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State of Washington

Bellingham Bay Regional Background Sediment Characterization

Bellingham, WA

Sampling and Analysis Plan

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Bellingham Bay Regional Background Sediment Characterization

Sampling and Analysis Plan

Prepared by

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List of Acronyms

ASB	aeration stabilization basin
BEHP	bis(2-ethylhexyl)phthalate
COPC	chemicals of potential concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CAP	cleanup action plan
CD	consent decree
CSL	Cleanup Screening Level
CSO	combined sewer overflow
CV	coefficient of variance
DGPS	differential global positioning system
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
FM	Field Manager
FS	feasibility study
GPC	gel permeation chromatography
GPM	Government Project Manager
HASP	Health and Safety Plan
LCS/LCSD	laboratory control sample/laboratory control sample duplicates
LMCL	lower method control limit
MS/MSD	matrix spike/matrix spike duplicate
MTCA	Model Toxics Control Act
NAD83	1983 North American Datum
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PPE	personal protective equipment
PQL	practical quantitation limit
PSEP	Puget Sound Estuary Program
QA	Quality Assurance
QC	Quality Control
QAPP	Quality Assurance Project Plan
RBC	risk based concentration
RI	remedial investigation
ROD	record of decision
RPD	relative percent difference
SAP	Sampling and Analysis Plan
SCL	Sediment Cleanup Level
SCO	Sediment Cleanup Objective
SCUM	Sediment Cleanup User’s Manual

SIM	select ion monitoring
SMARM	Sediment Management Annual Review Meetings
SMS	Sediment Management Standards
SQS	sediment quality standards
SOP	standard operating procedure
SVOC	semi-volatile organic contaminant
TBT	tributyltin
TCDD	2,3,7,8-Tetrachlorodibenzodioxin
TEF	toxic equivalent factor
TEQ	toxic equivalent quotient
TOC	total organic carbon
UCL	upper confidence limit
USEPA	U.S. Environmental Protection Agency
UTL	upper tolerance limit
WAAS	Wide Area Augmentation System
WAC	Washington Administrative Code
WHO	World Health Organization

1.0 Introduction

This SAP is designed to collect sufficient data to establish regional background concentrations for selected bioaccumulative chemicals of concern in Bellingham Bay. During the advisory group process for the Sediment Management Standards (SMS; Ecology 2013a) rule revisions, it was recommended that the Washington State Department of Ecology (Ecology) be responsible for establishing regional background sediment concentrations for the state. Bellingham Bay is the location of a multi-organization, comprehensive cleanup initiative known as the Bellingham Bay Demonstration Pilot. Under this initiative, Ecology is addressing 12 cleanup sites, including 8 sediment sites. Controlling pollution sources is also a component of the initiative. Regional background concentrations are needed to support these cleanup and source control activities.

The SAP for this study was prepared in accordance with the SMS and Sediment Cleanup User's Manual (SCUM II; Ecology 2014a). Sediment sampling procedures correspond to those presented in SCUM II (Ecology 2014a; WAC 173-204). Analytical procedures and methods are also identified in SCUM II in accordance with WAC 173-340-830 and WAC 173-204 (Ecology 2014a).

1.1. Definition of Regional Background

The 2013 revisions to the Sediment Management Standards (SMS), Chapter 173-204 WAC, included the concept of regional background as part of establishing the cleanup screening level (CSL). The CSL is set at the highest value of regional background, the lowest risk-based concentration, and the practical quantitation limit (PQL) for each chemical. Under the revised rule, the determination of a regional background concentration is a critical part of providing some flexibility in the site-specific cleanup level, particularly for bioaccumulative chemicals.

The SMS defines regional background in WAC 173-204-505(16) and includes parameters for establishing regional background in WAC 173-204-560(5):

> ***"Regional Background"*** *means the concentration of a contaminant within a department defined geographic area that is primarily attributable to diffuse sources, such as atmospheric deposition or storm water, not attributable to a specific source or release.*

The SMS provides flexibility in establishing regional background on a case-by-case basis and does not prescribe specifically how regional background should be established. Ecology's approach to establishing regional background has evolved over time through working on initial bays and after receiving comments from stakeholders and tribes, as described below.

1.2. Stakeholder Discussions

In 2013, Ecology received a number of comments from stakeholders and tribes on the initial Port Gardner Regional Background SAP (Ecology 2013b) and Supplement SAP (Ecology 2014b) and the North Olympic Peninsula Regional Background SAP (Ecology 2013c), some of which were incorporated into the final SAPs. Several people requested that for future regional background characterizations, they would like to work with Ecology as SAPs are developed.

In response, Ecology engaged interested persons earlier in the process for the Elliott Bay and the Lower Duwamish River regional background work. This included conducting a series of interviews with key regional organizations in June 2013 and holding a September 2013 technical workshop.

Based on the collective comments and discussions, Ecology determined that some modifications to the original sampling designs used to establish regional background were appropriate. A Supplemental SAP was developed for Port Gardner to reflect these new approaches (Ecology 2014a). The concepts described below are also reflected in this SAP and will be included in upcoming revisions to the Sediment Cleanup Users Manual II (SCUM II; Ecology 2014a).

The following modifications have been incorporated into this SAP:

- **Rationale and Conceptual Bay Model.** This SAP contains a discussion of the selected analytes, rationale and existing information informing development of the sampling area, and the rationale for the selected sampling method(s). These choices are based on a conceptual bay model for Bellingham Bay and key features of Bellingham Bay that influenced these decisions. These include known sites and sources, existing chemistry data, existing modeling information, hydrodynamic information, bathymetry, etc.
- **Determining Areas of Primary Influence.** The area in which sediment samples will be collected is consistent with the SMS definition of regional background (WAC 173-204-505(16)). This entails sampling closer to the shoreline, sources, and sites, while remaining outside areas of direct influence. Bay-specific information has been used, where available, to determine areas directly associated with depositional zones of outfalls or other point sources and areas directly affected by sites.
- **Differing Areas of Interest for Different Analytes.** Different analytes may be elevated above natural background in different areas of the bay. In Bellingham Bay, it was determined that polycyclic aromatic hydrocarbons (PAHs) were elevated over a larger area than other contaminants, and therefore has a larger Area of Interest (AOI) for sampling regional background concentrations.
- **Differentiating from Natural Background.** Existing data have been examined to identify areas that are within the range of natural background concentrations (as defined in SCUM II; Ecology 2014a). These areas have been excluded for calculation of regional background.

1.3. Project Team and Responsibilities

NewFields and associated subcontractors will implement the SAP under the direction of Ecology. The following sections describe the key roles and responsibilities of the project team.

1.3.1. Project Planning and Coordination

Chance Asher of Ecology will serve as the Project Manager who will oversee the overall project coordination, supply data and services, review reports, and coordinate with contractors. Tim Hammermeister will serve as the NewFields project manager and be responsible for executing the approved SAP, overseeing the collection and analysis of field samples, and reporting analytical results.

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1.3.2. Sample Collection

Mr. Tim Hammermeister of NewFields will serve as field manager (FM) responsible for collecting and processing samples in accordance with the SAP, and transporting samples to the analytical laboratories for analysis and testing. The FM will ensure accurate station positioning and reporting.

1.3.3. Laboratory Sample Preparation and Analysis

Dr. Will Hafner of NewFields will serve as laboratory coordinator responsible for subcontracting state-certified laboratories, and ensuring observation of established protocols for decontamination, sample preservation, holding times, chain-of-custody documentation, and laboratory reporting. Dr. Hafner will also coordinate the independent validation of the laboratory results (through EcoChem) to ensure that the analytical and QA/QC data are considered valid, and that procedures meet the required analytical quality control limits.

1.3.4. Health and Safety Manager

Jasper Boas will serve as the designated NewFields Health and Safety Manager. The Health and Safety Manager is responsible for ensuring that all personnel are properly trained, fully aware of potential site hazards, conduct all work in a safe manner, wear appropriate personal protective clothing (PPE), and abide by the conditions set forth in the site-specific Health and Safety Plan (HASP; Appendix B).

