

Quality Assurance Project Plan

The Puget Sound Assessment and Monitoring Program: Sediment Monitoring Component

DEPARTMENT OF ECOLOGY
State of Washington

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Author and Contact Information

Margaret Dutch, Valerie Partridge, Sandra Weakland, Kathy Welch, Ed Long, P.O. Box 47600, Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA 98504-7710.

For more information contact Carol Norsen, Communications Consultant, Phone: 360-407-7486

Washington State Department of Ecology - www.ecy.wa.gov/

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Bellevue 425-649-7000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Yakima 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

Cover photos: Sediment sampling for the Puget Sound Assessment and Monitoring Program (Left – collection of sediment into sample jars; Center – sediment and clams collected with the vanVeen grab sampler; Right – sampling sediments from a full vanVeen grab.)

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Approved by:

Margaret Dutch, Principal Investigator and Project Manager, MMU, WOS, EAP	Date: August 2009
Signature: Sandra Weakland, EIM Data Engineer, MMU, WOS, EAP	Date: August 2009
Signature: Valerie Partridge, Co-Author, MMU, WOS, EAP	Date: August 2009
Signature: Kathy Welch, Co-Author, MMU, WOS, EAP	Date: August 2009
Signature: Ed Long, Co-Author, MMU, WOS, EAP	Date: August 2009
Signature: Carol Maloy, Unit Supervisor, MMU, WOS, EAP	Date: August 2009
Signature: Robert Cusimano, Section Manager, WOS, EAP	Date: August 2009
Signature: Stuart Magoon, Director, Manchester Environmental Laboratory, EAP	Date: August 2009
Signature: Bill Kammin, Ecology Quality Assurance Officer	Date: August 2009

Signatures are not available on the Internet version.
MMU – Marine Monitoring Unit.
WOS – Western Operations Section.
EAP - Environmental Assessment Program.

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Glossary, Acronyms, and Abbreviations

Anthropogenic – caused by humans.

Bathymetric – measurement of water depth (in Appendix B-1).

Benthic – bottom.

Benthic infauna (or **benthos**) – tiny sediment-dwelling invertebrates, including a wide variety of organisms that live on or in marine sediments.

Geological – the rocks, minerals, and physical structure of a specific area (in Appendix B-1).

Geomorphic – relating to the surface features of the Earth (in Appendix B-1).

Hydrologic – relating to the water features of the Earth (in Appendix B-1).

Infauna – organisms living within the sediments.

Infaunal – relating to infauna.

Invertebrates – animals without backbones (e.g., crustaceans, worms, clams).

Macrofauna (macrobenthos) – in this work, benthic invertebrates that are retained on a 1.0-mm mesh screen

Meiofauna (meiobenthos) – in this work, benthic invertebrates that are smaller than macrofauna, but are retained on a 1.0-mm mesh screen

Spatial extent – determination of extent of conditions in a specified geographic area.

Stratum (strata) – a segment(s) of the study area/sampling frame with a defined set of characteristics.

Temporal – relating to changes over time.

Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CDF	Cumulative Distribution Function
CSL	Cleanup Screening Levels defined in SMSDGPS Differential Global Positioning System
DMMP	Dredged Material Management Program
DQOs	Decision Quality Objectives
EAP	Ecology’s Environmental Assessment Program
Ecology	Washington State Department of Ecology
EDCs	Endocrine-disrupting compounds
EIM	Ecology’s Environmental Information Management system

EMAP	USEPA's Environmental Monitoring and Assessment Program
ERL	Effects Range Low
ERM	Effects Range Median
GIS	Geographic Information System
GRTS	Generalized Random Tessellation Stratified sampling design
KCDNRP	King County Department of Natural Resources and Parks
MEL	Ecology's Manchester Environmental Laboratory
MESA	NOAA's Marine Ecosystems Analysis Puget Sound project
MQOs	Measurement Quality Objectives
MSMT	Ecology's Marine Sediment Monitoring Team
MTCA	Model Toxics Control Act
NCA	USEPA's National Coastal Assessment program
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NS&T	National Status and Trends
PAHs	Polycyclic aromatic hydrocarbons
PBDEs	Polybrominated diphenyl ethers
PCBs	Polychlorinated biphenyls
PPCPs	Pharmaceuticals and personal care products
PSAMP	Puget Sound Assessment and Monitoring Program
PSAT	Puget Sound Action Team
PSDDA	Puget Sound Dredged Disposal Analysis program
PSEP	Puget Sound Estuary Program
PSP	Puget Sound Partnership
PSWQA	Puget Sound Water Quality Authority
QA	Quality assurance
QC	Quality control
RCW	Revised Code of Washington
SMS	Sediment Management Standards (Washington State Sediment Management Standards, Chapter 173-204 WAC)
SOP	Standard operating procedures
SQS	Sediment Quality Standards defined in SMS
SQTI	Sediment Quality Triad Index
TOC	Total organic carbon
USEPA	U.S. Environmental Protection Agency
USACE	U.S. Army Corps of Engineers

Abstract

Sediment quality monitoring in Puget Sound has been conducted by the Washington State Department of Ecology's (Ecology's) Marine Sediment Monitoring Team (MSMT) since 1989 as part of the *Puget Sound Assessment and Monitoring Program* (PSAMP). Quality assurance parameters for the Sediment Monitoring Component of PSAMP were described and published at the inception of the program.

Since then, the sediment monitoring program has evolved. Elements from both the National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends (NS&T) Bioeffects Monitoring Program and the Environmental Protection Agency's Environmental Monitoring and Assessment Program (USEPA EMAP) have been incorporated. Portions of the original monitoring design have been retained on a small scale, while two new elements have been added.

Three distinct sampling elements, with different goals and sampling designs, are now conducted. They include the:

- Long-Term/Temporal Monitoring Element – Characterization of change in sediment quality over time at 10 long-term stations.
- Spatial/Temporal Monitoring Element – Characterization of the spatial extent of degraded sediment quality and change over time for sampling frames drawn at three geographic scales: Puget Sound, region, and stratum.
- Focus Study Element (including Ecology's Urban Waters Initiative) – Characterization of the spatial extent of degraded sediment quality and change over time at a small, local, geographic scale (e.g., embayment).

This Quality Assurance (QA) Project Plan describes the unique goals, study design, and methods for each element, as well as the common methods they still share.

Each study, or monitoring program, conducted by Ecology must have an approved QA Project Plan. The plan describes the objectives of the study, or monitoring program, and the procedures to be followed to achieve those objectives. Data and data summaries for each discrete segment of an ongoing monitoring element will be posted to the MSMT website as soon as they are generated and reviewed. A final report describing the results will be posted when complete.

Background

The Puget Sound Assessment and Monitoring Program

The Puget Sound Assessment and Monitoring Program (PSAMP), formerly known as the Puget Sound Ambient Monitoring Program, was developed in the late 1980s as a legislatively-mandated, long-term program designed to assess and monitor the health of the Puget Sound ecosystem. Tasks were assigned to and conducted by multiple natural resource agencies, originally under the coordination of the Puget Sound Water Quality Authority (PSWQA) (PSWQA, 1988). With passage in 2007 of Engrossed Substitute Senate Bill 5372 (Appendix A), PSAMP now falls under the authority of the Puget Sound Partnership (PSP).

The Washington State Department of Ecology (Ecology) began monitoring sediment quality throughout Puget Sound in 1989 as the *PSAMP Sediment Component*. Prior to PSAMP, sediment quality assessments had been conducted periodically in various regions of Puget Sound, often as a result of regulatory requirements. Sediment monitoring had never before been conducted as a systematic Puget Sound-wide monitoring program with internally consistent methods.

Details about the origin and evolution of the *PSAMP Sediment Component*, from its inception to the present, are provided in Appendix B. Two QA Project Plans have been published describing the details of the original program design (Striplin, 1988) and modifications made to the program beginning in 1997 (Dutch et al., 1998; Dutch, 1998). This document details revisions made to the program beginning in 2002 and replaces the earlier QA Project Plans.

The Puget Sound Study Area

The overall study area encompasses the basins, channels, and embayments of Puget Sound from the U.S./Canada border to the southern-most bays and inlets near Olympia and Shelton, Hood Canal, and portions of Admiralty Inlet, the San Juan Islands, and the eastern portion of the Strait of Juan de Fuca **(**Figure 1). Located in northwestern Washington, this study area comprises a variety of interconnected shallow estuaries and bays, deep fjords, broad channels and river mouths. It is bounded by three major mountain ranges: the Olympics to the west, the mountains of Vancouver Island to the north, and the Cascade Range to the east. The northern end of Puget Sound is open to the Strait of Georgia and to the Strait of Juan de Fuca, connecting Puget Sound to the Pacific Ocean. The estuary extends for about 130 km from Admiralty Inlet to Olympia, and ranges in width from 10 to 40 km (Kennish, 1998).

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

Major rivers entering Puget Sound include the Skagit, Stillaguamish, Snohomish, Cedar, Duwamish, Puyallup, and Nisqually (Figure 1). The Skagit, Stillaguamish, and Snohomish rivers account for more than 75% of the freshwater input into the Sound. Another big contributor of freshwater is the Fraser River in British Columbia. The mean residence time for water in the central basin is approximately 120-140 days, and longer in the isolated inlets and restricted deep basins in southern Puget Sound (Kennish, 1998).

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

The Sound is bordered by both relatively undeveloped rural areas and highly developed urban and industrial areas. Major urban centers include the cities of Bellingham, Everett, Seattle, Bremerton, Tacoma, and Olympia, all of which are located at the mouths of large river systems that feed into Puget Sound's largest estuarine embayments. Currently, approximately four million people live in the Puget Sound region. It is estimated that the population will grow to nearly 5.4 million by the year 2025, resulting in an increase in development and urbanization (PSAT, 2007a).

History of Chemical Contamination of Puget Sound Sediments

Puget Sound is a highly complex, biologically important ecosystem that supports major populations of benthic infaunal invertebrates (i.e., benthos), estuarine plants, resident and migratory fish, marine birds, and marine mammals. All of these resources depend upon uncontaminated habitats to sustain their population levels.

For more than a century, Puget Sound has been used as the receiving environment for various types of wastes generated and discharged from municipal and industrial activity, dumping operations, spills, urban and agricultural runoff, and other human activity (Kennish, 1998). These wastes include both inorganic and organic toxic chemicals, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides. More recently recognized contaminants include pharmaceuticals and personal care products (PPCPs), endocrine-disrupting compounds (EDCs), and flame-retardants (polybrominated diphenyl ethers, PBDEs).

Many of the toxic chemicals entering the waters of Puget Sound become bound to suspended particles. These tend to sink to the bottom of the Sound, accumulating in deposited sediments and throughout the food chain. This matrix therefore poses an important risk of biological damage to resident marine resources.

Contaminants are found in a wide range of concentrations in surficial (recently deposited) and deep sediments around Puget Sound. Although contaminant levels in some areas have decreased since pollution controls were established in the last few decades, levels in the deep central Puget Sound basin are still significantly higher than estimated pre-industrial levels. Near urban areas, present levels of contamination are as much as 100 – 300 times the levels in the cleanest rural bays (summary from PSAMP Sediment Component database, Weakland, 2007 - personal communication). As a result, accumulation of toxicants in sediments and the resulting damage to natural populations are recognized as serious threats to the Puget Sound marine and estuarine ecosystems (PSAT, 2007a,b).

Results of Previous Studies

Sediment surveys have been conducted in Puget Sound by various organizations since the early 1950s [1]. These surveys have been conducted at various scales and with a variety of goals and objectives. They range from small-scale site assessment to determine levels and effects of toxic contamination and regulatory clean-up activity to large-scale assessment and monitoring programs.

Early Sediment Baseline Surveys

One of the earliest large-scale assessment programs was the Marine Ecosystems Analysis (MESA) Puget Sound project, conducted in the late 1970s and early 1980s by the National Oceanic and Atmospheric Administration (NOAA). Sediments, bottom-dwelling fish and crabs, and sediment-dwelling (infaunal) invertebrates were collected from Puget Sound's urban embayments (Elliott Bay and lower Duwamish River, Commencement Bay, Sinclair Inlet, Budd Inlet, Everett Harbor, and Bellingham Bay) and reference locations (Case Inlet, Port Madison, Birch Bay, and Samish Bay).

Sediments and tissues of bottom-dwelling fish and invertebrates collected for the MESA project from urban areas had higher concentrations of toxic substances than those from reference areas. Liver lesions and tumors also occurred more frequently in fish and crab in the urban areas, and assemblages of infaunal invertebrates exhibited lower abundance and species richness than those in reference areas (Malins et al., 1980, 1982, 1984; Dexter et al., 1981). Toxicity tests of sediments and water samples indicated greater deleterious effects to survival, growth, and reproduction of test organisms in urban than in non-urban areas (Chapman et al., 1982, 1983, 1984a,b).

Further sediment quality evaluation of Puget Sound urban embayments was conducted for the U.S. Environmental Protection Agency's (USEPA's) Puget Sound National Estuary Program in the 1980s in Elliott Bay and the lower Duwamish, and in Everett Harbor (Tetra Tech, Inc., 1985a,b,c,d; 1986 a,b,c; 1988; PTI Environmental Services and Tetra Tech, Inc., 1988a,b,c,d; PTI Environmental Services, 1988 a,b). Data on contaminant sources, concentration in sediments and tissues, biological effects, and sediment toxicity bioassays were used to develop Action Plans for both urban water bodies. These Action Plans provided managers with the identity of toxic problem areas and prioritization for corrective action.

[1] The earliest recorded sediment monitoring data in Ecology's Environmental Information Management (EIM) database was conducted by Richard Roberts in Puget Sound and the Strait of Juan de Fuca in 1950.

Regulatory Sediment Monitoring In Urban Embayments

Sediment and other environmental samples have been collected in Puget Sound urban embayments to determine prioritization of clean-up actions for hazardous waste sites under the federal Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Superfund program (www.epa.gov/superfund/policy/cercla.htm) and the Washington State Model Toxics Control Act (MTCA) (www.ecy.wa.gov/biblio/9406.html). Extensive sediment sampling was conducted for prioritization of CERCLA clean-up in Commencement Bay's nearshore tideflats for USEPA and Ecology in the mid 1980s (Tetra Tech, Inc., 1985e). Many small-scale, site-specific studies have measured sediment contaminants at industrial sites in Puget Sound scheduled for clean-ups under MTCA (www.ecy.wa.gov/biblio/0509092.html).

Other sediment data has been generated by programs and studies with varied purposes. The Puget Sound Dredged Disposal Analysis (PSDDA) program, which currently operates as part of the multiagency Dredged Material Management Program (DMMP)[2], (www.nws.usace.army.mil/PublicMenu/Menu.cfm?sitename=dmmo&pagename=home) was implemented in 1988 to ensure the safe disposal of sediments dredged from waterways by the U.S. Army Corps of Engineers (USACE) to open-water marine disposal. Biennial reports, summarizing dredging activity and dredge site sediment characterization from 1989-2007 are available on their web site.

The King County Department of Natural Resources and Parks (KCDNRP) (dnr.metrokc.gov/wlr/waterres/marine/index.htm) has monitored sediments in Elliott Bay and central Puget Sound since the 1980s (Stober and Chew, 1984; Stark et al., 2006, 2009). Their work is performed primarily to ensure that the county meets requirements for National Pollutant Discharge Elimination System (NPDES) sewage-discharge permits.

The sediment monitoring programs listed above have provided, and continue to provide environmental managers and regulators with information on sediment chemical contamination and overall quality primarily from urban embayments and a limited number of reference locations. They have not, however, provided information on sediment quality in most non-urban areas or how widespread sediment contamination is throughout Puget Sound. They also have not provided estimates of the areal extent of sediment quality degradation in any defined area, nor have they measured changes in sediment quality over time.

Ambient Sediment Monitoring Puget Sound-Wide

PSAMP

The *PSAMP Sediment Component*, the focus of this QA Project Plan, was created by legislative mandate in 1988 to measure and assess sediment contamination on a larger Puget Sound-wide scale (Puget Sound Water Quality Authority, 1988). This program commenced in 1989. Monitoring has focused on measuring Puget Sound-wide changes in sediment quality over time and on quantifying the spatial extent of sediment quality degradation both regionally and Puget Sound-wide (www.ecy.wa.gov/programs/eap/psamp/index.htm).

[2] The DMMP consists of four cooperating agencies, including: 1) U.S. Army Corps of Engineers, Seattle District; 2) USEPA, Region 10; 3) Ecology; and 4) the Washington Department of Natural Resources.

