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Addendum 9 to Quality Assurance Project Plan

The Puget Sound Assessment and Monitoring Program: Sediment Monitoring Component, 2017

April 2017

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Addendum

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Addendum 9 to Quality Assurance Project Plan

The Puget Sound Assessment and Monitoring Program: Sediment Monitoring Component, 2017

April 2017

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Signatures are not available on the Internet version.
EAP: Environmental Assessment Program

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2.0 Abstract

The Puget Sound Ecosystem Monitoring Program[1] (PSEMP) Sediment Component is currently undergoing review and revision. Interim changes to the sampling elements were implemented in 2016, and further changes will be implemented in 2017 in preparation of a full program redesign in 2018.

This addendum to the 2009 Puget Sound Assessment and Monitoring Program (PSAMP) Sediment Monitoring Component Quality Assurance Project Plan (QAPP) provides details about changes to be made in 2017 for station locations, parameters, methods, and sampling and analysis schedules for the Long-term and Urban Bays elements of the program. This addendum also includes information regarding:

- Collection of sediment grab samples from eight Bellingham Bay stations for the Washington State Department of Ecology’s (Ecology) Toxics Cleanup Program.
- Collection of 25 sediment core samples in Bellingham Bay for measurement of nutrient flux processes by Western Washington University scientists.
- Sampling and analysis of zooplankton collected for up to seven co-located PSEMP sediment and water column stations.
- Incidental/opportunistic samples to be collected for and analyzed by non-Ecology researchers.

All other quality assurance elements remain unchanged and are as described in the 2009 QAPP (Dutch et al., 2009).

[1] Formerly known as the Puget Sound Assessment and Monitoring Program

3.0 Background

The PSEMP Sediment Component has been implemented by Ecology's Marine Sediment Monitoring Team (MSMT) since 1989. Recent evaluation of data collected since the inception of the program suggests that modifications be made to the sampling strategy and that the focus be expanded to include a broader suite of ecosystem pressures and stressors beyond the toxics emphasis of the original program (Striplin, 1988) and subsequent revisions (Dutch et al., 2009). With this in mind, the Long-term[2], Regional[3], and Urban Bays[4] elements of the program are currently undergoing review and revision.

Preliminary changes to the current sampling design were introduced in 2016 (Weakland et al., 2016). Further changes continue in 2017. These changes will serve as a springboard for future program modifications to facilitate better characterization of sediment conditions in geographically and oceanographically diverse locations throughout Puget Sound. New parameters will serve as indicators related to climate change and nutrient loading, as well as chemical contamination. A revised program will be implemented in 2018, with a fully updated QAPP published prior to sampling.

This QAPP addendum provides detailed information about the schedule, budget, measurement quality objectives, parameter list, sampling procedures, and measurement methods for the 2017 Long-Term and Urban Bays sediment surveys that differ from the original QAPP (Dutch et al., 2009). It also includes information regarding:

- Collection of sediment grab samples from eight Bellingham Bay stations for the Washington State Department of Ecology's (Ecology) Toxics Cleanup Program.
- Collection of 25 sediment core samples in Bellingham Bay for measurement of nutrient flux processes by Western Washington University scientists.
- Sampling and analysis of zooplankton collected for up to 7 co-located PSEMP sediment and water column stations.
- Incidental/opportunistic samples to be collected for and analyzed by non-Ecology researchers.

The numbering scheme for the sections of this addendum reflects Ecology's current required formatting for QAPPs and is not found in the original QAPP.

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[2] Formerly known as "Long-term/Temporal"
[3] Formerly known as "Spatial/Temporal"
[4] An expansion of Ecology's "Urban Waters Initiative"

4.0 Project Description

Interim PSEMP Sediment Monitoring

The three annual monitoring elements of the PSEMP Sediment Component which are currently under review and revision include:

- **Long-Term** – Since 1989, sediment sampling has been conducted in April at 10 stations located throughout Puget Sound.

  CHANGES: Sampling was expanded by 12 stations in 2016 to a total of 22. In 2017, an additional 28 randomly selected stations will be added, for a total of 50. Added random sample sites will provide sufficient data to calculate the spatial extent (km^2) of parameters measured for the Puget Sound-wide sampling frame. Additionally, modifications have been made to the parameters examined, including a reduction in the list of organic chemicals.

- **Regional** − Sediments at 40 stations have been sampled each June within one of eight geographic regions since 1997. Sampling rotated among the regions on roughly 10-year cycles through 2014. A new set of randomly selected stations was sampled each time a region was revisited. This approach was well-suited for characterization of annual regional and 10-year Puget Sound-wide sediment chemistry and toxicity trends. However, changes occurring to the targeted sediment-dwelling invertebrate community (benthos) could not be analyzed in concert with more rapidly changing oceanographic and climatic pressures on a Puget Sound-wide scale. To better understand the influence of these pressures, monitoring in 2017 and in the future will emphasize annual sediment monitoring Puget Sound-wide through expansion of the Long-Term monitoring element.

  CHANGES: Regional sampling was not conducted in 2016, and will be dropped in 2017 and subsequent years.

- **Urban Bays** − Sediments at 30 stations have been sampled each June within one of six urban bays in rotation since 2007. The same set of randomly selected stations is sampled each time an urban bay is revisited. Surveys of these bays provide an excellent characterization of bay-wide sediment chemistry and toxicity, and changes over time, at six-year intervals. These data serve, in part, as an effectiveness monitoring tool for the collective pollutant source control and cleanup activities conducted in these bays, and annual rotational monitoring will continue for this program.

  CHANGES: Sampling will resume in Bellingham Bay in June 2017, with a modified parameter list.

Toxics Cleanup Program sampling request – Bellingham Bay

Lucy McInerney, Ecology's Toxics Cleanup Program (TCP)

Lucy McInerney has requested that sediment grab samples be collected from eight locations in Bellingham Bay that are of interest to the Toxics Cleanup Program. Per Lucy's project request to Ecology's Environmental Assessment Program (EAP), three stations will be sampled near the South State Street Manufactured Gas Plant Site and five will be sampled near the Boulevard Park/Fairhaven Tidelands overwater walkway. Sediments will be analyzed for various physical and chemical parameters. With the exception of the use of high resolution analytical methods for polychlorinated biphenyls (PCBs), methods for sampling and sample analysis will follow Dutch et al., 2009.

Nutrient Flux Determination Pilot Study – Bellingham Bay

Dr. David Shull, Western Washington University (WWU)

Sediment cores will be collected by Dr. Shull and a student with a haps coring device from 25 of the 2017 PSEMP Bellingham Bay station locations for a nutrient flux pilot project. Samples will be incubated and sampled over time to determine fluxes of dissolved oxygen, dissolved inorganic carbon, ammonium, nitrate+nitrite, phosphate, silicate, and the rate of sedimentary organic carbon oxidation. Sediment pore-water nutrient profiles will also be determined at selected stations.

Data and a summary report will be generated by Dr. Shull and his student and will be available to the MSMT for comparison with concurrently-collected sediment and benthos data. Future collaborative work will be considered, with an emphasis on developing lab and field procedures which complement the ongoing monitoring program and provide a more integrated picture of biogeochemical processes occurring at Puget Sound's sediment-water interface.

Zooplankton Monitoring Pilot Study

Dr. Julie Keister, University of Washington – Seattle; Salish Sea Marine Survival Project

Dr. Keister conducts a Puget Sound-wide zooplankton monitoring program with many partners as part of the Salish Sea Marine Survival Project (SSMSP) (http://marinesurvivalproject.com/resources/). Zooplankton samples for this project are collected at 31 stations throughout Puget Sound, including two co-located PSEMP sediment and water stations in Hood Canal.

In addition to review of data generated for the SSMSP, the MSMT will conduct an in-house zooplankton pilot project. We will collect vertical tows for zooplankton at up to five additional co-located PSEMP sediment/water stations from April 2017 through March 2018, and also at two co-located PSEMP/SSMSP stations from November 2017 through February 2018.

To gain a sense of the benthic invertebrate contribution to the zooplankton, meroplankton (i.e., organisms that are planktonic for only a part of their life cycles, usually the larval stage) abundance, size class, and biomass will be quantified. Zooplankton and meroplankton data will also be correlated with condition of the benthos, sediment, and water quality at these co-located stations.

This pilot study will be conducted in conjunction with Ecology's monthly PSEMP Marine Waters sampling effort (Bos et al., 2015). Collection and sample processing methods used will match those developed for the SSMSP (Keister, 2016) and for the King County Marine Zooplankton Monitoring Program (Kolb, 2015) (provided in Appendix A). All data will be shared with these programs.

Partnerships with other monitoring programs: Leveraged sampling and data

As a way to leverage additional scientific knowledge from our field efforts and data, integrated partnerships, both long-standing and new, have been formed with other Ecology and regional scientists to generate sediment-related data which will help us interpret the condition and changes over time in Puget Sound sediments and benthos. Topics and collaborators include the following:

Water column physical and biogeochemical properties – Dr. Christopher Krembs and Ecology's Marine Monitoring Unit staff – PSEMP Water Column Component (since 2016)

Vertical water column profile measurements are collected at 36 core stations monthly, including 20 stations which are co-located with Long-Term core sediment stations (Table 11 in Bos et al, 2015; Table 8, below). In addition, particulate and total organic carbon and nitrogen data are collected from surface and bottom waters at the 20 co-located stations as part of a 15-month pilot project (Keyzers and Krembs, 2016). These data provide a record of monthly trends in water column condition and will be examined in relation to sediment and benthos condition in Puget Sound.

Microplastics – Julie Masura, University of Washington (since 2015)

The MSMT provides Ms. Masura and her students with approximately 200 ml of sediment collected from each PSEMP Sediment Component station sampled. Sediments collected for the Puget Sound Plastics Project are analyzed in Ms. Masura's lab using their own methods and standard operating procedures to determine the presence of plastics in sediments throughout the estuary. When plastics are recovered, they are counted, measured (dimensions and biomass), and mapped for each year. When these data become available, Ecology staff will use them to calculate the spatial extent (# pieces/km^2) of the plastics for the Puget Sound-wide and Urban Bays sampling frames.