1.3.5. Subcontractor Support

The NewFields project team will consist of the following subcontractors and external support to assist in the data collection activities and provide analytical laboratory services:

- Sampling Vessel
  Bio-Marine Enterprise
  R/V Kittiwake
  Charles Eaton
  2717 3rd Ave. N
  Seattle, WA 98109
  Phone: (206) 714-1055
  cmeaton@msn.com

- Analytical Chemistry (cPAHs and sediment conventionals)
  Analytical Resources, Incorporated
  Cheronne Oreiro
  4611 South 134th Place
  Tukwila, WA 98166
  Phone: (206) 695-6214
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- Dioxin/Furan and PCB Congener Analysis
  Axys Analytical Services, Ltd.
  Cynthia Tomey
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  Phone: (250) 655-5812
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- Statistical Guidance
  TerraStat Consulting Group
  Lorraine Read
  323 Union Avenue

Snohomish, WA 98290
Phone: (425) 344-6875
lorraine@premier1.net

- Sampling Design and Data Interpretation

  Avocet Consulting
  Teresa Michelsen
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  Olympia, WA 9502
  Phone: (360) 628-8339
  teresa@avocetconsulting.com

1.3.6. Schedule

The proposed schedule for field activities is the 9th through the 11th of September.

2.0 Bellingham Bay Conceptual Model

Bellingham Bay is located in the northern reaches of Puget Sound in Whatcom County. It is separated from the Strait of Georgia on the west by the Lummi Peninsula, Portage Island, and Lummi Island. It is bordered on the east by the City of Bellingham, Washington, to the southeast by the Chuckanut Mountain, and to the south by Samish Bay. The eastern shoreline, from north to south, is heavily developed. Much of this eastern shoreline is made up of commercial and industrial properties, such as the Port of Bellingham. A City of Bellingham trail system and park (Boulevard Park) is located between the downtown area of Bellingham and Fairhaven. Residential properties are located along the eastern shoreline south of Post Point including Chuckanut Bay. The southern-most eastern shoreline located in Samish Bay is primarily undeveloped grassland and tidal mud flats. The northeastern area of Bellingham Bay was evaluated to define the specific AOIs for regional background sampling (Figure 1).

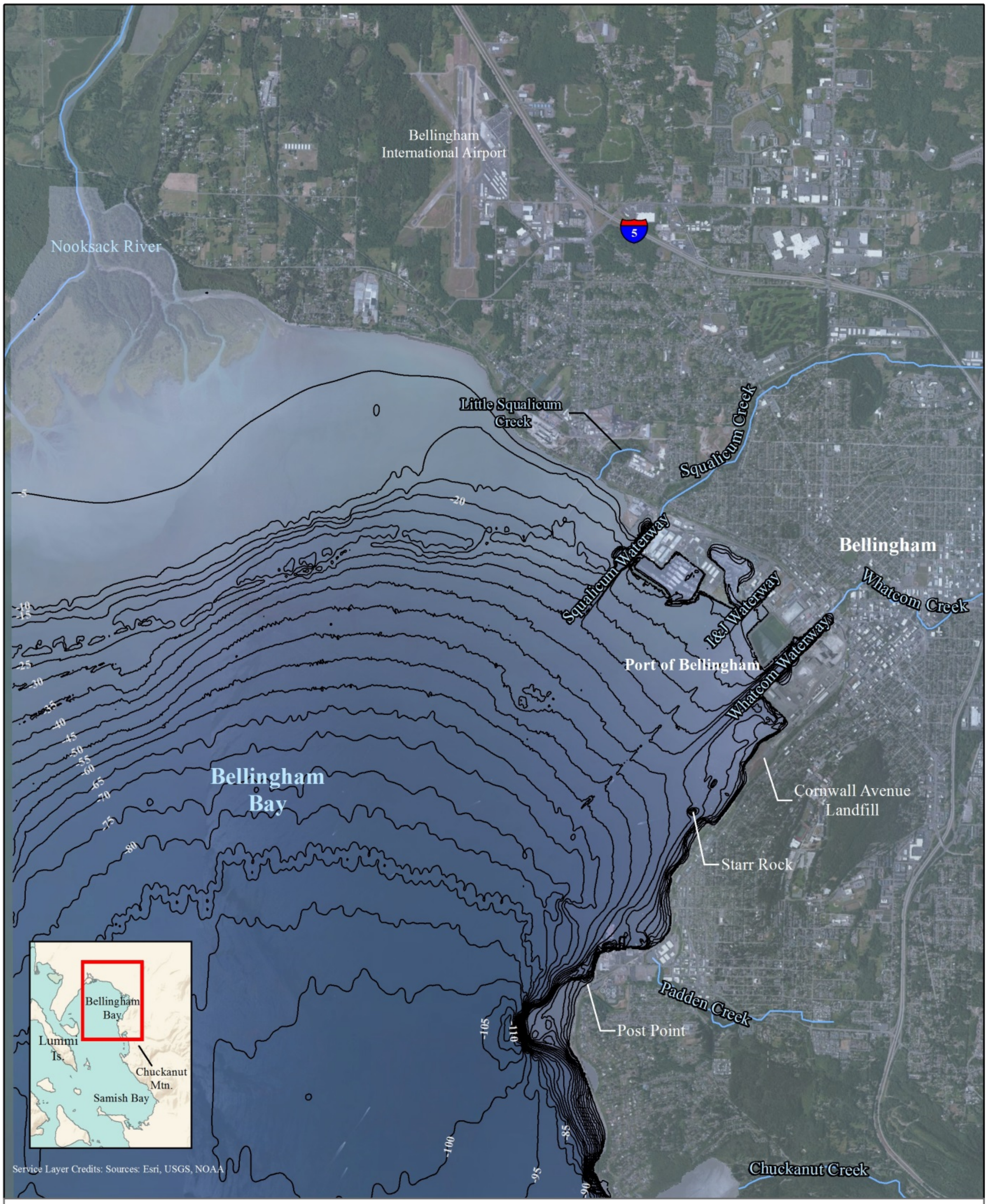

Figure 1. Bellingham Bay Regional Background Study Area

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2.1. Hydrology and Bathymetry

The bay encompasses more than 40 square miles of subtidal and intertidal habitat (Figure 1). The Nooksack River, Little Squalicum Creek, Squalicum Creek, Whatcom Creek, and Padden Creek all discharge into the bay. Of these, the Nooksack River has the greatest discharge and influence on the bay, and drains mainly rural and farming areas to the north. Little Squalicum Creek, Squalicum Creek and Whatcom Creek discharge along the Bellingham waterfront and drain urban areas from the northeast. Padden Creek drains a mix of land uses to the southeast ranging from urban to forested (RETEC 2006). The urban creeks may represent ongoing sources of contaminants primarily from stormwater runoff to localized areas around their mouths, while the Nooksack River is a source of substantial amounts of clean sediment to the bay, as discussed below.

Large intertidal flats are present at the mouth of the Nooksack River in the northern bay. Most areas of the northeastern inner bay are less than 30-40 feet deep, and there is a submerged rocky outcrop known as Starr Rock southeast of the Cornwall Avenue landfill, near which sediment was historically disposed from dredging in Whatcom Waterway in the 1950s. Depths gradually increase from north to south to 80–90 feet at the boundary of the study area (Figure 1).

Circulation in Bellingham Bay is controlled partially by tides, which propagate from the Strait of Juan de Fuca through the Strait of Georgia and Rosario Straits into Bellingham Bay around Lummi Island and then in a clockwise direction. Bottom currents are fairly low throughout the bay (<0.3 m/s; PNNL 2010; Colyer 1998), typically below velocities required to resuspend sediments, except in nearshore environments where waves, wakes, and wind can resuspend sediments and cause minor erosion. Surface currents can be either clockwise or counterclockwise depending primarily on wind direction, and both salinity and suspended solids are strongly affected by Nooksack River discharge.

Three federally authorized navigation channels, Squalicum Waterway, Whatcom Waterway, and I&J Waterway, are present in the inner harbor and have been subject to extensive shoreline modification, channelization, and historic dredging. The inner harbor of Bellingham Bay has in general been extensively modified for Port, commercial, and industrial uses.