Data from the PSAMP Sediment Component's Historical Monitoring Element provides a baseline of detailed sediment quality information from 76 stations located primarily in non-urban areas throughout Puget Sound from 1989-1995 (Tetra Tech, Inc. 1990, Striplin et al., 1992, EILS 1994, Dutch et al., 1993, Llansó et al., 1998a,b). Ten of these stations, designated as "sentinel" stations, are still monitored annually as the PSAMP Sediment Component's Long-Term/Temporal Monitoring Element. Data from these stations have suggested human-driven changes in contaminant levels, including decreases in metal concentrations and increases in PAHs. Changes in sediment grain size and biological communities in the Strait of Georgia, possibly linked with natural variation in rainfall and river flow, were also seen (Partridge et al., 2005; Dutch et al., 2005).

The 1997-2003 PSAMP Sediment Component's Spatial Monitoring Element (conducted in partnership with NOAA from 1997 to 1999[3]) provides a baseline of data quantifying the spatial extent of sediment quality degradation both Puget Sound-wide and regionally (Long et al., 1999, 2000, 2002, 2003, 2004, 2005). Sediment chemistry, toxicity, and benthic infaunal community structure are measured and reported as indicators of sediment health. These three indicators are also combined in Ecology's Sediment Quality Triad Index (SQTI) (www.ecy.wa.gov/programs/eap/psamp/Triadindexfiles/Triadindex.htm) to a single indicator which uses a 4-point scale to characterize sediment quality from High to Degraded. From 1997-2003, impaired sediments were measured in approximately 846 km^2, or 35% of the Puget Sound study area (Weakland et al., 2009).

The PSAMP data form a solid, statistically sound baseline of sediment quality data which currently characterize sediments regionally and Puget Sound-wide. They are the foundation against which future monitoring will be compared to evaluate sediment quality on a local, regional, and sound-wide scale. Estimates of change in sediment quality over time will be used as a measure of the effects of human-induced and natural stressors to the system, and as an effectiveness-monitoring tool to determine the success of source control and cleanup activities.

EMAP

Additional ambient sediment quality monitoring occurred in Puget Sound in 1999-2003 as part of the USEPA's Coastal Environmental Monitoring and Assessment Program (EMAP) Western Pilot study and in 2004-2006 as part of the USEPA's National Coastal Assessment (NCA) program, national surveys based on EMAP. These programs were led and financed by the USEPA and conducted by cooperative agreement with NOAA and coastal states (Ecology, for Washington) to monitor and quantitatively assess the condition of the coastal estuaries of the United States (Partridge, 2007; USEPA, 2001, 2004, 2007; Wilson and Partridge, 2007).[4] EMAP (including NCA) overlapped areas surveyed by PSAMP in Puget Sound and used 1997-1999 PSAMP sediment quality data for part of the 2000 survey.[5]

[3] The joint NOAA-Ecology 1997-1999 survey is known colloquially as PSAMP/NOAA.

[4] EMAP and NCA surveys also measured non-PSAMP water quality and fish populations and contamination as part of the assessments of estuarine condition.

[5] A separate USEPA QA Project Plan was used for EMAP and NCA (USEPA, 2001). However, the sediment-monitoring procedures of PSAMP were sufficiently similar that the data were acceptable for EMAP.

Availability of Existing Data

Data from the sediment baseline surveys from the 1970s and 1980s are available in the appendices of the original reports. Little is found in electronic format. The more recent regulatory data and all of the PSAMP ambient monitoring data are currently housed in Ecology's Environmental Information Management (EIM) database (www.ecy.wa.gov/eim/). PSAMP sediment quality data (1989-present) can also be downloaded from the Ecology's MSMT website (www.ecy.wa.gov/programs/eap/ psamp/index.htm). The Western Pilot Coastal EMAP data is available on the USEPA's website (www.epa.gov/emap/html/data/ index.html).

Regulatory Standards and Guidelines

Sediment quality chemical data collected for the PSAMP Sediment Component are compared with marine sediment quality standards set forth in the Washington State Sediment Management Standards (WAC 173-204) (Washington State Department of Ecology, 1995). These criteria are published under the authority of chapter 90.48 RCW, the Water Pollution Control Act; chapter 70.105D RCW, the Model Toxics Control Act; chapter 90.70 RCW, the Puget Sound Water Quality Authority Act; chapter 90.52 RCW, the Pollution Disclosure Act of 1971; chapter 90.54 RCW, the Water Resources Act of 1971; and chapter 43.21C RCW, the state Environmental Policy Act.

Washington State's Sediment Management Standards (SMS) include a suite of Sediment Quality Standard (SQS) and Cleanup Screening Level (CSL) chemical concentration criteria developed specifically for Puget Sound (Washington State Dept of Ecology, 1995). Also set forth in these standards are (1) biological effects criteria with set numerical guidelines, and (2) a suite of human health and other criteria determined on a case-by-case basis. The SMS were developed to correspond to a level of sediment quality that will result in no adverse acute or chronic effects to biological resources and no significant health risk to humans.

The PSAMP sediment chemical contaminant data are also compared to national sediment quality guidelines developed by Long et al. (1995) for NOAA using a national sediment quality database. These include Effects Range Low (ERL) and Effect Range Median (ERM) values, which correspond to sediment conditions in which effects would be rarely, occasionally, or frequently associated with adverse biological effects.

Evaluation of PSAMP sediment sample toxicity is determined by comparisons between the mean response in each sample with statistical critical values derived for each test as described in Long et al., 2005. For the currently conducted amphipod test, samples in which mean percent survival of amphipods is less than 80% of mean survival in the controls are classified as highly toxic, following Thursby el al. (1997). In the on-going sea urchin tests of 100% pore water, samples in which mean percent fertilization are <80% of controls are classified as highly toxic (Long et al., 1996; Turgeon et al., 1998).

Widely accepted multi-metric benthic infaunal indices equivalent to those developed elsewhere (e.g., Weisberg et al., 1997; Van Dolah et al., 1999; Smith et al., 2001) to classify benthic infaunal assemblages as impaired have not yet been developed for Puget Sound. The State SMS include methods for classifying benthos by comparing mean abundance of any major taxa groups in test sediments with those from reference sediments (Washington State Department of Ecology, 1995). Reference value ranges for selected benthic indices were also developed to represent reference area conditions (Striplin Environmental Associates, Inc, 1996; Striplin and Weston, 1999). Both methods have limitations and are not widely accepted procedures for classifying benthos in Puget Sound (Long et al., 2005).

Given the limitations of existing benthic indicators, Ecology's MSMT developed additional methods for evaluation of the condition of benthic communities. Nine benthic indices are calculated for each benthos sample, including total abundance, total taxa richness, evenness, dominance, and abundance of annelids, mollusks, arthropods, echinoderms and miscellaneous taxa. Presence/absence and abundance of pollution-tolerant and -sensitive species are also examined. Benthos were considered to be impaired when, based on best professional judgment, the majority of calculated indices and the species level composition indicated that the community was adversely different from communities in uncontaminated areas (Long et al., 2005).

The PSAMP Sediment Component data are collected as part of a large on-going ambient monitoring program, not a regulatory program, and comparisons with state and national sediment quality criteria and guidelines, as well as other criteria listed above, are not directly used for enforcement and regulatory purposes. Comparison of sediment values with regulatory criteria and guidelines is an integral part of the SQTI developed for the PSAMP Sediment Component. This index is used to characterize the incidence and severity of degraded sediment quality conditions in chosen embayments, regionally, and Puget Sound-wide. Sediment quality conditions are also examined to determine changes over time in response to both natural stressors and anthropogenic activity.

Project Description

The PSAMP Sediment Component has evolved since its inception in 1989 (Appendix B-1, B-2). The current program, described in this QA Project Plan, is composed of three elements, including:

- Long-Term/Temporal Monitoring – change in sediment quality over time at 10 long-term stations.
- Spatial/Temporal Monitoring – characterization and change over time of the spatial extent of degraded sediment quality at three scales: Puget Sound, region, stratum.
- Focus Studies (including Ecology's Urban Waters Initiative) – characterization and change over time of the spatial extent of degraded sediment quality at a local (i.e., embayment) scale.

PSAMP Sediment Component Goals

The following are the goals of the revised PSAMP Sediment Component, developed from the broader PSAMP goals set in 1997 by the PSAMP Steering and Management Committees:

1. Assess the health of Puget Sound sediments and document geographic patterns in the conditions of the sediments.
2. Document natural and human-caused changes over time in Puget Sound sediments.
3. Identify existing sediment problems and, where possible, provide data to help target sources.
4. Provide sediment data to assist the Puget Sound Partnership (formerly the Puget Sound Action Team) and others in measuring the success of environmental programs.
5. Support sediment-related research activities by making available scientifically valid sediment quality data.

Each of the three elements of the revised PSAMP Sediment Component has objectives that address some or all of these overarching goals. It is expected that the PSAMP and Sediment Component goals and objectives will evolve over time to meet the current and future needs of the recently formed Puget Sound Partnership.

For each element, sediments are collected from Puget Sound from designated study boundaries and sampling locations. The top 2-3cm of sediment are collected from each site, either in April or June, depending on the element. These recently deposited sediments are analyzed for grain size, TOC, and a suite of metal and organic chemical contaminants. They are also analyzed for sediment toxicity with a suite of bioassays (Spatial/Temporal and Focus Study monitoring only). Additionally, sediments are also collected from up to 17cm depth to be analyzed for composition of the infaunal invertebrate community.

This QA Project Plan has been written to describe all three elements of the revised *PSAMP Sediment Component*. Goals and objectives, constraints, and management application unique to each element are described in this section. Unique aspects of these elements, including target population, study boundaries, and sample locations are described later in the QA Project Plan, as are the methods and procedures that are shared by all three elements.

Long-Term/Temporal Monitoring

Ten of the 76 original PSAMP historical sediment monitoring stations (Striplin, 1988) have been chosen as "sentinel" stations for continued Long-Term/Temporal monitoring throughout Puget Sound, Hood Canal, and the Strait of Georgia.

Each station was chosen because it exhibited one or more of the following properties:

- An extensive (20+ years) historical database exists for the station.
- The station coincides with, and data support ongoing PSAMP fisheries and water column monitoring.
- The station is characterized by an assemblage of benthic infaunal invertebrates that is unique among the 10 stations.

Sediments from these 10 stations are sampled every April to assess grain size, total organic carbon, and benthic infaunal community structure. Levels of chemical contaminants are measured every five years. These data provide a long-term record of past and current conditions in Puget Sound sediments, and changes that have occurred over time.

Objectives

The objectives of the Long-Term/Temporal Monitoring Element of PSAMP include:

- Collect long-term data on physical and chemical sediment characteristics and macroinvertebrate communities at 10 long-term monitoring stations chosen from a variety of habitats and geographic locations throughout Puget Sound.
- Evaluate changes over time to the physical and chemical sediment characteristics and macroinvertebrate communities at these long-term monitoring stations.
- Evaluate over time the condition of Puget Sound benthic infaunal invertebrate communities in relation to natural and anthropogenic (human-caused) changes in sediment quality.
- Provide data for use by researchers and managers concerned with sediment quality.

Environmental Management Application/Sediment Quality Indicators

Continued annual monitoring of sediments at these 10 sentinel PSAMP stations provides a valuable long-term record of changes in sediment quality over time. Annual benthos data will be available annually on the MSMT website, and in a summary report with the chemistry data every five years. These data will be summarized as key sediment quality indicators. Managers can use this information to identify temporal trends in sediment quality that:

- Raise “red flags” highlighting issues of concern in Puget Sound.
- Measure the magnitude of environmental changes occurring either slowly (e.g., contaminant loading from stormwater runoff, global warming) or rapidly (e.g., introduction of invasive species, major oil spills).

Reports summarizing data collected for this program have been generated (Partridge, et al., 2005; Dutch, 2005).

Spatial/Temporal Monitoring

Although considerable information has been generated on the presence and concentrations of toxicants and their associated adverse effects in Puget Sound sediments, only the 1997-1999 PSAMP/NOAA spatial sediment monitoring (Dutch, et al., 1998; Dutch, 1998) determined the spatial extent of sediment quality degradation for all of Puget Sound.

After completion of the 1997-1999 PSAMP/NOAA work, the MSMT revised its spatial sediment monitoring program to include a more refined probabilistic stratified random sampling design. Modifications were made based on the USEPA EMAP-style sampling program.

Sediments sampled each June provide information on the spatial extent (km^2) of sediment quality degradation in eight Puget Sound regions, five strata, and Puget Sound-wide. Use of this method will enable comparisons among different areas within Puget Sound and also with other estuaries in the country, the latter of which have been studied by NOAA and the USEPA.

A temporal element was also built into this revised spatial program. Each region will be resampled on a 10-year cycle to facilitate quantification of regional-, stratum-, and Puget Sound-wide changes in sediment quality over time.

Objectives

Objectives of the Spatial/Temporal monitoring surveys are aligned with the broader PSAMP Sediment Component goals as follows:

1. Assess the quality of Puget Sound sediments and document geographic patterns in the condition of the sediments.
    - Determine spatial patterns and spatial extent of sediment quality parameters, including physical sediment measures, chemical contamination, sediment toxicity, and infaunal assemblage structure.
    - Determine relationships between the above sediment parameters to determine potential effects of both natural stressors and contaminated sediments on biota.
2. Document natural and human-caused changes over time in Puget Sound sediments.
    - Determine temporal patterns in sediment quality parameters, including physical sediment measures, chemical contamination, sediment toxicity, and infaunal assemblage structure.

3. Identify existing sediment problems and, where possible, provide data for in-depth point/non-point source investigations.
    - Identify existing sediment problems in objectives 1 and 2.
    - Coordinate with and provide data to appropriate regional sediment and toxic study programs.
4. Provide sediment data to assist the Puget Sound Partnership and others in measuring the success of environmental programs.
    - Identify and quantify appropriate sediment indicators, and their benchmark and endpoint values, that can be examined over space and time to determine the condition of the environment (*i.e.*, is the spatial extent of impacted sediments increasing or decreasing over time?).
5. Support sediment-related research activities by making available scientifically-valid sediment data.
    - Build and maintain adequate network with sediment "clients" throughout the Puget Sound region to understand and target the needs of sediment-related research activities conducted in Puget Sound.
    - Produce sediment data that has undergone appropriate QA/QC procedures ensuring high quality and scientific validity.
    - Make this high-quality sediment data available via the MSMT website (www.ecy.wa.gov/programs/eap/psamp/index.htm) and Ecology's EIM database (www.ecy.wa.gov/eim/index.htm).
    - Produce high quality reports which fully document the scientific work conducted for the monitoring program, accompanied by short, easy-to-read summaries prepared for the general public which highlight the major findings of each report.

Environmental Management Application/Sediment Quality Indicators

The current PSAMP Sediment Component Spatial Monitoring Element uses Ecology's SQTI designation (Long, et al., 2003, 2005) for each station sampled to calculate the spatial extent (km^2) of sediment quality degradation for regions, strata, and the whole Sound on both an annual and a 10-year cycle. This provides environmental managers with a recent characterization of sediment condition at multiple, nested geographic scales.

Temporal changes can also be assessed by comparison of new regional data with baseline data to determine whether sediment quality at each geographic scale is improving, degrading, or remaining the same over time.

Focus Studies

The Spatial/Temporal Monitoring Element is designed to characterize sediment condition on a relatively large geographic scale (i.e., Puget Sound-, region-, and stratum-wide). Small-scale focus studies can be developed and conducted for any defined area of concern in Puget Sound using the Spatial/Temporal probabilistic sampling design. Embayment-level surveys are an example of a small-scale Focus Study. Most of the details for PSAMP Sediment Component focus studies will be adequately defined in this QA Project Plan. When necessary, unique details will be summarized in a QA Project Plan addendum.

Objectives

Objectives of the focus studies are similar to those of the Spatial/Temporal Monitoring Element. Additional objectives may be added as required.

Environmental Management Application/Sediment Quality Indicators

As with the Spatial/Temporal Monitoring Element, the Focus Study Element uses the SQTI designation (Long, et al., 2003, 2005) for each station sampled to calculate the spatial extent (km^2) of sediment quality degradation for the designated focus area. This provides environmental managers with a recent characterization of sediment conditions at the embayment or other small scale. These data can then be nested within, and put into context with, the larger scale (i.e., strata, regions, Puget Sound Action Areas, Sound-wide) PSAMP sediment quality information available.

Temporal changes can also be assessed by comparison of newly-collected data with baseline data. In this sense, changes in sediment quality over time in a focus area serve as an "effectiveness monitoring" tool for adaptive management. They indicate whether sediment quality in a Puget Sound focus area is improving, degrading, or remaining the same over time in response to changes in both anthropogenic activity (e.g., collective contaminant source control and cleanup efforts), or natural environmental stressors.

Past and Current Focus Studies

Hood Canal Focus Study

A Focus Study was conducted in Hood Canal by the MSMT in 2004 (www.ecy.wa.gov/programs/eap/psamp/HoodCanal.htm). Newly collected sediment and bottom water dissolved oxygen data, as well as historical sediment and water column data provided information to environmental managers and scientists addressing low dissolved oxygen problems in Hood Canal. Interpretation and reporting of these data focused on the relationships between sediment-dwelling invertebrate communities and the sediment and water quality parameters in Hood Canal (Long et al., 2007; Dutch et al., 2007a, b).

