0.1% dry wt
Total inorganic carbon	RPD ≤ 20%	RPD ≤ 20%	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	< RL	0.1% dry wt
Total nitrogen	RPD ≤ 20%	RPD ≤ 20%	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	< RL	0.1% dry wt
Total sulfides	RPD ≤ 20%	RPD ≤ 20%	65 – 135%	Not applicable	75 – 125%	RPD ≤ 20%	Not applicable	< PQL	5.0 mg/kg dry wt
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes	<0.4 ‰	<0.3 ‰	<0.2 ‰	<0.3 ‰	Not applicable	Not applicable	Not applicable	< 0.5 MDL	1.4 µmol N
Biogenic silica	RPD ≤ 20%	RPD ≤ 20%	Internal lab reference materials	Not applicable	Not applicable	RPD ≤ 20%	Not applicable	< DL	1% dry wt
Metals (except mercury)	RPD ≤ 20%	Not applicable if below PQL, MS/MSD serve as lab duplicate	85 – 115%	Based on manufacturers set limits	75 – 125%	RPD ≤ 20%	Not applicable	<½ LLOQ; if > ½ LLOQ, lowest analyte concn. must be >10x method blank 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	RPD ≤ 20%	Not applicable if below PQL, MS/MSD serve as lab duplicate	85 – 115%	Based on manufacturers set limits	75 – 125%	RPD ≤ 20%	Not applicable	<½ LLOQ; if > ½ LLOQ, lowest analyte concn. must be >10x method blank or qualified as an estimate	5.0 mg/kg dry wt

Parameter	Blind Field Duplicate	Laboratory Duplicate	Lab Control Standard (LCS) %Recovery	Standard or Certified Reference Material (SRM/CRM) % Recovery	Matrix Spike (MS) % Recovery	Matrix Spike Duplicate (MSD)	Surrogate Spike % Recovery	Method Blank	Lowest Concentration of Interest
Phthalates	RPD ≤ 40%	RPD ≤ 40%	50 – 150%	NA	50 – 150%	RPD ≤ 40%	50 – 150%	Follows MEL protocol	2.03-5.71 µg/kg dry wt
Polycyclic aromatic hydrocarbons (PAHs)	RPD ≤ 40%	RPD ≤ 40%	50 – 150%	see table 9*	50 – 150%	RPD ≤ 40%	20 – 200%	<MDL; if > MDL, lowest analyte concn. must be >5x method blank or qualified as an estimate	0.07-0.94 µg/kg dry wt
Polychlorinated biphenyls (PCBs) - Aroclors	RPD ≤ 40%	RPD ≤ 40%	50 – 150%	Not applicable	50 – 150%	RPD ≤ 40%	30 – 150%	<MDL; if > MDL, lowest analyte concn. must be >5x method blank or qualified as an estimate	0.04-0.73 µg/kg dry wt
Polychlorinated biphenyls (PCBs) - Congeners	RPD ≤ 40%	RPD ≤ 40%	50 – 150%	see table 9*	50 – 150%	RPD ≤ 40%	30 – 150%	<MDL; if > MDL, lowest analyte concn. must be >5x method blank or qualified as an estimate	0.04-0.19 µg/kg dry wt
Polybrominated diphenyl ethers (PBDEs) - Congeners	RPD ≤ 40%	RPD ≤ 40%	50 – 150%	see table 9*	50 – 150%	RPD ≤ 40%	50 – 150%	<MDL; if > MDL, lowest analyte concn. must be >5x method blank or qualified as an estimate	0.04-0.18 µg/kg dry wt

* Surrogate recoveries are compound-specific.

† CV = coefficient of variation; D10, D50, and D90 = 10^{th}, 50^{th}, and 90^{th} percentiles, respectively, of the cumulative undersize distribution.

Table 9. Standard (Certified) Reference Material (NIST 1944) recovery limits (MEL, 2016).

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

6.2.1.1 Precision

Precision is a measure of variability among 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 8 and 9. Acceptable precision among three or more replicate sample results is expressed as relative standard deviation (RSD) or coefficient of variation (CV), as appropriate.

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 Table 8.

6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance when it is present. It is commonly described as a detection limit. Targets for acceptable sensitivity of all chemistry and biogeochemistry lab measurements, including method detection limits (MDL)[3], for this program are listed in 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 benthic infaunal 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. All procedures are reviewed every 2-3 years and updated to include improvements and necessary modifications. When comparing Sediment Program 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 for the Marine Monitoring program include the following:

Sampling methods

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

[3] The lowest quantity of a physical or chemical parameter that is detectable (above background noise) by each field instrument or laboratory method.

- PSEP, 1997a. Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissue in Puget Sound.
- PSEP, 1987. Recommended Protocols for Sampling and Analyzing Subtidal Benthic Macroinvertebrate Assemblages in Puget Sound.
- Weakland, 2021. Ecology's Standard Operating Procedures for Obtaining Marine Sediment Samples. EAP039 v1.4.
- Parsons et al., 2021. EAP070 v2.3 SOP – Minimize Spread of Invasive Species.
- EAP Field Operations and Safety Manual – 2021.

Sample analysis

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

Physical, biogeochemical

- PSEP, 1986. Recommended Protocols for Measuring Conventional Sediment Variables in Puget Sound.
- Syvitski James. 1991. Cambridge University Press, Principles, Methods, and Applications of Particle Size Analysis.
- Norton, Katherine K. 2019. Assessing the precision and accuracy of particle-size analysis with a laboratory laser-diffraction analyzer.
- Zimmerman, Keefe, and Bashe, 1997. Method 440.0 – Determination of Carbon and Nitrogen in Sediments and Particulates of Estuarine/Coastal Waters Using Elemental Analysis.
- 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.
- Mortlock and Froelich, 1989. A simple method for the rapid determination of biogenic opal in pelagic marine sediments.
- Conley and Schelske, 2002. Chapter 14. Biogenic Silica.
- Dunn Carter. 2018. Good practice guide for isotope ratio mass spectrometry.

Metals and organics chemistry

- PSEP, 1997b. Recommended Guidelines for Measuring Metals in Puget Sound Marine Water, Sediment and Tissue Samples.
- PSEP, 1997c. Recommended Guidelines for Measuring Organic Compounds in Puget Sound Water, Sediment and Tissue Samples.
- MEL, 2016. Manchester Environmental Laboratory Lab User's Manual. Version 10.
- USEPA, 1991. Method 245.5. Mercury In Sediment (Manual Cold Vapor Technique).
- USEPA, 1994. Method 3541. Automated Soxhlet Extraction. https://www.epa.gov/sites/production/files/2015-06/documents/epa-3541.pdf

- USEPA, 1996. Method 3050B. Acid digestion of sediments, sludges, and soils. https://www.epa.gov/sites/production/files/2015-06/documents/epa-3050b.pdf
- USEPA, 1996. Method 3660B. Sulfur cleanup. https://www.epa.gov/sites/production/files/2015-12/documents/3660b.pdf
- USEPA, 1996. Method 3665A. Sulfuric Acid/Permanganate Cleanup. https://www.epa.gov/sites/production/files/2015-12/documents/3665a.pdf
- USEPA, 2007. Method 8082A. Polychlorinated Biphenyls (PCBs) by Gas Chromatography. https://www.epa.gov/sites/production/files/2015-12/documents/8082a.pdf
- USEPA, 2014. Method 3620C. Florisil cleanup. https://www.epa.gov/sites/production/files/2015-12/documents/3620c.pdf
- USEPA, 2014. Method 6020B. Inductively Coupled Plasma-Mass Spectrometry. https://www.epa.gov/sites/production/files/2015-12/documents/6020b.pdf
- USEPA, 2014. Method 8270D. Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry. https://www.epa.gov/sites/production/files/2015-12/documents/8270d.pdf

Benthic infauna analysis

- Burgess, 2023. Standard Operating Procedures for Marine Macrobenthic Sample Analysis. EAP043 v1.4.
- Burgess, 2022. Standard Operating Procedure for Taxonomic Standardization of Benthic Invertebrate. Data EAP128 v1.2.

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 benthic infaunal assemblages residing down to 17 cm). A 0.1 m^2 modified double van Veen grab sampler will be used to collect a 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

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. There is no attainment objective established given the safety considerations specific to marine sampling. We make all efforts possible to complete all annual sampling to avoid gaps in the data record.

6.3 Acceptance criteria for quality of existing data

Sediment Quality data spanning many decades, and associated metadata such as Quality Assurance Plans and final reports, are available through Ecology's [Environmental Information Management database](#) (EIM). Data in EIM were generated by Ecology staff, contractors. and water discharge permit holders for many purposes including ambient monitoring, regulatory site assessments, and cleanup monitoring. Additionally, sediment quality data exists at the regional and county level.

Data quality varies depending on the type of quality assurance (QA) required when and where the projects were conducted. If MSMT staff choose to compare data from EIM and other programs to data collected for the Sediment Program, QA documentation for non-program data will be reviewed to ensure comparability of methods and MQOs.

All data collected since 1989 for the Sediment Program were collected according to quality standards specified in earlier versions of this QAMP and annual addenda. All future Sediment Program monitoring work is expected to meet the QC requirements specified in this QAMP. These requirements are summarized in the Quality Control Procedures Section 10.0 of this document and in the SOPs used for each analysis.

The Sediment Program monitoring will fill data gaps and improve the quality of available information by conducting annual characterizations of sediment quality and benthic infaunal assemblage condition Puget Sound-wide. Newly generated data will describe current conditions, be compared with existing data to examine changes over time, and may be used to inform and fill data gaps in the Salish Sea Model.

6.4 Model quality objectives

Not applicable.

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 and Dyes Inlets; Bellingham Bay; Budd Inlet; and East Possession Sound, including Port Gardner and 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.

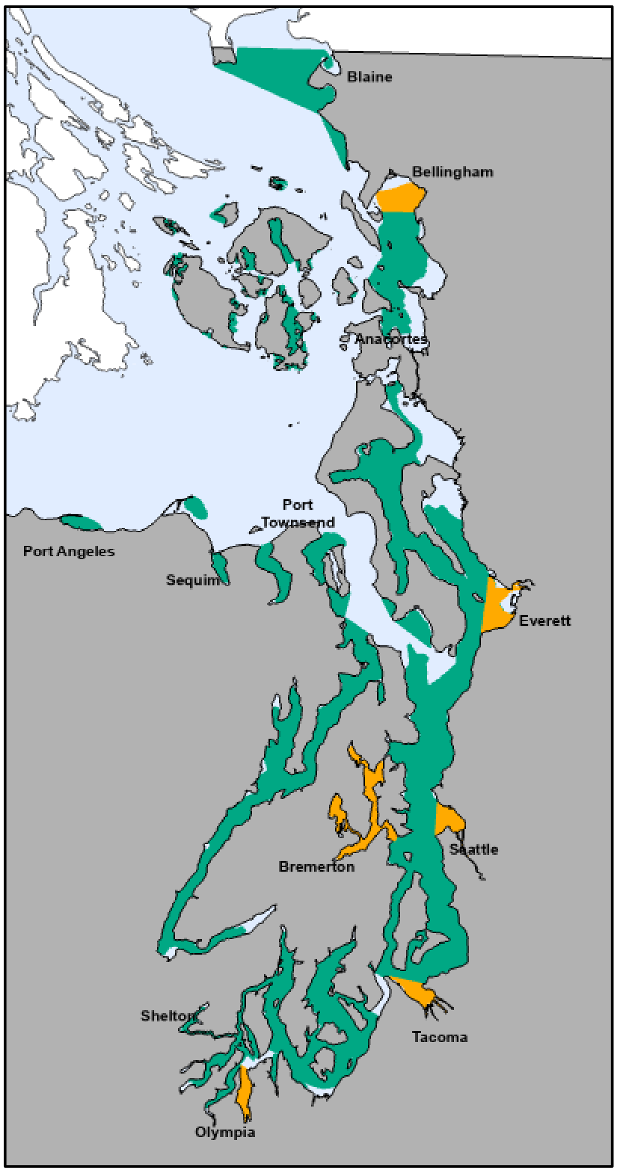

Figure 3. The Puget Sound-wide sampling frame (teal and orange) **and six nested Urban Bays sampling frames** (orange only).

7.2 Field data collection

7.2.1 Sampling locations and frequency

Long-Term element

The 50 Long-Term stations will be sampled once annually during early April through early May. This allows spatial and temporal assessment of sediment condition and the overwintering benthic infaunal community. Table 10 lists the Long-Term monitoring stations, sampling location, and sampling design from which the site originated. Locations for the 50 Long-Term monitoring stations are depicted in Figure 4. All but one Long-Term station, Station 3 in the Strait of Georgia, fall within the GTRS sample frame, leaving 49 stations that will be equally weighted, each representing 45.054 km^2 of the total 2207.641 km^2 in the sampling frame for estimates of spatial extent of conditions. Alternate coordinates will be chosen if any of the target stations are rejected.

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Table 10. Long-term element stations for the Marine Sediment Monitoring Program.

Station	Station type (Target or Alternate)	Location	Region	County	Watershed WRIA	Longitude (NAD83HARN)	Latitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme
3	Target	Strait of Georgia (North of Patos Island)	Strait of Georgia	Whatcom	Nooksack	-122.97842	48.87025	222	PSEMP Temporal
4	Target	Bellingham Bay	Strait of Georgia	Whatcom	Nooksack	-122.53820	48.68397	25	PSEMP Temporal
13	Target	North Hood Canal (South of Bridge)	Hood Canal	Kitsap	Kitsap	-122.62895	47.83758	20	PSEMP Temporal
19	Target	Saratoga Passage	Whidbey Basin	Island	Island	-122.47134	48.09792	122	PSEMP Historical
21	Target	Port Gardner (Everett)	Whidbey Basin	Snohomish	Snohomish	-122.24283	47.98547	22	PSEMP Temporal
29	Target	Shilshole	Central	Kitsap	Kitsap	-122.45403	47.70075	201	PSEMP Temporal
34	Target	Sinclair Inlet	Central	Kitsap	Kitsap	-122.66208	47.54708	9	PSEMP Temporal
38	Target	Point Pully (3-Tree Point)	Central	King	Duwamish-Green	-122.39363	47.42833	200	PSEMP Temporal
40	Target	Thea Foss Waterway (Commencement Bay)	Central	Pierce	Puyallup-White	-122.43730	47.26130	11	PSEMP Temporal
44	Target	East Anderson Island	South Sound	Pierce	Kitsap	-122.67358	47.16133	20	PSEMP Temporal
49	Target	Inner Budd Inlet	South Sound	Thurston	Deschutes	-122.91347	47.07997	7	PSEMP Temporal
52	Target	W of Devils Head, E end Nisqually Reach	South Sound	Pierce	Kitsap	-122.78051	47.17060	105	GRTS-1
119	Target	Admiralty Inlet, South	Central	Kitsap	Kitsap	-122.47816	47.87616	217	PSAMP/NOAA
191	Target	Central Elliott Bay	Central	King	Duwamish-Green	-122.37581	47.59842	99	PSAMP/NOAA
222	Target	Hood Canal, N of Seabeck	Hood Canal	Jefferson	Quilcene-Snow	-122.81466	47.67821	128	PSAMP/NOAA
252	Target	Case Inlet	South Sound	Pierce	Kitsap	-122.85101	47.26957	55	PSAMP/NOAA
265	Target	Carr Inlet	South Sound	Pierce	Kitsap	-122.66572	47.25240	107	PSAMP/NOAA
281	Target	Commencement Bay	Central	Pierce	Puyallup-White	-122.44193	47.29229	143	PSAMP/NOAA
40005	Target	Inner Port Angeles Harbor	Strait of Juan de Fuca	Clallam	Elwha-Dungeness	-123.44985	48.13872	23	GRTS-2
40006	Target	Murden Cove	Central	Kitsap	Kitsap	-122.49390	47.63777	57	GRTS-2
40007	Target	Saratoga Passage, North, Camano Island	Whidbey Basin	Island	Island	-122.54375	48.22609	55	GRTS-2
40008	Target	Carr Inlet, NE of Gertrude Island	South Sound	Pierce	Kitsap	-122.64787	47.22686	129	GRTS-2
40009	Target	Strait of Georgia, outer Birch Bay	Strait of Georgia	Whatcom	Nooksack	-122.82638	48.90625	28	GRTS-2