2.2. Sedimentation, Grain Size, and Organic Carbon

As a result of the relatively low velocity currents and sediment deposition from the Nooksack River described above, Bellingham Bay is largely a net depositional area, consistent with its overall fine-grained nature (Figure 2). Sediment deposition from the Nooksack River throughout the bay is significant, even in areas not directly adjacent to the river’s delta. Sediment deposition in the inner bay has been estimated at 1.52–1.77 cm/yr (RETEC 2006) and shoreline areas as much as 1.4 cm/yr (Landau 2013), resulting in substantial natural recovery of elevated contaminant concentrations over the last 20 years at a number of sites where sources have been controlled (RETEC 2006; Landau 2013).

Sediment grain size in the bay consists of sands near the mouth of the Nooksack River ranging to muds and clays throughout most of the rest of the bay. Limited areas of fine-grained sands are present at the mouths of Whatcom Waterway and the other creeks (Tetra Tech and HRA 1995). Total organic carbon (TOC) is <1% in the Nooksack River delta, then gradually increases to 2% and above southward throughout the bay due to low currents and the depositional nature of the bay. Areas with higher TOC are distributed along the developed shorelines, including in boat basins, waterways, in front of the former aeration stabilization basin (ASB or treatment lagoon) and RG Haley, south along the shoreline and extending outward at Post Point (Figure 3). While some of this TOC is likely due to fine-grained materials settling in quiescent environments (e.g., marinas and offshore deepwater areas), much of the rest may be due to historical sources of contamination, such as wood wastes and combined sewer overflow (CSO) discharges.