Ecology's Urban Waters Initiative

Baseline and repeated monitoring in urban embayments can be used to determine the overall extent of sediment contamination, changes in sediment quality over time, and the long-term effectiveness of collective toxics management efforts in these bays. Ecology's MSMT is currently conducting this type of effectiveness monitoring annually in Puget Sound urban embayments (www.ecy.wa.gov/programs/eap/psamp/UrbanWaters/urbanwaters.htm).

Urban Waters Initiative focus studies were conducted in Elliott Bay/Lower Duwamish in 2007 (Partridge et al., 2009) and Commencement Bay in 2008. Other embayments, including Sinclair and Dyes Inlets and the adjoining Bainbridge Basin, Bellingham Bay, Budd Inlet, and Port Gardner (including Everett Harbor), will be targeted in future years.

Other small-scale sampling frames have been suggested as focus studies, including both intertidal and shallow subtidal zones of the nearshore environment. Recognized as highly productive habitat, the nearshore is the feeding grounds, nursery, and migration corridor for many species of invertebrates, fish, birds, and marine mammals. It is highly sensitive to both human and natural disturbances.

Practical Constraints on the Study Designs

To ensure that data collected for the Long-term/Temporal, Spatial/Temporal, and Focus Study Monitoring Elements are comparable to data collected previously for each element, all sample collection and analysis methods must be held consistent between years. Additionally, Focus Study methods must be identical to those used for the Spatial/Temporal Monitoring Element, as the data for the two will eventually be merged for analysis. Examples of methods that must be applied consistently include the following:

- Sediments collected for chemical analyses must be removed from the top 2-3cm surface layer only. These surface sediments represent the most recently deposited material, which is the focus of this survey.
- The labs conducting the chemical and toxicity analyses must use the same procedures from year to year, or explain any procedure they wish to change, and provide evidence that procedural changes do not render the data incomparable.
- Annual collection of benthos must occur at the same time of year, in this case, early to mid-June, so that the population is in similar growth and reproductive condition.
- Sediment grabs used to collect infauna must collect identically-sized sampling areas.
- Taxonomic data must be standardized between years to account for changes to taxonomic nomenclature and naming discrepancies between individual taxonomists.

Organization and Schedule

Organization Chart and Project Schedule

Key individuals and their responsibilities for the PSAMP Sediment Component are indicated in Table 1. Schedules for completing field and laboratory work, EIM data entry, and reports for each monitoring element are indicated in Tables 2-4. The analytical cost for the Long-term/ Temporal, Spatial/Temporal, and Focus Studies will vary from year to year with each project based on analytes and number of samples chosen for each study. Cost estimates for each project will be generated for each study in an annually QA Project Plan addendum.

Quality Objectives

Quality objectives for the three PSAMP Sediment Component elements described here are to obtain and analyze sufficient numbers of high quality sediment chemistry, toxicity, and benthos samples to:

- Characterize sediment quality at each Long-Term/Temporal monitoring station in Puget Sound.
- Characterize sediment quality at each Spatial/Temporal and Focus Study monitoring station in Puget Sound, and, using the probabilistic sampling design, determine the spatial extent of sediment quality degradation (km^2) for the Spatial/Temporal monitoring regions and strata, Puget Sound Partnership Action Areas, and for Focus Study sampling frames in Puget Sound.
- Compare with past data collected for this monitoring program to determine changes in sediment quality over time for PSAMP Long-term/Temporal, Spatial/Temporal, and Focus Study monitoring stations in Puget Sound.
- Compare with SQS and other sediment quality guidelines set for these parameters.

Data quality indicators of precision, bias, sensitivity, representativeness, comparability, and completeness, defined in Lombard and Kirchmer (2004), were considered during establishment of Measurement Quality Objectives (MQOs) for the PSAMP Sediment Component. These MQOs, listed below, will be achieved through careful attention to sampling, measurement, and quality control (QC) procedures described in this plan.

Measurement Quality Objectives

Field Measurements

Measurements of sediment penetration depth, temperature, salinity of the water overlying the sediment surface, and sediment texture, color and odor are taken by Ecology personnel in the field during sample collection. Collection methods, reporting requirements, and QC procedures summarized in the *Measurement* and *Quality Control Procedures sections*, below, will provide field measurement data that meet MQOs and the needs of the three project components.

Sediment Grain Size, Total Organic Carbon and Chemistry

Sediment grain size analyses will be conducted through a contract between the MSMT and one or more private laboratories. Each laboratory must be accredited through Ecology's Laboratory Accreditation Program. Total organic carbon (TOC) and chemical analyses will be conducted by the Manchester Environmental Laboratory (MEL).

All work is expected to meet the QC requirements of the analytical methods used for this project. These requirements are summarized in the *Quality Control Procedures* section of this document and are found in detail in the Puget Sound Estuary Program (PSEP) Protocols (1986, 1997a, b,c,d) and in the peer-reviewed standard operating procedures (SOPs) for each test. The QC samples and MQOs designated for sediment grain size, TOC, and chemical analyses are summarized in Table 5.

Sediment Toxicity

All toxicity analyses for this project will be conducted through a contractual agreement between the MSMT and one or more private or government laboratories. Each laboratory must be accredited through Ecology's Laboratory Accreditation Program.

All work is expected to meet the QC requirements of the analytical methods used for this project. Each proposal for toxicity testing work is reviewed by Ecology staff to ensure that the proper QA/QC procedures are offered. These requirements are summarized in the *Quality Control Procedures* section of this document and are found in detail in the Puget Sound Estuary Program (PSEP) Protocols (PSEP, 1995) and in the peer-reviewed SOPs for each test. The QC samples and MQOs designated for sediment toxicity analyses are summarized in Table 6.

Benthic Infaunal Invertebrates

Sorting of benthic infauna for this project will be conducted either in-house by MSMT staff, or by an outside vendor experienced with this type of work. MSMT staff and contractors with extensive experience in the taxonomy of Puget Sound invertebrates will enumerate and identify all benthic invertebrates to the lowest taxonomic level possible.

MSMT staff and contractors are expected to follow all SOPs developed for sorting and taxonomic work, data reporting, and QC. These requirements are summarized in the *Quality Control Procedures* section of this document and are found in detail in the Puget Sound Estuary Program (PSEP) Protocols (PSEP, 1987). These procedures will provide benthos data that meet MQOs and the needs of the three project components.

Sampling Process Design (Experimental Design)

To meet their different objectives, the sampling process, or experimental design, differs for each of the three elements of the PSAMP Sediment Component. Designs for the Long-term/Temporal, Spatial/Temporal, and Focus Study Monitoring Elements are described separately, below. The sediment sampling schedule for all three PSAMP sediment monitoring elements is indicated in Table 7.

Long-Term/Temporal Monitoring: A Targeted Sampling Design

The experimental design for the PSAMP Long-Term/Temporal Monitoring Element includes sampling and analysis of sediments and benthos at 10 “sentinel” sediment monitoring stations to meet the goals and objectives described earlier.

Target Population

The target population for the PSAMP Sediment Component Long-Term/Temporal Monitoring Element is the top 2-3cm of sediment collected from 10 sentinel monitoring stations distributed throughout Puget Sound. Benthos samples are collected from sample grabs up to 17cm in depth. Samples are collected annually each April (Table 7).

Parameters Measured

Sediment grain size, percent total organic carbon (TOC), and the abundance of benthic infaunal invertebrates identified to the lowest taxonomic level are measured annually. Chemical contaminant concentrations in the sediments are measured at 5-year intervals for priority pollutant metals and semivolatile organics (Table 8). Three replicate samples are collected from each station for analysis. A fourth is collected and archived as a backup sample.

Field measurements recorded annually at each station include measures of sediment temperature, salinity of the overlying water, station depth, penetration depth of the grab sampler, and visual sediment quality characteristics (color, odor, texture, presence of organic matter or sheen).

Study Boundaries and Sampling Locations

Ten sentinel monitoring stations are distributed throughout Puget Sound, from the Strait of Georgia to Budd Inlet, and in Hood Canal (Figure 2). Seven of the 10 stations are in ambient locations, away from known industrial and municipal point sources. Three are located in or near urban water bodies. Target locations (latitude and longitude) for these sampling stations, along with parameters measured each year, are provided in Table 9.

From inception of the program in 1989, through 2004, all chemical and replicate benthos samples collected from each station were collected only from the target coordinates. In 2005, the MSMT adopted an expanded set of coordinates for each station. Chemistry samples, currently sampled once every five years, are collected from the original target locations, while replicate benthos grabs are collected from different locations at each station annually.

Benthos replicates 1 and 4 are collected from the station's target coordinates. Replicate 4 is held as an archive benthos sample. Replicates 2 and 3 are collected from two randomly-chosen, independent locations within a specified radius from the target location (Appendix C-1). These additional locations were adopted for each station to avoid alteration of the target location by oversampling, and to avoid pseudoreplication (Hurlbert, 1984).

Spatial/Temporal Monitoring: A Probabilistic Random Stratified Sampling Design

From 1997-1999, Ecology's MSMT conducted the PSAMP Sediment Component in partnership with the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (NS&T) Bioeffects Assessment Program. This combined program utilized a stratified, probabilistic, random sampling design which allowed calculation of the spatial extent of sediment quality degradation throughout Puget Sound.

In 1999, this spatial sediment monitoring program was modified with assistance from EPA's Aquatic Resources Monitoring Design and Analysis Team in Corvallis, Oregon. The probabilistic random, stratified sampling design was refined using a spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design, as described by Stevens (1997), and Stevens and Olsen (1999, 2003, 2004). Details of this design are described in Appendix D-1 and Appendix D, Table 1.

Target Population

The target population for the Spatial/Temporal Monitoring Element is the top 2-3cm of sediment collected from each monitoring station. A minimum of 30 randomly chosen stations are collected from within one of eight sediment monitoring regions, described below, per year. They serve as replicate samples for the region. Benthos samples are collected from sample grabs up to 17cm in depth. Samples are collected annually each June, on a regional rotational schedule (Table 7).

Parameters Measured

A refined list of sampling parameters was generated, and includes sediment grain size, percent TOC, and the SQTI parameters.

The SQTI parameters consist of over 140 metal and semivolatile organic chemical contaminants, up to four toxicity tests, and the abundance of infaunal invertebrates identified to the lowest taxonomic level (Table 10).

Field measurements recorded annually at each station include measures of sediment temperature, salinity of the overlying water, station depth, penetration depth of the grab sampler, and visual sediment quality characteristics (color, odor, texture, presence of organic matter or sheen).

Sampling Frames

A nested set of sampling frames was defined for the Spatial/Temporal Monitoring Element. This includes the basins, bays, inlets, and channels of Puget Sound from the US/Canada border to the southern terminus, Hood Canal, and portions of Admiralty Inlet, the San Juan Archipelago, and the eastern portion of the Strait of Juan de Fuca.

This "whole-Sound" sampling frame (Figure 1) has been subdivided into a number of multi-density categories which are combinations of eight geographical regions and five geophysical/anthropogenic-use categories which for this project will be called "strata"[6]. Regions and strata are nested within the "whole-Sound" frame. All sampling frames are subtidal, with a minimum 1 fathom (~2 m) water depth.

Regions

The geographical regions are defined to be consistent with those used by other PSAMP components and are depicted in Figure 3. They include:

- Strait of Georgia
- San Juan Islands
- Eastern Strait of Juan de Fuca
- Admiralty Inlet
- Whidbey Basin
- Central Sound
- South Sound
- Hood Canal

Strata

The strata are defined by major geological features and degree of anthropogenic activity, as specified in Table 11 and depicted in Figure 4.

- Harbor
- Urban
- Basin
- Passage
- Rural

Not all strata are found in each region – only 26 of the possible 40 multidensity combinations are present. The spatial area (km^2) represented by each region, stratum, and multidensity category is defined in Table 12.

[6] The use of the word "strata" in this case is meant to connote a segment of the population with a defined set of characteristics, and not a stratum in the strict sense of statistical sampling design.

10-Year Rotational Sampling Schedule

Each region is sampled, beginning in 2006, on an annual rotational cycle, alternating nine years of regional sampling with one year of focused embayment sampling or specialized projects (Table 7). Results will include spatial characterization and quantification of sediment quality for a different region each year, along with temporal comparison of this recently collected data to the older 1997-2003 Puget Sound sediment baseline data.

Focus Studies

The sampling process design (experimental design), for the Focus Study Monitoring Element is similar to the Spatial/Temporal Monitoring Element, and is based on use of the probabilistic random, stratified survey design to enable spatial characterization of a chosen sampling frame. Focus studies, however, are conducted on a small geographic scale. The sampling frame typically is nested within a spatial/temporal monitoring region, and can be defined at the embayment-scale or other small scale.

Target Population

The target population for focus studies is the top 2-3cm of sediment collected from each monitoring station. A minimum of 30 randomly chosen stations are sampled from within the designated Focus Study sampling frame, and serve as replicate samples for the sampling frame. Benthos samples are collected from sample grabs up to 17cm in depth.

Focus studies are built into the sampling schedule on a 10-year basis beginning in 2010. If the Focus Study results are to be compared with results from a PSAMP regional survey, samples would need to be collected in June so that infaunal populations would be similar in growth and reproductive condition to those collected for the regional survey.

Urban Waters Initiative focus studies are scheduled to occur annually, on a rotation through six urban embayments (Table 7). Sampling occurs at a minimum of 30 stations chosen from the 1997-1999 PSAMP/NOAA station location target (or alternate) coordinates (i.e., these stations are reoccupied).

Parameters Measured

Parameters measured for each Focus Study are similar or identical to those of the Spatial/ Temporal Monitoring Element. Additional parameters may be added or deleted as required.

Sampling Frame

The PSAMP Sediment Component's Focus Study Element was design for flexibility. Boundaries of any shape and size may be selected and nested anywhere within the Puget Sound-wide, regional, or strata sampling frames. The study boundaries for each Focus Study will be designed to best suit the goals and objectives of each study. The sampling frame for each Urban Waters Initiative embayment is based on the 1997-1999 PSAMP/NOAA strata boundaries.

Sampling Procedures

The sampling procedures, along with the remaining QA procedures described in this document for the PSAMP Sediment Component are generally identical for the Long-term/Temporal, Spatial/Temporal, and Focus Study Monitoring Elements. This allows for comparison of results among stations, regions and other defined sampling frames, and among years. Any variations necessary to meet the specific goals and objectives of each survey will be described in an annual QA Project Plan addendum, generated prior to each sampling event.

Collection of sediment for physical characteristics, chemistry, toxicity, and infaunal analyses will be led by personnel from Ecology's MSMT. Sampling methods will, in general, follow those described in PSEP (1997a). These methods are summarized below.

Sampling Platform and Station Positioning

A marine research vessel of adequate size and speed, and suitably equipped for deployment of sample collection equipment and shipboard sample processing, will be reserved from the Ecology fleet or contracted by Ecology for this work. From this platform, station-positioning protocols will follow PSEP (1998). Positioning will rely on Differential Global Positioning System (DGPS) with expected accuracy of better than 3 meters. Variable radar ranging, water depth, and line-of-sight fixes on land objects may supplement the DGPS if necessary.

Sample stations were selected from regional and Focus Study sampling frames whose boundaries were defined by nautical features in NOAA and Geographic Information System (GIS) nautical charts. Occasionally, the resolution in these sources is insufficient to indicate conditions at specific coordinates. As a result, a randomly-selected station which is supposed to be in at least 1 fathom (~2 m) of water is actually in the intertidal zone or on land. In such cases, or when the station lacks fine-grained particles in the sediment (*e.g.*, rocks prevent grab closure or the substrate is composed of all shell hash), it will be necessary to take alternate action.

If possible, the first course of action will be to move up to 300 m offshore, in a direction perpendicular to shore. If it is not possible to sample successfully after moving up to 300 m seaward, then that station will be rejected and must be replaced. Alternate stations must be of the same multi-density category (region-stratum combination) and must be taken in order from the list of randomly-selected sites provided by the USEPA (Corvallis, OR) when the sampling scheme was designed (Appendix D-1, Table D-1).

Field Logs

A field log will be completed during the sampling process at each station to record station information including:

- Sample identification, date, time, location, depth, description.
- Sampling crew.

- Weather and sea state.
- Collection gear.
- Collection status (i.e., successful, station rejected, station moved).
- Visual description of sediments and benthos.
- Field measurements.
- Parameters sampled.
- Information for individual sediment grabs.
- Who generated the field log.
- Comments.

Field Log information differs slightly between the Long-term/Temporal, Spatial/Temporal, and Focus Study Monitoring Elements (Appendix E-1, E-2, E-3). A daily log will also be generated with information on samples collected from each day (Appendix E-4). They are recorded on water-resistant paper.