Harmful algal blooms – Dr. Cheryl Greengrove and Julie Masura, University of Washington – Tacoma (since 2013)

The MSMT provides Dr. Greengrove and Ms. Masura with approximately 4 oz. of sediment collected from each PSEMP Sediment Component station sampled annually. With their students, they have examined the abundance and distribution of *Alexandrium* sp. cysts in the Puget Sound sediment samples. *Alexandrium* sp. is a dinoflagellate that spends part of its life-cycle as a cyst in the sediment before germinating to become a vegetative cell. This species produces a suite of neurotoxins that can accumulate in the tissues of filter-feeding shellfish and can be lethal to humans if ingested. This study evaluates whether the location or concentration of cysts exhibit patterns that can be associated with shellfish bed closures due to the presence of paralytic shellfish toxins (PSTs) above regulatory limits in shellfish.

Foraminifera monitoring – Dr. Liz Nesbitt, University of Washington (since 1997)

The MSMT provides Dr. Nesbitt with approximately 4 oz. of sediment collected from each PSEMP Sediment Component station sampled. She and her colleague, Dr. Ruth Martin, and their students examine the type, abundance, and distribution of foraminifera identified in our Puget Sound sediment samples. Foraminifera, marine protozoans with calcium carbonate or agglutinated sediment particle tests (shells), are an important component of the benthos. Their community structure and physical condition are sensitive indicators of chemical pollution and ocean acidification. Information generated is published in student reports and posters as well as in the primary literature.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 1. Organization of project staff and responsibilities.

Staff (all are EAP staff)	Title	Responsibilities
Margaret Dutch Marine Monitoring Unit Western Operations Section Phone: 360-407-6021	Benthic Ecologist, Project Manager	Marine Sediment Monitoring Team lead, QAPP preparation, field sampling preparation and conduct, lab contract oversight, data review, report preparation.
Sandra Weakland Marine Monitoring Unit Western Operations Section Phone: 360-407-6980	Benthic Ecologist	Database management, EIM data entry, data analysis, report preparation, field sampling preparation and conduct, GIS lead, lab contract oversight.
Valerie Partridge Marine Monitoring Unit Western Operations Section Phone: 360-407-7217	Benthic Ecologist	Statistician and lead data analyst, report preparation, field sampling preparation and conduct.
Dany Burgess Marine Monitoring Unit Western Operations Section Phone: 360-407-6685 & 360-407-3970	Lead Taxonomist	Primary and secondary invertebrate taxonomy, voucher sheet generation, voucher collection maintenance, field sampling.
Angela Eagleston Marine Monitoring Unit Western Operations Section Phone: 360-407-6517 & 360-407-3970	Taxonomist	Primary and secondary invertebrate taxonomy, voucher sheet generation, voucher collection maintenance, field sampling.
WCC IP (varies by year) Marine Monitoring Unit Western Operations Section Phone: 360-407-6711	Washington Conservation Corp Individual Placement	Various lab and field work duties for the MSMT.
Carol Maloy Marine Monitoring Unit Western Operations Section Phone: 360-407-6742	Unit Supervisor for the Project Manager	Reviews the project scope and budget, tracks progress, provides internal review of the draft QAPP, and approves the final QAPP.
Dale Norton Western Operations Section Phone: 360-407-6596	Section Manager for the Project Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
Joel Bird Manchester Environmental Laboratory Phone: 360-871-8801	Director	Reviews and approves the final QAPP.
William R. Kammin Phone: 360-407-6964	Ecology Quality Assurance Officer	Reviews and approves the draft QAPP and the final QAPP.

EAP: Environmental Assessment Program
EIM: Environmental Information Management system
QAPP: Quality Assurance Project Plan

5.4 Proposed project schedule

April/May 2017 – Long-Term Sediment Monitoring

Key activities for the Long-Term sediment monitoring are listed in Table 2.

Table 2. Proposed schedule for completing field and laboratory work, EIM data entry, and reports for the Long-Term sediment monitoring.

Field and laboratory work	Due date	Lead staff
Field work completed	May 2017	All MSMT staff
Laboratory analyses completed	TOC – June 2017 TC/TOC/TIC/TN – June 2017 Grain Size – June 2017 Sorting – August 2017 Taxonomy/Biomass – December 2017	
Environmental Information System (EIM) database		
EIM Study ID	PSAMP_LT	
Product	Due date	Lead staff
EIM data loaded	January 2018	Sandra Weakland
EIM data entry review	February 2018	MSMT staff – will vary
EIM complete	March 2018	Sandra Weakland
Final report		
Author lead / Support staff	MSMT staff – will vary	
Schedule		
Draft due to supervisor	September 2018	
Draft due to client/peer reviewer	October 2018	
Draft due to external reviewer(s)	October 2018	
Final (all reviews done) due to publications coordinator	November 2018	
Final report due on web	December 2018	

June 2017 – Urban Bays Sediment Monitoring

Key activities for the June 2017 PSEMP Urban Bays sediment monitoring are listed in Table 3.

Table 3. Proposed schedule for completing the field and laboratory work, EIM data entry, and reports for the Urban Bays sediment monitoring.

Field and laboratory work	Due date	Lead staff
Field work completed	June 2017	All MSMT staff
Laboratory analyses completed	TOC – August - same year TC/TOC/TIC/TN – August 2017 Grain Size – August 2017 Sorting – September 2017 Taxonomy/Size Class/Biomass – March 2018 Chemistry – March 2018	
Environmental Information System (EIM) database		
EIM Study ID	UWI2017	
Product	Due date	Lead staff
EIM data loaded	April 2018	Sandra Weakland
EIM data entry review	May 2018	MSMT staff – will vary
EIM complete	June 2018	Sandra Weakland
Final report		
Author lead / Support staff	MSMT staff – will vary	
Schedule		
Draft due to supervisor	September 2018	
Draft due to client/peer reviewer	October 2018	
Draft due to external reviewer(s)	October 2018	
Final (all reviews done) due to publications coordinator	November 2018	
Final report due on web	December 2018	

Toxics Cleanup Program sampling – Bellingham Bay stations

Field, laboratory, and EIM activities for the collection of sediments from eight stations for the TCP are listed in Table 4. MSMT staff will collect all samples and ship them to both Manchester Environmental Lab (MEL) and an appropriate contract laboratory (PCB samples only) for analysis. MEL staff will generate and oversee the contract work for the PCB analysis. Data are to be provided from both laboratories in EIM format. Data review will be conducted by MSMT and MEL staff. Loading to EIM will be conducted by MSMT staff. A written report will not be generated.

Table 4. Proposed schedule for completing the field and laboratory work and EIM data entry for the Bellingham Bay Toxics Cleanup Program sediment monitoring.

Field and laboratory work	Due date	Lead staff
Field work completed	May 2017	All MSMT staff
Laboratory analyses completed	TOC – June 2017 Grain Size – June 2017 Metals – June 2017 AXYS PCBs – June 2017; MEL Organics – July 2017	
Environmental Information System (EIM) database		
EIM Study ID	UWI2017	
Product (all except PCB congeners)	Due date	Lead staff
EIM data loaded	August 2017	Sandra Weakland
EIM data entry review	September 2017	MSMT staff – will vary
EIM complete	October 2017	Sandra Weakland

Nutrient Flux Determination Pilot Study – Bellingham Bay

Field sampling activities for the collection of sediment cores from 25 stations for nutrient flux determination will be conducted in June 2017. Ecology's Marine Monitoring Unit (MMU) staff will work with Dr. Shull and his student to collect all sediment cores. Dr. Shull and his student will then complete all core incubation, laboratory, database, and reporting activities by September 2017. All data and the final report will be shared with Ecology staff. A summary of this project is provided in Appendix B.

Zooplankton Monitoring Pilot Study

Key activities for the April 2017-March 2018 zooplankton pilot study are listed in Table 5. Data will be loaded into EIM and also provided to Dr. Keister and SSMSP staff.

Table 5. Proposed schedule for completing the field and laboratory work, EIM data entry, and report for the Zooplankton Monitoring Pilot Study.

Field and laboratory work	Due date	Lead staff
Field work completed monthly	March 2018	Sandra Weakland
Laboratory analyses completed	Sorting – July 2018 Taxonomy/Biomass – September 2018	Sandra Weakland
Environmental Information System (EIM) database		
EIM Study ID	UWI2017	
Product	Due date	Lead staff
EIM data loaded	October 2018	Sandra Weakland
EIM data entry review	November 2018	MSMT staff – will vary
EIM complete	December 2018	Sandra Weakland
Final report		
Author lead / Support staff	MSMT staff – will vary	
Schedule		
Draft due to supervisor	March 2019	
Draft due to client/peer reviewer	April 2019	
Draft due to external reviewer(s)	May 2019	
Final (all reviews done) due to publications coordinator	July 2019	
Final report due on web	August 2019	

5.5 Budget

April/May Long-Term and June Urban Bays Sediment Monitoring

The proposed budget for the 2017 annual PSEMP sediment monitoring is provided in Table 6. This budget does not include the full cost of the monitoring program. It is limited to direct expenses for the specific elements below.

Table 6. PSEMP project budget.

Expense	Long-term	Urban Bays	Taxonomy	Total
Boat	$10,500.00	$ 7,350.00		$ 17,850.00
Grain size	$11,934.00	paid in next biennium		$ 11,934.00
Tax WS/VS			$ 7,065.00	$ 7,065.00
Metals/Org.		$37,170.00		$ 37,170.00
TOC (PSEP, 1986)	$ 6,885.00	$ 1,485.00		$ 8,370.00
TC, TOC, TIC, TN (EPA 440)	$15,300.00	$ 3,300.00		$ 18,600.00
Grand Total	$44,619.00	$49,305.00	$ 7,065.00	$ 100,989.00

Toxics Cleanup Program sampling – Bellingham Bay stations

The proposed budget for the collection and analysis of sediments from eight stations for the TCP is provided in Table 7.