Station	Station type (Target or Alternate)	Location	Region	County	Watershed WRIA	Longitude (NAD83HARN)	Latitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme
40010	Target	Central Hood Canal, S of Triton Cove	Hood Canal	Mason	Skokomish-Dosewallips	-122.97817	47.59726	124	GRTS-2
40011	Target	Central Basin, N of Shilshole	Central	King	Cedar-Sammamish	-122.41759	47.76108	211	GRTS-2
40012	Target	Elliott Bay, Smith Cove	Central	King	Cedar-Sammamish	-122.38563	47.6259	19	GRTS-2
40013	Target	Reads Bay	San Juan Archipelago	San Juan	San Juan	-122.82139	48.49626	7	GRTS-2
40015	Target	Saratoga Passage, South	Whidbey Basin	Island	Island	-122.44853	48.08877	110	GRTS-2
40016	Target	Henderson Inlet	South Sound	Thurston	Deschutes	-122.83635	47.12549	4	GRTS-2
40017	Target	Boundary Bay	Strait of Georgia	Whatcom	Nooksack	-122.96789	48.99473	19	GRTS-2
40018	Target	Hood Canal, Hoodsport	Hood Canal	Mason	Skokomish-Dosewallips	-123.11736	47.41787	121	GRTS-2
40019	Target	South Possession Sound	Central	Snohomish	Cedar-Sammamish	-122.33076	47.90607	93	GRTS-2
40020	Target	Shilshole Bay	Central	King	Cedar-Sammamish	-122.42252	47.69588	87	GRTS-2
40021	Target	Crescent Harbor	Whidbey Basin	Island	Island	-122.61517	48.27948	13	GRTS-2
40022	Target	Brownsville	Central	Kitsap	Kitsap	-122.59952	47.67154	19	GRTS-2
40025	Target	West Sound	San Juan Archipelago	San Juan	San Juan	-122.96331	48.62446	20	GRTS-2
40026	Target	Dabob Bay	Hood Canal	Jefferson	Quilcene-Snow	-122.83153	47.76217	188	GRTS-2
40027	Target	Admiralty Inlet, N of Rose Point	Central	Kitsap	Kitsap	-122.5082	47.86624	21	GRTS-2
40028	Target	Totten Inlet	South Sound	Thurston	Kennedy-Goldsborough	-123.01006	47.136	7	GRTS-2
40029	Target	North Samish Bay	Strait of Georgia	Whatcom	Lower Skagit-Samish	-122.55226	48.63718	22	GRTS-2
40030	Target	Sinclair Inlet	Central	Kitsap	Kitsap	-122.65102	47.545	10	GRTS-2
40032	Target	Inner Case Inlet, Rocky Bay	South Sound	Pierce	Kitsap	-122.80549	47.34949	18	GRTS-2
40034	Target	Port Townsend, mouth of Kilisut Harbor	Admiralty Inlet	Jefferson	Quilcene-Snow	-122.73316	48.09354	3	GRTS-2
40036	Target	Des Moines	Central	King	Duwamish-Green	-122.35733	47.41975	173	GRTS-2
40037	Target	Central Basin, North	Whidbey Basin	Island	Island	-122.58646	48.19991	54	GRTS-2
40038	Target	North Central Basin	Central	Kitsap	Kitsap	-122.47829	47.69895	186	GRTS-2

Station	Station type (Target or Alternate)	Location	Region	County	Watershed WRIA	Longitude (NAD83HARN)	Latitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme
209R	Target	Skagit Bay	Whidbey Basin	Island	Island	-122.48846	48.29586	22	PSEMP Historical
305R	Target	Lynch Cove	Hood Canal	Mason	Kitsap	-122.93124	47.39717	20	PSEMP Historical
BLL009	Target	Bellingham Bay, Pt. Frances (Portage Is.)	Strait of Georgia	Whatcom	Nooksack	-122.5942	48.68593	18	PSEMP-waters
HCB003	Target	Hood Canal, Central	Hood Canal	Kitsap	Kitsap	-123.0096	47.53787	152	PSEMP-waters
40039	Alternate	Gedney Island	Whidbey Basin	Snohomish	Snohomish	-122.31735	48.02361	No Data	GRTS-2
40040	Alternate	NW Anderson Island, Drayton Passage	South Sound	Pierce	Kitsap	-122.72910	47.17831	No Data	GRTS-2
40041	Alternate	South Boundary Bay	Strait of Georgia	Whatcom	Nooksack	-122.89714	48.93582	No Data	GRTS-2
40042	Alternate	Hood Canal, Right Smart Cove	Hood Canal	Mason	Skokomish-Dosewallips	-122.87476	47.72126	No Data	GRTS-2
40043	Alternate	South Possession Sound	Central	King	Cedar-Sammamish	-122.39947	47.83917	No Data	GRTS-2
40044	Alternate	Central Basin, north of Alki	Central	King	Duwamish-Green	-122.42488	47.59770	No Data	GRTS-2
40045	Alternate	Bellingham Bay, Fairhaven	Strait of Georgia	Whatcom	Nooksack	-122.51920	48.72049	No Data	GRTS-2
40046	Alternate	Central Basin, north of Normandy Park	Central	King	Duwamish-Green	-122.38814	47.47329	No Data	GRTS-2
40047	Alternate	Admiralty Inlet, Outer Oak Bay	Admiralty Inlet	Jefferson	Quilcene-Snow	-122.66036	47.97690	No Data	GRTS-2
40048	Alternate	Case Inlet	South Sound	Pierce	Kennedy-Goldsborough	-122.84642	47.23001	No Data	GRTS-2

PSEMP Temporal: original suite of non-random monitoring stations sampled annually since 1989 with few exceptions (Striplin, 1988)

PSEMP Historical: original suite of non-random monitoring stations selected for the program in 1989 but not sampled after 1994 (Striplin, 1988)

GRTS-1: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.06 km^2 grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

GRTS-2: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.00184 km^2 grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

PSAMP/NOAA: NOAA’s National Status and Trends program randomly chosen sites within designated polygons or strata (Paul et al., 1992; Hyland et al., 2000).

PSEMP-waters: non-random, co-located with Ecology’s long-term marine water column monitoring (Keyzers et al., 2020)

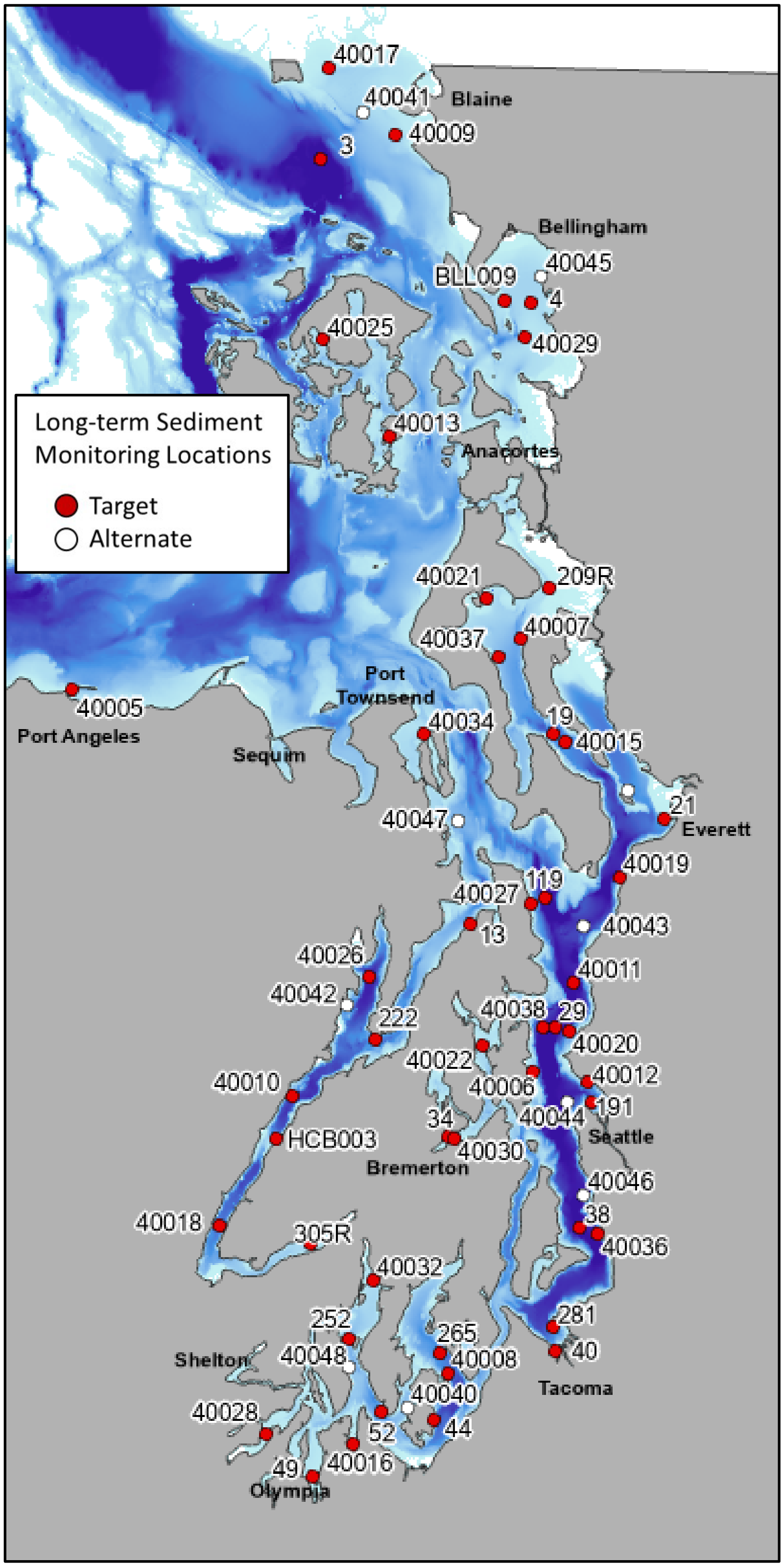

Figure 4. Long-Term monitoring station target and alternate locations.

Urban Bays monitoring element

A total of 30 to 36 samples will be collected annually in early June from one of six major urban embayments, based on the following schedule:

- **2023 Bainbridge Basin:** 33 sites from the PSAMP/NOAA design
- **2024 Bellingham Bay:** 10 sites from the GRTS-1 design, 5 sites from the GRTS-2 design, and 15 from the PSAMP/NOAA design
- **2025 Budd Inlet:** 12 sites from the GRTS-1 design, 12 sites from the GRTS-2 design, and 6 from the PSAMP/NOAA design
- **2026 East Possession Sound:** 30 sites from the GRTS-2 design
- **2027 Elliott Bay:** 35 sites from the PSAMP/NOAA design and one site from the GRTS-2 design
- **2028 Commencement Bay:** 25 sites from the PSAMP/NOAA design, 1 site from GRTS-1, and 4 from GRTS-2.

Tables 11-16 list the monitoring stations, sampling location, and sampling design from which the site originated for each urban bay. Monitoring locations for each urban bay are depicted in Figure 5-10.

Bellingham Bay

The sampling design for Bellingham Bay is drawn from a combination of PSAMP/NOAA and the GRTS designs. Most of the previously sampled stations originated in the PSAMP/NOAA design. Therefore, alternate coordinates are chosen from the GRTS-2 design with stratification. All stations are weighted according to which polygon or stratum they are located in, summing to a total study area of 41.293 km². Station weights for Bellingham Bay are noted in Table 11.

Table 11. Urban Bay stations for the Bellingham Bay study area.

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
A	Target	40065	Bellingham Bay	Whatcom	Nooksack	48.759030	-122.520720	4	GRTS-2	2.422
A	Target	20	Bellingham Bay	Whatcom	Nooksack	48.737780	-122.607230	9.5	PSAMP/NOAA	2.422
A	Target	21	Bellingham Bay	Whatcom	Nooksack	48.743050	-122.608900	7.6	PSAMP/NOAA	2.422
A	Target	22	Bellingham Bay	Whatcom	Nooksack	48.758330	-122.540280	7	PSAMP/NOAA	2.422
A	Alternate	40033	Bellingham Bay	Whatcom	Nooksack	48.742230	-122.613040	No Data	GRTS-2	
A	Alternate	40449	Bellingham Bay	Whatcom	Nooksack	48.740900	-122.603280	No Data	GRTS-2	
A	Alternate	40577	Bellingham Bay	Whatcom	Nooksack	48.753490	-122.521390	No Data	GRTS-2	
B	Target	23	Bellingham Bay	Whatcom	Nooksack	48.751420	-122.512780	7	PSAMP/NOAA	0.227
B	Target	24	Bellingham Bay	Whatcom	Nooksack	48.752800	-122.510830	5.5	PSAMP/NOAA	0.227
B	Target	25	Bellingham Bay	Whatcom	Nooksack	48.754150	-122.513320	5.5	PSAMP/NOAA	0.227
B	Target	195	Bellingham Bay	Whatcom	Nooksack	48.755210	-122.505140	3	GRTS-1	0.227
B	Target	42113	Bellingham Bay	Whatcom	Nooksack	48.753120	-122.516270	7.5	GRTS-2	0.227
B	Alternate	44161	Bellingham Bay	Whatcom	Nooksack	48.753400	-122.505260	No Data	GRTS-2	
B	Alternate	44289	Bellingham Bay	Whatcom	Nooksack	48.756240	-122.503920	No Data	GRTS-2	
B	Alternate	47233	Bellingham Bay	Whatcom	Nooksack	48.760590	-122.510600	No Data	GRTS-2	
C	Target	32	Bellingham Bay	Whatcom	Nooksack	48.725000	-122.545250	28	PSAMP/NOAA	1.430
C	Target	33	Bellingham Bay	Whatcom	Nooksack	48.716930	-122.545480	29	PSAMP/NOAA	1.430
C	Target	34	Bellingham Bay	Whatcom	Nooksack	48.714730	-122.566450	29	PSAMP/NOAA	1.430
C	Target	35	Bellingham Bay	Whatcom	Nooksack	48.753370	-122.536290	12	GRTS-1	1.430
C	Target	85	Bellingham Bay	Whatcom	Nooksack	48.744140	-122.567410	15	GRTS-1	1.430