Sample Collection and Field Measurements

Sediment samples will be collected using a double 0.1-m^2 stainless-steel modified van Veen grab sampler, which allows sediment for chemistry, TOC, grain size, and toxicity samples to be collected simultaneously with benthic infaunal samples. Sediment sampling protocols are specified in Ecology's Environmental Assessment Program (EAP) SOP for Marine Sediment Sample Collection (Appendix F-1), which generally follow PSEP, 1997a. They are summarized, below.

Sediment Collection

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

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

Field Measurements

For the first acceptable grab sample taken, one side of the double van Veen will be used for determination of various physical/environmental characteristics, including sample penetration depth, sediment temperature, salinity of the overlying water, and sediment texture, color, and odor.

Benthos Samples

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

Sediment Samples

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

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

Field Replicates

At 5% of the stations sampled, double the amount of sediment will be collected and homogenized. Two sets of sample containers for chemistry, TOC, and grain size analyses will be filled. These stations will be chosen by the MSMT project lead. The second set will be assigned a different sample identification number and submitted to the laboratories as a blind field replicate. Field replicates are not collected for toxicity or benthic infaunal analyses.

Archive Samples

A portion of each sample will be jarred and retained as grain size and TOC/chemistry archive samples. They will be kept for one year, in case re-extraction or retrospective analysis is required. Sediment grain size samples will be held at 4 °C. Chemistry and TOC samples will be frozen at –18 °C (0 °F). A fourth (archive) replicate benthos sample will be retained from each Long-Term/Temporal monitoring station. Archive benthos samples will not be collected for the Spatial/Temporal or the Focus Study Monitoring Elements.

Equipment Decontamination

Prior to sampling, and between sampling stations, the grab 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 is not produced 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.

Containers, Preservation, Holding Times

Recommended sample sizes, containers, preservation techniques, and holding times for all sediment samples are those listed for the PSEP (1997a) and the Manchester Environmental Laboratory Lab User's Manual (Washington State Department of Ecology, 2008) and are summarized in Table 13.

Sample Identification and Labeling

Each sample for TOC, grain size, chemistry, and toxicity analyses, including field replicates, will be identified by a label affixed to the outside of the container, indicating the project, station ID, Manchester Lab ID number (when appropriate), date of collection, and analysis to be performed (Appendix E-5). Bar codes containing this information will also be included on the label. The paper labels will be covered with clear packing tape for protection. The station and replicate numbers will be written on the lid of each sample with a permanent marker.

Each benthos sample will be identified by a label affixed to the outside of the container and a waterproof label placed inside the container with the sample, indicating the project, station ID, date of collection, and sieve mesh size (Appendix E-5). Bar coding is also used on these labels. Again, the external paper labels will be covered with clear packing tape for protection.

Samples for chemistry, TOC, grain size, and toxicity analyses will be stored in labeled, sealed containers placed in insulated chests filled with ice. Benthos sample containers will be sealed in plastic 5-gallon buckets labeled externally with contents, date, and hazardous materials (formaldehyde) warning label.

Sample Transport and Storage

Sediment samples will be off-loaded from the research vessel every 1-3 days and transferred to the walk-in refrigerator at Ecology's Operations Center in Lacey, Washington. There, they will be held at 4^{o} C until they are transported to Ecology's Manchester Environmental Laboratory (chemistry and TOC) or shipped to the appropriate contractors (toxicity and grain size) by overnight courier. Laboratory staff will be notified that samples have been shipped by either phone call or email message on the day they are shipped.

The formalin-preserved sediment samples collected for infaunal analyses will also be off-loaded from the research vessel every 1-3 days. They will be transported in the sealed buckets to Ecology's Operations Center for storage pending the rescreening process.

Archive grain size samples will be stored at 4^{o} C in the walk-in refrigerator and archive chemistry samples will be stored at -18^{o} C in a freezer at Ecology's Operations Center. Archive benthos replicates will be stored at Ecology's headquarters building in Lacey. All appropriate sample holding times (Table 13) will be observed.

Chain-of-Custody

Chain-of-custody procedures will follow those recommended by the PSEP (1997a). They will be initiated when the first sample is collected, updated continuously through the sampling event, and will be followed until all samples are relinquished to the analytical laboratory. Chemistry, TOC, grain size, archive chemistry and grain size, toxicity, and infaunal chain-of-custody forms designed for this project are depicted in (Appendix E-6, E-7, E-8, E-9, E-10). These procedures will provide an unbroken trail of accountability that tracks the physical location of samples, data, and records.

Excess Sample and Waste Disposal

All chemistry and toxicity labs will be required to dispose of all samples at the end of the tests using acceptable methods as a provision of their contracts. Waste formalin, retained during the benthic sample rescreening process, is considered hazardous waste. Additionally, sorted sediments are returned to Ecology from the sorting contractor. They are saturated with ethanol and are also considered hazardous waste. Both are disposed of through Ecology's hazardous waste contractor.

Safety Protocols

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

- Life vest or floatation suit.
- Hard hat.
- Steel toed boots.
- Rain jacket and pants.

- Protective gloves.
- Temperature-appropriate clothing.
- Sunscreen.

They are also required to read and follow all appropriate guidelines in the EAP Standard Operating Procedure for Marine Sediment Sample Collection and the EAP Field Operations Safety Manual (Appendix F-1, F-2).

Invasive Species Control Procedures

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 draft *Standard Operating Procedures to Prevent Accidental Introductions of Aquatic Organisms from Areas of Moderate Concern* (Ward, 2009) will be implemented.

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

Measurement Procedures

Field Measurements

Measurements of numerous characteristics of the sediment sample will be taken in the field during sample collection. They include sediment penetration depth, temperature, salinity of the water overlying the sediment surface, and sediment texture, color and odor. Collection methods and reporting requirements are summarized in Table 14.

Laboratory Measurements

Laboratory Accreditation

All laboratories performing the grain size, chemistry, and toxicity analyses must be accredited in the State of Washington for the parameters and methods used to ensure generation of accurate and defensible analytical data (Washington State Department of Ecology, 2002). Ecology's Manchester Environmental Laboratory (MEL) will conduct all TOC and chemistry analyses, while contract laboratories shall be retained for toxicity and a portion of the benthos analyses. An accreditation process is not available for sorting and taxonomy of benthos. The limited number of recognized regional experts in these fields are utilized and are required to follow established QA protocols.

Laboratory Notification

Prior to sampling, the MSMT will submit *Pre-Sampling Notification, Sample Container Request,* and *Laboratory Analyses Required* forms to MEL regarding specifications for all chemical analyses. For grain size, toxicity, and benthos analyses, contract laboratory notification procedures will be as specified in the Scope of Work prepared for each parameter.

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

Grain Size Analysis

Analysis for grain size will be contracted to an external laboratory and follow methods outlined in the PSEP protocols (PSEP, 1986). The expected range of results and required reporting limits are specified in Table 15. A brief description of the analytical procedures is available in Appendix G.

TOC and Chemical Analyses

Analyses for total organic carbon (TOC) and all chemical contaminants (Tables 8 and 10) for the three PSAMP Sediment Component elements will be performed by MEL. Manchester personnel will use the PSEP protocols (PSEP, 1986, 1997b, 1997c), most of which are based on USEPA Standard Methods, as the standard for analysis, data validation and review, reporting, and other laboratory activities related to this project. Requirements for sample preparation and analysis methods are specified in Table 15. Brief descriptions of the analytical procedures and USEPA method descriptions are available in Appendix G-1.

Analytical procedures will provide performance equivalent to those of the PSEP protocols, and include all QA procedures outlined in Table 5. Required reporting limits are specified in Table 15. A portion of all samples collected will be frozen at –18 °C (0 °F) and archived by Ecology for one year, in case re-extraction or retrospective analysis is required.

Toxicity Tests

A total of six different toxicity tests have been performed for the various PSAMP Sediment Component elements since 1989. The number and types of tests have differed between projects and over time based on project objectives and funding availability. The methods and endpoints for all six tests are listed in Table 16.

After 1993, no toxicity tests were performed on samples collected for the Long-Term/Temporal Monitoring Element. Since 2007, only two tests have been performed on each sample from the Spatial/Temporal and Focus Study Monitoring Elements. These tests include:

- Amphipod (*Eohaustorius estuarius*) survival in solid phase sediments (10-day test).
- Sea urchin (*Strongylocentrotus purpuratus*) fertilization in porewater (20-minute test).

All toxicity tests will be conducted by contract laboratories which have received Washington State accreditation for each test.

Amphipod survival testing procedures generally follow PSEP protocols (PSEP, 1995), based on American Society for Testing and Materials (ASTM) guidelines (ASTM, 2004a). Sea urchin fertilization testing procedures generally follow ASTM for acute toxicity tests with echinoid embryos (ASTM, 2004b) and are modified slightly from published procedures for sediment testing with embryos of the sea urchin (*Arbacia punctulata)* (Carr et al., 1996). Modifications to the testing protocols were necessary to account for the spawning methods, water temperature and duration of the tests, specific for *S. purpuratus*, used for testing in Puget Sound. They are different from those used when *A. punctulata* is used elsewhere in the nation. Summaries of the toxicity testing procedures are available in Appendix H.

Tests of all samples will be accompanied by simultaneous tests of a non-toxic (negative) control sediment and a reference (positive) toxicant. The negative controls are sediments collected from uncontaminated locations (often the "home" sediments where the animals are collected) previously determined to be non-toxic.

The maximum holding times for all samples shall be 10 days from the date of collection. That is, laboratory exposures or extractions of test media (i.e., porewater or elutriates) will be initiated no later than 10 days following collection of each sample. The empirically determined 10-day holding time is required to ensure that the data from the various Puget Sound regions and from different sampling years are comparable.

Benthos Samples

Processing and analysis of benthos samples will be conducted by both Ecology personnel at their headquarters and Operations Center, and by regional contractors who specialize in benthos sorting and taxonomy.

All methods are described briefly, below, and in detail in EAP's SOP for Macrobenthic Sample Analysis (Appendix I-1). They are similar to those described for the PSEP (1987).

Sample Rescreening

Upon completion of field collection, the benthos samples will be stored at Ecology's Operations Center. After a minimum fixation period of 24 hours (and maximum of 10 days), the 1.0-mm samples will be rescreened on a 0.5-mm sieve and transferred to 70% ethanol. Each sample is recorded on a sample-tracking log (Appendix E-11).

Sample Sorting

After staining with rose Bengal, samples will be examined under dissection microscopes. All macrofaunal invertebrates and fragments larger than 1.0-mm will be removed and sorted into the following major taxonomic groups: Annelida, Arthropoda, Mollusca, Echinodermata, and Miscellaneous Taxa. Meiofaunal organisms such as nematodes and foraminiferans will not be removed from samples, although their presence and relative abundance will be recorded. Representative samples of colonial organisms such as hydrozoans, sponges, and bryozoans will be collected and their relative abundance noted (Table 17). The presence of bottom-dwelling fish, and pelagic fish and invertebrates accidentally trapped in the grab will be recorded.

Sorted sediment will be retained until QA procedures are performed, then will be disposed of, along with the formalin left from rescreening, using a Washington State-contracted hazardous-waste disposal firm.

All vials of organisms sorted into major taxonomic groups are recorded on Chain-of-Custody Record forms (Appendix E-12). These Chain-of-Custody Records remain with the vials as they progress through the sorting QA process and as they are distributed to specialists for taxonomic identification and taxonomic QA.

Taxonomic Identification

Personnel in the Marine Sediment Monitoring Unit will conduct portions of the taxonomic identifications in-house and will contract the remainder of the taxonomic work to recognized regional specialists.

Upon completion of sorting, all organisms will be enumerated and identified to the lowest taxonomic level possible, generally to species, using dissecting and compound microscopes. If possible, at least two taxonomic publications (preferably including the original description) will be used for each species identification, and identifications will be checked against a reference specimen from a verified reference collection maintained at Ecology headquarters or Operations Center (Table 17).

Each taxonomist will select no more than three representative organisms of each species or taxon to place in a voucher collection that will be used for QA/QC of the identifications. Taxonomists who have provided complete voucher collections to the Marine Sediment Monitoring Unit for previous projects, and who have passed taxonomy QA, only need to provide vouchers of species new to the voucher collection for subsequent projects.

Safety and Chemical Hygiene

All Ecology personnel will be trained in the safe handling and disposal of waste formaldehyde and ethanol, waste sediments, and preserved benthos samples generated during the sampling work. Safe procedures are described in the Environmental Assessment Program's Safety Manual and Ecology's Chemical Hygiene Plan (Appendix F-2, I-2).

Quality Control Procedures

In general, the recommended QA/QC guidelines for the collection of environmental data in Puget Sound will be followed (PSEP, 1997d). Procedures used for the PSAMP Sediment Component Monitoring Elements are detailed below.

Field Measurements

Field personnel will be trained to follow measurement and QC methods specified in Table 14 to obtain consistent field measurements of the various sediment sample characteristics.

Field Sampling

Field personnel will be trained in the sampling methods specified in this QA Project Plan. All completed sample labels, chain-of-custody forms, and field logs will be double-checked by members of the field crew after sample collection.

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

Laboratory Analyses

Grain Size

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

TOC and Chemistry

All TOC and chemistry analyses conducted by Ecology's Manchester Environmental Laboratory will adhere to analytical QC methods outlined in PSEP (1986; 1997b,c,d) and in MEL's in-house standard operating procedures. Five percent (5%) of the TOC samples per batch of 20 shall be analyzed in triplicate (Table 5). QC methods for organic analyses include both instrument calibration and analytical QC procedures (i.e., use of method blanks, surrogate spike compounds, analytical replicates, matrix spikes, spiked method blanks, and reference materials). QC for metals analyses also includes both instrument (calibration, etc.) and method (method blank, matrix spike, etc.) procedures. The frequency of each chemistry QC test is specified in Table 5.

Toxicity

All bioassay work conducted by contractors shall adhere to general QC procedures that apply to all sediment bioassays, as outlined in PSEP (1995) and other published protocols (e.g., ASTM, Standard Methods, other) specific to each test (Table 16). These include use of both non-toxic (negative) and toxic (positive) controls as well as reference test sediments; use of healthy test organisms; observance of sediment holding times, proper equipment-cleaning procedures, and standard laboratory procedures; measurement and maintenance of water quality; and blind testing. Contract laboratories will follow QC procedures specific to each of the individual bioassays.

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

The negative controls must be tested with each batch of samples from the field using the same methods applied to the test samples and at least the same number of replicates. It is anticipated that some samples from within the study area will be non-toxic in all tests, as well as un-contaminated, and they may suffice as reference samples. However, the results from tests of the negative controls are highly important, because they will be used in statistical analyses to classify samples as either toxic or non-toxic.

In all cases, the maximum holding time for the samples shall be no more than 10 days from the date of collection. That is, all tests must commence within 10 days or, for porewater tests, the samples must be extracted for either preservation or testing within 10 days.

Benthos

Sorting of Infaunal Samples

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

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

The QC technician will also check all major taxa vials for missorted organisms (i.e., organisms placed in the incorrect vials).

Taxonomic Identification of Infaunal Samples

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

Ecology's Marine Sediment Monitoring Unit houses a large collection of marine infaunal invertebrate organisms from Puget Sound. The collection contains over 2400 specimens from 908 taxa, and includes all reference and voucher specimens collected from PSAMP work conducted since 1989, as well as some earlier Puget Sound studies. The collection is an extremely valuable tool that may be used by taxonomists to help ensure consistency in taxonomic identifications in future PSAMP work.

In addition to specimen re-identification, Ecology personnel have developed, and have extensive experience applying, a standardization review process for QA/QC of taxonomic data generated by numerous contracted taxonomists. This review process was developed by Ecology personnel while reviewing 20 years of PSAMP data. It is a method of comparing taxa designations between stations and between years of a study to locate nomenclature and identification discrepancies invariably generated when multiple taxonomists work on a project.

The process attempts to minimize the unavoidable inconsistencies in taxonomic nomenclature due to changing taxonomic nomenclature in the published literature and to assignment of species names by taxonomists with varying backgrounds and skill levels. A continuously-updated list of previous taxonomic discrepancies has been maintained over the years of developing this process, which will be helpful in checking for and avoiding common discrepancies in future taxonomic work.

The standardization review process will be applied to all taxonomic data to ensure consistency among different taxonomists both within and between years. The process will be applied at regular intervals as data are generated, so that inconsistencies can be resolved and data can be standardized while the taxonomic identification of samples is still being conducted.

Data Management Procedures

Field Data and Observations

Field data and observations will be recorded on field logs (Appendix E-1, E-2, E-3) printed on write-in-the-rain paper and kept in a three-ring binder aboard the research vessel during sampling. A new log will be completed at every station, including those that are rejected. This information will be entered into the MSMT database upon completion of annual sampling. All entries will be independently verified for accuracy by another individual on the project team.