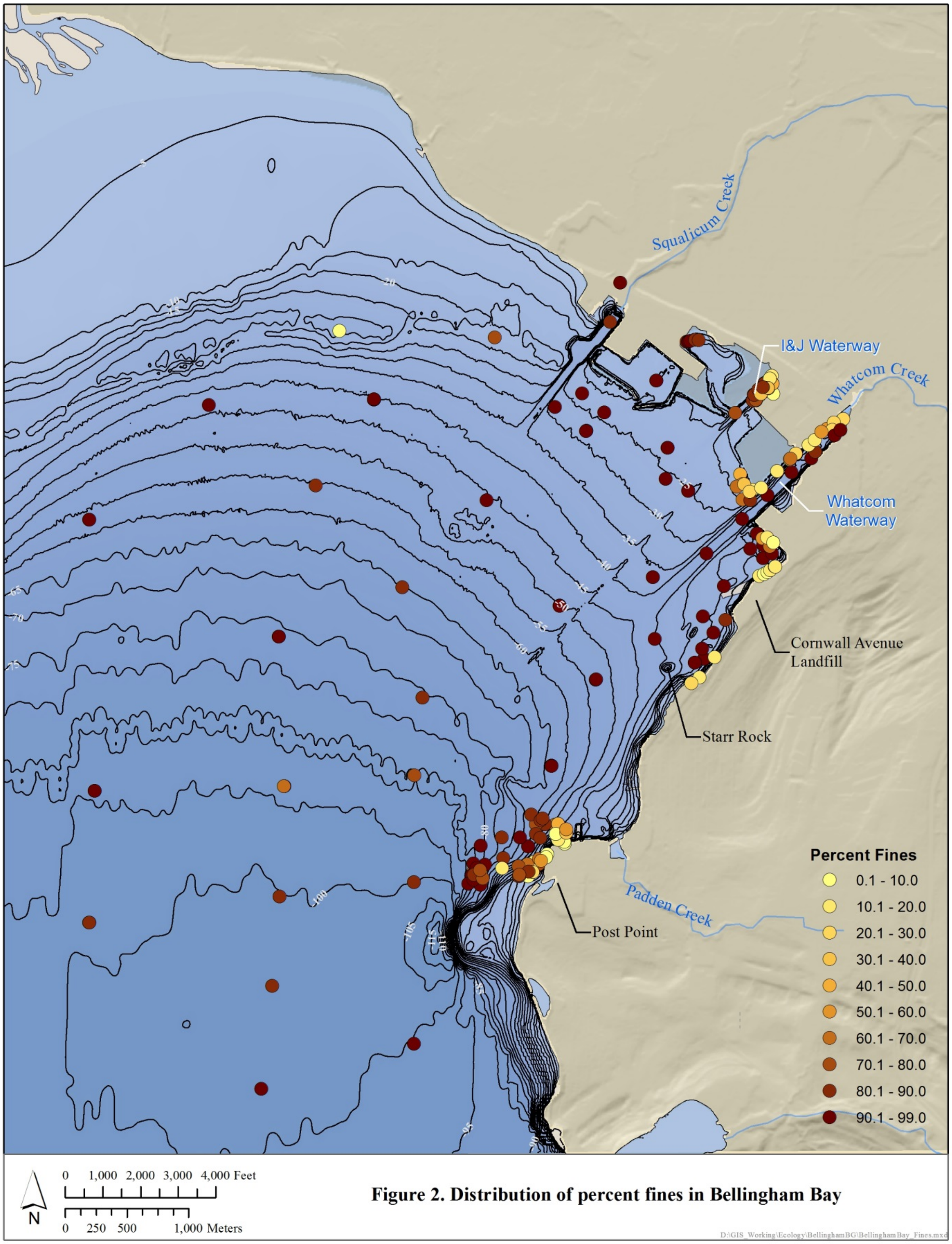

Figure 2. Distribution of percent fines in Bellingham Bay

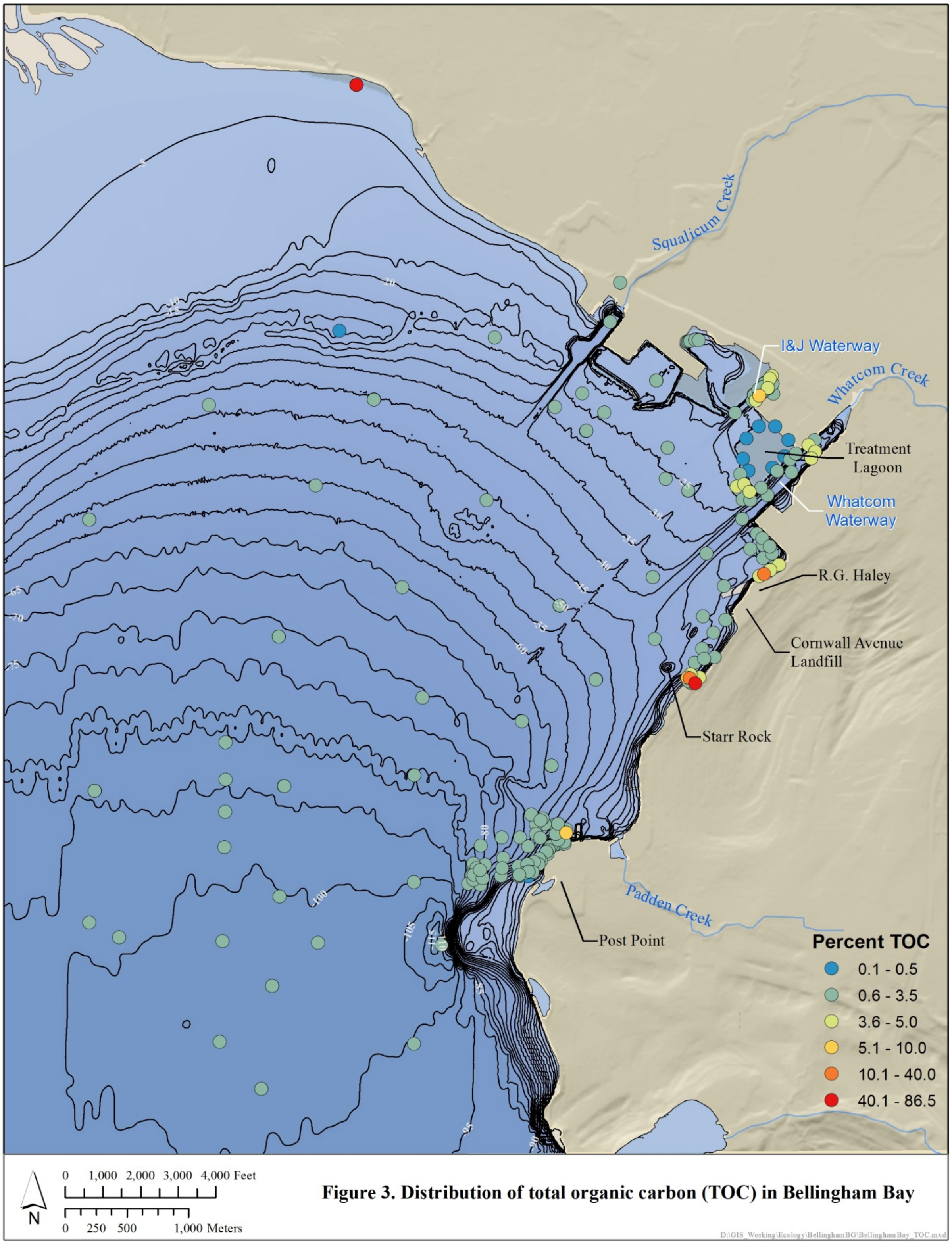

Figure 3. Distribution of total organic carbon (TOC) in Bellingham Bay

2.3. Sites and Sources

Bellingham Bay has been the focus of a number of substantial sediment cleanup projects in the inner harbor and in other locations, along with a comprehensive waterfront redevelopment plan currently underway. Together, these processes have eliminated or reduced many contaminant sources (particularly industrial sources) to the bay, allowing natural recovery to begin. However, a number of sites have significant remaining contamination that could affect concentrations in sediments in Bellingham Bay and are in various stages of the investigation and cleanup process (Figure 4), described below (from north to south):

- **Oeser Company.** This is a wood treating company located adjacent to Little Squalicum Park which includes Little Squalicum Creek. Little Squalicum Creek discharges to the bay just north of Squalicum Creek. Historic wood treating practices resulted in contamination of company property, as well as the park and creek, and designation as a federal Superfund site. Contaminants at the site include pentachlorophenol, dioxins/furans, copper, zinc, and PAHs. A Record of Decision (ROD) was finalized in 2003 and site cleanup activities were undertaken in 2005–2009. In 2010, EPA determined that additional cleanup activities were required in Little Squalicum Park and these were conducted in 2010–2011.
- **Eldridge Municipal Landfill.** This is a former City of Bellingham municipal landfill located in Little Squalicum Park, next to Little Squalicum Creek. Contaminants at the site included PAHs, phthalates, pentachlorophenol, and metals (cadmium, copper, lead, mercury, and zinc). In 2011, over 4,000 tons of debris and soil were excavated and disposed of in Roosevelt Landfill. A remedial investigation/feasibility study (RI/FS) and a consent decree/cleanup action plan (CD/CAP) are in the process of being completed.
- **Weldcraft Steel & Marine.** This site is located in Outer Squalicum Harbor and has been used for boat repair, maintenance, and fabrication. Contaminants in sediments from past practices include metals, tributyltin, gasoline, and diesel. An interim cleanup action to remove contaminated sediment was completed in 2006. Contamination remains in upland areas of the site and a RI/FS has been completed.
- **Marine Services Northwest.** This site is located in Inner Squalicum Harbor. Contaminated sediments are located adjacent to a historical boat maintenance lift. Contaminants include metals, tributyltin (TBT), and PAHs. This is a quiescent and enclosed area. A draft RI/FS was developed by the Port under the Voluntary Cleanup Program.
- **I&J Waterway.** This site consists of contaminated sediments in and adjacent to the federally authorized navigation lane. Historic industrial operations on the waterway include a lumber mill, rock-crushing plant, and frozen food processing. A seafood processing plant is currently in operation. Contaminants identified in sediments include phthalates, phenols, PAHs, dioxins/furans, nickel, and mercury. An RI/FS is in the process of being completed.

- **Central Waterfront.** This site is located between I&J and Whatcom Waterways and consists of 55 acres of the waterfront with various historical industrial uses, including concrete manufacturing, lumber mill operations, boat repair, two bulk fuel terminal, rock processing, and a landfill. The site is adjacent to the former Georgia-Pacific treatment lagoon. Contaminants found in upland areas of this site include petroleum mixtures, PAHs, and a variety of metals. In 2013, an interim cleanup action was completed at the site. It included removal of over 1000 tons of petroleum-contaminated soil, removal of creosoted pilings, and beach restoration. The RI/FS for the rest of the site is expected to be completed in 2015.
- **Holly St. Landfill.** This historic City of Bellingham municipal waste landfill is bisected by Whatcom Creek as it enters Whatcom Waterway. Contaminants at the site include refuse along the shoreline, as well as copper and zinc releases to the waterway. Cleanup was completed in 2005.
- **Whatcom Waterway.** This sediment site is over 200 acres and includes the waterway itself, as well as the adjacent former Georgia-Pacific treatment lagoon. Contamination consists mainly of mercury and phenols from the former Georgia-Pacific pulp mill operations. Untreated wastewater was discharged to the bay until 1979, when the wastewater treatment lagoon and deepwater outfall with diffuser was built. Prior to construction of the Post Point Wastewater Treatment Plant and outfall in 1974, primary treated wastewater was also discharged from the Whatcom Creek Waterway Wastewater Treatment Plant into the Whatcom Waterway. Contaminants in sediments include wood waste, phthalates, phenols, mercury, PAHs, various metals, and dioxins/furans. In 2001, an interim action resulted in the placement of dredged material over the approximately 6-acre Log Pond area of the site. The first phase of the final cleanup action is expected to begin in 2015 and will include dredging and capping in the inner portion of the waterway, additional capping in the Log Pond, and removal of structures and pilings.
- **Georgia-Pacific West.** This is the upland property where the main operations area of the former Georgia-Pacific mill was located on the south shoreline of Whatcom Waterway. Contaminants on the 74-acre site include PAHs, metals, dioxins/furans, various petroleum mixtures, and volatile organic compounds. The RI was completed in 2013 and interim actions to remove petroleum-contaminated and mercury-contaminated soil were conducted in 2011 and 2013. The site has two separate and distinct areas of contamination and has been divided accordingly. An FS and CD/CAP for the northern Pulp & Tissue Mill Remedial Action Unit is expected to be finalized in 2014, followed by the FS and CD/CAP for the southern Chlor-Alkali Remedial Action Unit in 2015.
- **R.G. Haley.** This site is located south of the Georgia-Pacific west site and north of the Cornwall Avenue Landfill site. Former wood treating operations, as well as lumber, coal, and wharf facilities have resulted in soil, groundwater and sediment contamination. Contaminants include wood waste, diesel plumes, pentachlorophenol, dioxins/furans, and PAHs. An emergency action was taken in 2001to contain oil releases to Bellingham Bay,

including building a sheet-pile wall, installing oil recovery wells, and some sediment removal. In 2013, a sand/clay layer was placed on a portion of the shoreline to address an oil seep. An RI has been conducted and an FS is underway.

- **Cornwall Ave. Landfill.** This site is south and adjacent the R.G. Haley site and was originally used as a sawmill and for wood storage. It was later used as a City of Bellingham municipal waste landfill, followed by log storage after closure of the landfill. Erosion of the landfill into the bay has occurred over the years. Sediment contaminants include wood waste, metals, phthalates, polychlorinated biphenyls (PCBs), PAHs, phenols, diesel, and heavy oils. An interim action was conducted in 2011/2012 to cap much of the upland solid waste with stabilized dredged sediments and an impermeable liner. An RI/FS was completed in 2013 and a CD/CAP is currently being finalized.
- **South State St. Manufactured Gas Plant.** This site is located along the southeast shoreline of Bellingham Bay at the north end of Boulevard Park. A former manufactured gas plant operated at this location until the late 1940s. Contaminants in sediments include various petroleum products, PAHs, and volatile hydrocarbons. An RI has been conducted and the feasibility study is underway.
- **Harris Avenue Shipyard.** This site is located at the southern end of the study area along the shoreline in Fairhaven. Sediments at the site have been contaminated by former shipbuilding and maintenance operations and contain metals, PCBs, phthalates, PAHs, and possibly dioxins/furans. An RI/FS is in the process of being completed.