Table 7. Toxics Cleanup Program project budget and SIC codes

EAP Staff (J1240)	no. staff	no. hours	$/hour	Total	Comments
planning and sampling preparation	3	12	$ 45.00	$ 1,620.00	
field crew	2	24	$ 45.00	$ 2,160.00	
Skookum operator	1	24	$ 45.00	$ 1,080.00	
data prep and EIM entry	1	10	$ 45.00	$ 450.00	
Field work travel (Whatcom Co. rate) (J1240)	no. staff	no. days, nights	$/day, night		
lodging	3	2	$ 91.00	$ 546.00	
per diem	3	3	$ 51.00	$ 459.00	
Skookum costs (J1240)		no. days, nights	$/day, night		
moorage		2	$ 50.00	$ 100.00	
launch		1	$ 10.00	$ 10.00	
Lab Analysis (J7140)		no. samples	$/sample		
grain size		8	$ 78.00	$ 624.00	use PSEMP June field duplicate, lab QA values
TOC		8	$ 44.00	$ 352.00	
metals		8	$ 197.00	$ 1,576.00	
PAHs		8	$ 434.00	$ 3,472.00	
PCB congeners High Resolution - contract lab		9	$ 875.00	$ 7,875.00	8 samples +1 field duplicate
MEL 25% overhead (contracts, QA, validation)				$ 1,968.75	
			Grand Total:	$22,292.75	

SIC: Super Index Code

Nutrient Flux Determination Pilot Study – Bellingham Bay

Collection of sediment cores will be conducted in conjunction with PSEMP Urban Bays sediment sampling. Dr. Shull and/or his student will complete the sampling aboard the RV Skookum with MSMT staff. MSMT staff costs are included, in part, in Table 6 above, and detailed in Table 8.

Table 8. Nutrient Flux Determination Pilot Study budget.
(MSMT costs only, does not include WWU expenses)

EAP Staff	no. staff	no. hours	$/hour	Total
planning and sampling preparation	1	20	$ 45.00	$ 900.00
field crew	1	48	$ 45.00	$ 2,160.00
Skookum operator	1	48	$ 45.00	$ 2,160.00
Field work travel (Whatcom Co. rate)	no. staff	no. days, nights	$/day, night	
lodging	2	6	$ 91.00	$ 1,092.00
per diem	2	6	$ 51.00	$ 612.00
Skookum costs		no. days, nights	$/day, night	
moorage		6	$ 50.00	$ 300.00
launch		1	$ 10.00	$ 10.00
Lab Supplies		no.	$/per case	
30mm syringe filters		500	$ 1,125.00	$ 1,125.00
20ml scintillation vials		500	$ 131.00	$ 131.00
			Grand Total:	$ 8,490.00

Zooplankton Monitoring Pilot Study

Sampling for zooplankton will be conducted in conjunction with Ecology's monthly PSEMP Marine Waters sampling. One vertical plankton tow will be collected at each of up to seven stations, adding a small amount of staff time to the sampling program. Staff have purchased the necessary collection equipment, including a plankton net and flow meter, for approximately $2500. Sample collection jars and the formaldehyde are already available as part of monitoring the benthos. Sample processing and identification of zooplankton will be conducted by Ecology staff at no additional cost to the program. MSMT staff costs are included in Table 9.

Table 9. Zooplankton Monitoring Pilot Study 12-month budget.

EAP Staff	no. staff	no. hours	$/hour	Total
planning and sampling preparation	1	6	$ 45.00	$ 270.00
field crew	2	68	$ 45.00	$ 6,120.00
Skookum operator	1	34	$ 45.00	$ 1,530.00
Lab work - taxonomic identification, biomass	1	136	$ 45.00	$ 6,120.00
data prep and EIM entry	1	5	$ 45.00	$ 225.00
			Grand Total:	$14,265.00

Leveraged partnership sampling – Microplastics, Harmful Algal Blooms, Foraminifera

A small amount of sample collected from each Long-Term and Urban Bays station is set aside for the microplastics, harmful algal blooms, and foraminifera partnership projects described earlier. Costs incurred by the MSMT are minimal staff time, and outlined in Table 10.

Table 10. Leveraged partnership sampling project budget.

EAP Staff	no. staff	no. hours	$/hour	Total	Comments
planning and sampling preparation	2	1	$ 45.00	$ 90.00	
field crew	1	1	$ 45.00	$ 45.00	
sample check-in and transfer	1	2	$ 45.00	$ 90.00	
Supplies		number	$/each	Total	
Zip-lock baggies (HAB, Foram samples)		80	na	na	provided by partner
sample jars (microplastics)		80	na	na	provided by partner
			Grand Total:	$ 225.00	

7.0 Study Design

7.2 Field data collection

7.2.1 Sampling locations and frequency

Surface soft sediments and benthos will be sampled at each of 50 Long-Term and 30 Bellingham Bay monitoring stations. Sediments will also be collected from an additional eight stations for the Toxics Cleanup Program (TCP). Plankton will be sampled monthly from April 2017 through March 2018 at up to five co-located sediment and water column monitoring stations, and also from November 2017 through February 2018 at two additional stations.

April/May 2017 – Long-Term Sediment Monitoring

- 10 non-random core stations sampled annually with only a few exceptions since 1989.
- 12 additional non-random core stations sampled in 2016 and occasionally since 1989.

Twenty of these 22 stations are co-located with Ecology's Marine Waters Monitoring Program stations (Bos et al., 2015; Keyzers and Krembs, 2016). The additional 12 sites will allow for a wider-ranging characterization of sediment conditions in geographically and oceanographically diverse locations throughout Puget Sound. Establishing baseline conditions at co-located sediment and water column monitoring stations will support future comparison of sediment and water column parameters spatially and temporally.

- 28 new randomly-selected stations.

These stations have been chosen from the spatially-balanced, generalized random tessellation stratified (GRTS) multi-density survey design developed for the PSEMP Sediment Component by the U.S. Environmental Protection Agency (EPA) (Dutch et al., 2009). These stations are located throughout the Puget Sound sampling frame and provide the program with additional, spatially-balanced Puget Sound-wide coverage. Data generated from these new stations, along with the 22 non-random stations, will allow calculation of the spatial extent of sediment quality for parameters sampled Puget Sound-wide and annual comparison over time.

Station locations and alternates are depicted in Figure 1-2 and summarized in Tables 11-12.

Zooplankton Monitoring Pilot Study – Monthly

Five of the 20 co-located Long-Term stations (Figure 1 and Table 11) have been chosen for monthly zooplankton monitoring. Stations 305R and HCB003 in Hood Canal will be sampled by MSMT staff from November through February, as they are sampled in other months by the Hood Canal Salmon Enhancement Group as part of the Salish Sea Marine Survival Project. All sampling for this pilot study will occur as schedule, staff time, and logistics allow.

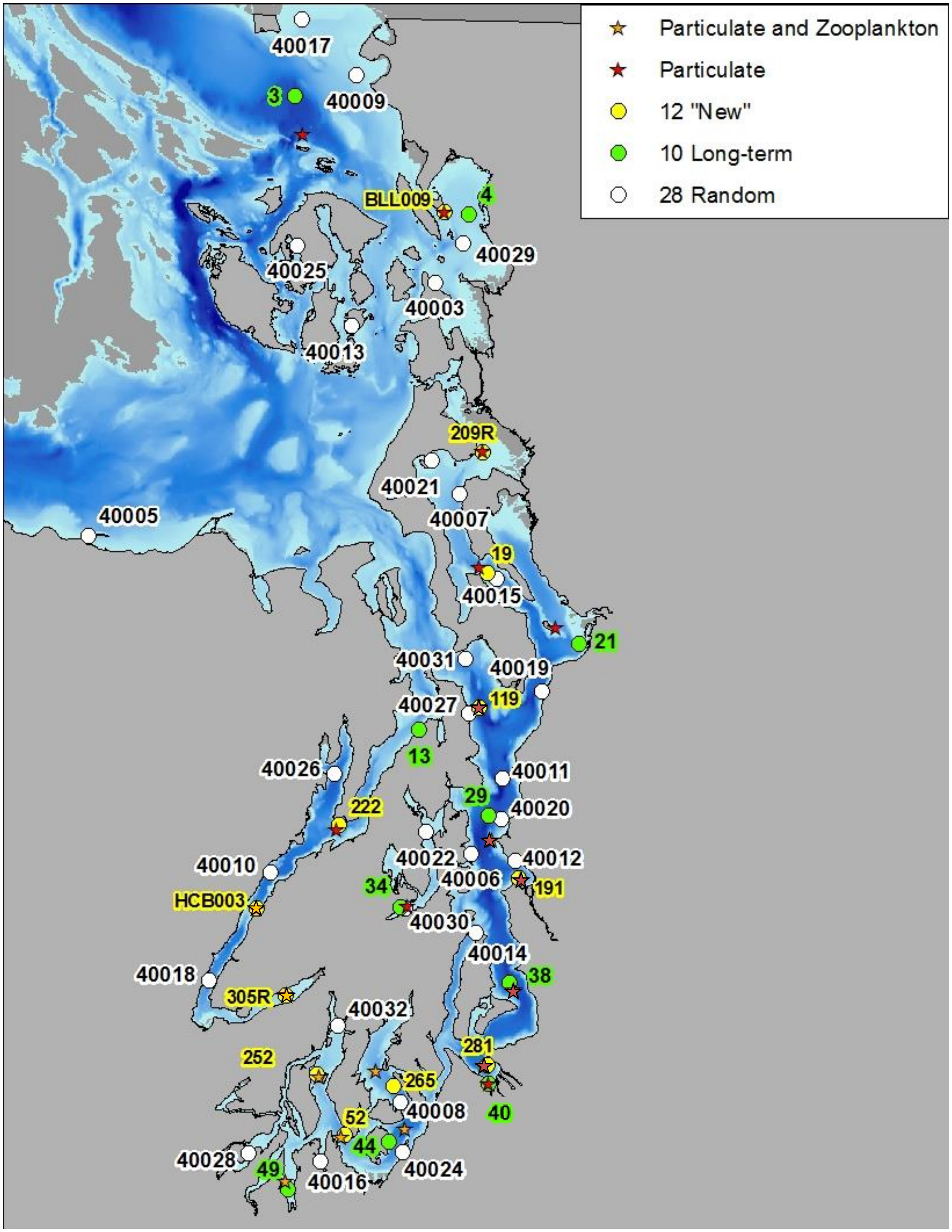

Figure 1. Long-Term sediment and monthly zooplankton monitoring stations.

Table 11. Long-Term sediment monitoring stations.