The MSMT is currently considering switching from paper field logs to entering the field data directly onto spreadsheets on a weather-resistant laptop computer used aboard the vessel. Electronic files would be regularly backed up during sampling onto a flash drive (i.e., memory stick).

Laboratory Data

Grain Size, TOC, and Chemistry

The data packages from the contract lab for grain size and from MEL for TOC and chemical contaminants will include:

- Printed values for all parameters measured at each station.
- A case narrative or report detailing methods used, any problems with the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers.
- All associated QC results. This information is needed to evaluate the accuracy of the data and to determine whether the MQOs have been met. This will include results for all required field and analytical (laboratory) control replicates, laboratory control samples, reference materials, method blanks, matrix spike, matrix spike duplicates, and surrogate spikes (Table 5).
- An electronic version of the data and report in Ecology's EIM or other specified format. Output from MEL's Laboratory Information Management System will be submitted electronically for upload into EIM. Data entered into EIM follow a formal data review procedure in which data are reviewed by the project manager of the study, the person entering the data, and an independent reviewer.

All deliverables expected from the contract lab for grain size are specified in the Scope-of-Work sent to contractors (Appendix J-1).

Toxicity

The data packages from the contract toxicology labs will include:

- Printed values for all parameters measured at each station.
- Measures of within sample variability, sample and test organism holding time, and test organism lengths (for amphipod tests only).
- A report detailing methods used, any problems with the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers.
- All associated QC results. This information is needed to evaluate the accuracy of the data and to determine whether the MQOs have been met. This will include results for all negative and positive controls, and all water quality measurements (Table 6).
- An electronic version of the data and report in Ecology's EIM or other specified format. Data entered into EIM follow a formal procedure where data are reviewed by the project manager of the study, the person entering the data, and an independent reviewer.

All deliverables expected from the contract toxicity labs for the currently used toxicity tests are specified in the Scope-of-Work sent to contractors (Appendix J-2, J-3).

Benthos

The data packages from the benthos sorting and taxonomy contractors will include:

Sorting

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

Sorting QA

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

Taxonomy

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

Taxonomic QA

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

All deliverables expected from the contract benthic labs for sorting and taxonomy are specified in the Scope-of-Work sent to contractors (Appendix I-3, I-4).

Data Storage – MSMT Access and Ecology's EIM Database

All sediment quality data generated for this project will be evaluated through the data verification process outlined later in this QA Project Plan. Acceptable results will be used by Ecology scientists to prepare the final report and will be entered into the MSMT's PSAMP sediment quality database. This database can be downloaded from the MSMT website (www.ecy.wa.gov/programs/eap/psamp/index.htm). The data will also be uploaded to Ecology's EIM database, made available to the public via Ecology's web site (www.ecy.wa.gov/eim/myEIM.htm).

Audits and Reports

Manchester Environmental Laboratory (MEL) participates in routine performance and system audits of various analytical procedures. Audit results are available upon request. The Laboratory Accreditation Unit of Ecology's EAP accredits all contract laboratories that conduct environmental analyses for the agency, and the accreditation process includes performance testing and periodic lab assessments. No additional audits are envisioned.

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

MSMT staff will be responsible for analyzing the data and determining how the results will be summarized and documented in each PSAMP Sediment Component report. MSMT personnel will prepare both detailed technical reports and short summary "glossy" reports describing the results of each study. The reporting schedule for each PSAMP sediment monitoring element is summarized in Table 7. Annual reports will be generated for the Spatial/Temporal and Focus Study Monitoring Elements, while Long-Term/Temporal reports will summarize the appended data set every five years.

A general outline for the Spatial/Temporal element reports is given in Appendix K-1. Outlines for temporal and Focus Study reports will be modified from this and detailed in QA Project Plan amendments prepared prior to commencement of annual sampling. Draft reports will undergo peer review within Ecology and externally, followed by publication of the final document as an Ecology EAP technical report. Data will also be presented periodically at scientific symposia and summarized for publication in peer-reviewed journals as time allows.

Finally, MSMT personnel will keep Ecology managers apprised of the status of field work, sample analyses, data analysis, and report preparation for the study.

Public access to electronic versions of the data and reports generated from this project will be available via Ecology's home page (www.ecy.wa.gov/ecyhome.html) and the MSMT home page (www.ecy.wa.gov/programs/eap/psamp/index.htm).

Data Verification

Data verification will be conducted by MSMT, MEL, and contract lab staff by examining all field and laboratory-generated data to ensure:

1. Specified methods and protocols were followed.
2. Data are consistent, correct, and complete, with no errors or omissions.
3. Data specified in the *Sampling Process Design* section were obtained.
4. Results for QC samples as specified in the *Measurement Quality Objectives* and *Quality Control* sections accompany the sample results.
5. Established criteria for QC results were met.
6. Data qualifiers are properly assigned where necessary.

Field Data

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

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

Grain Size, TOC, Chemical, Toxicity, and Benthos Data

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

The report should include:

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

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

Data Quality (Usability) Assessment

Upon completion of the data verification process, Data Quality (Usability) Assessment will be conducted (Lombard and Kirchmer, 2004). If the MQOs have been 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 quantity is sufficient to meet project objectives. MSMT staff will be responsible for analyzing the data and determining how the results will be summarized and documented in each PSAMP Sediment Component report.

Sampling Design Evaluation and Meeting Project Objectives

Study designs are determined by the questions to be answered. Minimum acceptable sample sizes for those study designs are determined by the required significance level, precision, and statistical power. In practice, sample sizes are constrained by budgets.

The sampling designs for the PSAMP Spatial/Temporal and focus studies were developed by statisticians in NOAA (Wolfe, et al. 1993; Long et al., 1996; Long, 2000) and USEPA (Stevens and Olsen, 2004) and have been peer-reviewed at this national level. The PSAMP Long-Term/Temporal study design was peer-reviewed regionally, as described in Appendix B.

Sample results from laboratory analyses are examined for completeness (all samples, all analyses). Case narratives or contract-laboratory reports are scrutinized for adherence to the specified methods and QA/QC requirements.

Long-term/Temporal Monitoring

The sampling design for the Long-Term/Temporal Monitoring Element, described in detail in the *Sampling Process Design* section above, consists of collection of three replicate benthos samples annually, and three replicate chemistry samples every five years, from all 10 monitoring stations. A fourth "archive" replicate is collected at each station and held in appropriate storage. If one of three of the station's replicates is lost or damaged, or the data are compromised in any way, that replicate will be rejected and replaced with data from the fourth replicate.

The data from the three replicates are not merged; instead, they are used to evaluate the inherent, small-scale variability in the benthos within a station.

Spatial/Temporal Monitoring and Focus Studies

The probabilistic random stratified sampling design used for the Spatial/Temporal and Focus Study Monitoring Elements is described in detail in the *Sampling Process Design* section, above. This design consists of sampling sediments from a minimum of 30 "replicate" stations within a chosen sampling frame. All samples are analyzed to determine various physical, chemical, toxicity, and benthos measures.

The data generated are weighted to the sizes of the areas represented by each sample. Ultimately, the sizes of the areas that exceed the various criteria are summed to estimate the total area that is either contaminated, toxic, home to adversely affected benthos, or all of the above. Additionally, currently collected data are compared with past data to determine changes in these values over time.

This sampling design was adopted from the NOAA NS&T program, with later modifications made to align it with USEPA's GRTS multi-density survey design. Adequacy of this design to meet the objectives of these monitoring elements is documented in Stevens (1997), and Stevens and Olsen (1999, 2003, 2004).

Data Analysis and Presentation Methods

The statistical descriptive and inferential techniques used are determined by the questions to be answered (i.e., the research hypotheses). The choice of methods is updated to use best available, appropriate practices according to statistical research in peer-reviewed literature. Examples of methods currently used are listed 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 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) 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 the probability-based sample designs, cumulative distribution functions (CDF) of a given variable are computed and graphed, to describe spatial extent. The calculation of the CDFs includes the weighting of each sample result by the amount of area (within the study area) that that sample represents.

Summary statistics are computed for all variables. When nondetects are present in sediment chemistry data, summary statistics are estimated using accepted state-of-the-science techniques (currently robust regression on order statistics (ROS) or Kaplan-Meier censoring techniques (Helsel, 2005)).

Similarities of multiple multivariate samples, especially of benthic invertebrate assemblages, are graphically displayed with nonmetric multidimensional scaling (MDS) or other graphical descriptive procedures. Appropriate measures of similarity are calculated, depending on the type of data (currently, the Bray-Curtis similarity measure for benthos and Euclidean distance for environmental variables). Species abundances and environmental variables are first transformed or normalized as appropriate (Clarke and Warwick, 2001).

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.

For those contaminants for which there are Washington State SQS (Washington State Dept of Ecology, 1995) or NOAA Effects Range-Median (ERM; Long et al., 1995) sediment-quality guidelines, SQS or ERM quotients (ratio of measured chemical contamination to the respective SQS or ERM) are calculated. The mean ERM and mean SQS quotients are calculated to account for not only the presence of the chemicals that exceed these respective values but also the degree by which they exceed the values as mixtures.

Relationships Among Variables

The PSAMP 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 RELATE procedure in PRIMER v.6 (PRIMER-E Ltd., 2006), are used.

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

Comparisons

Because the PSAMP Spatial/Temporal and focus studies use a probability-based sampling design with unequal weighting, temporal or spatial comparisons of population estimates are conducted by comparing the CDFs (calculated as described above) with the Wald F or other appropriate statistical tests (Kincaid, 2000). Unweighted (or equally-weighted) comparisons of populations are made with appropriate nonparametric procedures. The CDFs being compared, along with their confidence bands, are graphed.

In the case of temporal comparisons involving repeat sampling of stations, appropriate paired-comparison tests are used (e.g., Wilcoxon signed ranks test). When nondetects are present, the paired Prentice-Wilcoxon test (Helsel, 2005) is used.

Comparisons of proportions (e.g., percent of study area exceeding mercury SQS) are done with appropriate statistical tests (e.g., two-proportion test). Area proportions (spatial extent) are calculated using the (unequal) 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 sets of samples (e.g., benthic assemblages from the same urban bay in two different years), based on their similarities (Clarke and Warwick, 2001). 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.

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Figures

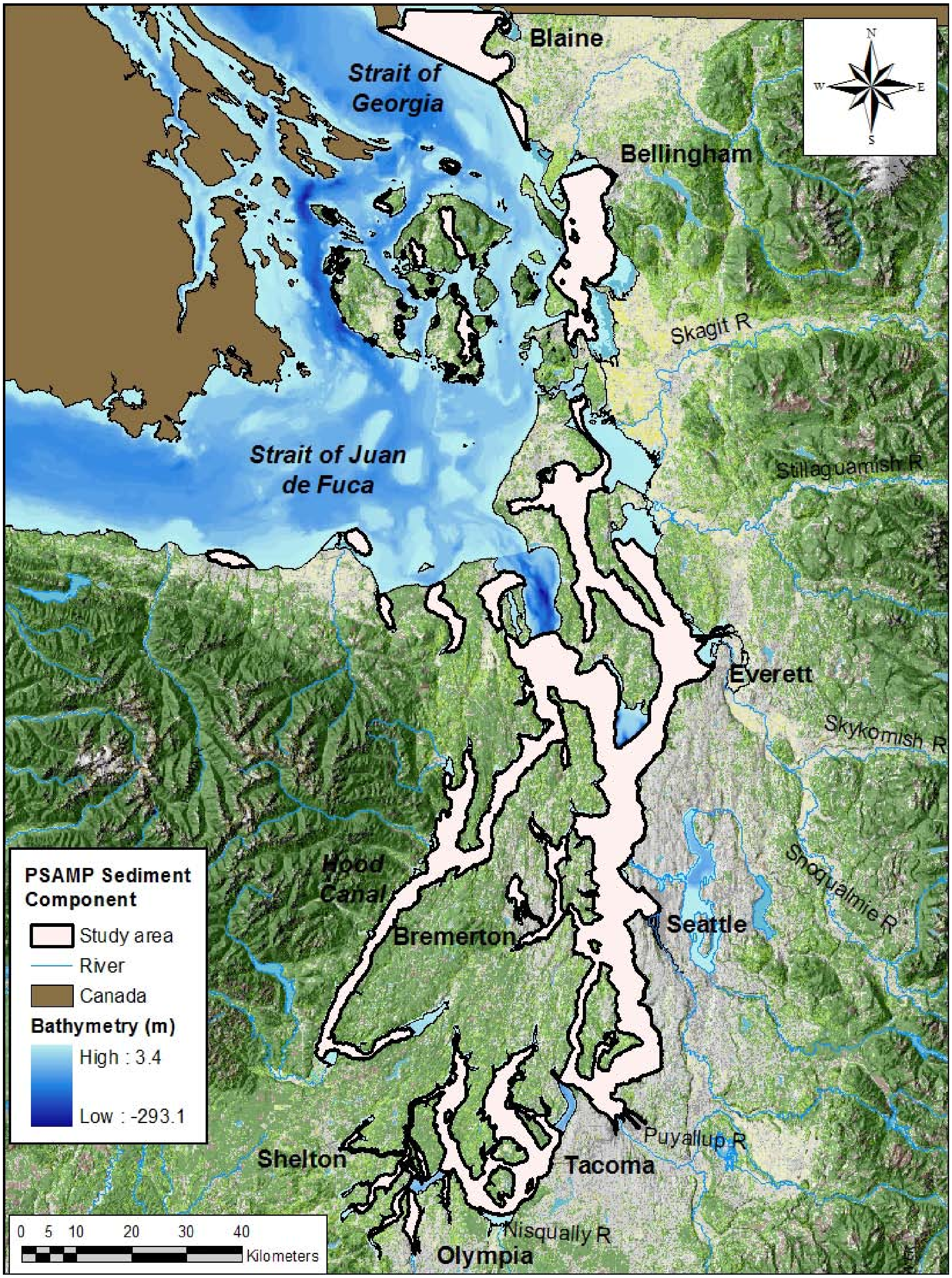

Figure 1. PSAMP Sediment Monitoring Component Puget Sound study area.

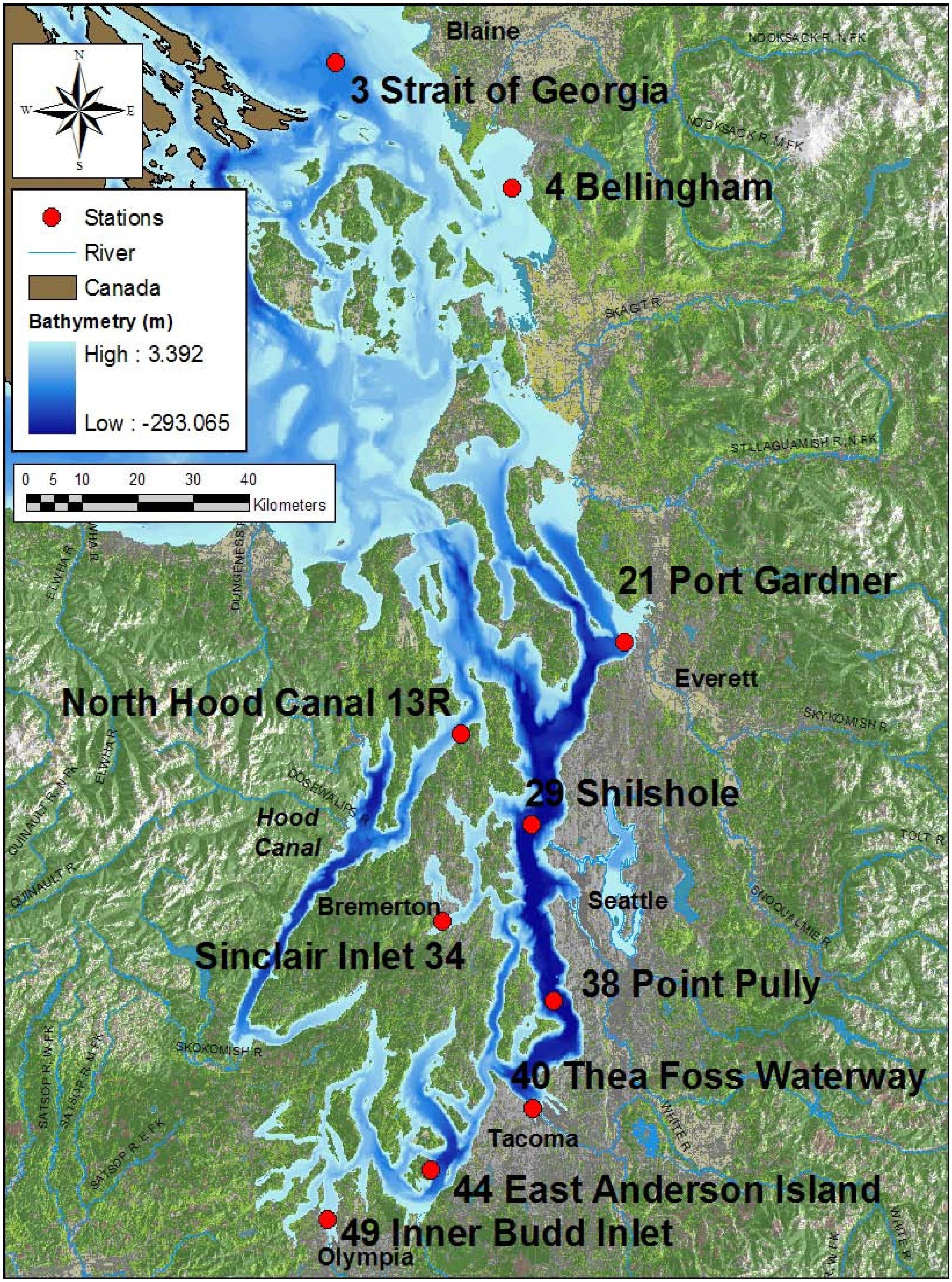

Figure 2. PSAMP Long-term/Temporal sediment monitoring station locations.