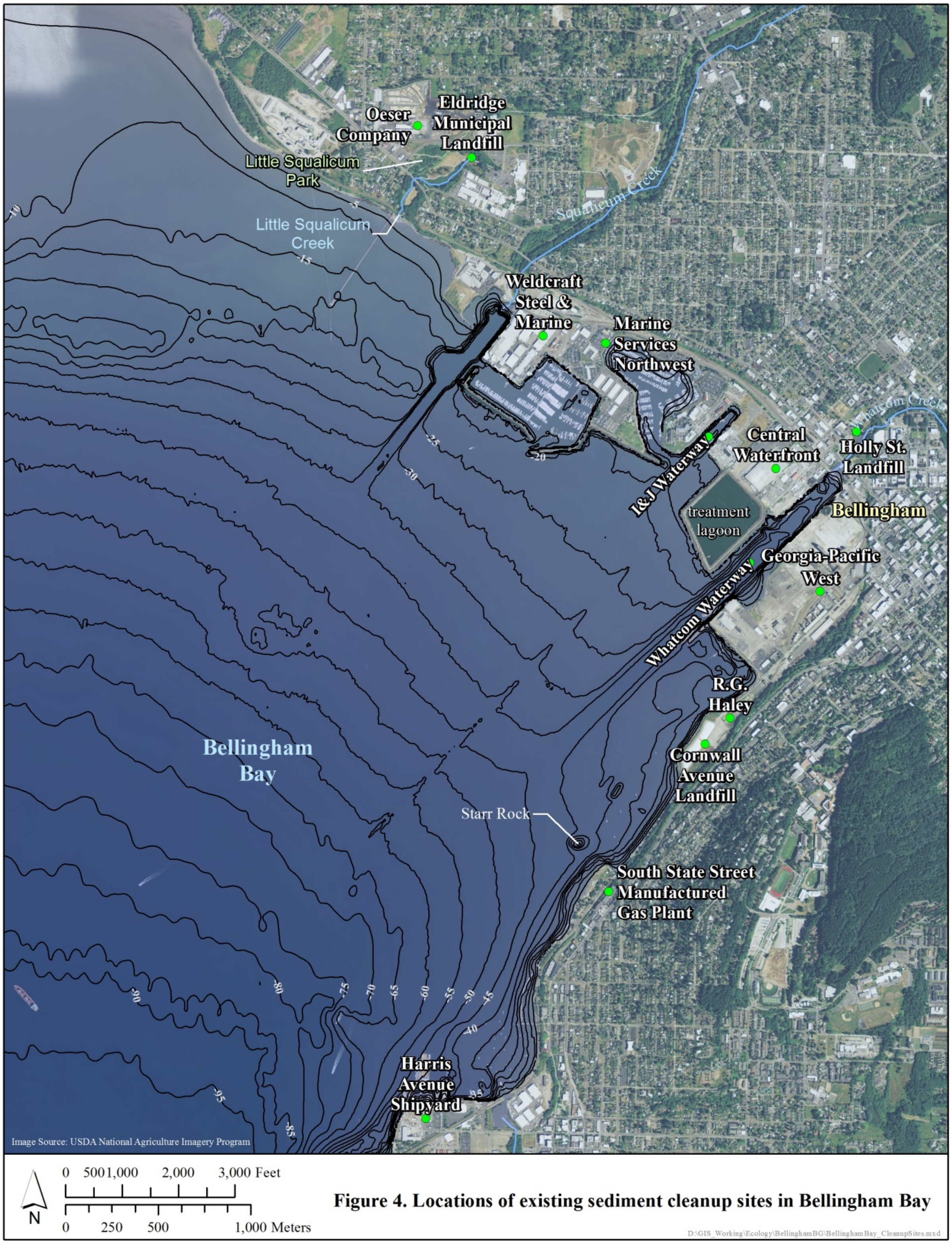

Image Source: USDA National Agriculture Imagery Program

Figure 4. Locations of existing sediment cleanup sites in Bellingham Bay

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In addition to the sites listed above, the following potential point and nonpoint sources of contamination have been identified (Figure 5; Tetra Tech and HRA 1995):

- **Post Point Wastewater Treatment Plant Outfall.** This outfall is at the southern boundary of the study area and discharges offshore at approximately 100 ft depth. The treatment plant has handled municipal sewage, stormwater, and industrial wastewaters, and was upgraded to secondary treatment in 1993. Due to high organic loading, high ammonia and sulfides have been measured in sediments, resulting in intermittent bioassay failures.
- **Former Georgia-Pacific Deepwater Outfall.** This outfall extends 8,000 feet in a southwesterly direction from the former Georgia-Pacific treatment lagoon and includes a 2000-ft-long diffuser section discharging into 55 feet of water. Since the mill operations stopped in 2007, substantial natural recovery has occurred in this area.
- **Urban Watersheds.** As noted above, several creeks carry stormwater discharges and historically received industrial discharges and can represent historical and/or current sources of contaminants to Bellingham Bay. Whatcom Creek discharges into Whatcom Waterway and would be included in that site. Little Squalicum Creek and Padden Creek could also have areas of elevated contaminants near their mouths, but recent data is not available to determine their status.
- **CSOs.** After the Post Point Treatment Plant was built in 1974, CSO overflows occurred in four locations, including at the Post Point Treatment Plant, at the C Street Interceptor (former Whatcom Waterway Treatment Plant outfall), at the lower Cornwall pump station, and at the Oak Street pump station. CSO reduction programs since then have minimized CSO overflows so that they only occur at the C Street Interceptor in Whatcom Waterway.
- **Starr Rock.** In 1969, 130,000 cubic yards of sediment was dredged from Whatcom Waterway for maintenance and disposed of near Starr Rock, a natural rocky formation south of the Cornwall Avenue Landfill site. These sediments were likely contaminated with chemicals from wastewater discharged from the Georgia-Pacific pulp mill into Whatcom Waterway. Known contaminants include mercury, dioxins/furans, and various semi-volatile organic contaminants (SVOCs).
- **Early Sediment Disposal Sites.** The I&J Waterway was dredged in 1966 and the sediments were disposed of in an area about ¼ mile west of the terminus of the Georgia-Pacific deepwater outfall. The Squalicum Creek Waterway was also dredged in 1963 and these sediments were disposed of just east of the mouth of Little Squalicum Creek. Between 1979 and 1983, several dredging projects disposed of sediments in a disposal site northeast of the I&J site. Many of these sites may have contained contaminated sediments and several were likely impacted by mercury from the deepwater Georgia-Pacific outfall. However, all have been subject to decades of natural recovery as well. Current contaminant concentrations at these disposal sites are unknown.

- **DMMP Deepwater Disposal Site.** A deepwater non-dispersive disposal site has been established offshore of Post Point in the deeper areas of the bay. This disposal site has received mainly clean dredged material that is not necessarily representative of surrounding sediments. However, the last disposal event at this site was in 1998.