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
C	Target	213	Bellingham Bay	Whatcom	Nooksack	48.724360	-122.566150	26	GRTS-1	1.430
C	Target	227	Bellingham Bay	Whatcom	Nooksack	48.725740	-122.591230	22	GRTS-1	1.430
C	Target	277	Bellingham Bay	Whatcom	Nooksack	48.735900	-122.546210	22	GRTS-1	1.430
C	Target	299	Bellingham Bay	Whatcom	Nooksack	48.738420	-122.591350	12	GRTS-1	1.430
C	Target	40045	Bellingham Bay	Whatcom	Nooksack	48.720490	-122.519200	19	GRTS-2	1.430
C	Target	40205	Bellingham Bay	Whatcom	Nooksack	48.715530	-122.567590	28	GRTS-2	1.430
C	Alternate	40173	Bellingham Bay	Whatcom	Nooksack	48.713960	-122.529460	No Data	GRTS-2	
C	Alternate	40301	Bellingham Bay	Whatcom	Nooksack	48.733780	-122.553760	No Data	GRTS-2	
C	Alternate	40321	Bellingham Bay	Whatcom	Nooksack	48.751110	-122.552090	No Data	GRTS-2	
D	Target	26	Bellingham Bay	Whatcom	Nooksack	48.748050	-122.503880	5	PSAMP/NOAA	0.189
D	Target	27	Bellingham Bay	Whatcom	Nooksack	48.747230	-122.501380	5	PSAMP/NOAA	0.189
D	Target	28	Bellingham Bay	Whatcom	Nooksack	48.749650	-122.490220	3	PSAMP/NOAA	0.189
D	Target	507	Bellingham Bay	Whatcom	Nooksack	48.750320	-122.503740	4.5	GRTS-1	0.189
D	Alternate	41857	Bellingham Bay	Whatcom	Nooksack	48.751560	-122.496870	No Data	GRTS-2	
D	Alternate	45953	Bellingham Bay	Whatcom	Nooksack	48.751750	-122.499790	No Data	GRTS-2	
D	Alternate	48385	Bellingham Bay	Whatcom	Nooksack	48.753190	-122.494290	No Data	GRTS-2	
E	Target	29	Bellingham Bay	Whatcom	Nooksack	48.738620	-122.515280	14	PSAMP/NOAA	1.165
E	Target	59	Bellingham Bay	Whatcom	Nooksack	48.738050	-122.499470	9	PSAMP/NOAA	1.165
E	Target	60	Bellingham Bay	Whatcom	Nooksack	48.734980	-122.499220	8	PSAMP/NOAA	1.165
E	Target	61	Bellingham Bay	Whatcom	Nooksack	48.736350	-122.504700	11	PSAMP/NOAA	1.165
E	Target	163	Bellingham Bay	Whatcom	Nooksack	48.740850	-122.505060	11.5	GRTS-1	1.165
E	Target	40193	Bellingham Bay	Whatcom	Nooksack	48.740720	-122.494625	1.5	GRTS-2	1.165
E	Alternate	40833	Bellingham Bay	Whatcom	Nooksack	48.743460	-122.507220	No Data	GRTS-2	
E	Alternate	42881	Bellingham Bay	Whatcom	Nooksack	48.740900	-122.510610	No Data	GRTS-2	
E	Alternate	43393	Bellingham Bay	Whatcom	Nooksack	48.742910	-122.506280	No Data	GRTS-2	
F	Target	30	Bellingham Bay	Whatcom	Nooksack	48.733280	-122.511130	14	PSAMP/NOAA	2.331
F	Target	31	Bellingham Bay	Whatcom	Nooksack	48.726930	-122.515820	18	PSAMP/NOAA	2.331

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
F	Target	53	Bellingham Bay	Whatcom	Nooksack	48.722680	-122.514940	12	PSAMP/NOAA	2.331
F	Alternate	42093	Bellingham Bay	Whatcom	Nooksack	48.722090	-122.507950	No Data	GRTS-2	
F	Alternate	43021	Bellingham Bay	Whatcom	Nooksack	48.729890	-122.517970	No Data	GRTS-2	
F	Alternate	44045	Bellingham Bay	Whatcom	Nooksack	48.732440	-122.509090	No Data	GRTS-2	

GRTS-1: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.06 km^2 grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

GRTS-2: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.00184 km^2 grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

PSAMP/NOAA: NOAA's National Status and Trends program randomly chosen sites within designated polygons or strata (Paul et al., 1992; Hyland et al., 2000).

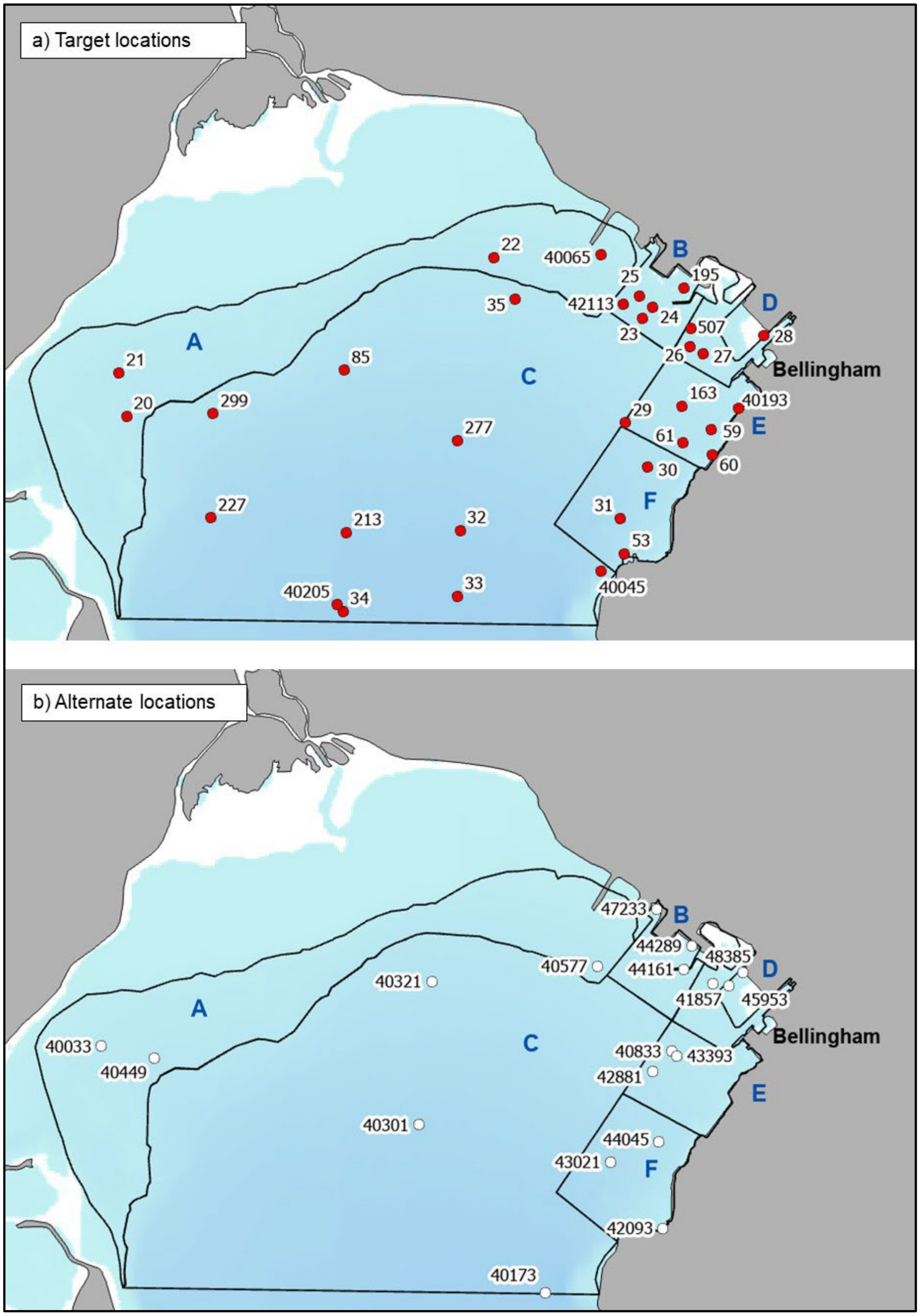

Figure 5. Bellingham Bay sampling frame and monitoring station locations.

East Possession Sound

The sampling design for East Possession is drawn from the GRTS-2 design. Although the intent in 2019 was to resample the same 30 stations from 2012, four stations in the Snohomish Delta could not be resampled. Randomly-selected replacement from the GRTS-2 design stations were sampled, resulting in decreased representation of the Snohomish Delta portion of the study area in 2019. Post-sampling, the East Possession Sound study area was stratified into two strata to address the unbalanced representation of the delta. All stations are now weighted according to which stratum they are located in, for a total study area of 38.082 km². Station weights for East Possession Sound are noted in Table 12.

Table 12. Urban Bay stations for the East Possession Sound study area.

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
A	Target	40591	Snohomish River Delta	Snohomish	Snohomish	48.008460	-122.261780	2	GRTS-2	1.723
A	Target	41735	Possession Sound	Snohomish	Snohomish	48.022430	-122.272310	3	GRTS-2	1.723
A	Target	42639	Possession Sound	Snohomish	Snohomish	48.015730	-122.268040	3	GRTS-2	1.723
A	Target	42759	Possession Sound	Snohomish	Snohomish	48.023698	-122.278090	15	GRTS-2	1.723
A	Alternate	40023	Snohomish River Delta	Snohomish	Snohomish	48.026590	-122.249860	No Data	GRTS-2	
A	Alternate	40535	Snohomish River Delta	Snohomish	Snohomish	48.037420	-122.223100	No Data	GRTS-2	
A	Alternate	41935	Snohomish River Delta	Snohomish	Snohomish	48.043650	-122.191840	No Data	GRTS-2	
A	Alternate	42071	Snohomish River Delta	Snohomish	Snohomish	48.016850	-122.259230	No Data	GRTS-2	
A	Alternate	42583	Snohomish River Delta	Snohomish	Snohomish	48.027420	-122.234310	No Data	GRTS-2	
B	Target	40079	Port Gardner	Snohomish	Snohomish	47.959910	-122.280590	57.5	GRTS-2	1.200
B	Target	40179	Possession Sound	Snohomish	Snohomish	47.983800	-122.298930	141.5	GRTS-2	1.200
B	Target	40207	Port Gardner	Snohomish	Snohomish	47.975510	-122.237490	94	GRTS-2	1.200
B	Target	40307	Possession Sound	Snohomish	Snohomish	47.978680	-122.297270	142.5	GRTS-2	1.200
B	Target	40335	Possession Sound	Snohomish	Snohomish	48.003290	-122.281790	61	GRTS-2	1.200
B	Target	40455	Possession Sound	Snohomish	Snohomish	48.012560	-122.284950	102	GRTS-2	1.200
B	Target	40463	Port Gardner	Snohomish	Snohomish	47.971420	-122.258670	114	GRTS-2	1.200
B	Target	40711	Possession Sound	Snohomish	Snohomish	48.022660	-122.289900	94	GRTS-2	1.200
B	Target	40719	Possession Sound	Snohomish	Snohomish	47.988170	-122.261630	118	GRTS-2	1.200
B	Target	40819	Possession Sound	Snohomish	Snohomish	47.979880	-122.287870	136	GRTS-2	1.200

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
B	Target	40847	Possession Sound	Snohomish	Snohomish	47.996700	-122.275280	105	GRTS-2	1.200
B	Target	40967	Possession Sound	Snohomish	Snohomish	48.000910	-122.282020	22	GRTS-2	1.200
B	Target	40975	Possession Sound	Snohomish	Snohomish	47.973000	-122.269770	130	GRTS-2	1.200
B	Target	41103	Everett Harbor	Snohomish	Snohomish	47.984500	-122.220210	12	GRTS-2	1.200
B	Target	41223	Possession Sound	Snohomish	Snohomish	48.015780	-122.292390	100	GRTS-2	1.200
B	Target	41231	Everett Harbor	Snohomish	Snohomish	47.981940	-122.225200	11	GRTS-2	1.200
B	Target	41331	Possession Sound	Snohomish	Snohomish	47.977730	-122.280640	129	GRTS-2	1.200
B	Target	41359	Possession Sound	Snohomish	Snohomish	47.993023	-122.292987	137	GRTS-2	1.200
B	Target	41479	Possession Sound	Snohomish	Snohomish	47.994960	-122.294890	40	GRTS-2	1.200
B	Target	41487	Port Gardner	Snohomish	Snohomish	47.964960	-122.264870	108	GRTS-2	1.200
B	Target	41615	Possession Sound	Snohomish	Snohomish	48.012140	-122.277240	97	GRTS-2	1.200
B	Target	41743	Possession Sound	Snohomish	Snohomish	47.984620	-122.248820	61	GRTS-2	1.200
B	Target	41843	Possession Sound	Snohomish	Snohomish	47.971080	-122.293790	148	GRTS-2	1.200
B	Target	41871	Possession Sound	Snohomish	Snohomish	47.987660	-122.289940	140	GRTS-2	1.200
B	Target	42739	Possession Sound	Snohomish	Snohomish	47.990220	-122.297790	140	GRTS-2	1.200
B	Target	42867	Possession Sound	Snohomish	Snohomish	47.964860	-122.297700	160	GRTS-2	1.200
B	Alternate	41999	Possession Sound	Snohomish	Snohomish	47.984920	-122.256620	No Data	GRTS-2	
B	Alternate	42023	Possession Sound	Snohomish	Snohomish	48.037230	-122.281230	No Data	GRTS-2	
B	Alternate	42127	Possession Sound	Snohomish	Snohomish	47.961180	-122.273320	No Data	GRTS-2	
B	Alternate	42255	Possession Sound	Snohomish	Snohomish	47.981000	-122.235040	No Data	GRTS-2	
B	Alternate	42355	Possession Sound	Snohomish	Snohomish	47.961410	-122.292400	No Data	GRTS-2	

GRTS-2: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.00184 km^2 grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

PSAMP/NOAA: NOAA's National Status and Trends program randomly chosen sites within designated polygons or strata (Paul et al., 1992; Hyland et al., 2000).

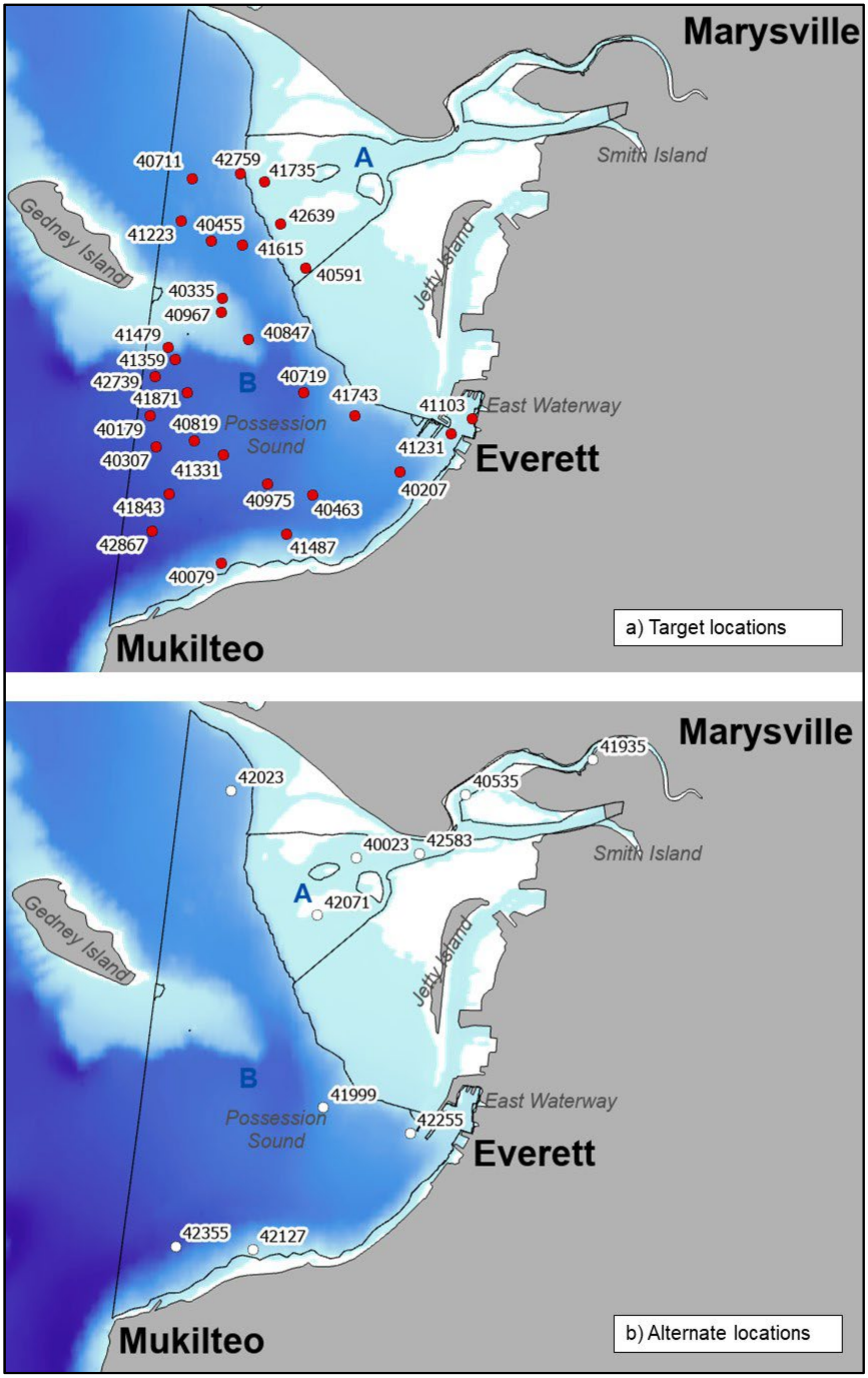

Figure 6. East Possession Sound sampling frame and monitoring station locations.