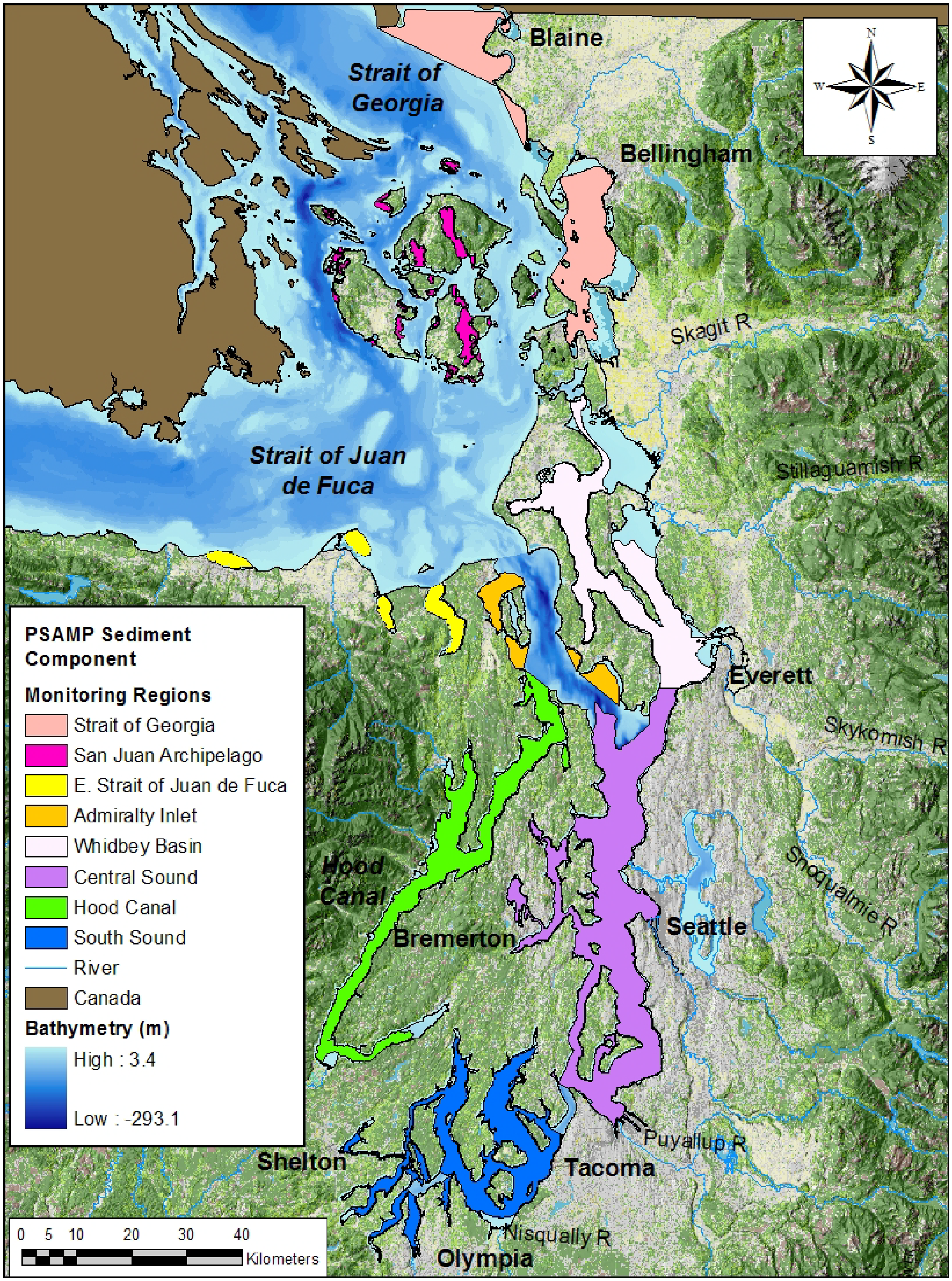

Figure 3. PSAMP Spatial/Temporal 8 sediment monitoring regions.

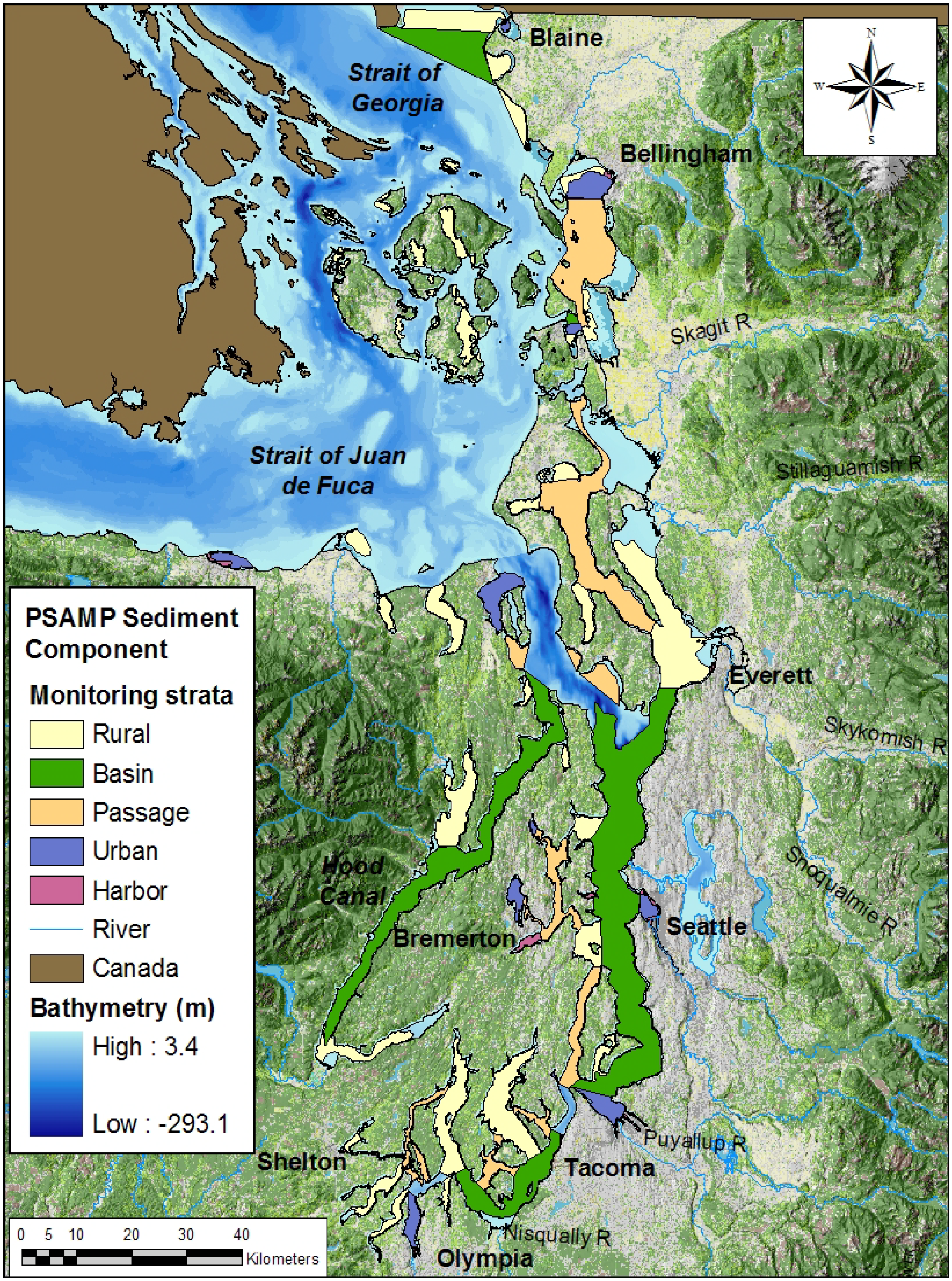

Figure 4. PSAMP Spatial/Temporal 5 sediment monitoring strata.

Tables

Table 1. Organization of project staff and responsibilities.

Name, unit, section, phone	Title	Responsibilities
Margaret Dutch Marine Monitoring Unit Western Operations Section Ecology - EAP (360) 407-6021	PSAMP Sediment Component Principal Investigator/ Project Manager, Report Writer	PSAMP Steering Committee member; MSMT lead; QA Project Plan preparation/editing; field work and lab contract oversight; data review, analysis, and interpretation; report writing/editing.
Sandra Weakland Marine Monitoring Unit Western Operations Section Ecology - EAP (360) 407-6980	Data Manager, Field Logistics, Report Preparation	Database management, EIM data entry, data analysis, report preparation, field sampling preparation and conduct.
Edward Long Marine Monitoring Unit Western Operations Section Ecology - EAP (503) 763-0263	Data Analyst, Report Writer	Data analysis and report writing/editing.
Valerie Partridge Marine Monitoring Unit Western Operations Section Ecology - EAP (360) 407-7217	Statistician, Data Analyst, Report Writer	Database management, statistical analysis of data, report writing/editing, field sampling preparation and conduct.
R. Eugene Ruff Marine Monitoring Unit Western Operations Section Ecology - EAP (253) 770-7007	Annelid Taxonomist	Primary and QA taxonomy of polychaete annelids collected from sediment samples.
Kathy Welch Marine Monitoring Unit Western Operations Section Ecology - EAP (360) 407-6035	Taxonomic Coordinator, Annelid Taxonomist	Contracting and coordination of all taxonomic work, primary and QA taxonomy of polychaete annelids, report writing/editing.
Carol Maloy Marine Monitoring Unit Western Operations Section Ecology - EAP (360) 407-6742	Unit Supervisor	Review and approval of QA Project Plan, budget tracking and management
John Weakland Ecology - EAP, Manchester Environmental Laboratory (360) 871-8820	Organics Unit Supervisor	Delivery and QC of all organic sediment chemistry data.
Dean Momohara Ecology - EAP, Manchester Environmental Laboratory (360) 871-8808	Inorganics Unit Supervisor	Delivery and QC of all inorganic sediment chemistry data.

Name, unit, section, phone	Title	Responsibilities
Stuart Magoon Ecology - EAP, Manchester Environmental Laboratory (360) 871-8801	Director	Approves the final QA Project Plan.
William R. Kammin Ecology - EAP (360) 407-6964	Ecology Quality Assurance Officer	Reviews the draft QA Project Plan and approves the final QA Project Plan.
Program Lead - Integrated and Coordinated Monitoring and Assessment Program for Puget Sound Puget Sound Partnership (360) 725-5463	Stakeholder	Oversight, review, and coordination of all Puget Sound monitoring programs.
9-member Science Panel Puget Sound Partnership (360) 725-5463	Stakeholders	Oversight, review, and coordination of all Puget Sound science programs and scientific liaison with PSP Leadership Council and Ecosystem Coordination Board.

EAP - Environmental Assessment Program.

Table 2. Proposed schedule for completing PSAMP Long-Term/Temporal Monitoring field and laboratory work, EIM data entry, and reports.

Field and laboratory work		
Field work completed	Annually in April	
Laboratory analyses completed	TOC – July of same year, Grain size – September of same year, Taxonomy – March of following year, Chemistry – March of following year (every 5 years)	
Environmental Information System (EIM) system		
Product	Due date*	Lead Staff
EIM data loaded	January of following year	Sandra Weakland
EIM QA	February of following year	Maggie Dutch
EIM complete	March of the following year	Sandra Weakland
**when chemistry data is generated every fifth year of this study, this EIM data loading schedule will follow that of the Spatial/Temporal and Focus Study elements.*		
Final report to be generated every 5 years after collection of chemistry samples (i.e., 2005, 2010, 2015, ...)		
Author lead	Sediment Team member to be designated for each report.	
Schedule		
Summary statistics, graphics, and text generated and posted to web	To be determined for each report	
Draft due to supervisor	To be determined for each report	
Draft due to client/peer reviewer	To be determined for each report	
Draft due to external reviewer	To be determined for each report	
Final (all reviews done) due to publications coordinator (Joan)	To be determined for each report	
Final report due on web	To be determined for each report	

Table 3. Proposed schedule for completing PSAMP Spatial/Temporal Monitoring field and laboratory work, EIM data entry, and reports.

A QA Project Plan addendum will be generated for each annual regional survey, providing sampling, organizational, and scheduling details for each study.

Field and laboratory work		
Field work completed	Annually in June	
Laboratory analyses completed	TOC – July of same year, Grain size – September of same year, Chemistry – March of following year, Toxicity – January of following year, Taxonomy – March of following year	
Environmental Information System (EIM) system		
Product	Due date	Lead Staff
EIM data loaded	March of following year	Sandra Weakland
EIM QA	April of following year	Maggie Dutch
EIM complete	May of following year	Sandra Weakland
Final report		
Author lead	Sediment Team member to be designated for each report.	
Schedule		
Summary statistics, graphics, and text generated and posted to web	To be determined for each report.	
Draft due to supervisor	May of following year	
Draft due to client/peer reviewer	May of following year	
Draft due to external reviewer	May of following year	
Final (all reviews done) due to publications coordinator (Joan)	June of following year	
Final report due on web	July of following year	

Table 4. Proposed schedule for completing Focus Study field and laboratory work, data entry into EIM, and reports.

A QA Project Plan addendum will be generated for each Focus Study, providing sampling, organizational, and scheduling details for each study.

Field and laboratory work		
Field work completed	To be determined for each project, but typically completed simultaneously with the PSAMP Spatial/Temporal Sediment Monitoring field work.	
Laboratory analyses completed	Same as PSAMP Spatial/Temporal Sediment Monitoring work if collected simultaneously, otherwise to be determined for each project.	
Environmental Information System (EIM) system		
Product	Due date	Lead Staff
EIM data loaded	March of the following year	Sandra Weakland
EIM QA	April of the following year	Maggie Dutch
EIM complete	May of the following year	Sandra Weakland
Final report		
Author lead	Sediment Team member to be designated for each report	
Schedule		
Summary statistics, graphics, and text generated and posted to web	To be determined for each report	
Draft due to supervisor	To be determined for each report	
Draft due to client/peer reviewer	To be determined for each report	
Draft due to external reviewer	To be determined for each report	
Final (all reviews done) due to publications coordinator (Joan)	To be determined for each report	
Final report due on web	To be determined for each report	

Table 5. Field and laboratory Measurement Quality Objectives for sediment grain size, total organic carbon, and chemistry analyses.

Parameter	Field Blank	Field Replicate (Split Sample)	Analytical (Laboratory) Replicate	Laboratory Control Sample	Reference Material[1]	Method Blank	Matrix Spike (and Matrix Spike Duplicates)	Surrogate Spike[2]
Measurement Frequency	Conducted in 1997	Duplicate analysis for 5% of samples	Triplicate analysis/batch of 20 samples for grain size and TOC. Duplicate analysis/batch for metals and organics samples.	1/batch of 20	1/batch of 20	1/batch of 20	1/batch of 20	every organics sample, blank, and QC sample (minimum of 3 for neutrals, 3 for acids)
MQO measured	RPD	RPD	RSD or RPD	% recovery limits	% recovery limits	comparison of analyte concentration in blank to quantification limit	% recovery limits	% recovery limits
Grain size	RPD $\leq$ 20%	NA	RSD $\leq$ 20%	NA	NA	NA	NA	NA
TOC	RPD $\leq$ 20%	NA	RSD $\leq$ 20%	Reference material serves as lab control sample	based on manufacturers set limits	Analyte concentration <MDL; if $\geq$ MDL, lowest analyte concn. must be $\geq$ 40x method blank concn. or qualified as an estimate	NA	NA
Metals	RPD $\leq$ 20%	RPD $\leq$ 20%	NA - when concentrations are low or below PQL, matrix spike/matrix spike duplicates serve as analytical duplicate	85-115	based on manufacturers set limits	Analyte concentration <MDL; if $\geq$ MDL, lowest analyte concn. must be $\geq$ 40x method blank concn. or qualified as an estimate	75-125	NA
Total mercury	RPD $\leq$ 20%	RPD $\leq$ 20%	NA - when concentrations are low or below PQL, matrix spike/matrix spike duplicates serve as analytical duplicate	85-115	based on manufacturers set limits	Analyte concentration <MDL; if $\geq$ MDL, lowest analyte concn. must be $\geq$ 40x method blank concn. or qualified as an estimate	75-125	NA
Butyl Tins	RPD $\leq$ 20%	RPD $\leq$ 20%	RPD $\leq$ 50%	40-130	40-130	Analyte concentration <PQL; if $\geq$ PQL, lowest analyte concn. must be $\geq$ 40x method blank concn.	40-130	40-130

Batch = a collection of 20 or fewer samples undergoing the same analyses at the same time.
MDL = Method Detection Limit
PQL = Practical Quantitation Limit
RPD = Relative Percent Difference
RSD = Relative Standard Deviation
NA = Not Applicable

Table 5. Continued.