<table>
<tr><th>Station Id</th><th>Station location</th><th>Latitude</th><th>Longitude</th><th>Station type</th><th>Co-located with Marine Waters</th><th>Zoo-plankton collection</th></tr>
<tr><td>3</td><td>Strait of Georgia</td><td>48.87025</td><td>-122.97842</td><td>Long-term</td><td></td><td></td></tr>
<tr><td>4</td><td>Bellingham Bay</td><td>48.68397</td><td>-122.5382</td><td>Long-term</td><td>x</td><td></td></tr>
<tr><td>BLL009</td><td>Bellingham Bay - Pt. Frances</td><td>48.68593</td><td>-122.59962</td><td>New in 2016</td><td>x</td><td></td></tr>
<tr><td>209R</td><td>Skagit Bay</td><td>48.29533</td><td>-122.4885</td><td>New in 2016</td><td>x</td><td></td></tr>
<tr><td>19</td><td>Saratoga Passage</td><td>48.09792</td><td>-122.47134</td><td>New in 2016</td><td>x</td><td></td></tr>
<tr><td>21</td><td>Port Gardner/ Everett Harbor</td><td>47.98547</td><td>-122.24283</td><td>Long-term</td><td>x</td><td></td></tr>
<tr><td rowspan="3">119</td><td rowspan="3">Admiralty Inlet</td><td>47.87615</td><td>-122.48217</td><td>New in 2016</td><td>x</td><td></td></tr>
<tr><td>47.87616</td><td>-122.47816</td><td>2017</td><td>x</td><td></td></tr>
<tr><td colspan="5">2017 - Target coordinates shifted 300m east to avoid buried utility cables.</td></tr>
<tr><td>29</td><td>Shilshole</td><td>47.70075</td><td>-122.45403</td><td>Long-term</td><td>x</td><td></td></tr>
<tr><td>191</td><td>Central</td><td>47.59842</td><td>-122.37581</td><td>New in 2016</td><td>x</td><td></td></tr>
<tr><td>34</td><td>Sinclair Inlet</td><td>47.54708</td><td>-122.66208</td><td>Long-term</td><td>x</td><td></td></tr>
<tr><td>38</td><td>Point Pully (3 Tree Point)</td><td>47.42833</td><td>-122.39363</td><td>Long-term</td><td>x</td><td></td></tr>
<tr><td>281</td><td>Commencement Bay</td><td>47.29229</td><td>-122.44193</td><td>New in 2016</td><td>x</td><td></td></tr>
<tr><td>40</td><td>Thea Foss Waterway</td><td>47.2613</td><td>-122.4373</td><td>Long-term</td><td>x</td><td></td></tr>
<tr><td>44</td><td>East Anderson Island</td><td>47.16133</td><td>-122.67358</td><td>Long-term</td><td>x</td><td>x</td></tr>
<tr><td>265</td><td>Carr Inlet</td><td>47.2524</td><td>-122.66572</td><td>New in 2016</td><td>x</td><td>x</td></tr>
<tr><td>252</td><td>Case Inlet</td><td>47.26957</td><td>-122.85101</td><td>New in 2016</td><td>x</td><td>x</td></tr>
<tr><td>52</td><td>W. of Devils Head, Case Inlet (Nisqually Reach)</td><td>47.17060</td><td>-122.78051</td><td>New in 2016</td><td>x</td><td>x</td></tr>
<tr><td>49</td><td>Budd Inlet</td><td>47.07997</td><td>-122.91347</td><td>Long-term</td><td>x</td><td>x</td></tr>
<tr><td>13R</td><td>Hood Canal (north of bridge)</td><td>47.83758</td><td>-122.62895</td><td>Long-term</td><td></td><td></td></tr>
<tr><td>222</td><td>Hood Canal</td><td>47.67821</td><td>-122.81466</td><td>New in 2016</td><td>x</td><td></td></tr>
<tr><td>HCB003</td><td>Hood Canal - Central</td><td>47.53787</td><td>-123.0096</td><td>New in 2016</td><td>x</td><td rowspan="2">x (Dec-Feb only, other months sampled by HCSEG)</td></tr>
<tr><td>305R</td><td>Lynch Cove</td><td>47.39717</td><td>-122.93124</td><td>New in 2016</td><td>x</td></tr>
<tr><td>40003</td><td>Guemes Island</td><td>48.57092</td><td>-122.61857</td><td>Random</td><td></td><td></td></tr>
<tr><td>40005</td><td>Inner Port Angeles Harbor</td><td>48.13872</td><td>-123.44985</td><td>Random</td><td></td><td></td></tr>
<tr><td>40006</td><td>Murden Cove</td><td>47.63777</td><td>-122.4939</td><td>Random</td><td></td><td></td></tr>
<tr><td>40007</td><td>Saratoga Passage, north, Camano Island</td><td>48.22609</td><td>-122.54375</td><td>Random</td><td></td><td></td></tr>
<tr><td>40008</td><td>Carr Inlet, NE of Gertrude Island</td><td>47.22686</td><td>-122.64787</td><td>Random</td><td></td><td></td></tr>
<tr><td>40009</td><td>Strait of Georgia, outer Birch Bay</td><td>48.90625</td><td>-122.82638</td><td>Random</td><td></td><td></td></tr>
</table>

Station Id	Station location	Latitude	Longitude	Station type	Co-located with Marine Waters	Zoo-plankton collection
40010	Central Hood Canal, south of Triton Cove	47.59777	-122.97953	Random		
40011	Central Basin, north of Shilshole	47.76107	-122.42159	Random 2016		
		47.76108	-122.41759	2017		
		Target coordinates shifted 300m east to avoid buried utility cables.				
40012	Elliott Bay, Smith Cove	47.625896	-122.38563	Random		
		Target coordinates shifted 100m SW to avoid ship berth at Pier 91.				
40013	Reads Bay	48.49626	-122.82139	Random		
40014	North Vashon Island	47.50823	-122.47764	Random		
		Moved 100m west (original coordinates in intertidal zone, according to Nobeltec)				
40015	Saratoga Passage, south	48.08877	-122.44853	Random		
40016	Henderson Inlet	47.12549	-122.83635	Random		
40017	Boundary Bay	48.99473	-122.96789	Random		
40018	Hood Canal, Hoodsport	47.41787	-123.11736	Random		
40019	South Possession Sound	47.90607	-122.33076	Random		
40020	Shilshole Bay	47.69588	-122.42252	Random		
40021	Crescent Harbor	48.27948	-122.61517	Random		
40022	Brownsville	47.67154	-122.59952	Random		
40024	South Ketron Island	47.14498	-122.63831	Random		
40025	West Sound	48.62526	-122.96208	Random		
40026	Dabob Bay	47.76217	-122.83153	Random		
40027	Admiralty Inlet north of Rose Point	47.86624	-122.5082	Random		
40028	Totten Inlet	47.13600	-123.01006	Random		
40029	North Samish Bay	48.63718	-122.55226	Random		
40030	Sinclair Inlet	47.54500	-122.65102	Random		
40031	Useless Bay, Outer	47.95533	-122.51782	Random		
40032	Inner Case Inlet, Rocky Bay	47.34949	-122.8055	Random		

HCSEG: Hood Canal Salmon Enhancement Group

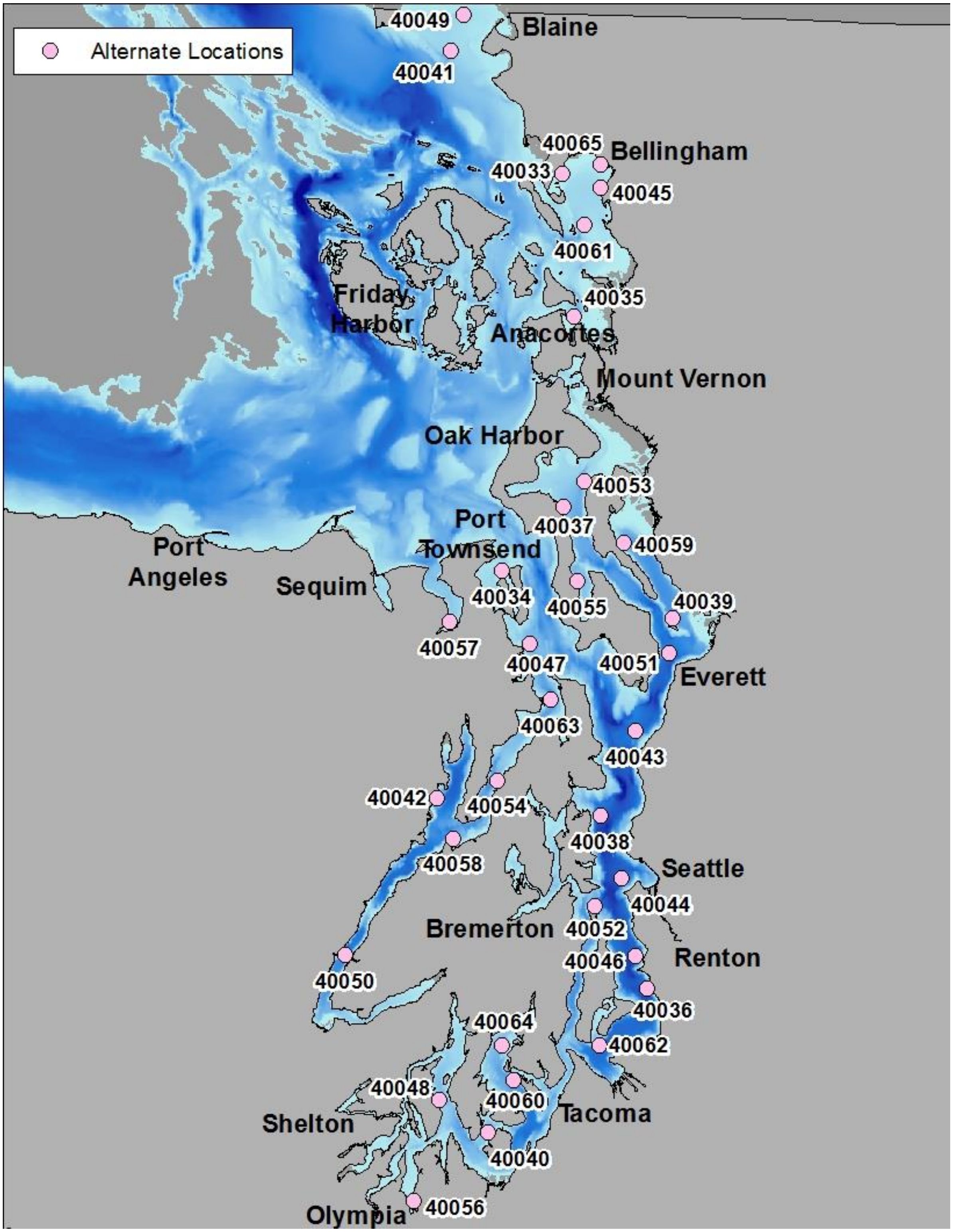

Figure 2. Long-Term alternate sediment monitoring stations.