Elliott Bay

The sampling design for Elliott Bay is drawn from the PSAMP/NOAA design. Therefore, alternate coordinates are chosen from the GRTS-2 design with stratification. All stations are weighted according to which polygon or stratum they are associated with for a total study area of 26.071 km². Station weights for Elliott Bay are noted in Table 13.

Table 13. Urban Bay stations for the Elliott Bay study area.

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
A	Target	176	Elliott Bay, West of EB Marina	King	Cedar-Sammamish	47.629170	-122.399120	10	PSAMP/NOAA	0.343
A	Target	177	Magnolia Bluff	King	Cedar-Sammamish	47.632355	-122.402750	2.5	PSAMP/NOAA	0.343
A	Target	178	Elliott Bay, South of EB Marina	King	Cedar-Sammamish	47.625798	-122.393560	20.3	PSAMP/NOAA	0.343
A	Alternate	40012	Shoreline Elliott Bay	King	Cedar-Sammamish	47.626540	-122.384690	No Data	GRTS-2	
A	Alternate	45132	Shoreline Elliott Bay	King	Cedar-Sammamish	47.635340	-122.408540	No Data	GRTS-2	
A	Alternate	49100	Shoreline Elliott Bay	King	Cedar-Sammamish	47.634030	-122.406950	No Data	GRTS-2	
B	Target	172	West of Duwamish Head	King	Duwamish-Green	47.594400	-122.412660	152	PSAMP/NOAA	2.777
B	Target	173	Northwest of Duwamish Head	King	Duwamish-Green	47.603738	-122.399365	146	PSAMP/NOAA	2.777
B	Target	174	SW of Elliott Bay Marina	King	Cedar-Sammamish	47.624803	-122.399848	40	PSAMP/NOAA	2.777
B	Target	40396	Outer Elliott Bay	King	Cedar-Sammamish	47.621278	-122.397153	60	GRTS-2	2.777
B	Alternate	40556	Outer Elliott Bay	King	Duwamish-Green	47.596240	-122.416350	No Data	GRTS-2	
B	Alternate	40652	Outer Elliott Bay	King	Cedar-Sammamish	47.616980	-122.405280	No Data	GRTS-2	
B	Alternate	40908	Outer Elliott Bay	King	Cedar-Sammamish	47.629210	-122.410530	No Data	GRTS-2	
C	Target	115	Elliott Bay, east side Pier 90	King	Cedar-Sammamish	47.628108	-122.379380	9.5	PSAMP/NOAA	0.337

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km²)
C	Target	179	Elliott Bay, west of Pier 86	King	Cedar-Sammamish	47.623943	-122.374080	24.5	PSAMP/NOAA	0.337
C	Target	180	Elliott Bay, South of Pier 89-90	King	Cedar-Sammamish	47.624815	-122.378680	20.5	PSAMP/NOAA	0.337
C	Target	181	Elliott Bay, West of Piers 70-71	King	Cedar-Sammamish	47.615033	-122.362300	34.3	PSAMP/NOAA	0.337
C	Alternate	41036	Shoreline Elliott Bay	King	Cedar-Sammamish	47.631420	-122.379640	No Data	GRTS-2	
C	Alternate	43444	Shoreline Elliott Bay	King	Cedar-Sammamish	47.624740	-122.372410	No Data	GRTS-2	
C	Alternate	43828	Shoreline Elliott Bay	King	Cedar-Sammamish	47.610940	-122.350360	No Data	GRTS-2	
D	Target	185	North of Duwamish Head	King	Cedar-Sammamish	47.609983	-122.382020	157	PSAMP/NOAA	1.062
D	Target	186	Elliott Bay, W. of Denny Way	King	Cedar-Sammamish	47.618178	-122.365360	35.5	PSAMP/NOAA	1.062
D	Target	187	Elliott Bay, West of Pier 59	King	Cedar-Sammamish	47.607180	-122.359020	103	PSAMP/NOAA	1.062
D	Target	188	Elliott Bay, West of Pier 57	King	Cedar-Sammamish	47.606030	-122.343890	32.5	PSAMP/NOAA	1.062
D	Alternate	40372	Mid Elliott Bay	King	Cedar-Sammamish	47.621610	-122.384040	No Data	GRTS-2	
D	Alternate	40884	Mid Elliott Bay	King	Cedar-Sammamish	47.615540	-122.368170	No Data	GRTS-2	
D	Alternate	41396	Mid Elliott Bay	King	Cedar-Sammamish	47.613160	-122.383570	No Data	GRTS-2	
E	Target	182	Elliott Bay, West of Pier 54	King	Cedar-Sammamish	47.604192	-122.344160	32	PSAMP/NOAA	0.118
E	Target	183	Elliott Bay, Pier 54	King	Cedar-Sammamish	47.603998	-122.340390	14	PSAMP/NOAA	0.118
E	Target	184	Elliott Bay, Pier 55	King	Cedar-Sammamish	47.604670	-122.340980	15.5	PSAMP/NOAA	0.118
E	Alternate	45876	Shoreline Elliott Bay	King	Cedar-Sammamish	47.608140	-122.344700	No Data	GRTS-2	
E	Alternate	54964	Shoreline Elliott Bay	King	Cedar-Sammamish	47.603350	-122.340620	No Data	GRTS-2	

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km²)
E	Alternate	60212	Shoreline Elliott Bay	King	Cedar-Sammamish	47.609670	-122.347610	No Data	GRTS-2	
F	Target	189	Elliott Bay, E. of Duwamish Head	King	Duwamish-Green	47.590513	-122.380505	14.5	PSAMP/NOAA	0.704
F	Target	190	Elliott Bay, Duwamish Head	King	Duwamish-Green	47.597160	-122.385080	7	PSAMP/NOAA	0.704
F	Target	191	Elliott Bay, E. of Duw. Hd.	King	Duwamish-Green	47.598420	-122.375810	97	PSAMP/NOAA	0.704
F	Target	192	Elliott Bay, Central	King	Duwamish-Green	47.602270	-122.365950	67	PSAMP/NOAA	0.704
F	Alternate	40244	Mid Elliott Bay	King	Duwamish-Green	47.592450	-122.368940	No Data	GRTS-2	
F	Alternate	40628	Mid Elliott Bay	King	Duwamish-Green	47.602420	-122.366510	No Data	GRTS-2	
F	Alternate	41268	Mid Elliott Bay	King	Duwamish-Green	47.596660	-122.379880	No Data	GRTS-2	
G	Target	193	Elliott Bay, West of Pier 48	King	Duwamish-Green	47.599965	-122.354230	78	PSAMP/NOAA	0.726
G	Target	194	Elliott Bay, West of Pier 48	King	Cedar-Sammamish	47.600253	-122.347308	66.5	PSAMP/NOAA	0.726
G	Target	195	Elliott Bay, Bay Center, West of Pier 48	King	Duwamish-Green	47.599578	-122.361030	75	PSAMP/NOAA	0.726
G	Target	196	Elliott Bay, west of Yesler Way	King	Cedar-Sammamish	47.601218	-122.349650	71.6	PSAMP/NOAA	0.726
G	Alternate	41140	Mid Elliott Bay	King	Duwamish-Green	47.595920	-122.349420	No Data	GRTS-2	
G	Alternate	41652	Mid Elliott Bay	King	Duwamish-Green	47.593430	-122.361720	No Data	GRTS-2	
G	Alternate	42164	Mid Elliott Bay	King	Duwamish-Green	47.598580	-122.352430	No Data	GRTS-2	
H	Target	198	Elliott Bay, south	King	Duwamish-Green	47.588208	-122.366555	47	PSAMP/NOAA	0.267
H	Target	114	West Waterway, Terminal 5	King	Duwamish-Green	47.575445	-122.360705	20	PSAMP/NOAA	0.267
H	Target	197	Elliott Bay, south Pier 4	King	Duwamish-Green	47.586370	-122.363738	24.4	PSAMP/NOAA	0.267

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km²)
H	Target	199	Elliott Bay, South just west of Pier 4	King	Duwamish-Green	47.586665	-122.365030	30.3	PSAMP/NOAA	0.267
H	Alternate	42804	West Harbor Island	King	Duwamish-Green	47.586720	-122.364390	No Data	GRTS-2	
H	Alternate	46900	West Harbor Island	King	Duwamish-Green	47.584180	-122.358980	No Data	GRTS-2	
H	Alternate	49972	West Harbor Island	King	Duwamish-Green	47.574430	-122.359020	No Data	GRTS-2	
I	Target	200	East Waterway, Terminal 18	King	Duwamish-Green	47.584643	-122.345790	16.3	PSAMP/NOAA	0.177
I	Target	201	East Waterway, Pier 32	King	Duwamish-Green	47.582618	-122.343445	16.75	PSAMP/NOAA	0.177
I	Target	202	East Waterway, south end	King	Duwamish-Green	47.574320	-122.343328	17.5	PSAMP/NOAA	0.177
I	Alternate	40756	East Harbor Island	King	Duwamish-Green	47.580670	-122.344520	No Data	GRTS-2	
I	Alternate	44588	East Harbor Island	King	Duwamish-Green	47.569690	-122.344140	No Data	GRTS-2	
I	Alternate	44724	East Harbor Island	King	Duwamish-Green	47.591310	-122.343270	No Data	GRTS-2	
J	Target	203	Duwamish River, North	King	Duwamish-Green	47.561400	-122.347435	12.5	PSAMP/NOAA	0.222
J	Target	204	Duwamish River, North	King	Duwamish-Green	47.560923	-122.345088	7.1	PSAMP/NOAA	0.222
J	Target	205	Duwamish River, S.W. of Slip 2	King	Duwamish-Green	47.545110	-122.336870	9.25	PSAMP/NOAA	0.222
J	Alternate	40492	Duwamish Waterway	King	Duwamish-Green	47.540080	-122.329390	No Data	GRTS-2	
J	Alternate	42540	Duwamish Waterway	King	Duwamish-Green	47.560320	-122.348400	No Data	GRTS-2	
J	Alternate	52780	Duwamish Waterway	King	Duwamish-Green	47.557890	-122.344370	No Data	GRTS-2	

GRTS-2: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.00184 km² grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

PSAMP/NOAA: NOAA's National Status and Trends program randomly chosen sites within designated polygons or strata (Paul et al., 1992; Hyland et al., 2000).

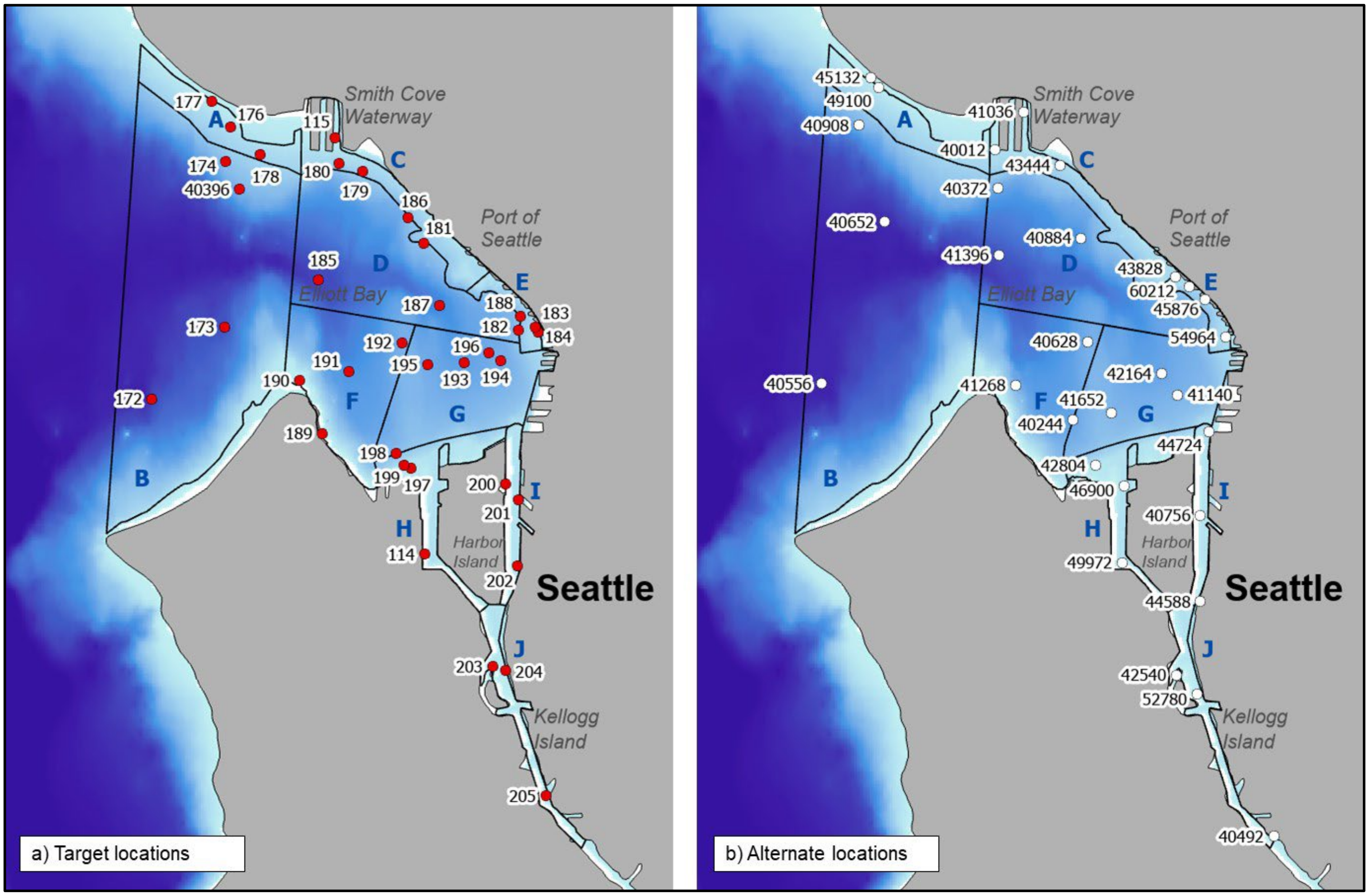

Figure 7. Elliott Bay sampling frame and monitoring station locations.

Bainbridge Basin

The Bainbridge Basin study area encompasses 81.853 km². The sampling design for the basin is drawn from the PSAMP/NOAA design. Alternate coordinates are chosen from the GRTS-2 design with stratification. All stations are weighted according to which polygon or stratum they are associated with. Station weights for the Bainbridge Basin are noted in Table 14.

Table 14. Urban Bay stations for the Bainbridge Basin study area.