Parameter	Field Blank	Field Replicate (Split Sample)	Analytical (Laboratory) Replicate	Laboratory Control Sample	Reference Material[1]	Method Blank	Matrix Spike (and Matrix Spike Duplicates)	Surrogate Spike[2]
Measurement Frequency	Conducted in 1997	Duplicate analysis for 5% of samples	Triplicate analysis/batch of 20 samples for grain size and TOC. Duplicate analysis/batch for metals and organics samples.	1/batch of 20	1/batch of 20	1/batch of 20	1/batch of 20	every organics sample, blank, and QC sample (minimum of 3 for neutrals, 3 for acids)
MQO measured	RPD	RPD	RSD or RPD	% recovery limits	% recovery limits	comparison of analyte concentration in blank to quantification limit	% recovery limits	% recovery limits
Base/Neutral/ Acid Organic Compounds	RPD ≤ 20%	RPD ≤ 20%	Compound specific RPD ≤ 40%	50-150	50-150	Analyte concentration <MDL; if ≥ MDL, lowest analyte concn. must be ≥ 10x method blank concn.	50-150	See detail in Table 5b
Polynuclear Aromatic Hydrocarbons	RPD ≤ 20%	RPD ≤ 20%	Compound specific RPD ≤ 40%	40-140	40-140	Analyte concentration <MDL; if ≥ MDL, lowest analyte concn. must be ≥ 10x method blank concn.	40-140	20-200
Chlorinated Pesticides	RPD ≤ 20%	RPD ≤ 20%	Compound specific RPD ≤ 40%	50-150	See Detail in Table 5a	Analyte concentration <MDL; if ≥ MDL, lowest analyte concn. must be ≥ 10x method blank concn.	50-150	50-150
PCB Arochlors and PCB Congeners	RPD ≤ 20%	RPD ≤ 20%	Compound specific RPD ≤ 40%	50-150	See Detail in Table 5a	Analyte concentration <MDL; if ≥ MDL, lowest analyte concn. must be ≥ 10x method blank concn.	50-150	50-150
Polybrominated Dichloroethylene (PBDE)	RPD ≤ 20%	RPD ≤ 20%	Compound specific RPD ≤ 40%	50-150	50-150	Analyte concentration <MDL; if ≥ MDL, lowest analyte concn. must be ≥ 10x method blank concn.	50-150	50-150

Batch = a collection of 20 or fewer samples undergoing the same analyses at the same time.
MDL = Method Detection Limit
PQL = Practical Quantitation Limit
RPD = Relative Percent Difference
RSD = Relative Standard Deviation
NA = Not Applicable

Explanations for Table 5.

Method Blanks: Analyzed to assess possible laboratory contamination of samples associated with all stages of preparation and analysis of sample extracts.

Surrogate Spike Compounds: A type of check standard that is added to each sample in a known amount prior to extraction or purging.

Analytical replicates: Provide precision information on the actual samples. Useful in assessing potential samples heterogeneity and matrix effects.

Matrix Spikes: Percent recoveries of matrix spikes are reported, should include a wide range of representative analyte types. Compounds should be spiked about 5x the concentration of compounds in the sample or 5x the quantification limit.

Laboratory Control Samples: Sometimes called check standards or laboratory control samples, are method blanks spiked with surrogate compounds and analytes. Useful in verifying acceptable method performance prior to and during routine analysis of samples.

Reference Materials: A material or substance whose property values are sufficiently well established to be used for calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials

Certified Reference Material: A reference material, provided by standard setting organizations such as NIST, CRM, etc., accompanied by or traceable to a certificate or other documentation that is issues by a certifying body

[1] Recovery limits for standard and certified reference material (SRM/CRM) (Table 5a) are based on the low and high confidence limits for each analyte.
[2] See surrogate sheet (Table 5b) for surrogate specific recovery limits.

Table 5a. Standard Reference Material (NIST 1944) recoveries for chemistry analyses.

Analyte	Std Dv	QC LIMITS			Range of certified values			Certified mid pt value
					+/-	low	high	
		Low	High	Average				
Hexachlorobenzene	13.8	59	141	94.8%	0.35	5.68	6.38	6.03
trans-Chlordane*	52.4	-57	257	202.1%	*2*	*6.00*	*10.00*	*8.00*
2,4'-DDE	*20.1*	40	160	*103.8%*	*3*	*16.00*	*22.00*	*19.00*
cis-Chlordane	18.4	45	155	82.7%	0.83	15.68	17.34	16.51
4,4'-DDE	*8.9*	73	127	*73.3%*	*12*	*74.00*	*98.00*	*86.00*
2,4'-DDD	*21.0*	37	163	*72.9%*	*8*	*30.00*	*46.00*	*38.00*
4,4'-DDD	*12.3*	63	137	*82.3%*	*16*	*92.00*	*124.00*	*108.00*
4,4'-DDT	25.4	24	176	133.2%	11	108.00	130.00	119.00
PCB- 8	15.7	53	147	104.7%	2.3	20.00	24.60	22.30
PCB- 18	11.2	66	134	95.9%	2.6	48.40	53.60	51.00
PCB- 28	10.8	68	132	103.2%	2.7	78.10	83.50	80.80
PCB- 44	11.2	66	134	91.4%	2	58.20	62.20	60.20
PCB- 52	11.4	66	134	79.7%	2	77.40	81.40	79.40
PCB- 66	9.9	70	130	79.1%	4.3	67.60	76.20	71.90
PCB-101	14.1	58	142	82.4%	2.5	70.90	75.90	73.40
PCB-118	10.5	69	132	71.5%	4.3	53.70	62.30	58.00
PCB-153	10.4	69	131	67.5%	2.9	71.10	76.90	74.00
PCB-105	16.8	50	150	78.7%	1.1	23.40	25.60	24.50
PCB-138	9.6	71	129	85.2%	3	59.10	65.10	62.10
PCB-128	15.3	54	146	91.3%	0.28	8.19	8.75	8.47
PCB-180	11.0	67	133	72.8%	1.2	43.10	45.50	44.30
PCB-170	9.5	72	129	69.0%	1.4	21.20	24.00	22.60
PCB-187	10.8	68	132	77.9%	1	24.10	26.10	25.10
PCB-195	16.3	51	149	81.0%	0.39	3.36	4.14	3.75
PCB-206	10.0	70	130	74.5%	0.51	8.70	9.72	9.21
PCB-209	21.3	36	164	92.5%	0.33	6.48	7.14	6.81

*trans-Chlordane co-elutes with PCB congener 169.
Values NOT certified.
Pesticide limits based on 19-23 distinct analyses.
PCB congener limits based on 18 distinct analyses.

Table 5b. Surrogate specific recovery limits for chemistry analyses.

Analysis	Matrix	Analyte	Surrogate control limits
BNASQS	Sediment/Soil	Terphenyl-D14	18-137
BNASQS	Sediment/Soil	1,2-Dichlorobenzene-D4	20-130
BNASQS	Sediment/Soil	2-Chlorophenol-D4	20-130
BNASQS	Sediment/Soil	Nitrobenzene-D5	23-130
BNASQS	Sediment/Soil	Phenol-D5	24-113
BNASQS	Sediment/Soil	2-Fluorophenol	25-121
BNASQS	Sediment/Soil	2-Fluorobiphenyl	30-115
BNASQS	Sediment/Soil	Pyrene-D10	50-150

Table 6. Field and Laboratory Quality Control Tests and Measurement Quality Objectives for sediment toxicity analyses.

				water quality measurements						
Parameter	**Negative Controls** (clean, nontoxic sediment or porewater)	**Positive (Toxic) Controls** (Reference Toxicant Dilution Series)	**Grain Size**	**Salinity (ppt)**	**Dissolved oxygen (percent saturation)**	**pH**	**Temper-ature (°C)**	**Sulfide**	**Total ammonia**	**Unionized ammonia**
Measurement Frequency:	**1/batch**	**1/batch; 1/test**	**1/sample**	**Daily**				**Day 0 and at test termination**		**calculated for Day 0 and test termination**
MQO measured:	**test acceptance criteria**	**deviation from control chart mean**	**target measurement/range**							
Amphipod (*Eohaustorius estuarius*) 10-day survival in bulk sediments	mean >90% survival in each batch control and ≥80% in all individual replicates	95% confidence intervals (± 2 standard deviations) around the mean	<70% clay	26 ppt or less in overlying water or can be acceptable with overlying water salinity ranging from 1-32ppt or pore water: 1-34ppt for *E. estuarius*	>90% (SOP requires continuous aeration)	7.7	15°C	NA	<60 total mg/L	<0.8 mg/L
Echinoderm (*Dendraster excentricus*) mortality and abnormality (20 min exposure)	mean 60-95% fertilization in each batch control	95% confidence intervals (± 2 standard deviations) around the mean	NA	30±1ppt	>80%	<8.1	12±1°C	<0.1 mg/L total sulfide	N/A	NOEC: 170ug/L

NOEC - No observable effects concentration.

Table 7. PSAMP Spatial/Temporal, PSAMP Long Term/Temporal, Focus, and Urban Waters Initiative sediment sampling schedule (1997-2025).

	Number of Samples Collected													Minimum number of samples required, by year															
year sampled:	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Spatial/Temporal Monitoring																													
San Juan Archipelago																	30										30		
Eastern Strait of Juan de Fuca						90 (81 new +9 old)												30										30	
Admiralty Inlet																			30										30
Strait of Georgia and Bellingham	100									40										30									
Whidbey Basin											40										30								
Central Sound (north)		100										30										30							
Central Sound (south)													50										30						
South Sound			100												30										30				
Hood Canal																30										30			
Long Term/Temporal Monitoring*	30	30	30	30+	30	30	30	30	30+	30	30	30	30	30+	30	30	30	30	30+	30	30	30	30	30+	30	30	30	30	30+
Focus Study/Special Projects								30						30										30					
Focus Study - Urban Waters Initiative																													
Elliott Bay/Lower Duwamish											30						30						30						30
Commencement Bay												30						30						30					
Bainbridge Basin, including Sinclair and Dyes Inlets													30						30						30				
Bellingham Bay														30						30						30			
Budd Inlet															30						30						30		
Everett Harbor/Port Gardner																30						30						30	

Reporting Level and Frequency	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Spatial/Temporal - Regional	x	x	x				x			x	x		x		x	x	x	x	x	x	x		x		x	x	x	x	x
Spatial/Temporal - Whole sound/strata			x				x												x										x
Long Term/Temporal Monitoring				x					x					x					x					x					x
Focus Study/Special Projects								x						x										x					
Focus Study - Urban Waters Initiative											x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

* 30 = Grain Size/Total Organic Carbon/Benthos collected; 30+ = Grain Size/Total Organic Carbon/Benthos/Chemistry collected.

Table 8. Parameters measured in Puget Sound sediments for the PSAMP Sediment Component Long-term/Temporal Monitoring Element.

Field Measurements
Sediment temperature
Salinity of overlying water

Macroinvertebrate Abundance
Total Abundance
Major Taxa Abundance
Taxa Richness
Pielou's Evenness
Swartz's Dominance Index

Related Parameters
Grain Size
Total organic carbon

Metals

Priority Pollutant Metals
Arsenic
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Zinc

Organics

Chlorinated Alkenes
Hexachlorobutadiene

Chlorinated and Nitro-Substituted Phenols
Pentachlorophenol

Chlorinated Aromatic Chemicals
1,2,4-trichlorobenzene
1,2-dichlorobenzene
1,3-dichlorobenzene
1,4-dichlorobenzene
2-chloronaphthalene
Hexachlorobenzene

Chlorinated Pesticides
2,4'-DDD
2,4'-DDE
2,4'-DDT
4,4'-DDD
4,4'-DDE
4,4'-DDT
Aldrin
Alpha-chlordane
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Endrin aldehyde
Endrin ketone
Gamma-BHC (Lindane)
Heptachlor
Heptachlor epoxide
Toxaphene
Trans-Chlordane (Gamma)

Polynuclear Aromatic Hydrocarbons

LPAHs
1-Methylnaphthalene
2-Methylnaphthalene
Acenaphthene
Acenaphthylene
Anthracene
Fluorene
Naphthalene
Phenanthrene
Retene

calculated values:
LPAHs

HPAHs
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene

Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Chrysene
Dibenzo(a,h)anthracene
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Perylene
Pyrene
calculated values:
HPAH
total Benzofluoranthenes

Miscellaneous Extractable Chemicals
Benzoic acid
Benzyl alcohol
Beta-coprostanol
Cholesterol
Dibenzofuran
Isophorone

Organonitrogen Chemicals
9(H)carbazole
Caffeine
N-nitrosodiphenylamine

Phenols
2,4-dimethylphenol
2-methylphenol
4-methylphenol
Phenol
Phenol, 4-Nonyl-

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

Polychlorinated Biphenyls
PCB Aroclor 1016
PCB Aroclor 1221
PCB Aroclor 1232
PCB Aroclor 1242
PCB Aroclor 1248
PCB Aroclor 1254
PCB Aroclor 1260
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

Recently added
Bisphenol A
Tri(2-chloroethyl) phosphate (TCEP)
Triclosan
Triethyl citrate

Table 9. PSAMP Sediment Component Long-Term/Temporal Monitoring Stations, including: station number, station name, location, and sampling schedule through 2020.

Station	Station Name	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (meters)	Year sampled 1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
3	Strait of Georgia (North of Patos Island)	48 52.22	122 58.695	223.0	X	X	X	X	X	X	X		*	*	*	X	*	*	*	*
4	Bellingham Bay	48 41.04	122 32.29	24.0	X	X	X	X	X	X	X		*	*	*	X	*	*	*	*
13R	North Hood Canal (South of Bridge)	47 50.26	122 37.74	20.0	X		X			X			*	*	*	X	*	*	*	*
21	Port Gardner (Everett)	47 59.13	122 14.575	20.0	X	X	X	X	X	X	X	X	*	*	*	X	*	*	*	*
29	Shilshole	47 42.06	122 27.23	199.0	X	X	X	X	X	X	X	X	*	*	*	X	*	*	*	*
34	Sinclair Inlet	47 32.84	122 39.725	9.5	X	X	X	X	X	X	X	&	*	*	*	X	*	*	*	*
38	Point Pully (3-Tree Point)	47 25.71	122 23.61	199.0	X	X	X	X	X	X	X	X	*	*	*	X	*	*	*	*
40	Thea Foss Waterway (Commencement Bay)	47 15.68	122 26.22	10.0	X	X	X	X	X	X	X	+	*	*	*	X	*	*	*	*
44	East Anderson Island	47 09.68	122 40.41	20.0	X	X	X	X	X	X	X	+	*	*	*	X	*	*	*	*
49	Inner Budd Inlet	47 04.82	122 54.82	5.3	X	X	X	X	X	X	X		*	*	*	X	*	*	*	*

Station	Station Name	Latitude (deg min N)	Longitude (deg min W)	Approx. Water Depth (meters)	Year sampled 2005	2006	2007	2008	2009	Year anticipated 2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
3	Strait of Georgia (North of Patos Island)	48 52.22	122 58.695	223.0	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X
4	Bellingham Bay	48 41.04	122 32.29	24.0	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X
13R	North Hood Canal (South of Bridge)	47 50.26	122 37.74	20.0	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X
21	Port Gardner (Everett)	47 59.13	122 14.575	20.0	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X
29	Shilshole	47 42.06	122 27.23	199.0	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X
34	Sinclair Inlet	47 32.84	122 39.725	9.5	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X
38	Point Pully (3-Tree Point)	47 25.71	122 23.61	199.0	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X
40	Thea Foss Waterway (Commencement Bay)	47 15.68	122 26.22	10.0	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X
44	East Anderson Island	47 09.68	122 40.41	20.0	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X
49	Inner Budd Inlet	47 04.82	122 54.82	5.3	X	*	*	*	*	X	*	*	*	*	X	*	*	*	*	X

X - sampling for sediment chemistry, total organic carbon, grain size, and benthic macrofauna

* - sampling for benthos, total organic carbon, and grain size only

& - sampling for chemistry and grain size only

+ - sampling for chemistry only

Table 10. Parameters measured in Puget Sound sediments for the PSAMP Spatial/ Temporal and Focus Monitoring Elements.