Table 12. Long-Term alternate sediment monitoring stations.

Station Id	Station location	Latitude	Longitude
40033	Northwest Bellingham Bay	48.74223	-122.61304
40034	Port Townsend, mouth of Kilisut Harbor	48.09354	-122.73316
40035	Outer Fidalgo Bay, near Cap Sante	48.50940	-122.57580
40036	Des Moines	47.41975	-122.35733
40037	Saratoga Passage, Race Lagoon	48.19991	-122.58646
	Target coordinates shifted 100m north to avoid buried utility cables.		
40038	North Central Basin	47.69895	-122.47829
40039	Gedney Island	48.02425	-122.31831
	Target coordinates shifted 100m northwest to avoid buried utility cables.		
40040	NW Anderson Island, Drayton Passage	47.17831	-122.72910
40041	South Boundary Bay	48.93582	-122.89714
40042	Hood Canal, Right Smart Cove	47.72126	-122.87476
40043	South Possession Sound	47.83918	-122.39813
	Target coordinates shifted 100m east to avoid buried utility cables.		
40044	Central Basin, north of Alki	47.59770	-122.42488
40045	Bellingham Bay, Fairhaven	48.72049	-122.51920
40046	Central Basin, north of Normandy Park	47.47329	-122.38814
40047	Admiralty Inlet, Outer Oak Bay	47.97690	-122.66036
40048	Case Inlet	47.23001	-122.84642
40049	North Boundary Bay	48.99486	-122.86743
40050	South Central Hood Canal	47.46115	-123.08273
40051	Possession Sound	47.96634	-122.32130
	Target coordinates shifted 100m east to avoid buried utility cables.		
40052	Blake Island	47.55178	-122.48852
40053	North Saratoga Passage, NW Camano Island	48.24346	-122.53814
40054	North Hood Canal, south of Sill	47.75254	-122.72937
40055	Holmes Harbor	48.07917	-122.54856
40056	Budd Inlet, East Bay	47.06458	-122.90270
40057	Discovery Bay	48.00749	-122.85752
40058	Hood Canal, Seabeck	47.65606	-122.83394
40059	Port Susan, Elger Bay	48.14451	-122.43855
40060	Central Carr Inlet, NW Fox Island	47.26597	-122.67126
40061	Bellingham Bay, NE of Eliza Island	48.66018	-122.55564
40062	Central Basin, south of Maury Island	47.32628	-122.46802
40063	Hood Head	47.88565	-122.60570
40064	Inner Carr Inlet	47.32049	-122.70162
40065	Inner Bellingham Bay	48.75903	-122.52072

June 2017 – Urban Bays Sediment Monitoring, Nutrient Flux Determination – Bellingham Bay

- 30 randomly selected stations sampled in 1997 and 2010 in Bellingham Bay will be resampled in 2017.
- 25 of the 30 stations will be sampled with a haps corer for the Nutrient Flux Determination Pilot Study.

Station locations and alternates are depicted in Figures 3-4 and summarized in Tables 13-14.

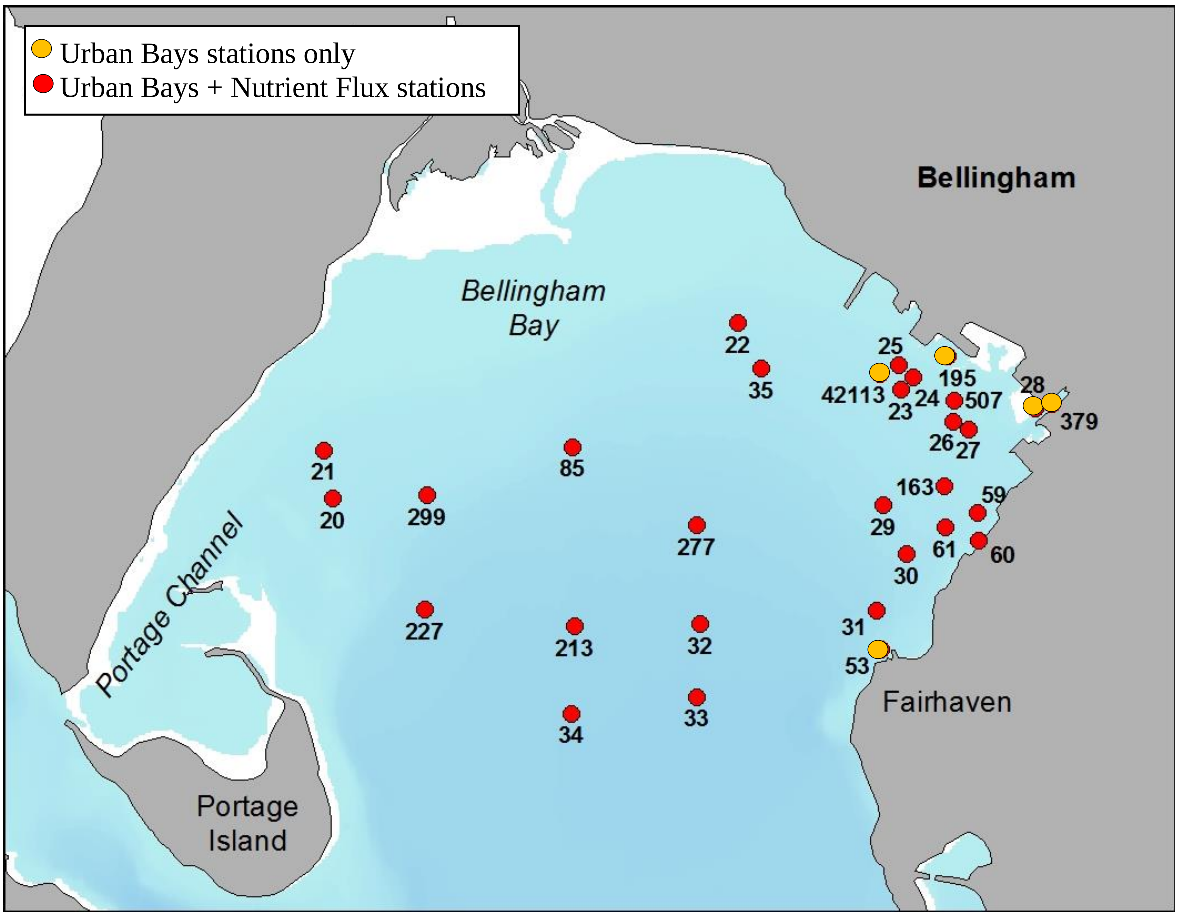

Figure 3. Urban Bays and Nutrient Flux sediment monitoring stations – Bellingham Bay.

Table 13. Urban Bays and Nutrient Flux sediment monitoring stations – Bellingham Bay.

Station	Target (NAD 83, decimal degrees)		Nutrient Flux Determination
	Latitude	Longitude	
20	48.73778	-122.60723	x
21	48.74305	-122.60890	x
22	48.75833	-122.54028	x
23	48.75142	-122.51278	x
24	48.75280	-122.51083	x
25	48.75415	-122.51332	x
26	48.74805	-122.50388	x
27	48.74723	-122.50138	x
28	48.74965	-122.49022	
29	48.73862	-122.51528	x
30	48.73328	-122.51113	x
31	48.72693	-122.51582	x
32	48.72500	-122.54525	x
33	48.71693	-122.54548	x
34	48.71473	-122.56645	x
35	48.75337	-122.53629	x
53	48.72268	-122.51494	
59	48.73805	-122.49947	x
60	48.73498	-122.49922	x
61	48.73635	-122.50470	x
85	48.74414	-122.56741	x
163	48.74085	-122.50506	x
195	48.75521	-122.50514	
213	48.72436	-122.56615	x
227	48.72574	-122.59123	x
277	48.73590	-122.54621	x
299	48.73842	-122.59135	x
379	48.75025	-122.48746	
507	48.75032	-122.50374	x
42113	48.75312	-122.51627	