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km²)
A	Target	124	Port Madison	Kitsap	Kitsap	47.713818	-122.527320	28	PSAMP/NOAA	5.558
A	Target	125	Port Madison	Kitsap	Kitsap	47.733040	-122.537250	38	PSAMP/NOAA	5.558
A	Target	126	Port Madison	Kitsap	Kitsap	47.726022	-122.530480	42	PSAMP/NOAA	5.558
A	Alternate	40075	Port Madison	Kitsap	Kitsap	47.743390	-122.494420		GRTS-2	
A	Alternate	40102	Port Madison	Kitsap	Kitsap	47.725600	-122.510910		GRTS-2	
A	Alternate	40230	Port Madison	Kitsap	Kitsap	47.723270	-122.545740		GRTS-2	
B	Target	142	Liberty Bay	Kitsap	Kitsap	47.723160	-122.647020	5	PSAMP/NOAA	0.623
B	Target	143	Liberty Bay	Kitsap	Kitsap	47.720342	-122.648990	3	PSAMP/NOAA	0.623
B	Target	144	Liberty Bay	Kitsap	Kitsap	47.721818	-122.642105	10	PSAMP/NOAA	0.623
B	Alternate	40326	Liberty Bay	Kitsap	Kitsap	47.716470	-122.643900		GRTS-2	
B	Alternate	41206	Liberty Bay	Kitsap	Kitsap	47.732970	-122.654300		GRTS-2	
B	Alternate	41350	Liberty Bay	Kitsap	Kitsap	47.730680	-122.650470		GRTS-2	
C	Target	145	Liberty Bay	Kitsap	Kitsap	47.714690	-122.629300	4	PSAMP/NOAA	0.986
C	Target	146	Liberty Bay	Kitsap	Kitsap	47.719400	-122.641285	8	PSAMP/NOAA	0.986
C	Target	147	Liberty Bay	Kitsap	Kitsap	47.706498	-122.635540	4	PSAMP/NOAA	0.986
C	Alternate	40198	Liberty Bay	Kitsap	Kitsap	47.719330	-122.627860		GRTS-2	
C	Alternate	42246	Liberty Bay	Kitsap	Kitsap	47.708670	-122.615830		GRTS-2	
C	Alternate	42886	Liberty Bay	Kitsap	Kitsap	47.706150	-122.611470		GRTS-2	
D	Target	148	Southeast of Keyport	Kitsap	Kitsap	47.692928	-122.610110	13	PSAMP/NOAA	4.320
D	Target	149	North Port Orchard Pt. Bolin	Kitsap	Kitsap	47.688762	-122.588940	6	PSAMP/NOAA	4.320

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
D	Target	150	North Port Orchard	Kitsap	Kitsap	47.681230	-122.585490	19	PSAMP/NOAA	4.320
D	Alternate	40022	North Port Orchard	Kitsap	Kitsap	47.671370	-122.604850		GRTS-2	
D	Alternate	40278	North Port Orchard	Kitsap	Kitsap	47.676580	-122.606990		GRTS-2	
D	Alternate	40454	North Port Orchard	Kitsap	Kitsap	47.688110	-122.572550		GRTS-2	
E	Target	151	North Port Orchard E. of Brownsville	Kitsap	Kitsap	47.649428	-122.603480	19	PSAMP/NOAA	3.400
E	Target	152	Port Orchard Illahee	Kitsap	Kitsap	47.602370	-122.589060	26	PSAMP/NOAA	3.400
E	Target	153	Port Orchard	Kitsap	Kitsap	47.625812	-122.581298	36	PSAMP/NOAA	3.400
E	Alternate	40070	Port Orchard	Kitsap	Kitsap	47.625650	-122.587030		GRTS-2	
E	Alternate	40110	Port Orchard Illahee	Kitsap	Kitsap	47.602620	-122.586400		GRTS-2	
E	Alternate	40534	North Port Orchard E. of Brownsville	Kitsap	Kitsap	47.648430	-122.603820		GRTS-2	
F	Target	169	Dyes Inlet SE of Silverdale	Kitsap	Kitsap	47.635728	-122.679080	6	PSAMP/NOAA	3.891
F	Target	170	Dyes Inlet North Chico Bay	Kitsap	Kitsap	47.613075	-122.701320	13	PSAMP/NOAA	3.891
F	Target	171	Dyes Inlet	Kitsap	Kitsap	47.627382	-122.691895	12	PSAMP/NOAA	3.891
F	Alternate	40154	Dyes Inlet	Kitsap	Kitsap	47.616720	-122.699010		GRTS-2	
F	Alternate	40282	Dyes Inlet	Kitsap	Kitsap	47.639900	-122.697190		GRTS-2	
F	Alternate	40430	Dyes Inlet	Kitsap	Kitsap	47.610920	-122.677320		GRTS-2	
G	Target	166	Dyes Inlet Tracyton	Kitsap	Kitsap	47.608898	-122.663430	17	PSAMP/NOAA	1.062
G	Target	167	Phinney Bay	Kitsap	Kitsap	47.584720	-122.663030	9	PSAMP/NOAA	1.062
G	Target	168	Phinney Bay	Kitsap	Kitsap	47.588352	-122.659960	27	PSAMP/NOAA	1.062
G	Alternate	40174	Port Washington Narrows	Kitsap	Kitsap	47.598570	-122.657260		GRTS-2	

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
G	Alternate	40750	Port Washington Narrows	Kitsap	Kitsap	47.579880	-122.639010		GRTS-2	
G	Alternate	41198	Port Washington Narrows	Kitsap	Kitsap	47.584690	-122.648370		GRTS-2	
H	Target	154	Rich Passage Pleasant Beach	Kitsap	Kitsap	47.593422	-122.537360	8	PSAMP/NOAA	3.335
H	Target	155	Rich Passage Lynwood Center	Kitsap	Kitsap	47.600570	-122.553790	8	PSAMP/NOAA	3.335
H	Target	156	South Port Orchard	Kitsap	Kitsap	47.579190	-122.584095	47	PSAMP/NOAA	3.335
H	Alternate	40238	Rich Passage	Kitsap	Kitsap	47.590400	-122.561230		GRTS-2	
H	Alternate	40366	Rich Passage	Kitsap	Kitsap	47.594280	-122.543790		GRTS-2	
H	Alternate	40622	Rich Passage	Kitsap	Kitsap	47.576930	-122.532170		GRTS-2	
I	Target	157	South Port Orchard East Bremerton	Kitsap	Kitsap	47.569060	-122.602330	22	PSAMP/NOAA	1.978
I	Target	158	South Port Orchard	Kitsap	Kitsap	47.569502	-122.587315	10	PSAMP/NOAA	1.978
I	Target	159	South Port Orchard Pt. Herron	Kitsap	Kitsap	47.566195	-122.610910	14	PSAMP/NOAA	1.978
I	Alternate	41006	South Port Orchard Pt. Herron	Kitsap	Kitsap	47.560820	-122.613130		GRTS-2	
I	Alternate	41054	South Port Orchard Pt. Herron	Kitsap	Kitsap	47.551280	-122.619080		GRTS-2	
I	Alternate	41518	South Port Orchard Pt. Herron	Kitsap	Kitsap	47.550290	-122.606300		GRTS-2	
J	Target	163	Sinclair Inlet	Kitsap	Kitsap	47.545702	-122.654090	12	PSAMP/NOAA	1.126
J	Target	164	Sinclair Inlet	Kitsap	Kitsap	47.549008	-122.665350	8	PSAMP/NOAA	1.126
J	Target	165	Sinclair Inlet	Kitsap	Kitsap	47.547245	-122.666428	10	PSAMP/NOAA	1.126
J	Alternate	40494	Sinclair Inlet	Kitsap	Kitsap	47.552130	-122.638910		GRTS-2	
J	Alternate	41262	Sinclair Inlet	Kitsap	Kitsap	47.542820	-122.667240		GRTS-2	

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
J	Alternate	41774	Sinclair Inlet	Kitsap	Kitsap	47.557990	-122.628570		GRTS-2	
K	Target	160	Sinclair Inlet	Kitsap	Kitsap	47.534238	-122.676885	8	PSAMP/NOAA	1.005
K	Target	161	Sinclair Inlet	Kitsap	Kitsap	47.543710	-122.641488	13	PSAMP/NOAA	1.005
K	Target	162	Sinclair Inlet	Kitsap	Kitsap	47.547243	-122.641488	13	PSAMP/NOAA	1.005
K	Alternate	40030	Sinclair Inlet	Kitsap	Kitsap	47.545000	-122.651020		GRTS-2	
K	Alternate	40542	Sinclair Inlet	Kitsap	Kitsap	47.535870	-122.673550		GRTS-2	
K	Alternate	42078	Sinclair Inlet	Kitsap	Kitsap	47.542330	-122.652410		GRTS-2	

PSAMP/NOAA: NOAA’s National Status and Trends program randomly chosen sites within designated polygons or strata (Paul et al., 1992; Hyland et al., 2000).

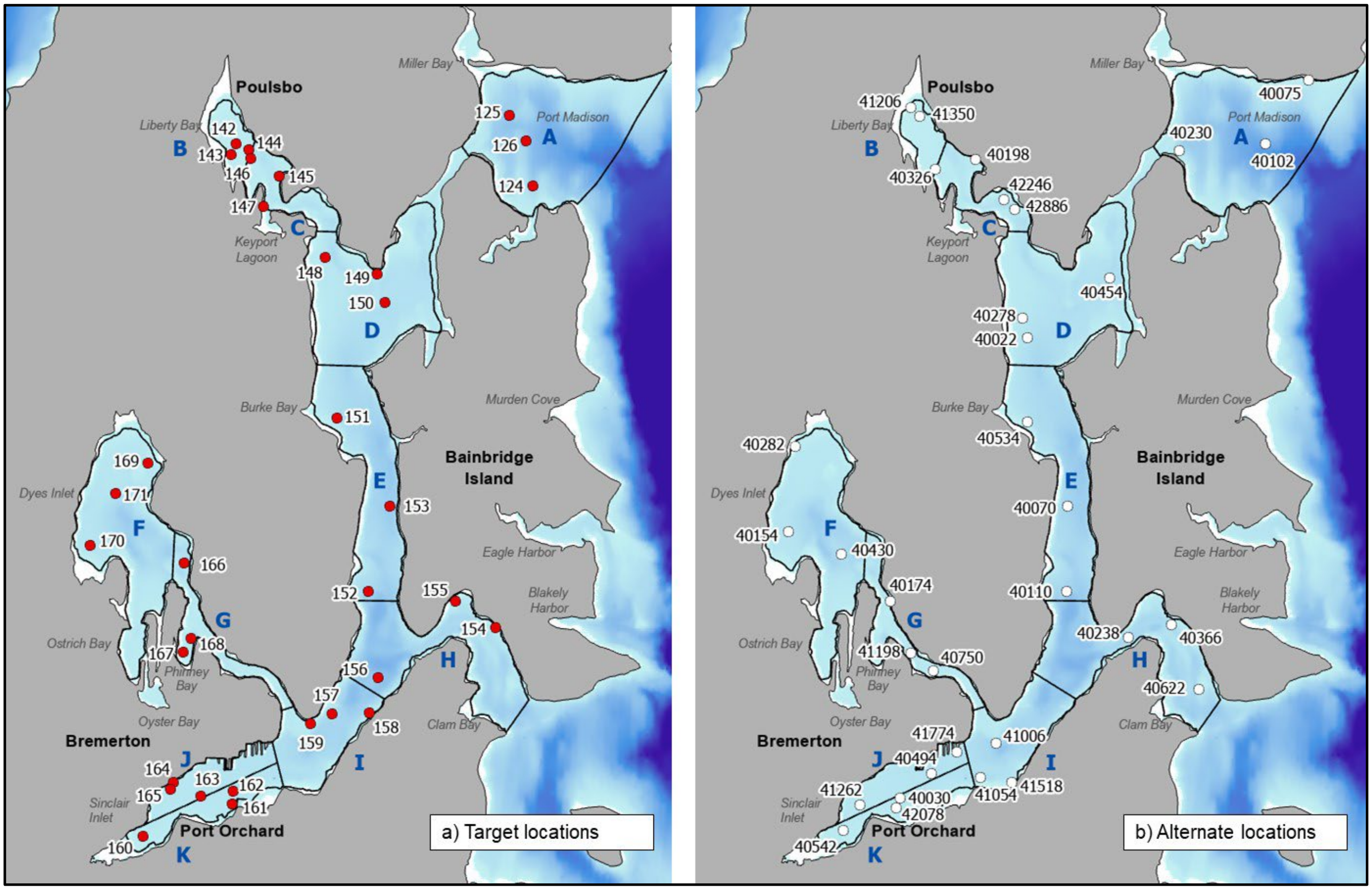

Figure 8. Bainbridge Basin sampling frame and monitoring station locations.

Commencement Bay

The sampling design for Commencement Bay is drawn from the PSAMP/NOAA design. Therefore, alternate coordinates are chosen from the GRTS-2 design with stratification. All stations are weighted according to which polygon or stratum they are associated with for a total study area of 24.059 km². Station weights for Commencement Bay are noted in Table 15.

Table 15. Urban Bay stations for the Commencement Bay study area.

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
A	Target	222	S.E. Commencement Bay	Pierce	Puyallup-White	47.304938	-122.474542	176	GRTS-1	1.851
A	Target	281	S.E. Commencement Bay	Pierce	Puyallup-White	47.292286	-122.441920	144	PSAMP/NOAA	1.851
A	Target	282	S.E. Commencement Bay	Pierce	Chambers-Clover	47.285005	-122.464878	154	PSAMP/NOAA	1.851
A	Target	283	S.E. Commencement Bay	Pierce	Puyallup-White	47.305116	-122.456870	172	PSAMP/NOAA	1.851
A	Target	284	S.E. Commencement Bay	Pierce	Chambers-Clover	47.307718	-122.482145	170	PSAMP/NOAA	1.851
A	Target	318	S.E. Commencement Bay	Pierce	Chambers-Clover	47.288886	-122.464605	158	GRTS-2	1.851
A	Target	380	S.E. Commencement Bay	Pierce	Chambers-Clover	47.297450	-122.487524	146	GRTS-2	1.851
A	Alternate	40574	S.E. Commencement Bay	Pierce	Chambers-Clover	47.293690	-122.467560	No Data	GRTS-2	
A	Alternate	40600	S.E. Commencement Bay	Pierce	Chambers-Clover	47.278790	-122.459120	No Data	GRTS-2	
A	Alternate	40862	S.E. Commencement Bay	Pierce	Puyallup-White	47.303810	-122.467060	No Data	GRTS-2	
B	Target	285	S.E. Commencement Bay	Pierce	Chambers-Clover	47.279041	-122.469893	21	PSAMP/NOAA	0.786
B	Target	286	S.E. Commencement Bay	Pierce	Chambers-Clover	47.284871	-122.472073	110	PSAMP/NOAA	0.786
B	Target	287	S. Shoreline Commencement Bay	Pierce	Puyallup-White	47.269555	-122.447010	33	PSAMP/NOAA	0.786

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
B	Alternate	41404	S.E. Commencement Bay	Pierce	Chambers-Clover	47.291680	-122.486230	No Data	GRTS-2	
B	Alternate	43160	S.E. Commencement Bay	Pierce	Chambers-Clover	47.280170	-122.471220	No Data	GRTS-2	
B	Alternate	43708	S.E. Commencement Bay	Pierce	Chambers-Clover	47.285520	-122.472730	No Data	GRTS-2	
C	Target	88	East Commencement Bay	Pierce	Puyallup-White	47.278353	-122.424779	61	GRTS-2	0.791
C	Target	288	S.E. Commencement Bay	Pierce	Puyallup-White	47.279333	-122.439961	98	PSAMP/NOAA	0.791
C	Target	289	S.E. Commencement Bay	Pierce	Chambers-Clover	47.277466	-122.450973	122	PSAMP/NOAA	0.791
C	Target	290	S.E. Commencement Bay	Pierce	Puyallup-White	47.280666	-122.447410	120	PSAMP/NOAA	0.791
C	Alternate	41028	S.E. Commencement Bay	Pierce	Puyallup-White	47.275490	-122.425410	No Data	GRTS-2	
C	Alternate	41112	S.E. Commencement Bay	Pierce	Puyallup-White	47.280750	-122.435880	No Data	GRTS-2	
C	Alternate	41944	S.E. Commencement Bay	Pierce	Puyallup-White	47.269130	-122.434570	No Data	GRTS-2	
D	Target	4	N.E. Commencement Bay	Pierce	Puyallup-White	47.283060	-122.411900	12	GRTS-2	0.831
D	Target	291	N.E. Commencement Bay	Pierce	Puyallup-White	47.287868	-122.430570	93	PSAMP/NOAA	0.831
D	Target	292	N.E. Commencement Bay	Pierce	Puyallup-White	47.292133	-122.419880	24	PSAMP/NOAA	0.831
D	Target	293	N.E. Commencement Bay	Pierce	Puyallup-White	47.296933	-122.429278	12	PSAMP/NOAA	0.831
D	Alternate	40830	S.E. Commencement Bay	Pierce	Puyallup-White	47.286590	-122.415130	No Data	GRTS-2	
D	Alternate	42052	S.E. Commencement Bay	Pierce	Puyallup-White	47.285320	-122.419190	No Data	GRTS-2	
D	Alternate	42366	S.E. Commencement Bay	Pierce	Puyallup-White	47.283090	-122.425310	No Data	GRTS-2	