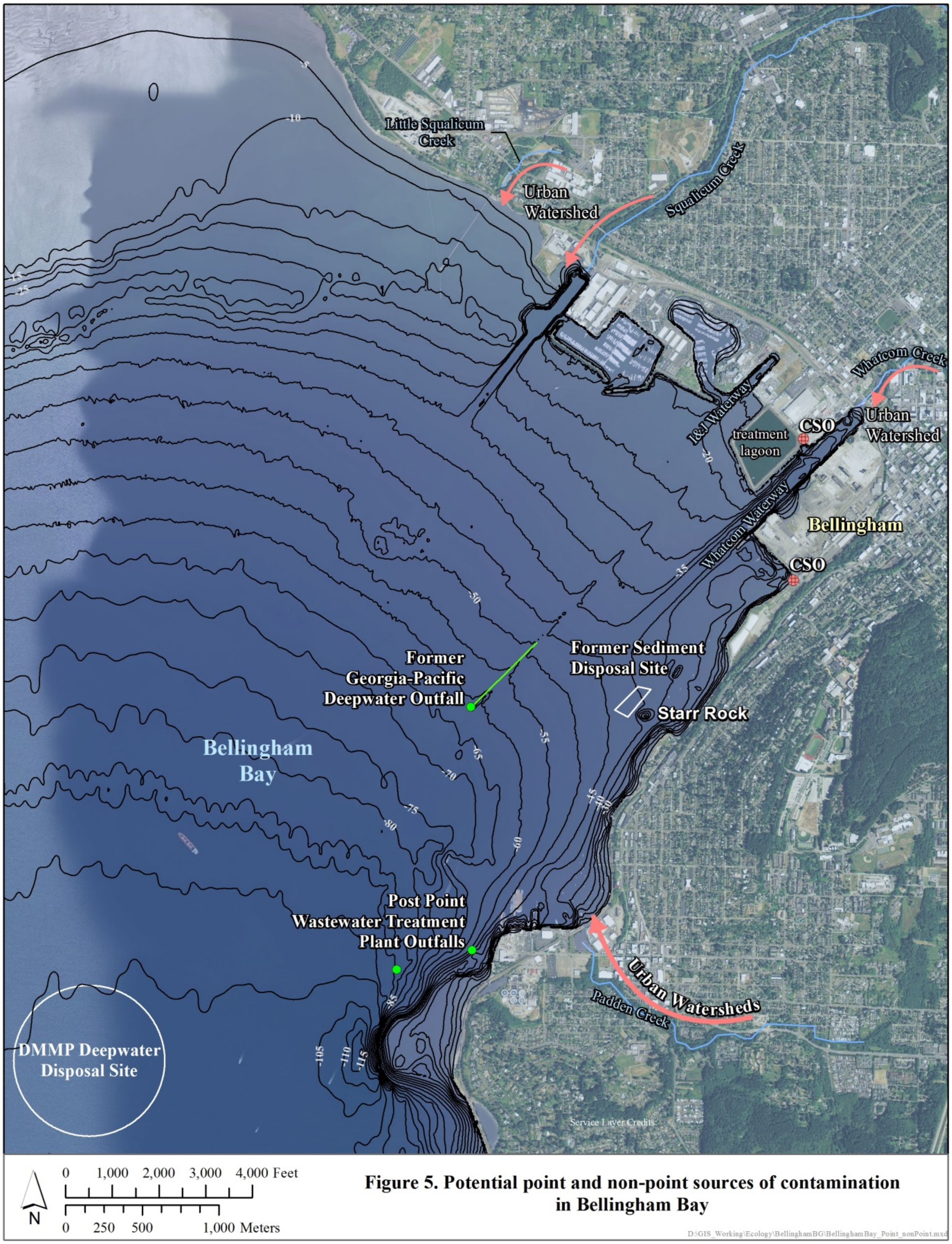

Figure 5. Potential point and non-point sources of contamination in Bellingham Bay

2.4. Summary of Existing Chemistry Data

Chemistry results from previous studies were reviewed and mapped to identify chemicals of concern and areas of primary influence of the sites and sources described above (Figures 6–10). All available data from 2003 and later within the 0 to 2 foot interval from Ecology's Environmental Information Management (EIM) are presented on these figures. In addition, the six most recent (sampled in 1998) sediment samples collected in the vicinity of Starr Rock have been included to help delineate that historical disposal site. In general, blue dots on the maps indicate concentrations below the 90/90 upper tolerance limit (UTL) for natural background (defined in SCUM II, Ecology 2014a), while other colors represent multiples of that concentration. Maps for mercury, arsenic, and phthalates do include concentration breaks representing the benthic sediment cleanup objective (SCO) and CSL values.

- **Mercury.** Mercury concentrations are generally quite low in the bay, except for nearshore areas related to cleanup sites (Figure 6). Mercury concentrations have declined greatly over the last 20 years, presumably due to cessation of the Georgia-Pacific mercury source and related sediment cleanup actions, and natural recovery associated with sedimentation from the Nooksack River.
- **Arsenic and Cadmium.** Arsenic (Figure 7) and cadmium (not shown) concentrations appear to be within natural background concentrations at all locations in the bay, except at the Harris Ave. Shipyard site.
- **Lead.** Lead concentrations
- **Phthalates.** Elevated concentrations of bis(2-ethylhexyl) phthalate (BEHP) can be seen in nearshore areas related to cleanup sites (Figure 8). Very few of these concentrations exceed the benthic standards, and no areas exceed the benthic standards in the rest of the bay. While potentially elevated above natural background, the contaminants are not considered bioaccumulative and do not appear to be at levels of concern in the bay.
- **PAHs.** High PAH concentrations related to sites can be observed in nearshore areas(Figure 9). Areas within the Nooksack Delta appear to be similar to natural background, while areas in between may represent regional background concentrations.
- **PCB Congeners.** Some PCB congener data exist (not shown), but are nearly all non-detected at levels well above current PQLs. Therefore, additional data are needed to draw any conclusions.
- **Dioxins/Furans.** Near shore areas with elevated dioxins/furans related to sites are clearly visible (Figure 10). Throughout most of the rest of the bay concentrations are approaching natural background. However, it appears there may be regionally elevated levels offshore of the eastern shoreline.

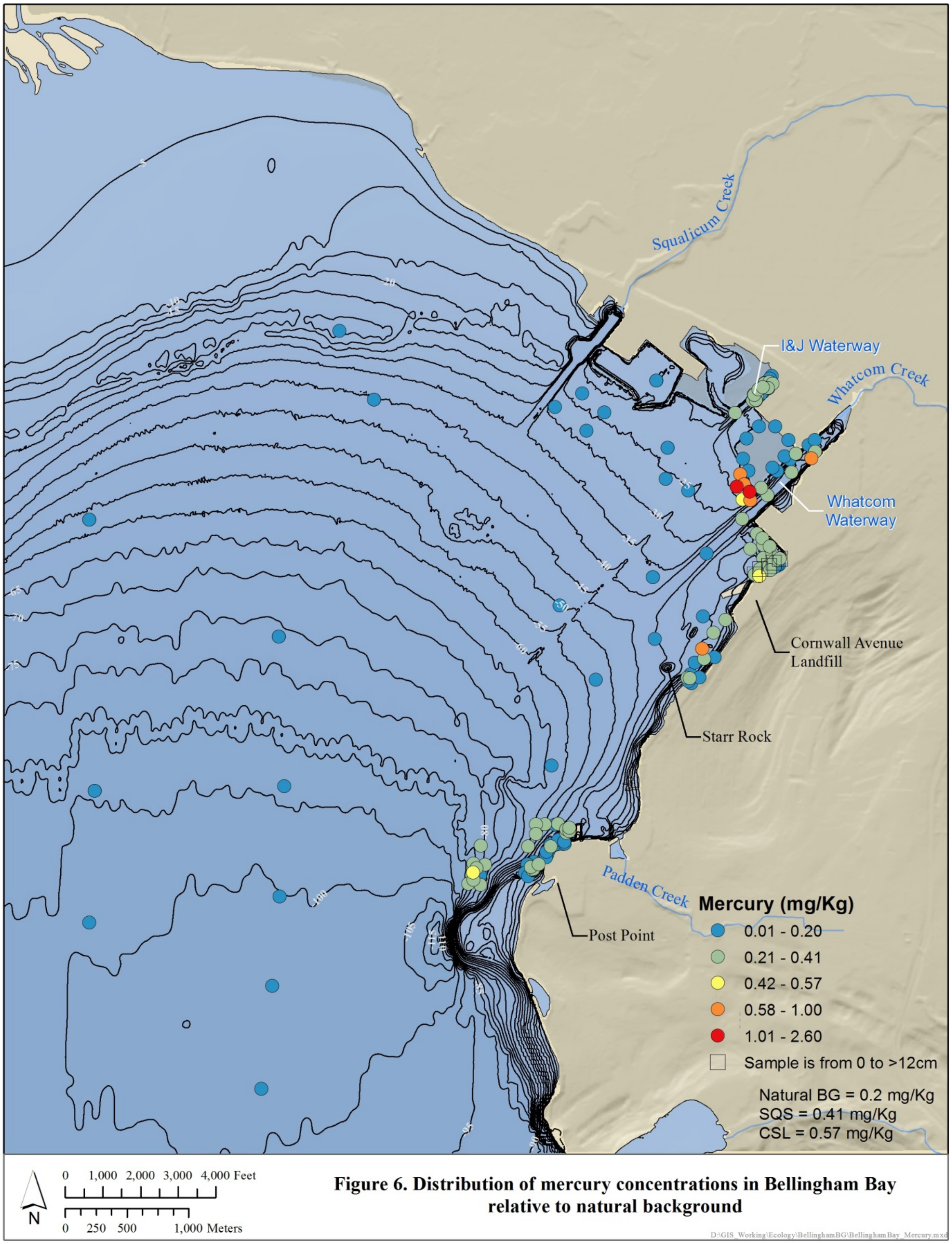

Figure 6. Distribution of mercury concentrations in Bellingham Bay relative to natural background