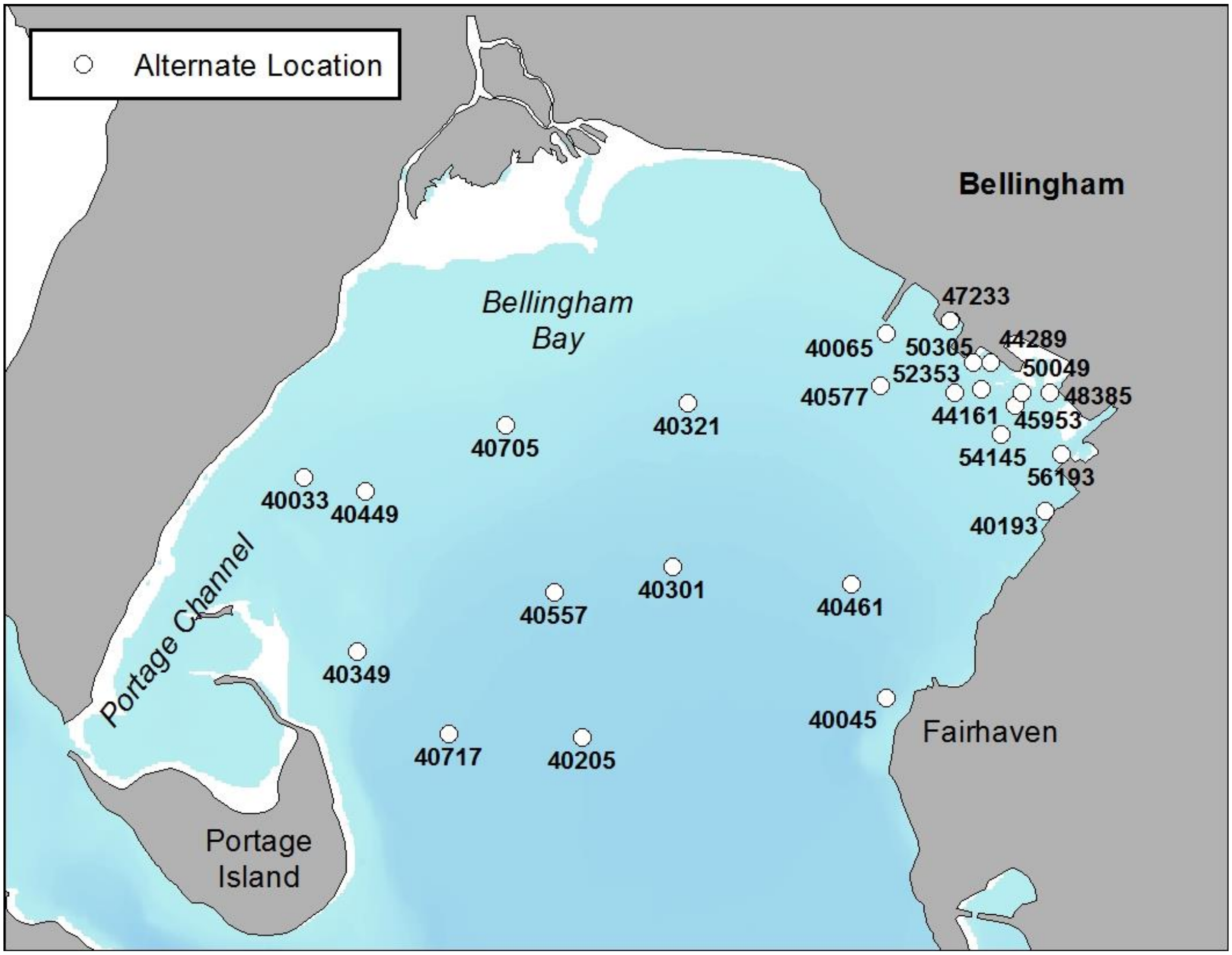

Figure 4. Urban Bays and Nutrient Flux alternate sediment monitoring stations – Bellingham Bay.

Table 14. Urban Bays and Nutrient Flux alternate sediment monitoring stations – Bellingham Bay.

Station	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
40033	48.74223	-122.613036
40045	48.72049	-122.519202
40065	48.75903	-122.520724
40193	48.74072	-122.494625
40205	48.71553	-122.567592
40301	48.73378	-122.553759
40321	48.75111	-122.552091
40349	48.72396	-122.603811
40449	48.74090	-122.603280
40461	48.73247	-122.525214
40557	48.73075	-122.572510
40577	48.75349	-122.521392
40705	48.74833	-122.581100
40717	48.71558	-122.588787
44161	48.75340	-122.505264
44289	48.75624	-122.503920
45953	48.75175	-122.499789
47233	48.76059	-122.510596
48385	48.75319	-122.494293
50049	48.75317	-122.498748
50305	48.75620	-122.506598
52353	48.75298	-122.509451
54145	48.74863	-122.501933
56193	48.74674	-122.492194

June 2017 – Toxics Cleanup Program stations – Bellingham Bay

- Eight selected stations in Bellingham Bay. Locations were non-randomly chosen by TCP staff. Sediments will be collected to a depth of 12cm from a double vanVeen grab sampler.

Station locations are depicted in Figure 5 and summarized in Table 15.

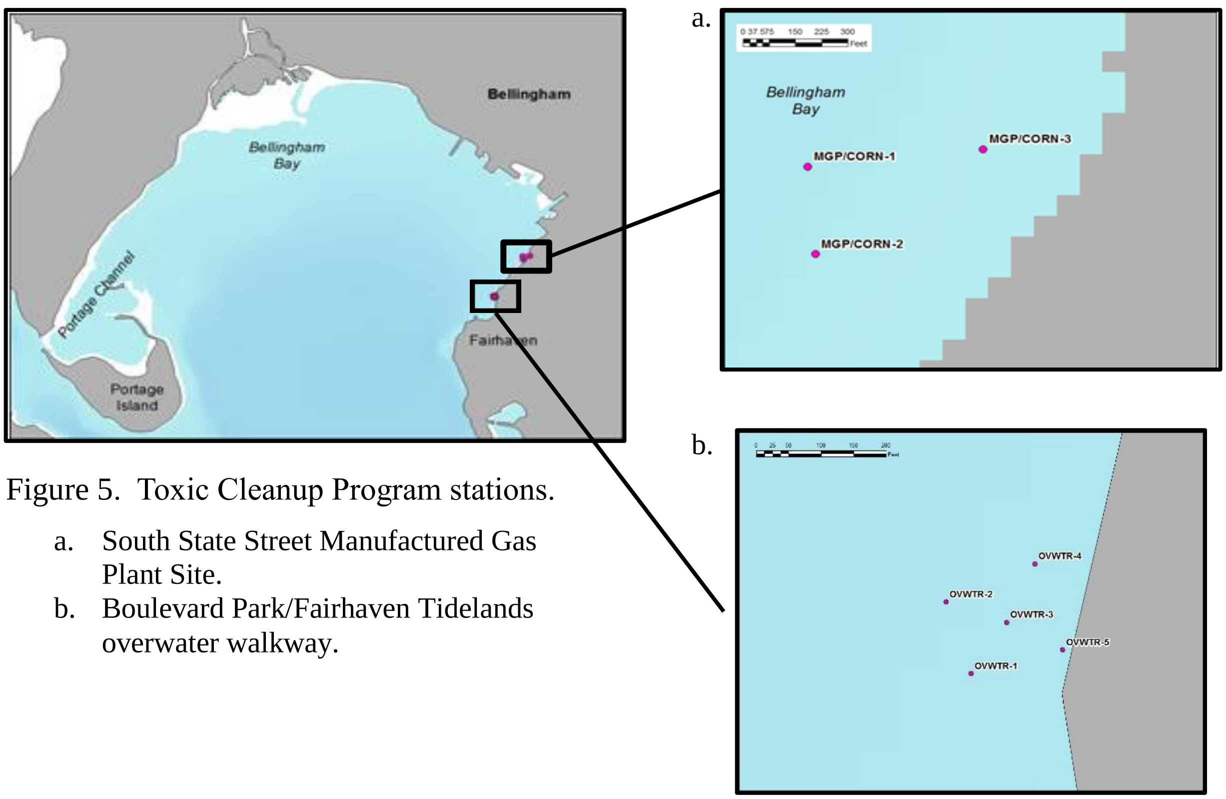

Figure 5. Toxic Cleanup Program stations.

a. South State Street Manufactured Gas Plant Site.
b. Boulevard Park/Fairhaven Tidelands overwater walkway.

Table 15. 2017 Toxic Cleanup Program stations – Bellingham Bay.

Station ID	Target (NAD 83, decimal degrees)	
	Latitude	Longitude
MGP/CORN-1	48.73690	-122.49825
MGP/CORN-2	48.73614	-122.49813
MGP/CORN-3	48.73709	-122.49617
OVWTR-1	48.72713	-122.50724
OVWTR-2	48.72743	-122.50741
OVWTR-3	48.72735	-122.50702
OVWTR-4	48.72760	-122.50685
OVWTR-5	48.72724	-122.50666

7.2.2 Field parameters and laboratory analytes to be measured

Measurements to be taken in 2017 for the April/May Long-Term, June Urban Bays, TCP, and monthly zooplankton are listed in Tables 16-19, respectively. New PSEMP Sediment Component parameters include:

- Total carbon/total organic carbon/total inorganic carbon/total nitrogen – Long-Term and Urban Bays stations.
- Benthos size class and biomass – Long-Term and Urban Bays stations.
- Zooplankton – Monthly at a subset of the co-located Sediment and Marine Waters stations.

Table 20 lists water column parameters measured by the PSEMP Marine Waters Component. These parameters will be measured at co-located stations and compared with PSEMP sediment, benthos, and plankton data.

Table 16. Parameters measured for Long-Term sediment monitoring. Those new to the monitoring program are highlighted in bold.

Field Measurements
Sediment temperature
Salinity of overlying water

Biota
Benthos
Total Abundance
Major Taxa Abundance
Taxa Richness
Pielou's Evenness^{+}
Swartz's Dominance Index^{+}
Size Class
Biomass^{+}

Biogeochemistry
Grain size
Total organic carbon (PSEP, 1986)

TC/TOC/TIC/TN (EPA 440):
Total carbon
Total organic carbon
Total inorganic carbon^{+}
Total nitrogen
C:N ratio^{+}

$^{+}$*calculated values*

Samples will be collected from three replicate locations from each of the 50 Long-Term stations for grain size, total organic carbon, and the TC/TOC/TIC/TN suite. Benthos will be collected from only one grab at the 22 previously sampled Long-Term stations, while three replicates will be collected at the 28 new randomly-selected stations. Justification for collection of replicates at the Long-Term stations is provided in Appendix C. For the Urban Bays program, only one set of samples will be collected from each of the 30 stations (Dutch et al., 2009).

Table 17. Parameters measured in sediments for Urban Bays monitoring – Bellingham Bay.

Field Measurements
Sediment temperature
Salinity of overlying water

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

Biogeochemistry
Grain size
Total organic carbon (PSEP, 1986)
TC/TOC/TIC/TN (EPA 440):
Total carbon
Total organic carbon
Total inorganic carbon⁺
Total nitrogen
C:N ratio⁺

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

Element
Tin

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

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

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

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

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

Other Chemicals
Bisphenol A
Tri(2-chloroethyl)phosphate
Triclosan
Triethyl citrate

⁺*calculated values*

Table 18. Parameters measured in sediments for the 2017 Toxics Cleanup Program sampling.

Field Measurements
Sediment temperature
Salinity of overlying water

Biogeochemistry
Grain size
Total organic carbon (PSEP, 1986)

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

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

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

Polychlorinated Biphenyls
PCB congeners 001-209 - see Table F-3 in TCP, 2015

[+] *calculated values*

Table 19. Parameters measured for monthly Zooplankton monitoring.

Zooplankton (Invertebrate larvae)
Major Taxa Abundance of Meroplankton and Holoplankton

Size Class
Biomass[+]
Total Plankton: Meroplankton ratio[+]

[+] *calculated values*

Table 20. Water column parameters measured monthly by Ecology's PSEMP Marine Waters monitoring (Bos et al., 2015; Keyzers and Krembs, 2016).