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
E	Target	294	Thea Foss Waterway	Pierce	Puyallup-White	47.249161	-122.431663	3	PSAMP/NOAA	0.126
E	Target	295	Thea Foss Waterway	Pierce	Puyallup-White	47.258048	-122.434440	12	PSAMP/NOAA	0.126
E	Target	296	Thea Foss Waterway	Pierce	Puyallup-White	47.258856	-122.435090	13	PSAMP/NOAA	0.126
E	Alternate	48792	S.E. Commencement Bay	Pierce	Puyallup-White	47.243100	-122.430360	No Data	GRTS-2	
E	Alternate	52888	S.E. Commencement Bay	Pierce	Puyallup-White	47.258420	-122.435310	No Data	GRTS-2	
E	Alternate	61080	S.E. Commencement Bay	Pierce	Puyallup-White	47.262300	-122.436280	No Data	GRTS-2	
F	Target	297	Middle Waterway	Pierce	Puyallup-White	47.265278	-122.433330	13	PSAMP/NOAA	0.016
F	Target	298	Middle Waterway	Pierce	Puyallup-White	47.264583	-122.433471	8	PSAMP/NOAA	0.016
F	Target	299	Middle Waterway	Pierce	Puyallup-White	47.264305	-122.432778	12	PSAMP/NOAA	0.016
F	Alternate	99992	S.E. Commencement Bay	Pierce	Puyallup-White	47.263430	-122.430770	No Data	GRTS-2	
F	Alternate	116376	S.E. Commencement Bay	Pierce	Puyallup-White	47.261420	-122.429400	No Data	GRTS-2	
F	Alternate	149144	S.E. Commencement Bay	Pierce	Puyallup-White	47.264920	-122.432890	No Data	GRTS-2	
G	Target	300	Blair Waterway	Pierce	Puyallup-White	47.262173	-122.388040	18	PSAMP/NOAA	0.387
G	Target	301	Blair Waterway	Pierce	Puyallup-White	47.261965	-122.387280	18	PSAMP/NOAA	0.387
G	Target	302	Blair Waterway	Pierce	Puyallup-White	47.258420	-122.381210	18	PSAMP/NOAA	0.387
G	Alternate	42648	S.E. Commencement Bay	Pierce	Puyallup-White	47.270080	-122.418200	No Data	GRTS-2	
G	Alternate	46142	S.E. Commencement Bay	Pierce	Puyallup-White	47.262940	-122.387380	No Data	GRTS-2	

Polygon ID	Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
G	Alternate	46148	S.E. Commencement Bay	Pierce	Puyallup-White	47.278660	-122.411310	No Data	GRTS-2	
H	Target	303	Hylebos Waterway	Pierce	Puyallup-White	47.275728	-122.386020	11	PSAMP/NOAA	0.223
H	Target	304	Hylebos Waterway	Pierce	Puyallup-White	47.278648	-122.398431	14	PSAMP/NOAA	0.223
H	Target	305	Hylebos Waterway	Pierce	Puyallup-White	47.280316	-122.401471	8	PSAMP/NOAA	0.223
H	Alternate	43076	S.E. Commencement Bay	Pierce	Puyallup-White	47.279200	-122.396080	No Data	GRTS-2	
H	Alternate	44094	S.E. Commencement Bay	Pierce	Puyallup-White	47.275930	-122.384600	No Data	GRTS-2	
H	Alternate	48190	S.E. Commencement Bay	Pierce	Puyallup-White	47.265040	-122.363820	No Data	GRTS-2	

GRTS-1: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.06 km^2 grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

GRTS-2: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.00184 km^2 grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

PSAMP/NOAA: NOAA's National Status and Trends program randomly chosen sites within designated polygons or strata (Paul et al., 1992; Hyland et al., 2000).

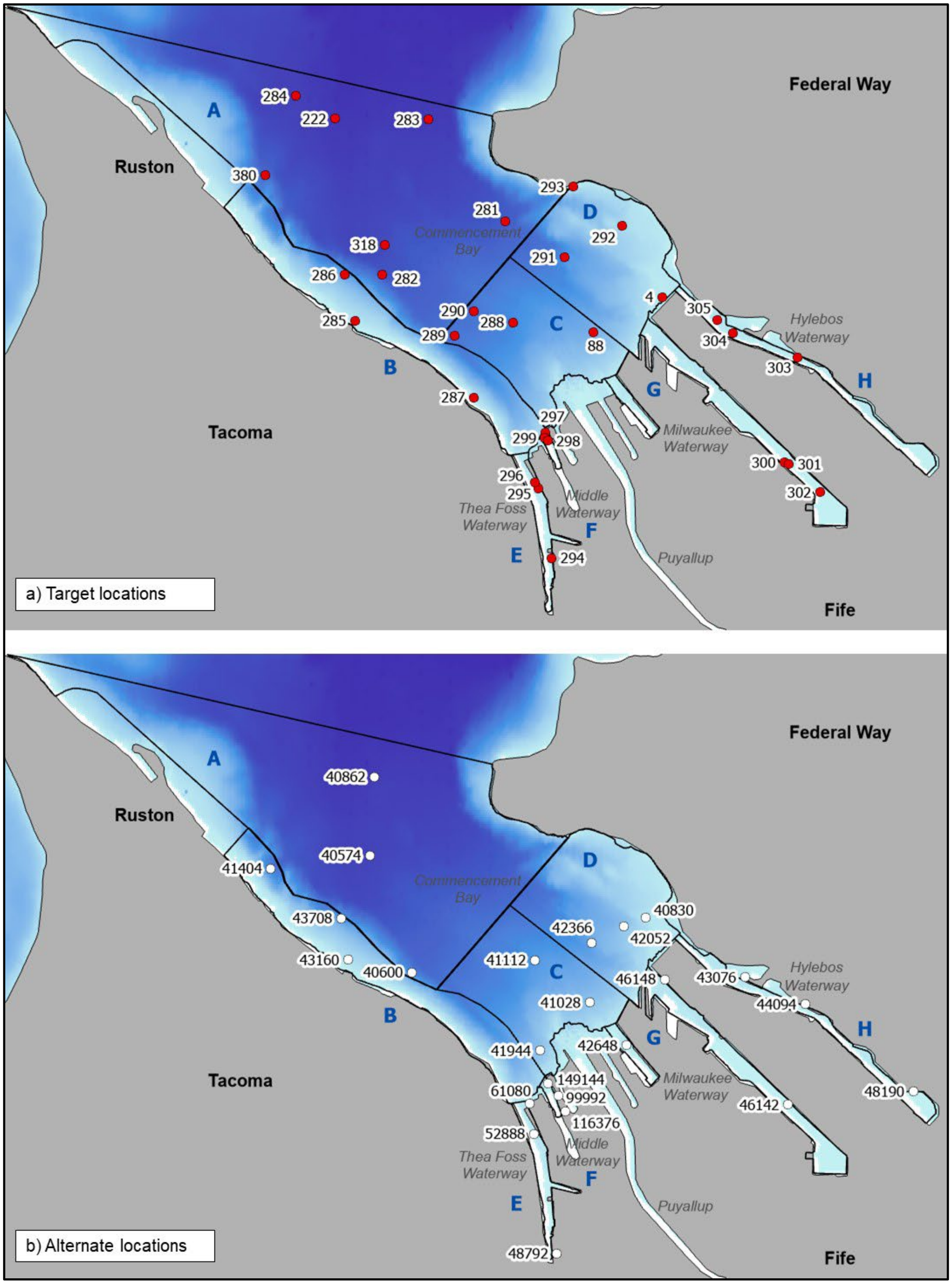

Figure 9. Commencement Bay sampling frame and monitoring station locations.

Budd Inlet

Most of the previously sampled stations in Budd Inlet were drawn from the GRTS designs with only 6 from the PSAMP/NOAA design. Therefore, alternate coordinates are chosen from the GRTS-2 design without stratification. All stations in Budd Inlet are equally weighted, each representing 0.578 km² of the total 17.350 km² area.

Table 16. Urban Bay stations for Budd Inlet.

Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
Target	PSUW012	Budd Inlet	Thurston	Deschutes	47.124070	-122.907050	14	GRTS-1	0.578
Target	PSUW020	Budd Inlet	Thurston	Deschutes	47.081540	-122.914730	5	GRTS-1	0.578
Target	PSUW084	Budd Inlet	Thurston	Deschutes	47.100080	-122.930650	7.5	GRTS-1	0.578
Target	PSUW100	Budd Inlet	Thurston	Deschutes	47.062410	-122.897780	4.5	GRTS-1	0.578
Target	PSUW116	Budd Inlet	Thurston	Deschutes	47.131270	-122.910920	15	GRTS-1	0.578
Target	PSUW140	Budd Inlet	Thurston	Deschutes	47.122420	-122.909330	14	GRTS-1	0.578
Target	PSUW148	Budd Inlet	Thurston	Deschutes	47.098750	-122.911610	10	GRTS-1	0.578
Target	PSUW228	Budd Inlet	Thurston	Deschutes	47.056800	-122.908990	8.5	GRTS-1	0.578
Target	PSUW244	Budd Inlet	Thurston	Deschutes	47.145880	-122.920640	30	GRTS-1	0.578
Target	PSUW268	Budd Inlet	Thurston	Deschutes	47.110600	-122.903080	10	GRTS-1	0.578
Target	PSUW300	Budd Inlet	Thurston	Deschutes	47.052669	-122.905736	13	GRTS-1	0.578
Target	PSUW556	Budd Inlet	Thurston	Deschutes	47.045097	-122.904651	3.5	GRTS-1	0.578
Target	UW40056	Budd Inlet	Thurston	Deschutes	47.064580	-122.902700	5	GRTS-2	0.578
Target	UW40216	Budd Inlet	Thurston	Deschutes	47.099170	-122.916110	11	GRTS-2	0.578
Target	UW40272	Budd Inlet	Thurston	Deschutes	47.126330	-122.905710	19	GRTS-2	0.578
Target	UW40528	Budd Inlet	Thurston	Deschutes	47.119280	-122.915730	15	GRTS-2	0.578
Target	UW40728	Budd Inlet	Thurston	Deschutes	47.089060	-122.908770	5.5	GRTS-2	0.578
Target	UW40984	Budd Inlet	Thurston	Deschutes	47.080670	-122.909880	7	GRTS-2	0.578
Target	UW41040	Budd Inlet	Thurston	Deschutes	47.105510	-122.894200	7	GRTS-2	0.578
Target	UW41240	Budd Inlet	Thurston	Deschutes	47.096400	-122.911970	9	GRTS-2	0.578
Target	UW41296	Budd Inlet	Thurston	Deschutes	47.098530	-122.896040	5.5	GRTS-2	0.578
Target	UW41552	Budd Inlet	Thurston	Deschutes	47.117750	-122.900430	12	GRTS-2	0.578
Target	UW41680	Budd Inlet	Thurston	Deschutes	47.135080	-122.922850	27	GRTS-2	0.578

Station type (Target or Alternate)	Station	Location	County	Watershed WRIA	Latitude (NAD83HARN)	Longitude (NAD83HARN)	Approx. Depth (m)	Sampling Scheme	Station Weight (km^2)
Target	UW41752	Budd Inlet	Thurston	Deschutes	47.104280	-122.924960	7	GRTS-2	0.578
Target	UWNO236	Budd Inlet	Thurston	Deschutes	47.114230	-122.896950	9	PSAMP/NOAA	0.578
Target	UWNO237	Budd Inlet	Thurston	Deschutes	47.129270	-122.913780	11	PSAMP/NOAA	0.578
Target	UWNO241	Budd Inlet	Thurston	Deschutes	47.135460	-122.914490	11	PSAMP/NOAA	0.578
Target	UWNO242	Budd Inlet	Thurston	Deschutes	47.052860	-122.897360	5	PSAMP/NOAA	0.578
Target	UWNO243	Budd Inlet	Thurston	Deschutes	47.051638	-122.895880	3	PSAMP/NOAA	0.578
Target	UWNO244	Budd Inlet, Port of Olympia	Thurston	Deschutes	47.057500	-122.909100	2	PSAMP/NOAA	0.578
Alternate	41880	Budd Inlet	Thurston	Deschutes	47.076530	-122.920050	No Data	GRTS-2	
Alternate	42008	Budd Inlet	Thurston	Deschutes	47.046480	-122.906040	No Data	GRTS-2	
Alternate	42064	Budd Inlet	Thurston	Deschutes	47.102610	-122.907590	No Data	GRTS-2	
Alternate	42264	Budd Inlet	Thurston	Deschutes	47.100070	-122.924640	No Data	GRTS-2	
Alternate	42320	Budd Inlet	Thurston	Deschutes	47.096530	-122.903690	No Data	GRTS-2	
Alternate	42576	Budd Inlet	Thurston	Deschutes	47.123880	-122.905690	No Data	GRTS-2	
Alternate	42704	Budd Inlet	Thurston	Deschutes	47.129820	-122.918890	No Data	GRTS-2	
Alternate	42776	Budd Inlet	Thurston	Deschutes	47.088820	-122.924580	No Data	GRTS-2	
Alternate	42904	Budd Inlet	Thurston	Deschutes	47.069030	-122.916510	No Data	GRTS-2	
Alternate	43032	Budd Inlet	Thurston	Deschutes	47.074660	-122.916100	No Data	GRTS-2	

GRTS-1: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.06 km^2 grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

GRTS-2: spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design based on 0.00184 km^2 grid (Stevens, 1997; Stevens and Olsen 1999, 2003, 2004)

PSAMP/NOAA: NOAA's National Status and Trends program randomly chosen sites within designated polygons or strata (Paul et al., 1992; Hyland et al., 2000).

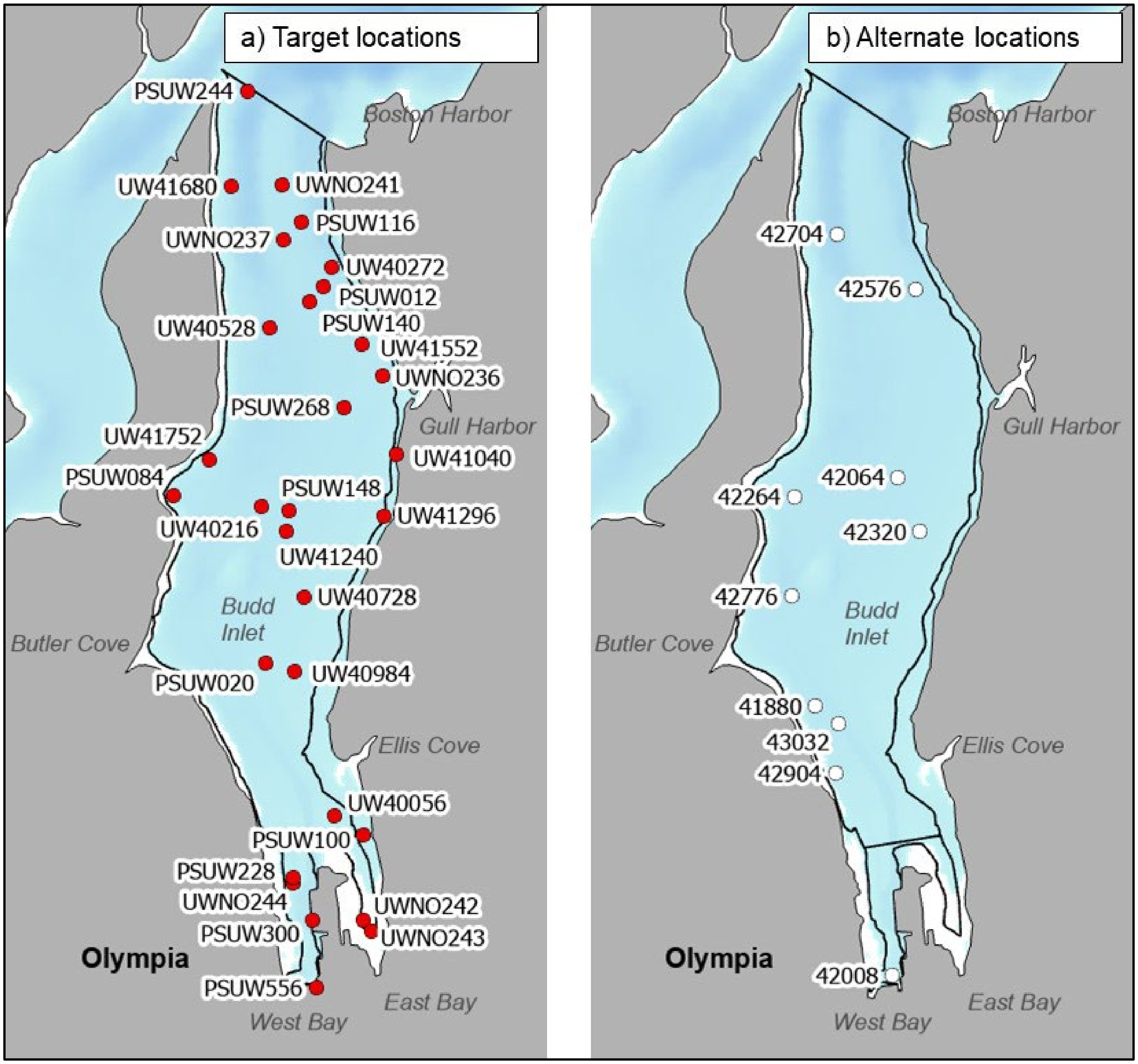

Figure 10. Budd Inlet sampling frame and monitoring station locations.