Field Measurements
Sediment temperature
Salinity of overlying water

Toxicity Parameters
Amphipod Survival (solid phase)
Urchin Fertilization (porewater)

Macroinvertebrate Abundance
Total Abundance
Major Taxa Abundance
Taxa Richness
Pielou's Evenness
Swartz's Dominance Index

Related Parameters
Grain Size
Total organic carbon

Metals

Priority Pollutant Metals
Arsenic
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Zinc

Element
Tin

Organics

Chlorinated Alkenes
Hexachlorobutadiene

Chlorinated and Nitro-Substituted Phenols
Pentachlorophenol

Chlorinated Aromatic Chemicals
1,2,4-Trichlorobenzene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
2-Chloronaphthalene
Hexachlorobenzene

Chlorinated Pesticides
2,4'-DDD
2,4'-DDE
2,4'-DDT
4,4'-DDD
4,4'-DDE
4,4'-DDT
Aldrin
Cis-Chlordane (Alpha-Chlordane)
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan Sulfate
Endrin
Endrin Aldehyde
Endrin Ketone
Gamma-BHC (Lindane)
Heptachlor
Heptachlor Epoxide
Mirex
Oxychlordane
Toxaphene
Trans-Chlordane (Gamma)

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
calculated values:
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
calculated values:
total HPAH
total Benzofluoranthenes

Miscellaneous Extractable Chemicals
Benzoic Acid
Benzyl Alcohol
Beta-coprostanol
Carbazole
Cholesterol
Dibenzofuran
Isophorone

Organonitrogen Chemicals
Caffeine
N-Nitrosodiphenylamine

Phenols
2,4-Dimethylphenol
2-Methylphenol
4-Methylphenol
Phenol
Phenol, 4-Nonyl-

Phthalate Esters
Bis(2-Ethylhexyl) Phthalate
Butylbenzylphthalate
Diethylphthalate
Dimethylphthalate
Di-N-Butylphthalate
Di-N-Octyl Phthalate

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

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

Recently added
Bisphenol A
Tri(2-chloroethyl) phosphate (TCEP)
Triclosan
Triethyl citrate

Table 11. Definitions of geophysical/anthropogenic-use strata for PSAMP Spatial/Temporal Monitoring Element.

Type	Natural features	Anthropogenic features
Harbor	• semi-enclosed embayments, terminal inlets - head of bay/estuary. • shallow.	• maritime activity - commercial vessel traffic and/or ports and/or shipyards. • adjacent to urban/industrial centers. • high numbers of point and/or nonpoint sources of discharge. • frequently dredged. • presence of docks, breakwaters, jetties.
Urban	• semi-enclosed embayments, sometimes head of bay/estuary, includes outer harbors. • shallow to mid-depth.	• adjacent to urban/industrial centers. • lower numbers of point and/or nonpoint source discharge. • may or may not be dredged.
Basin	• deep. • associated with a sill.	• may or may not be adjacent to urban/ industrial centers. • lowest numbers of point and/or nonpoint source discharge (although some receive treated effluent from municipal point source outfalls).
Passage	• bounded by two shorelines and open at both ends (*i.e.*, doesn't end in an embayment). • deep. • not associated with a sill.	• not adjacent to urban/industrial centers. • lowest numbers of point and/or nonpoint source discharge.
Rural	• includes semi-enclosed embayments and terminal inlets, as well as larger inlets. • shallow to deep.	• not adjacent to urban/industrial centers or maritime activity; adjacent land mass is largely undeveloped. • lightly populated. • lowest numbers of point and/or nonpoint source discharges. • frequently used as reference locations.

Table 12. Target area (km^2) of PSAMP Sediment Component Spatial/Temporal Monitoring Element.

Shown by geographical region and geophysical/anthropogenic-use stratum.

Region	Stratum					Area	
	Basin	Harbor	Passage	Rural	Urban	**Total (km^2)**	**Percent (%)**
Strait of Georgia/Bellingham	92.8	1.9	139.6	115.8	36.8	386.9	16.5
San Juan Islands	--	--	--	83.4	--	83.4	3.6
Eastern Strait of Juan de Fuca	--	3.5	--	54.7	11.3	69.6	3
Admiralty Inlet	--	--	42.3	--	33.8	76.1	3.2
Whidbey Basin	--	0.7	172.9	196.1	--	369.7	15.8
Central Puget Sound	482.1	13.9	86.3	54.6	47.1	683.9	29.2
South Puget Sound	84.9	1.1	54.4	184.6	16.6	341.6	14.6
Hood Canal	230.8	--	--	101.0	--	331.7	14.2
Total (km^2)	890.5	21.2	495.5	790.2	145.6	2343.0	
Percent (%)	38	0.9	21.1	33.7	6.2		100

Table 13. Sample volumes and preservation for laboratory analysis.

Parameter	Size of Sample	Container	Preservation	Maximum Holding Time
Grain Size	8 oz.	1 8-oz wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC	6 months
Grain Size Archive Sample	8 oz.	1 8-oz wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC	6 months
Total Organic Carbon	2 or 4 oz.	1 2-oz wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	14 days
Metals	4 oz.	1 4-oz wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	All metals except mercury: 6 months at 4ºC or 2 years at -18ºC; Mercury: 28 days at 4ºC
Butyl Tins	8 oz.	1 8-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	14 days at 4ºC or 1 year at -18ºC
PAH	8 oz.	1 8-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	1 year
Chlorinated Pesticides, PCB, PBDE	8 oz.	1 8-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	1 year
Base/Neutral/Acid Organic Compounds	8 oz.	1 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.	1 16-oz certified organic-free wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4ºC or freeze at -18°C	1 year
Amphipod Survival (Solid Phase)	1 gallon	1-gallon high-density polyethylene, acid-stripped, wide-mouth jugs*	Refrigerate at 4ºC	10 days
Urchin Fertilization (Pore Water)	1 gallon	1-gallon high-density polyethylene, acid-stripped, wide-mouth jugs*	Refrigerate at 4ºC	10 days
Benthic Macrofauna	0.1 m^2	1-gallon zip-lock freezer bags or 1-gallon polyethylene wide-mouth jugs	Screen through 1.0-mm mesh, and store in 10% aqueous solution of borax-buffered formalin	48 hours to 14 days

*Or as specified by the contract laboratory.

Table 14. Sediment Quality Field Parameters: Field analytical methods, required reporting limits, and QA/QC procedures.

Parameter	Expected Range Of Results	Technique/ Instrument	Measurement Method	Required Reporting Limit	Quality Assurance/ Quality Control
Sediment Penetration Depth	0-17 cm	Metric Ruler	Measure the amount of space between the top of the sample and the top of the grab and subtracting from the maximum grab depth (17 cm).	1 cm	Careful measurement
Sediment Temperature	7-15 °C	Digital or Alcohol Thermometer	Read from thermometer inserted into the sediment sample.	1.0 °C	Calibration of thermometer
Overlying Salinity	7-34 ppt	Refractometer	Pipet a drop of the water overlying the sample onto the refractometer and read the salinity from the measurement scale.	1.0 ppt	Set refractometer to 0 ppt with DI water daily
Sediment Type	Cobble, gravel, sand, silt-clay	N/A	Visually examine the sediment in the grab.	N/A	Training from experienced personnel
Material in Sediment	Wood, shell, plant fragments and macroalgae	N/A	Visually examine the sediment in the grab.	N/A	Training from experienced personnel
Sediment Color	Olive, gray, brown, black	N/A	Visually examine the sediment in the grab.	N/A	Training from experienced personnel, use of color chart
Sediment Odor	Hydrogen sulfide, petroleum, other	N/A	Smell the sediment in the grab.	N/A	Training from experienced personnel

Table 15. Laboratory analysis and reporting requirements for sediment grain size, total organic carbon, and metals and organic chemistry analyses for the PSAMP Sediment Component.

The number of samples collected each year varies between the Long Term/Temporal, Spatial, and Focus Study Monitoring Elements.

Parameter	Expected Range Of Results	Extraction Method	Clean-Up Method	Analysis Method	Technique/ Instrument	Required Reporting Limit
Grain Size	<20% - >80% silt+clay	N/A	N/A	PSEP, 1986	sieve-pipette method	1.0%
Total Organic Carbon	0.01-15.0%	Drying sediment material	N/A	PSEP, 1986	determination of CO_2 by non-dispersive infrared spectroscopy	0.1%
Metals (except mercury)	< 0.1 - 500 ppm (up to 1500 for zinc)	USEPA 3050B	N/A	USEPA 200.8	ICP-MS	0.1 mg/kg dry weight (0.2 for Sn, 0.5 for Cr and Se, 5.0 for Zn)
Total Mercury	0.001-10 ppm	USEPA 245.5	N/A	USEPA 245.5	CVAA	0.005 mg/kg dry weight
Butyl Tins	< 0.1 – 3,500 ppb	Manchester Method (MEL, 2000)	USEPA 3630 silica gel	Manchester Method (MEL, 2000)	Capillary GC/AED	2 µg/kg dry weight or ≤ 0.1x reference concentration
Base/Neutral/ Acid Organic Compounds (BNAs)	0.1 – 55,000 ppb	USEPA 3541	USEPA 3630 through 1999, then discontinued	USEPA 8270	Capillary GC/MS	20 µg/kg dry weight (for ≥ 50% solids)
Polynuclear Aromatic Hydrocarbons (PAHs)	0.01 – 50,000 ppb	USEPA 3545	USEPA 3630C	USEPA 8270 with isotopic dilution	Manchester modification with capillary GC/MS-SIM isotopic dilution analysis	0.5-2.0 µg/kg dry weight
Chlorinated Pesticides	< 0.1 - 50 ppb	USEPA 3545	USEPA 3620 and USEPA 3665	USEPA 8081	GC-DDC/ECD	1 µg/kg dry weight (20 for toxaphene)
PCB Aroclors	1 – 4,000 ppb	USEPA 3545	USEPA 3620 and USEPA 3665	USEPA 8082	GC-DDC/ECD	10 µg/kg dry weight
PCB Congeners	< 0.1 – 4,000 ppb	USEPA 3545	USEPA 3620 and USEPA 3665	USEPA 8082	GC-DDC/ECD	1 µg/kg dry weight
PBDE Congeners	< 0.1 – 4,000 ppb	USEPA 3545	USEPA 3620, 3665	USEPA 8270	Capillary GC/MS-SIM	1 µg/kg dry weight

"N/A" = not applicable

Table 16. Sediment toxicity bioassays: Laboratory analytical methods and endpoints. Shading indicates those tests currently in use.

Toxicity Test	Years Conducted For *PSAMP Sediment Component*	Test Method	Sediment Matrix	Test Organism	Life History Stage	Endpoint	Expected Range of Results
Amphipod 10-day	1989-present	PSEP, 1995; ASTM, 2004a	bulk sediment	*Eohaustorius estuarius* (2002-present) *Ampelisca abdita* (1997-1999) *Rhepoxynius abronius* (1989-1993)	adult	survival as % of control	
Sea urchin fertilization	1997-present	ASTM, 2004b; Carr et al., 1996	sediment pore water	*Strongylocentrotus purpuratus*	gametes	mean egg fertilization in 100% porewater as % of control	
Echinoderm larvae 48 hour	2002-2003, 2006	PSEP, 1995; ASTM, 2004b	sediment/ water elutriate	*Dendraster excentricus*	larval	% normal embryo development and survival	
Microtox™	1997-1999	PSEP, 1995	organic solvent extract	*Vibrio fischerii*	cellular reaction	microbial bioluminescence activity	
Microtox™	2002-2003	PSEP, 1995	sediment porewater	*Vibrio fischerii*	cellular reaction	microbial bioluminescence activity	
Cytochrome P450 Human Reporter Gene System (HRGS)	1997-1999	Anderson, 1995, 1997; APHA, 1996; ASTM, 1997	organic solvent extract	human liver cell culture	cellular reaction	cellular production of benzo[a]pyrene (µgB[a]p/gm) equivalence	

Table 17. Benthic Infaunal Parameters: Laboratory analytical methods and resolution.

Parameter	Method	Resolution
Infaunal Sorting	All benthic macroinfaunal invertebrates are removed from sample with use of a dissection microscope.	• Macroinfauna: Sorted into Annelida, Arthropoda, Mollusca, Echinodermata, and Miscellaneous Taxa. • Meiofauna: Presence and relative abundance of recorded. • Colonial organisms: Representative samples collected and relative abundance noted.
Taxonomic Identification	Identification with dissection and compound microscopes, taxonomic literature, and voucher specimens.	Lowest taxonomic level possible, preferably to species.
Taxonomic Enumeration	Count.	Count all whole organisms.

Appendices

All appendices for this report are stored in electronic format that can be accessed from this report at www.ecy.wa.gov/biblio/0903121.html or from the compact disk distributed with this report.

Appendix A. Puget Sound Partnership – Engrossed Substitute Senate Bill 5372 (July 1, 2007)

- A-1. Puget Sound Partnership – Engrossed Substitute Senate Bill 5372 (July 1, 2007)

Appendix B. Puget Sound Assessment and Monitoring Program (PSAMP) Sediment Monitoring in Puget Sound: Historical Background

- B-1. Puget Sound Assessment and Monitoring Program (PSAMP) Sediment Monitoring in Puget Sound: Historical Background

- B-2. 1998 Sediment Component revisions memo

Appendix C. PSAMP Temporal Field Replicate Selection

- C-1. Station positioning of benthic infaunal invertebrate "field replicate" samples
- Figure C-1. Hexagonal grid centered on target location.
- Figure C-2. Adaptation of grid to follow depth contour when target location is on a slope.
- Figure C-3. Adaptation of grid when target location is near shore.
- Figure C-4. Distances from target location to hexagon centroids.
- Figure C-5. Possible numbering schemes.
- Table C-1. Station Coordinates for Field Replicates

Appendix D. PSAMP Spatial/Temporal Probabilistic Random Stratified Sampling Design

- D-1. Details of the PSAMP Spatial/Temporal Sediment Monitoring Element Probabilistic Random Stratified Sampling Design.

- Table D-1. Adjusted PSAMP Spatial/Temporal sample allocation by region.

Appendix E. Sampling Forms for the PSAMP Sediment Monitoring Component

- E-1. PSAMP Long-term/Temporal Field Log.
- E-2. PSAMP Spatial/Temporal Field Log.
- E-3. Urban Waters Initiative Field Log.
- E-4. Daily Log.
- E-5. Sample Labels.
- E-6. Grain Size Chain-of-Custody Form.
- E-7. Chemistry Chain-of-Custody Form.
- E-8. Toxicity Chain-of-Custody Form.
- E-9. Archive Samples Chain-of-Custody Form.
- E-10. Benthic Infaunal Chain-of-Custody Form.
- E-11. Benthic Infaunal Tracking Form.
- E-12. Benthic Infaunal Taxonomy Chain-of-Custody Form.

Appendix F. Standard Operating Procedure for Obtaining Marine Sediment Samples

- F-1. ECY EAP SOP 039 – Standard Operating Procedure for Obtaining Marine Sediment Samples - Washington State Department of Ecology, Environmental Assessment and Monitoring Program .

- F-2. Environmental Assessment Program Safety Manual 2009.

Appendix G. Physical and Chemical Sediment Analyses and EPA Methods Performed

- G-1. A Brief Description of Physical and Chemical Analyses and USEPA Methods Performed for the *PSAMP Sediment Component.*

Appendix H. Sediment Bioassay Methods

- H-1. ASTM E1367 – Amphipod 10-day bioassay.
- H-2. ASTM E1563 – Echinoderm larval test.

Appendix I. Benthic Infaunal Sample Processing

- I-1. ECY EAP SOP 043 – Standard Operating Procedures for Macrobenthic Sample Analysis, Washington State Department of Ecology, Environmental Assessment and Monitoring Program.
- I-3. Ecology Chemical Hygiene Plan 2006.
- I-4. Sorting Specifications to Contractors.
- I-5. Taxonomy Specifications to Contractors.

Appendix J. Grain Size and Toxicity Sample Processing

- J-1. Grain Size Sample Processing Scope-of-Work.
- J-2. Amphipod 10-day Sediment Bioassay Scope-of-Work.
- J-3. Sea Urchin Fertilization – Porewater Toxicity Testing Scope of Work.

Appendix K. PSAMP Spatial Report Template

- K-1. PSAMP Spatial report template.