Water samples
Chlorophyll a
Chlorophyll
Fluorescence
Conductivity
Density
Dissolved oxygen
Light transmission
Marine ammonium
Marine nitrate
Marine nitrite
Marine orthophosphate
Marine silicate
PAR (Photosynthetically Active Radiation)
pH
Pressure
Salinity
Secchi depth
Temperature
Turbidity

Water column particulates
Particulate nitrogen
Particulate organic carbon
Total nitrogen
Total organic carbon
Dissolved organic carbon[+]

[+] *calculated values*

8.0 Field Procedures

Field procedures that are new to this program and not included in the 2009 program QAPP (Dutch et al., 2009) are described here.

8.2 Measurement and sampling procedures

8.2.1 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 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 10 meters 95% of the time.

The 22 non-random Long-Term core stations and the 30 Bellingham Bay stations have been sampled successfully in the past, and resampling in 2017 should not pose any difficulties. All station locations have been examined on nautical charts. Some stations have been adjusted to avoid sampling near underwater utility cables. Adjustments are indicated above.

The 28 randomly-selected Long-Term stations have not previously been sampled by the program. Based on charted information, it is expected that the sediments at these locations can be sampled with a vanVeen grab. If during the course of field sampling, it is found that any station has changed and cannot be sampled (e.g., station lacks fine-grained particles in the sediment, rocks prevent grab closure, the substrate is composed of all shell hash), it will be necessary to take alternative 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 a new station will be selected from the list of alternates as detailed in Section 7.2.1.

For the TCP sampling in Bellingham Bay, if we are not able to sample a target location, the station may be moved 25 m seaward up to three times, for a total distance of 75 m from the target coordinates. The station will be rejected if it needs to be moved further than 75 m.

8.2.2 Sampling procedures

Sampling for the new parameters is conducted as follows:

- **Total carbon, total organic carbon, total inorganic carbon (calculated), total nitrogen — Long-Term and Urban Bays stations – CHN elemental analyzer** – These parameters will be measured in surface sediments (upper 3cm) collected with a double vanVeen grab sampler as described in Dutch et al., 2009, and in Ecology's *Standard Operating Procedures for Obtaining Marine Sediment Samples,* SOP EAP039 (Weakland, 2015a). Sediment collection procedures are based on those described in PSEP, 1986.

- **Benthos size class and biomass – Long-Term and Urban Bays stations** – Benthos field collection methods have been augmented from those described in Dutch et al., 2009, and in Ecology's *Standard Operating Procedures for Obtaining Marine Sediment Samples*, SOP EAP039 (Weakland, 2015a). An *SOP for Macrofaunal Size Classification and Biomass* (Burgess, 2017) has been written, and includes procedures for obtaining size class and biomass information for megafaunal organisms collected and identified to species during field sampling.
- **Zooplankton monitoring – Up to seven Long-Term stations** – Zooplankton, including invertebrate larvae, will be collected by means of vertical plankton net tows through the water column, as described in Keister, 2016 and Kolb, 2015 (Appendix A).

8.3 Containers, preservation methods, holding times

Containers, preservation methods, and holding time for the new sampling parameters are indicated in Table 21.

Table 21. Containers, preservation methods, and holding time for the new sampling parameters.

Parameter	Matrix	Minimum Quantity Required	Container	Preservative	Holding Time
Total carbon, total organic carbon, total nitrogen (for CHN analyzer)	Bulk sediment	10g	1 - 2 (or 4) oz. wide-mouth glass jar with Teflon-lined lid	Refrigerate at 4°C Freeze at -20°C	14 day 6 months
Zooplankton	Water column	Contents of cod end from one vertical plankton tow (200µm mesh) through water column	700mL HDPE plastic jar	Fixed and stored in 5% buffered formalin	4 months

9.0 Laboratory Procedures

Laboratory procedures for new parameters are as follows:

- **Total carbon, total organic carbon, total nitrogen** – **Long-Term and Urban Bays stations** – Measurements for these parameters will be made with a CHN analyzer at Manchester Environmental Laboratory (MEL). Lab procedures follow EPA method 440.0, Revision 1.4, listed in Table 22.
- **Benthos size class and biomass – Long-Term and Urban Bays stations** – With the exception of megafauna identified, measured, and released in the field, benthos size class and biomass determination will be conducted in the MSMT Benthic Lab. Identification is first made to the species level following SOP EAP043 (Weakland, 2015b). Each organism is then assigned to one of four size/age categories with an average biomass designation calculated from the 2016 Puget Sound Benthos Size Class Reference Collection. Method details are provided in a new *SOP for Macrofaunal Size Classification and Biomass* (Burgess, 2017) and are based on methods developed and used in British Columbia (CORI, 2015).
- **Zooplankton Monitoring – Long-Term stations** – Zooplankton samples will be split if necessary based on abundance of organisms collected. Whole or sub-samples will be examined under a dissecting microscope. Organisms will be identified and placed in separate vials by major taxonomic group (annelids, arthropods, molluscs, echinoderms, and miscellaneous taxa). Major taxa abundance, size class, and biomass values will be generated for each plankton tow.

Methods for Urban Bays and TCP samples that differ from Dutch et al., 2009:

- **PAH analyses** – In 2016, MEL changed extraction methods from Accelerated Solvent (Soxhlet) Extraction with methylene chloride (USEPA 3545) to Soxtherm with methylene chloride (USEPA 3451(Me)) for all polynuclear aromatic hydrocarbon (PAH) analyses. Bias and precision differences associated with this method change are documented in a method comparison study performed by MEL (Weakland, 2016).
- **PCB analysis** – **Toxics Cleanup Program stations – Bellingham Bay** – High Resolution Gas Chromatography/High Resolution Mass Spectrophotometry will be conducted for the PCB analysis for the TCP project. Lab procedures follow EPA 1668C methods listed in Table 22.

Table 22. Lab procedures for total carbon, total organic carbon, total nitrogen, and high resolution PCB congeners analyzed in bulk sediments.

Parameter	Expected Range of Results	Preparation Method	Analysis Method	Technique / Instrument	Practical Quantitation Limit
Total carbon, total organic carbon*, total nitrogen	0.1-7.2%	102-105ºC drying; Vapor phase acidification (HCL) for organic and inorganic particulate C	EPA method 440.0, Revision 1.4 (after Hedges and Stern, 1984)	CE-440 Elemental Analyzer; Exeter Analytical, Inc.	0.1%
PCB Congeners (High Resolution) for TCP work	0.50-900 ng/kg dry weight	EPA 1668C	EPA 1668C	High Resolution Gas Chromatography/High Resolution Mass Spectrophotometry (HRGC/HRMS)	0.4 ng/kg dry weight (exception: PCB 156/157 = 0.8 ng/kg dry weight)

*total inorganic carbon is calculated by subtraction

9.4 Laboratories accredited for methods

MEL will conduct the analysis for total carbon, total organic carbon, total inorganic carbon, and total nitrogen; MEL is accredited by the Washington State Department of Ecology for this work. Zooplankton samples will be processed by MSMT staff in their benthic lab based on methods developed and used for the SSMSP. AXYS Analytical Lab will conduct the high resolution PCB Congener work for TCP.

10.0 Quality Control Procedures

Quality control procedures for parameters added to the sediment monitoring program for 2017 include the following:

- **Total carbon, total organic carbon, total nitrogen – Long-Term stations** – Quality control measures for carbon and nitrogen assessments are listed in Table 23.
- **Benthos size class and biomass – Long-Term and Urban Bays stations** – Quality control measures for collection of benthos size class and biomass information are detailed in the new *SOP for Macrofaunal Size Classification and Biomass* (Burgess, 2017). They include 5% taxonomic re-identification of organisms identified to the species level, and comparison of 2017 organism size measurements to the 2016 Puget Sound Benthos Size Class Reference Collection for placement into the correct size class. This collection will be updated as necessary to reflect any changes in the observed size ranges of benthic organisms.
- **Zooplankton – Long-Term stations** – Five percent of all larval invertebrates identified and placed in separate vials by major taxonomic group (annelids, arthropods, molluscs, echinoderms, and miscellaneous taxa) will be re-identified by another Puget Sound regional taxonomic expert.

Table 23. Quality control samples, types, and frequency for total carbon, total organic carbon, and total nitrogen sampling with CHN analyzer.

	Field	Laboratory		
Parameter	Replicates	Check Standards	Method Blanks	Analytical Duplicates
Measurement frequency:	Duplicate analysis for 5% of samples	1/batch of 20		
MQOs measured:	RPD	% recovery limits	Comparison of analyte concentration in blank to quantification limit	RPD
Total carbon, total organic carbon, total nitrogen	RPD≤20%	TOC: 70%-130% TC, TIC, TN: 80%-120% (caffeine check standard)	< RL	RPD≤20%

MQO = Measurement Quality Objective
RPD = Relative Percent Difference
RL = Reporting Limit

10.2 Corrective action processes

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

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

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Appendices

Appendix A. Zooplankton Monitoring Methods

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Appendix B. Nutrient Flux Determination Pilot Study – Measurement of biogeochemical processes in Bellingham Bay sediments – Pilot project with WWU – David Shull

Executive summary

In order to better understand processes that influence the structure of benthic communities in Puget Sound, Western Washington University (WWU) has partnered with the WA Department of Ecology to assess ways to improve the sediment component of the Puget Sound Ecosystem Monitoring Program. The goal is to measure biogeochemical processes that are intimately connected with the natural functions of benthic soft-bottom communities. We expect that these measurements will enable better understanding of the connection between benthic and water column processes. And, we hope that these measurements will improve understanding of the observed variation in benthic community structure and will provide a means to track ecosystem changes in Puget Sound in response to changes in climate, nutrient inputs, and other anthropogenic stressors.

The proposed partnership between WWU and the Department of Ecology will include, but not be limited to, a pilot study in Bellingham Bay in June 2017 and a larger-scale sampling of Puget Sound in spring of 2018. At stations where the PSEMP sediment monitoring group collects samples for sediment properties and benthic community structure, WWU will collect samples for the determination of sediment oxygen consumption and dissolved inorganic carbon production (both measures of sedimentary organic carbon mineralization) and the exchange of nutrients (N, P, Si) between the sediment and overlying water. The rates of DIC and nutrient exchange will be used to infer rates of sedimentary denitrification (the major loss of usable N from most marine systems). The flux of silica along with measurements of the vertical distribution of silica in the sediment will be used to estimate rates of sedimentary bioirrigation, the contribution of benthic communities to the flux of oxygen, nutrients, and DIC. It is also hoped that these estimates of organic carbon mineralization and nutrient cycling will enable a better understanding of the distribution of benthic biomass and community structure in Puget Sound, improving the ability to interpret anthropogenic change on this part of the Puget Sound ecosystem.