7.2.2 Field parameters and laboratory analytes to be measured

For Long-Term monitoring, all benthic or infaunal samples and measurements, and all sediment sample field measurement, physical, and biogeochemical parameters will be collected annually at the 50 stations. A complete set of sediment chemistry data for all 50 stations will be available every five years. Sediment chemistry parameters, listed in table 17, will be measured at 10 of the 50 stations each year on the following schedule:

- **2023** chemistry stations: 191, 281, 40005, 40006, 40007, 40008, 40009, 40010, 40011, 40012
- **2024** chemistry stations: 21, 34, 40, 40013, 40015, 40016, 40017, 40018, 40019, 40020
- **2025** chemistry stations: 40021, 40022, 40025, 40026, 40027, 40028, 40029, 40030, 40032, 40034
- **2026** chemistry stations: 3, 4, 13, 29, 38, 44, 49, 40036, 40037, 40038
- **2027** chemistry stations: 19, 52, 119, 209R, 222, 252, 265, 305R, BLL009, HCB003

Table 17. Parameters measured in sediments for the Marine Sediment Monitoring Program.

+Denotes calculated values (see Section 14).

Benthic infauna

Total abundance$^+$
Major taxa abundance$^+$
Taxa richness$^+$
Pielou's evenness$^+$
Swartz's dominance index$^+$
Size class
Biomass$^+$

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

7.3 Modeling and analysis design

Not applicable.

7.3.1 Analytical framework

Not applicable.

7.3.2 Model setup and data needs

Not applicable.

7.4 Assumptions underlying design

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 conditions within the sediment and benthic infaunal assemblage. 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. Station locations, monitoring methods, and schedules are updated as information priorities and logistics evolve. Any updates will be captured in future addenda to this monitoring plan or, if significantly different, will be captured in a new Quality Assurance Monitoring Plan.

7.5.1 Logistical problems

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 has occasionally been denied. When access is denied, stations are rejected and replaced with alternates which are outside the restricted areas.

Sediment type

The target population for this project is the top 2-3 cm of soft sediment and the benthic organisms that dwell within the sediments up to 17 cm in depth. Samples are collected with a modified van Veen 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 are rejected and replaced with alternate stations.

7.5.2 Practical constraints

Budgetary resources

Funding for the Sediment Program requires staff to conduct sample collection and analysis. EAP's Marine Monitoring Unit (MMU) supervisor and the Marine Sediment Monitoring Team (MSMT) lead must work with EAP's Management Team to ensure adequate annual funding. 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 data and knowledge gaps.

Staffing capacity

Sample collection on the Ecology vessels typically requires (1) three MSMT members to collect samples and operate the winch, and (2) at least one, preferably two, of the Environmental Assessment Program's (EAP's) 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 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

After 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. Benthic infaunal samples will be processed by the MSMT in Ecology's benthic lab, with QA performed by contract taxonomists. Careful planning of sample intake and flow is needed to ensure timely processing of samples.

7.5.3 Schedule limitations

Even with the best planning, challenges may arise when working on marine waters and with contract vendors, such as unfavorable weather and tidal conditions, changes in staffing, and equipment issues. Every effort is made to sample all scheduled stations and obtain credible and timely results. Whenever possible, field work is rescheduled until completed. The following activities will help mitigate potential scheduling issues:

- Prepare and implement annual schedule to ensure that adequate time is provided for
  - QAMP review and approval
  - Obtaining sampling permits
  - Successful contract awards to vendors
  - Confirm laboratory capacity
- Schedule multiple field back-up dates
- Train multiple staff on field procedures
- Have back-up platform options (viable Ecology sampling platforms are Salish Seacat and Skookum)
- Maintain interchangeable sets of auxiliary equipment, ensure equipment is well maintained, and thoroughly check functionality before starting fieldwork.

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 v2.3; Parsons et al., 2021) will be implemented.

During collection of sediments and benthic infauna 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 benthic infauna will be conducted at or within five nautical miles of the collection site. Additionally, both the van Veen 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

Field sampling and field analyses Standard Operating Procedures (SOPs) have been established for the Marine Sediment Monitoring Program and are listed in section 6.2.2. These protocols are followed during all sampling efforts. If deviations from the protocols occur, a brief explanation is given in the addenda to this plan.

8.3 Containers, preservation methods, holding times

Recommended sample sizes, containers, preservation techniques, and holding times for all sediment, and samples of benthic infauna are those listed for the PSEP (1997a), the MEL's Lab User's Manual (MEL, 2016), or from published laboratory methods, and are summarized in Table 18.

Table 18. Sample containers, preservation, and holding times for Marine Sediment Monitoring Program.

Parameter	Minimum Quantity Required	Container	Preservative	Holding Time
Benthic Infauna	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	Minimum of 48 hours to a maximum of 14 days
Grain Size/Archive	8 oz.	8-oz wide-mouth polyethylene jar with Teflon-lined lid	Refrigerate at 4ºC	6 months
Total Carbon, Total Organic Carbon, Total Inorganic Carbon, and 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	10-mL polyethylene centrifuge tubes	Refrigerate at 4ºC or freeze at -18°C	Indefinite
Total Sulfides	2 oz.	2-oz wide-mouth glass jar with Teflon-lined lid	4°C, 5ml of 2 N zinc acetate for a 250 ml bulk sediment 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 Whirlpack bag (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	6 months at 4ºC or 2 years at -18ºC
PAHs and 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 and 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

8.4 Equipment decontamination

Equipment decontamination procedures will follow Ecology's SOP EAP039 v1.4 (Weakland, 2021). 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. These precautions are taken to avoid contamination of the samples from engine exhaust, atmospheric particulates, and rain.

8.5 Sample ID

All collected sediment samples are labeled with preprinted waterproof labels to the outside of the containers with indicating the project, station ID, MEL ID number (when appropriate), date of collection, and analysis to be performed. 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 benthic infaunal 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.

8.6 Chain of custody

Chain-of-custody procedures will follow those recommended by PSEP (1997a), with modifications to include the use of 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 Ecology Operations Center (OC). There, biogeochemistry and chemistry 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. 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.

Benthic infaunal 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 rescreening, sorting, and identification, and a chain-of-custody form is used when samples are sent to a contract lab for Quality Assurance taxonomic identification.

8.7 Field log requirements

Information on station positioning and station and sample disposition are recorded in a digital field log. The following information must be included in the field logs for every sample that is collected:

- station identification
- collection success
- crew
- collection gear
- collection coordinates
- sample description
- parameters collected
- grab penetration depth
- sediment temperature
- overlying water salinity
- presence of wood, shell, or plant materials
- sediment odor
- collection date and time
- station depth

A paper log is brought along on every survey to use as a backup if the electronic form or device should fail. Digital copies of the field and sample logs are stored for future reference on a shared, secure network that is frequently backed up.

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 in the schedule will be communicated to MEL and the contract labs so they can revise their plans accordingly.

Briefings for field staff and boat operators

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

Excess sample and waste disposal

Disposal of all samples will occur at the end of the tests using acceptable methods. Waste formalin, retained during the benthic infaunal sample rescreening process, is considered hazardous waste, and is disposed of through Ecology's hazardous waste contractor.

9.0 Laboratory Procedures

9.1 Lab procedures table

See Table 19.

9.2 Sample preparation methods

Standard preparation, extraction, and cleanup techniques for laboratory analyses are shown in Table 19.

9.3 Special method requirements

Not applicable.

9.4 Lab accredited for methods

All labs performing grain size, biogeochemistry, and chemistry 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 labs for analysis of sediment for grain size determined by laser diffraction, biogenic silica, or analysis of stable isotopes of C and N. For these parameters, the accreditation requirement has been waived based on laboratory experience and demonstration of method performance. Neither does Ecology accredit for benthic infaunal taxonomic analysis or benthic community assessment. The Sediment Program instead relies on regional taxonomic experts to conduct this work following established QC protocols.

Table 19. Laboratory methods and reporting limits for parameters measured in bulk sediments at 50 Long-Term and 30-36 Urban Bays stations annually.

Analyte	Labora-tory type	Expected Range of Results	Sample Prep Method	Clean-up Method	Analytical Method	Technique/ Instrument	Reporting Limit
Particle Size Distribution referred to as Grain size	Contract lab	<20% - >80% silt+clay	Not applicable	Not applicable	Norton, 2019 (prepped with natural sediment)	Laser diffraction	0.1%
Total carbon, Total organic, carbon, Total inorganic, carbon, Total nitrogen	MEL	0.1-7.2%	70°C drying; vapor phase acidification (HCl) for organic and inorganic particulate C	Not applicable	EPA method 440.0, Revision 1.4 (after Hedges and Stern, 1984)	CE-440 Elemental Analyzer; Exeter Analytical, Inc.	0.1%
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes	Contract lab	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.	Not applicable	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	MEL	5.0 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.	Not applicable	Plumb, 1981; PSEP, 1986	Iodometric titration and methylene blue colorimetry	10.0 mg/kg dry weight (to nearest 0.1 unit)
Biogenic Silica	Contract lab	1 – 8 mM	Sample preparation by freeze drying and grinding, followed by rapid wet-alkaline extraction of biogenic silica.	Not applicable	Mortlock and Froelich, 1989	Measurement of dissolved silicon concentration in extract by molybdate-blue spectrophotometry.	0.1%
Metals (except mercury)	MEL	< 0.1 - 500 ppm (up to 1500 for zinc)	EPA 3050B	Not applicable	EPA 6020B	ICP-MS	0.1 mg/kg wet weight (0.2 for Sn, 0.5 for Cr and Se, 5.0 for Zn)

Analyte	Labora-tory type	Expected Range of Results	Sample Prep Method	Clean-up Method	Analytical Method	Technique/ Instrument	Reporting Limit
Total mercury	MEL	0.05-10 ppm	EPA 245.5	Not applicable	EPA 245.5	CVAA	0.05 mg/kg wet weight
Phthalate esters	MEL	0.001-10 ppm	EPA 3541	EPA 3620C	EPA 8270D	MEL modification with capillary GC/MS analysis	0.5-2.0 µg/kg wet weight
Polycyclic aromatic hydrocarbons (PAHs)	MEL	0.01 – 50,000 ppb	EPA 3541	EPA 3620C	EPA 8270D with isotopic dilution	MEL modification with capillary GC/MS-SIM isotopic dilution analysis	0.5-2.0 µg/kg wet weight
PCB Aroclors	MEL	1 – 4,000 ppb	EPA 3541	EPA 3620/ 3665	EPA 8082A	GC- ECD	2.5 µg/kg dry weight
PCB congeners	MEL	< 0.1 – 4,000 ppb	EPA 3541	EPA 3620/ 3665	EPA 8082A	GC- ECD	0.5 µg/kg dry weight
PBDE congeners	MEL	< 0.1 – 4,000 ppb	EPA 3541	EPA 3620/ 3665	EPA 8270D	Capillary GC/MS-SIM	0.4-2.0 µg/kg dry weight
Infaunal Sorting	ECY benthic lab	All invertebrates encountered, sorted into 5 major phyla groups	Not applicable	Not applicable	EAP043 v1.4		1 individual
Taxonomic identification, size-classing, and enumeration	ECY benthic lab	Count of all invertebrates encountered in each taxon-specific size class	Not applicable	Not applicable	EAP043 v1.4		1 individual
Estimated Infaunal Biomass	ECY benthic lab	Estimated weight in grams, of all invertebrates encountered	Not applicable	Not applicable	EAP126 v1.2		0.0001 g

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.

See Table 8 for field and laboratory MQOs (Section 6.2.1) that will be used to evaluate the quality and usability of the results.

The ongoing effort to provide high-quality data occurs in many steps before, during, and after data collection. QA/QC procedures include the following activities:

- Training personnel
- Preparing, maintaining, and following SOPs
- Maintaining equipment
- Calibrating equipment
- Field data and analytical laboratory and QA/QC procedures (see Section 11.2)
- Performing proper sample chain of custody (see Section 8.6)
- Performing proper data and information management
- Verifying data through regular data review and validating using EPA guidelines
- Assessing data usability (see Section 14)
- Conducting audits (see Section 12)

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.

10.1 Table of field and laboratory quality control

Table 20. Quality control samples, types, and frequency for the Marine Sediment Monitoring Program.

Parameter	Field replicate (% of stations)	Laboratory Replicate	Lab Control Standard (LCS) % Recovery	Standard or Certified Reference Material (SRM/CRM) % Recovery	Matrix Spike (MS) % Recovery	Matrix Spike Duplicate (MSD)	Surrogate Spike % Recovery	Method Blank
Percent Solids	%5	Duplicate 1/batch of 20	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	2/batch of 20
Grain Size	%5	Duplicate 1/batch of 20	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	1/batch of 20
Total carbon, Total organic carbon, Total inorganic carbon, and Total nitrogen	%5	Triplicate 1/batch of 20	1/batch of 20	1/batch of 20, except total nitrogen	Not applicable	Not applicable	Not applicable	1/batch of 20
Total sulfides	%5	Duplicate 1/batch of 20	1/batch of 20	Not applicable	1/batch of 20	Not applicable	Not applicable	1/batch of 20
$\delta^{13}C$ and $\delta^{15}N$ stable isotopes	%5	Duplicate 1/batch of 20	1/batch of 20	1/batch of 20	Not applicable	Not applicable	Not applicable	1/batch of 20
Biogenic silica	%5	Duplicate 1/batch of 20	1/batch of 20	1/batch of 20	Not applicable	Not applicable	Not applicable	1/batch of 20
Metals (except mercury)	%5	MS/MSD serve as lab duplicate	1 LCS + 1 LCS duplicate/ batch of 20	1/batch of 20	1/batch of 20	1/batch of 20	Not applicable	1/batch of 20
Total mercury	%5	MS/MSD serve as lab duplicate	1 LCS + 1 LCS duplicate/ batch of 20	1/batch of 20	1/batch of 20	1/batch of 20	Not applicable	1/batch of 20
Phthalates	%5	Duplicate 1/batch of 20	1 LCS + 1 LCS duplicate/ batch of 20	1/batch of 20	1/batch of 20	1/batch of 20	all samples including QC	1/batch of 20
Polycyclic aromatic hydrocarbons (PAHs)	%5	Duplicate 1/batch of 20	1 LCS + 1 LCS duplicate/ batch of 20	1/batch of 20	1/batch of 20	1/batch of 20	all samples including QC	1/batch of 20
Polychlorinated biphenyls (PCBs) - Aroclors	%5	Duplicate 1/batch of 20	1 LCS + 1 LCS duplicate/ batch of 20	1/batch of 20	1/batch of 20	1/batch of 20	all samples including QC	1/batch of 20
Polychlorinated biphenyls (PCBs) - Congeners	%5	Duplicate 1/batch of 20	1 LCS + 1 LCS duplicate/ batch of 20	1/batch of 20	1/batch of 20	1/batch of 20	all samples including QC	1/batch of 20
Polybrominated diphenyl ethers (PBDEs) - Congeners	%5	Duplicate 1/batch of 20	1 LCS plus 1 LCS duplicate/ batch of 20	1/batch of 20	1/batch of 20	1/batch of 20	all samples including QC	1/batch of 20
Infaunal Sorting	triplicate of first time visited stations	25% of each sample resorted	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Taxonomic Identification and enumeration	triplicate of first time visited stations	Re-identifi-cation of 5% of all samples	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Estimated Infaunal Biomass	triplicate of first time visited stations	Not applicable	100% check against reference collection	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

11.0 Data Management Procedures

11.1 Data recording and reporting requirements

Data and information management are critical to maintaining an efficient, organized, long-term monitoring system capable of generating high-quality, up-to-date, informative products for managers and scientists. Data used for analysis and reporting and distributed to the public must pass all QA/QC. The Environmental Information System (EIM) database is used to facilitate distribution and long-term secure storage of sediment data. The data for Long-Term and Urban Bays programs are stored under the Study IDs PSEMP_LT and UWI, respectively. Figure 11 depicts the organization of the data workflow and products generated.