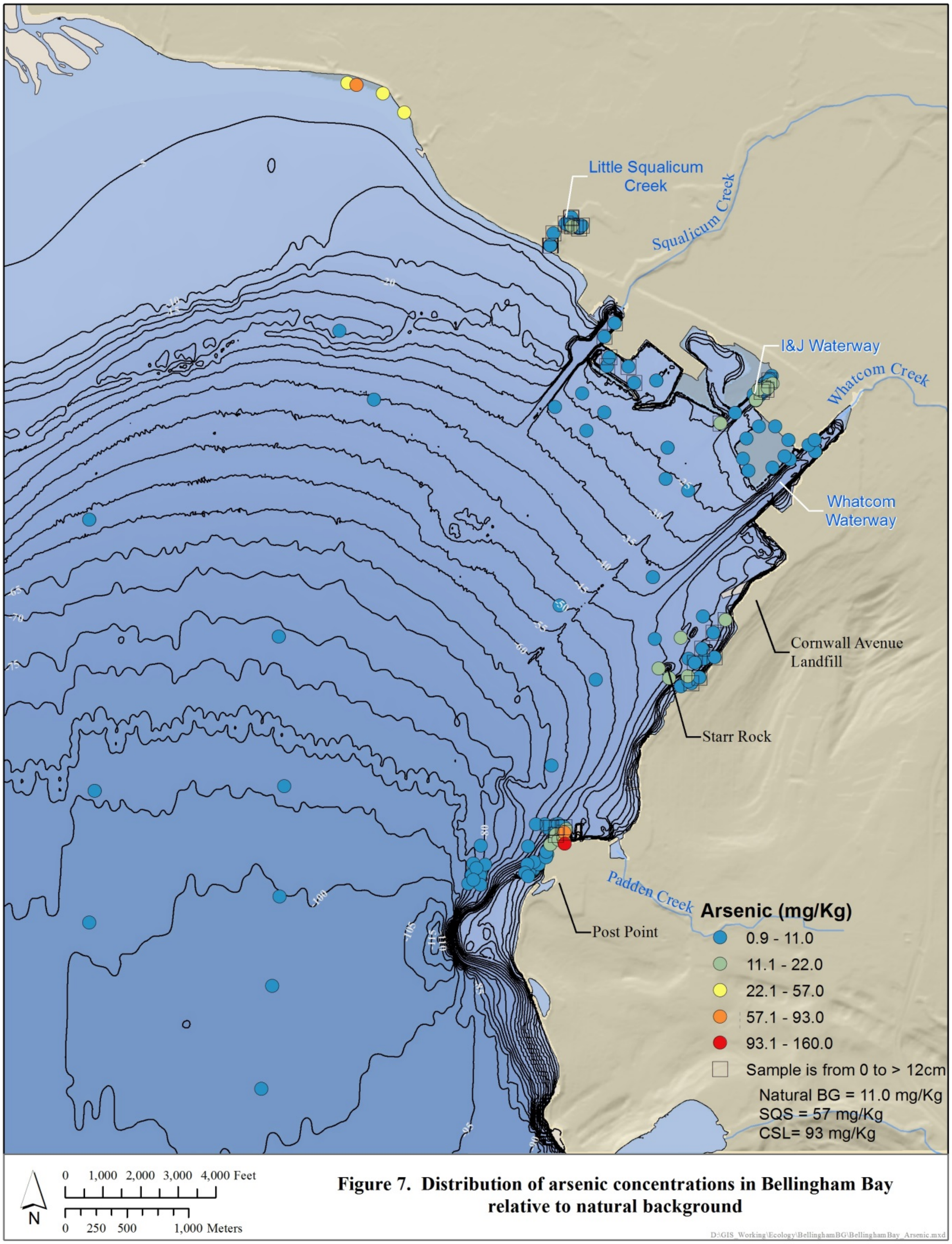

Figure 7. Distribution of arsenic concentrations in Bellingham Bay relative to natural background

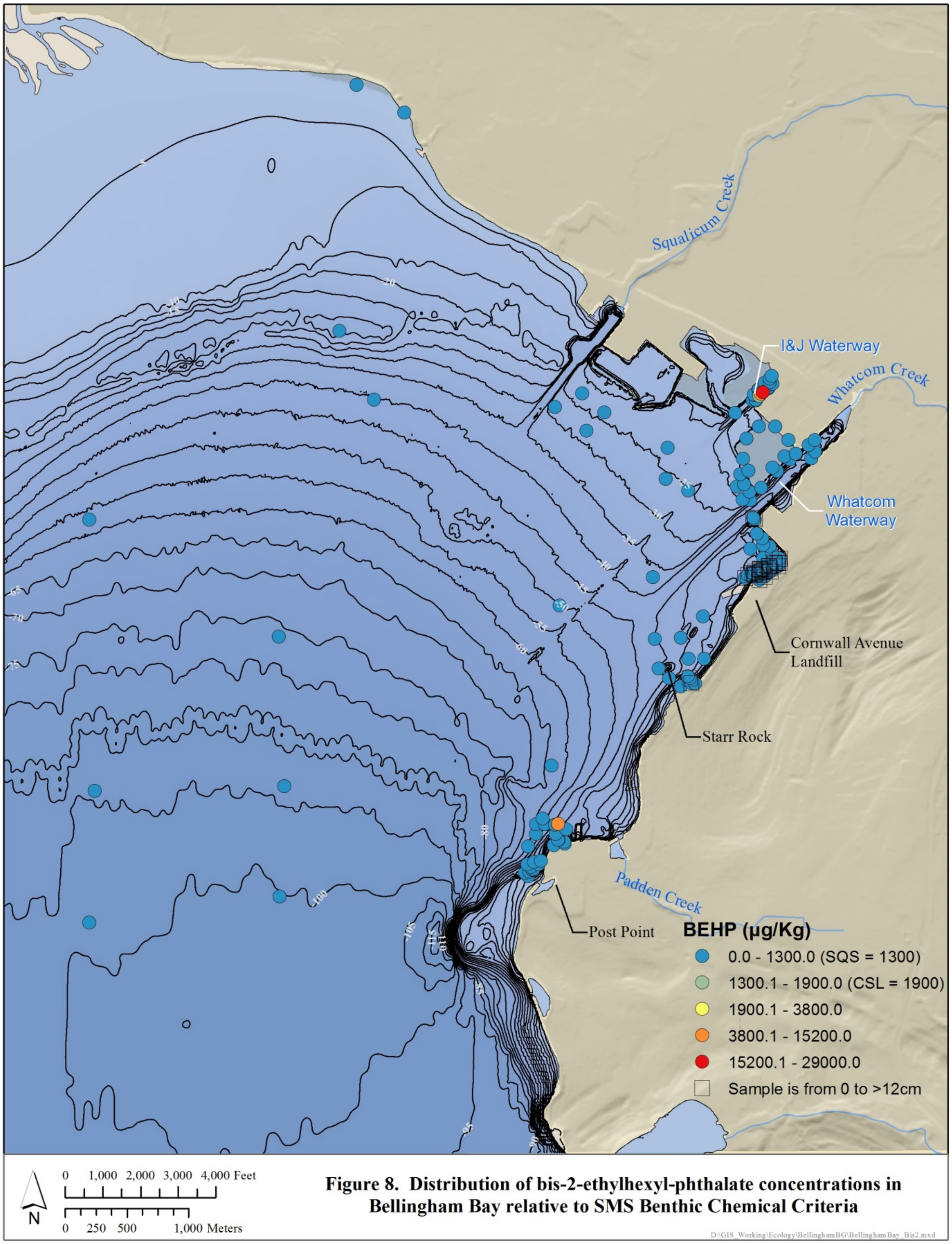

Figure 8. Distribution of bis-2-ethylhexyl-phthalate concentrations in Bellingham Bay relative to SMS Benthic Chemical Criteria