Project description

A central goal of marine monitoring programs is to assess the impacts of environmental pollution or climate change on ecosystem structure and function. But, observed changes in benthic community structure are impossible to relate to environmental disturbance unless we first understand how natural processes influence these communities. The purpose of this proposed project is to carry out a pilot study in Bellingham Bay in collaboration with the Department of Ecology to assess manner in which benthic community structure covaries with organic matter oxidation and nutrient cycling. I expect the results of this study to form the basis for a larger proposal to be submitted to WA Sea Grant and the findings will also be used by the Department of Ecology to improve their Salish Sea sediment monitoring program.

Hypotheses

There are a variety of potential relationships between benthic community structure and sediment biogeochemistry. Here are listed hypotheses that could most easily be tested in Bellingham Bay.

H1: Benthic biomass positively covaries with sedimentary organic carbon oxidation rate.

Because carbon burial efficiency is typically low in marine sediments (Hartnett et al., 1998), the rate of sedimentary carbon oxidation approximates the rate of food supply to the seafloor. If benthic biomass is food limited, it should covary with food supply.

H2: Benthic deposit feeder biomass more strongly covaries with organic matter oxidation compared to filter feeder biomass.

Because deposit feeders collect organic matter that has become incorporated into sedimentary deposits, whereas filter feeders collect food directly from the overlying water, deposit feeder biomass should reflect the food supply to the sediment. In contrast, filter feeder biomass is likely to be better correlated with other environmental parameters such as bottom water velocity, which in part determines the rate of delivery of food suspended in bottom water.

H3: Benthic biomass positively covaries with water depth and nutrient flux into the water column.

Much of Bellingham Bay is shallow enough that sunlight penetrates all the way to the bottom. In these areas, a large flux of nutrients from the sediment, plus available light, enables photosynthesis to occur on the sediment surface. Thus, sediments with higher rates of organic carbon production (due to high nutrient fluxes + light availability) will have higher benthic biomass.

Field sampling

We will collect sediment cores from 25 stations in Bellingham Bay using a haps corer owned by WWU. This instrument can collect undisturbed 12.7-cm diameter cores up to 30-cm in length. Two cores from each station will be sub-cored into 8.2-cm diameter glycol-modified polyethylene terephthalate (PETG) cores which will be used for measurement of dissolved oxygen, dissolved inorganic carbon (DIC), and nutrient fluxes. These cores will be filled with sediment and approximately 10 cm of overlying water and will be sealed using PVC caps fitted with magnetic stirring bars and sampling ports. These cores also possess a planar optode spot for the measurement of dissolved oxygen in the overlying water. Flux cores will then be incubated in a water bath in the dark at near ambient temperature following collection. We will also collect bottom-water samples at each station to replace the overlying water in the flux cores when samples are taken from the cores.

The flux core data will enable the calculation of sedimentary oxygen consumption and sedimentary DIC production. These are both measures of organic carbon oxidation; differences between the oxygen flux and the DIC flux indicate the oxidation or storage of reduced compounds in the sediment such as sulfides. Because organic carbon burial efficiency is typically low, the organic carbon oxidation rate approximates the rate of supply of organic matter to the seafloor (Hartnett et al., 1998). The rate of transfer of nutrients between the sediment and the overlying water will quantify the role of the benthos in nutrient cycling. Because the ratio of C:N:P in marine organic material is typically 106:16:1 (known as the Redfield ratio, Redfield 1958), differences between the DIC flux and the nitrogen flux can be used to estimate the rate of denitrification, the primary mechanism of the loss of usable nitrogen in the ocean (Christensen et al., 1987).

At several stations we will also measure a sediment profile of pore-water NO_3, NO_2, NH_4, phosphate and silicate. These pore-water profiles will enable us to (1) better interpret the flux core results and (2) estimate rates of sediment pore-water exchange due to diffusion and the biological irrigation of sediments in the bay.

Laboratory procedures

Samples for nutrient analysis will be filtered through 0.2-µm filters and stored in 20-ml plastic scintillation vials. Nutrients will be measured within 24 hours of collection. Samples for DIC will be filtered through 0.2 µm filters and stored in sealed glass vials at 0°C until measurement (within approximately one week of collection). We will determine fluxes of dissolved O_2, DIC, $NO_3 + NO_2$, NH_4, phosphate and silicate by collecting a time series of samples from the overlying water. Fluxes will be calculated from concentration changes observed over time. We will measure changes in dissolved O_2 by use of a Presens optical oxygen sensor. Concentrations of nitrate, nitrite, ammonia, phosphate, and silicate will be determined by standard colorimetric methods using a Unity Scientific Smartchem autoanalyzer (Gordon et al., 1993). DIC will be measured using a Apollo SciTech DIC analyzer (precision ±0.1%).

Products

David Shull will calculate fluxes of dissolved oxygen, DIC, and nutrients at all sampling stations and share these data with the WA Department of Ecology. He will also contribute to the PSEMP report as needed. It is also expected that this work will result in the publication of a peer-reviewed paper.

Scientific linkages with Ecology's PSEMP Sediment Component

The primary goal of this project is to improve the PSEMP Sediment Component by providing relevant measures of sediment geochemistry that likely influence benthic community structure in the Salish Sea and that better link the function of the benthos to the rest of the ecosystem. The findings of this study will be used to develop procedures that the PSEMP Sediment Component can use to enhance their benthic monitoring program.

Benefits for the Department of Ecology and for WWU

The findings of this collaboration will be used to improve monitoring of benthic communities, the core mission of the PSEMP Sediment Component. The findings will also support the research of several undergraduate students and at least one graduate student at WWU. This collaboration is truly synergistic. David Shull will contribute equipment and experience in measuring biogeochemical processes. He will leverage funds from other sources: the WWU NSF summer REU – research for undergraduates – program and the WWU MESP (Marine and

Estuarine Science Program) graduate program. The Department of Ecology will provide data on benthic community structure and sediment properties (grain size, organic carbon content, contaminants) that will be compared to the biogeochemical data. Thus, this collaboration will enable both groups to address scientific questions relevant to the PSEMP that would not otherwise be feasible.

Proposed future collaborative work

The Department of Ecology and WWU plan to work together in spring of 2018 to apply the lessons from this pilot study to the larger Puget Sound Sediment monitoring program. Also, David Shull (WWU) will be submitting a proposal to Washington Sea Grant to secure funding to address broader questions of the linkages between benthic biogeochemistry and water column processes. The ultimate goal is to provide PSEMP with an improved sediment monitoring program with more power to understand variation in benthic communities and how they respond due to changes in the larger ecosystem.

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Appendix C. Rationale for Replicate Sampling for Long-Term Stations – Valerie Partridge

Replicate samples will be analyzed for TOC and grain size, as well as TC/TOC/TN/TON for all 50 stations in 2017, for several reasons:

Method comparison

One of the strengths of the PSEMP Sediment Component has been the consistency of methods used over the entire almost three decades of the program. The 2017 survey marks the first major departure from one of the conventional sediment characterization methods, the PSEP (1986) protocol for analysis of total organic carbon (TOC). Because measurements of total nitrogen, in addition to TOC, are crucial to understanding benthic nutrient cycling in Puget Sound, and because the Manchester lab now has the technology to analyze both carbon and nitrogen from the same aliquot of sediment, it makes sense to analyze TOC as part of the TC/TOC/TN/TON analyses. However, for comparison of results to those of the past, for trend determination, it is necessary to measure the same quantity (TOC) using both methods for all samples, so that a relationship between the results of the different methods can be determined.

Variability inherent in aliquot size

The volume of sediment used for the TC/TOC/TN/TON analyses will be a tiny fraction of the volume required for determination of TOC with the PSEP (1986) protocol, and statistically theoretically inherently more variable. Analyzing all samples by both methods will enable determination of the degree of variability as a function of the aliquot size.

Spatial variability

Since 2005, the PSEMP Sediment Component has deliberately specified locations for field replicates based on station depth, potential wire angle, GPS error, etc., in order to assure independence. Analysis of variability between field replicates indicates that coefficient of variation (a.k.a. relative standard deviation, ratio of standard deviation to mean) range up to 50% for TOC and up to 100% for most grain sizes, for samples taken 20-30 meters apart – in other words, there is considerable heterogeneity in the environment. It will be necessary to analyze all samples for TOC by both methods in order to rule out the possibility that differences in the results might be due to local heterogeneity on the seafloor.

Furthermore, the variability in TOC/Fines relationship ranges up to 40%, depending on the station. Likewise, because of the spatial heterogeneity, it is necessary to measure TOC and Fines from the same van Veen grabs in order to most accurately capture the spatial variability in the relationship between them.

Formation of statistical prior

The 2017 sampling will be the first time that the 28 random stations will be sampled as part of the revised Long-Term sediment monitoring program. To have direct measurements of local variability each sampling event would be ideal, statistically. However, in the event that that might not be feasible in the future, the next-best method would be to use what direct measures of local variability are available as a prior distribution to model the likely variability to apply to future single measurements. Therefore, the best possible, most current estimates of local variability are necessary.

Relationships between sediment and benthos

Analyses of correlations between benthic invertebrate communities and multiple environmental parameters for 862 unique sites in Puget Sound have indicated that sediment grain size and TOC are among the most important variables. Therefore, it is important to have synoptic measurements of both grain size and TOC with the benthos.

Data analysis

On a practical level, it is more efficient and less error-prone to prepare, assess, and analyze data with matching sets of parameters than to deal with inconsistent amounts of information for subsets of stations.

Appendix D. Acronyms and Abbreviations

EAP	Environmental Assessment Program (Dept of Ecology)
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
MEL	Manchester Environmental Laboratory (Dept of Ecology)
MSMT	Marine Sediment Monitoring Team
PSEMP	Puget Sound Ecosystem Monitoring Program
QAPP	Quality Assurance Project Plan
SSMSP	Salish Sea Marine Survival Project
TC	Total carbon
TCP	Toxics Cleanup Program (Dept of Ecology)
TIC	Total inorganic carbon
TN	Total nitrogen
TOC	Total organic carbon
TON	Total organic nitrogen
WWU	Western Washington University