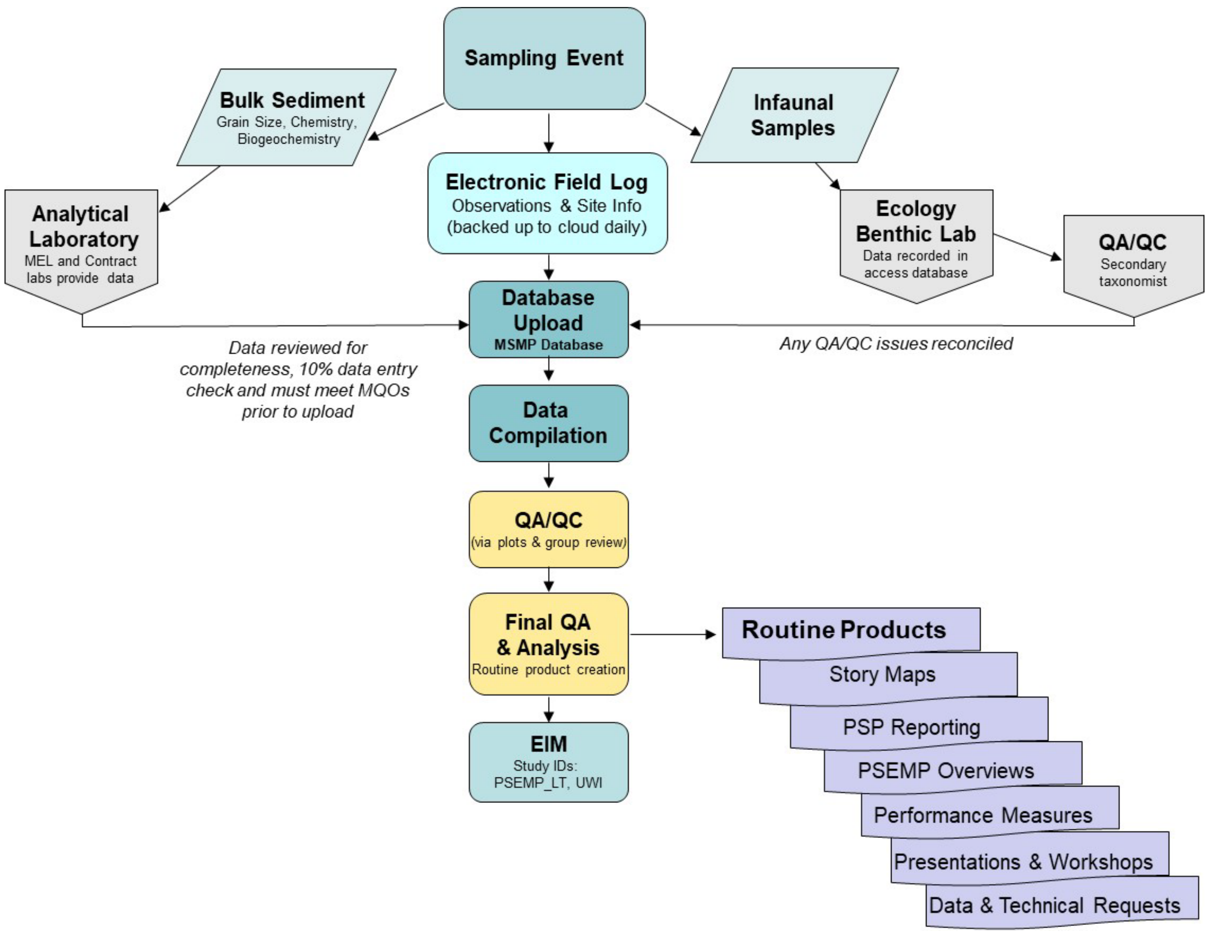

Figure 11. Data workflow for the Marine Sediment Monitoring Program.

11.2 Laboratory data package requirements

Data packages from contract laboratories will include:

- 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 laboratory 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 data received from external providers are verified and reviewed by MSMT staff. Any discrepancies are discussed with the laboratories or contractors for amendment. Once data have been reviewed and verified, MSMT staff enter final data into EIM database.

11.3 Electronic transfer requirements

All contract labs will be required to submit data electronically in Ecology's EIM templates. These are pre-formatted 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://apps.ecology.wa.gov/eimhelp/).

11.4 EIM data upload procedures

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.

11.5 Model information management

Not applicable.

12.0 Audits and Reports

12.1 Field, laboratory, and other 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.

All labs 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 labs, 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 infaunal 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.

12.3 Frequency and distribution of reports

MSMT staff will be responsible for analyzing annual sediment and benthic infaunal data and determining how the results will be summarized and documented for the Long-Term and Urban Bays monitoring. 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.

Reporting will occur annually for the Urban Bays element and on a 5-year cycle for the Long-term element. Additionally, MSMT staff regularly produce the following products:

- Focus sheets
- Interactive story maps
- Interactive data dashboards
- Puget Sound Partnership reports
- PSEMP workgroup overviews
- Technical memos
- Performance measures
- Eyes Under Puget Sound blog posts, including Critter of the Month
- Peer-reviewed journal publications
- Presentations, conferences, and workshops
- Data and technical requests

12.4 Responsibility for reports

Report authors will vary for different reports generated for this program and will be identified 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.
- Data are consistent, correct, and complete, with no errors or omissions.
- 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, senior staff 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, particularly with the new implementation of electronic field logs.

13.2 Laboratory data verification

MSMT personnel will check all data received against the following verification criteria:

- 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

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

Not applicable.

13.4 Model quality assessment

Not applicable.

13.4.1 Calibration and validation

Not applicable.

13.4.1.1 Precision

Not applicable.

13.4.1.2 Bias

Not applicable.

13.4.1.3 Representativeness

Not applicable.

13.4.1.4 Qualitative assessment

Not applicable.

13.4.2 Analysis of sensitivity and uncertainty

Not applicable.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

Upon completion of the data verification process, a Data Quality (Usability) Assessment will be conducted (Lombard and Kirchmer, 2004). Data from all field and lab procedures will be examined to determine whether the data 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. The data 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 non-detects

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 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, weighted-mean and CDF-comparison analyses (Kincaid, 2000; Kincaid et al., 2016) will be conducted on detected values only. CDFs will be drawn only when the detection rate is ≥ 90%. Confidence intervals will not be 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). 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 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), hierarchical agglomerative clustering, or other graphical descriptive procedures. Appropriate measures of similarity are calculated, depending on the type of data (currently, the Bray-Curtis similarity measure is used for benthic invertebrates and Euclidean distance is used 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 21).

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 of Dutch et al., 2018). 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 of Dutch et al., 2018.

Table 21. Calculated parameters for Long-Term and Urban Bays monitoring.

Calculated parameter	Definition	Calculation
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 Dominance Index (SDI)(Swartz et al., 1985)	The minimum number of taxa whose combined abundance accounts for 75% of the total abundance in each sample	Sum of the minimum number of taxa whose combined abundance accounts for 75% of the total abundance in each sample
Size class	Organisms are separated into five species-specific size classes based on length: small, medium, large, x-large, and megafauna	Length and wet-weight are measured for reference specimens for each taxon and size class. Averages are then calculated for each taxon and size class combination.
Biomass	The mass of living biological organisms in a given area or ecosystem at a given time	Biomass estimates are averages of size-specific weights of reference specimens for each taxon. Megafaunal organisms (those weighing > 2 g) are analyzed separately and excluded from the results shown because their large mass has the potential to skew the dataset.
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. Reports must state explicitly which calculation was used to generate the results.
$\delta^{13}C$	Isotopic signature of carbon, based on relative abundances of two stable isotopes, ^{13}C and ^{12}C, in a sample compared to a standard	$\delta^{13}\mathrm{C} = \left[\frac{(^{13}\mathrm{C}/^{12}\mathrm{C})_{sample}}{(^{13}\mathrm{C}/^{12}\mathrm{C})_{standard}}\right] \times 1000$
$\delta^{15}N$	isotopic signature of nitrogen, based on relative abundances of two stable isotopes, ^{15}N and ^{14}N, in a sample compared to air:	$\delta^{15}\mathrm{N} = \left[\frac{(^{15}\mathrm{N}/^{14}\mathrm{N})_{sample}}{(^{15}\mathrm{N}/^{14}\mathrm{N})_{air}}\right] \times 1000$
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.

Calculated parameter	Definition	Calculation
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, and 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.. The data are tested for normality. If tests for normality are rejected, i.e., the data are not normally distributed or if the plot of the two variables indicates strong non-linearity, a nonparametric measure of association (usually Spearman's rho) is calculated. Otherwise, we calculate the Pearson correlation coefficient.

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 benthic assemblages and habitat variables (Anderson et al., 2008). Techniques such as partial least squares regression may be used to find relationships between habitat and chemical variables.

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 using EPA's spsurvey analysis routines (Kincaid et al., 2016). 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 with sediment quality indicators meant to inform environmental managers about the current condition of sediments collected from stations and sampling frames for this program.

The Sediment Chemistry Index (Appendix B-1 of Dutch et al., 2018) is calculated for chemical contaminants in bulk sediments. While the Sediment Chemistry Index is based on sediment criteria set forth by the Washington State Sediment Management Standards (WAC 173-204) (Ecology, 2013), it is not used for regulatory purposes.

A new Marine Benthic Index (Partridge and Schoolmaster, 2022) for assessment and reporting of benthic conditions is currently in testing. A graphical causal model (Partridge and Schoolmaster, 2022) for testing of hypotheses of causation and effects of management actions is currently in development.

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 of Dutch et al., 2018).

Four quality categories, characterizing sediment exposure to toxic contaminants from minimum to maximum exposure 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 impairment to benthic assemblages (Appendix B-1 of Dutch et al., 2018; 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.

Benthic Infaunal Assemblage

A new Marine Benthic Index (Partridge and Schoolmaster, 2022) is currently in development and testing. The Marine Benthic Index has been developed using methods adapted from the fields of machine learning (artificial intelligence) and causal inference (statistical modeling). The approach uses broadscale environmental drivers and patterns of benthic species occurrence and abundance to inform an estimate of human-caused impact, with uncertainty. These estimates can be used to screen for hypothesized environmental responses of human disturbance.

Although the reporting format for the Marine Benthic Index has not yet been finalized, interim results have been summarized in several ways. The index can be expressed as a standard normal variate centered at zero or transformed by integration to a (0,1) scale centered at 0.5. In both cases, the variable is continuous, thus amenable to calculation of weighted means or CDFs. The combination of the Marine Benthic Index value and its confidence interval gives rise to easily-generated and easily-interpreted categories of benthic quality. The categories are then amenable to analyses of spatial extent and mapping.

The Washington State SMS considers benthic assemblages to be adversely affected when 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). This method has limitations and is not a widely accepted procedure for classifying benthic assemblages in Puget Sound (Long et al., 2005). However, at present there are no plans to use the Marine Benthic Index for regulatory purposes.

Other Parameters

There are no existing regulatory criteria or standards for the new parameters added in the program redesign (Dutch et al., 2018), including benthic assemblage biomass, contribution to the zooplankton, and tissue chemistry (other than human consumption limits for edible crustaceans and mollusks), 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.

Puget Sound Vital Sign Indicators

The SCI was adopted by the Puget Sound Partnership in 2011 as a Puget Sound Vital Sign Indicator (O'Neill, 2014; PSP, 2017). With the 2020 revision of the Puget Sound Vital Signs the SCI is now included as an indicator of the Marine Water Vital Sign (McManus et al., 2020). Vital Sign Indicators are used by stakeholders and environmental managers to assess habitat quality in Puget Sound and establish target management goals in the Puget Sound Action Agenda (PSP, 2022).

Development of the Marine Benthic Index as an indicator for the Marine Water Vital Sign was funded by the Puget Sound Partnership in 2021, for completion and adoption by 2023 (Partridge and Schoolmaster, 2022). A target value for the Marine Benthic Index has not yet been adopted by the Puget Sound Partnership; however, a draft target has been proposed that corresponds to the highest benthic quality category.

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 resampling of the same sites improves the ability to detect change beyond that of designs without resamples.

14.5 Documentation of assessment

Data usability will be documented in the Marine Sediment Monitoring Program database, EIM database and in annual reports. Data will be unqualified if all specifications are met, and the quality of the data meet the project objectives. If the MQOs have not 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. MSMT staff will be responsible for analyzing the data and determining how the results will be summarized and documented. Data and analytical results are analyzed and summarized regularly and reported in a variety of products listed in section 12.3.

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16.0 Appendix. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

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

Anthropogenic: Human-caused.

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.

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.

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.

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

50th percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 50th percentile value is a statistically derived estimate of the division between 50% of samples, which should be less than the value, and 50% of samples, which are expected to exceed the value. Also known as the **median**.

90th percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90th 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.

Acronyms and Abbreviations

CV	Coefficient of variation
D10	Particle diameter corresponding to the 10th percentile
D50	Particle diameter corresponding to the 50th percentile
D90	Particle diameter corresponding to the 90th percentile
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
GRTS-1	Generalized Random Tessellation Stratified multi-density survey design based on 0.06 km^2
GRTS-2	Generalized Random Tessellation Stratified multi-density survey design based on 0.00184 km^2 grid
i.e.	In other words
MDL	Method detection limit
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
MSMT	Marine Sediment Monitoring Team (Dept of Ecology)
NOAA	National Oceanographic Atmospheric Administration
PAH	Polycyclic aromatic hydrocarbon
PBDE	Polybrominated diphenyl ether
PCB	Polychlorinated biphenyl
PQL	Practical quantitation limit
PSAMP	Puget Sound Ambient Monitoring Program (now PSEMP)
PSEMP	Puget Sound Ecosystem Monitoring Program
QA	Quality assurance
QAMP	Quality assurance monitoring plan
QC	Quality control
RL	Reporting limit
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedure
SRM	Standard reference material
USGS	United States Geological Survey
WAC	Washington Administrative Code

Units of Measurement

°C	degrees centigrade
cm	centimeter, a unit of length equal to 0.01 (one-hundredth) meter
g	gram, a unit of mass
kg	kilogram, a unit of mass equal to 1,000 grams
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mM	millimolar, a unit of concentration equal to the number of millimoles of solute per liters of solution
mm	millimeter, a unit of length equal to 0.001 (one-thousandth) meter
mmol	one-thousandth of a mole, where a mole is defined as 6.02 x 10^{23}
mg	milligram, a unit of mass equal to 0.001 (one-thousandth) gram
mg/kg	milligrams per kilogram (parts per million)
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
µg	microgram, a unit of mass equal to 0.000001 (one-millionth) gram
µg/kg	micrograms per kilogram (parts per billion)
µmol	one-millionth of a mole, where a mole is defined as 6.02 x 10^{23}

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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