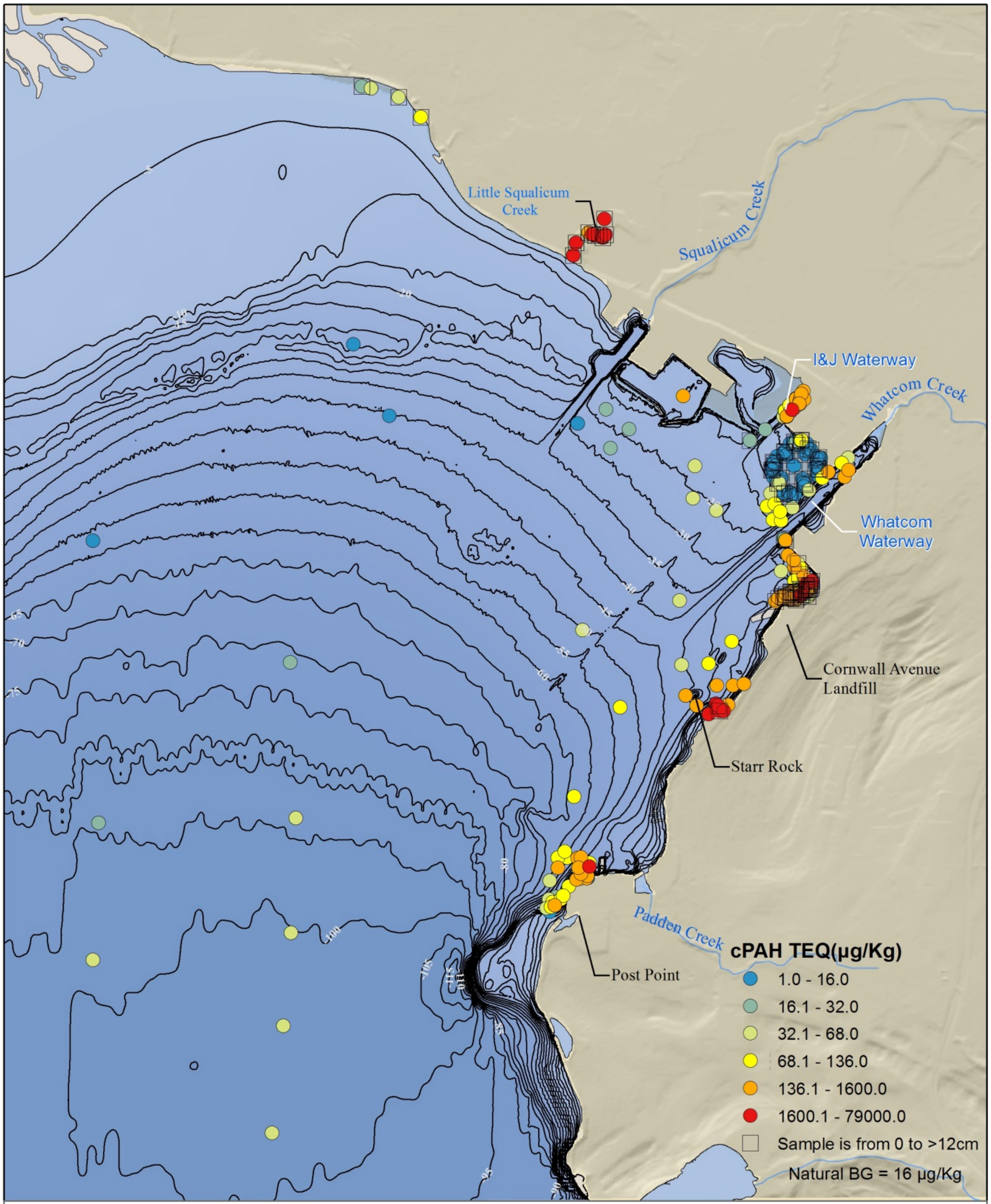

Figure 9. Distribution of carcinogenic polycyclic aromatic hydrocarbon (cPAH) concentrations in Bellingham Bay relative to natural background

D:\GIS_Working\Ecology\BellinghamBG\BellinghamBay_cPAH.mxd

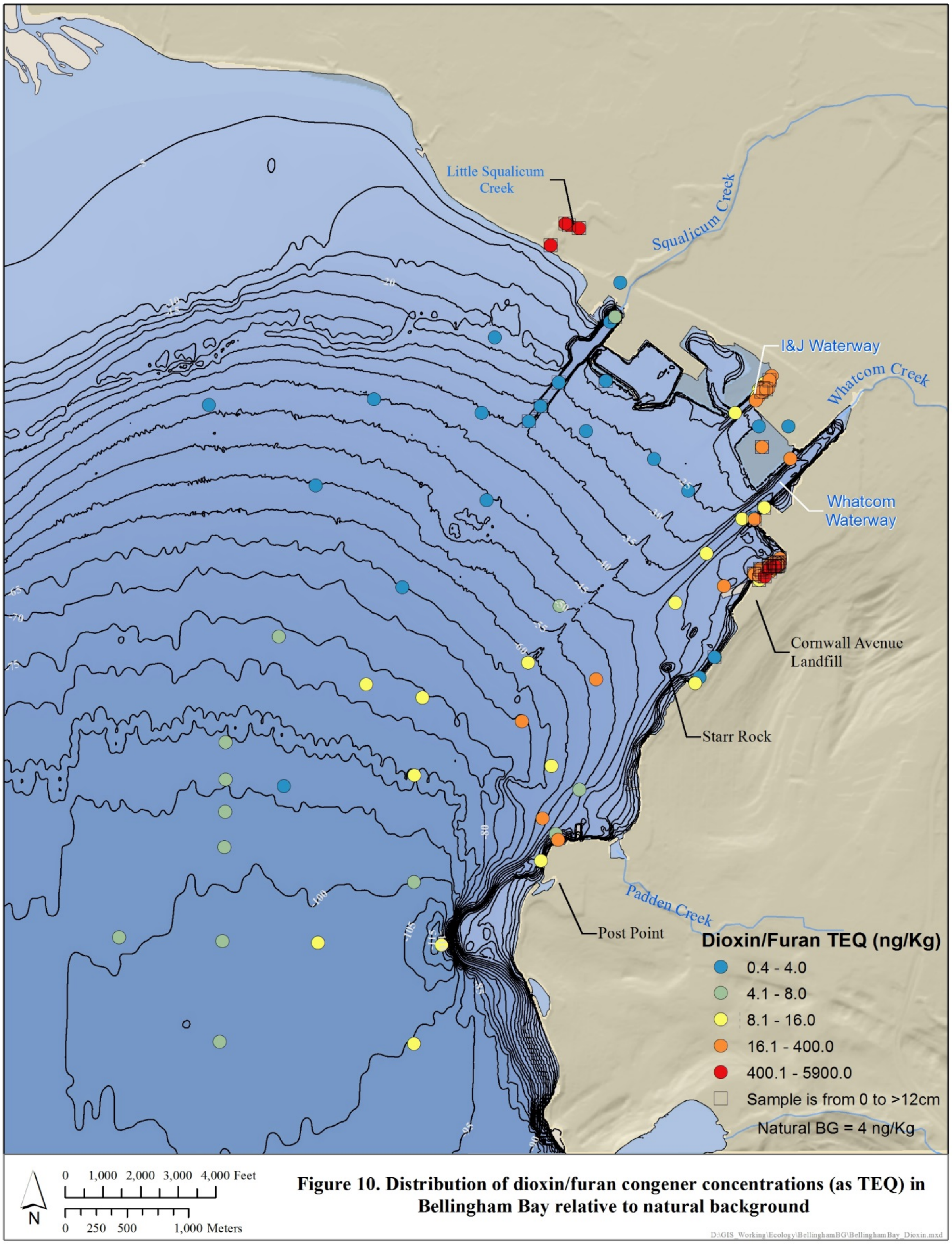

Figure 10. Distribution of dioxin/furan congener concentrations (as TEQ) in Bellingham Bay relative to natural background

2.5. Bioaccumulative Contaminants of Concern

The bioaccumulative contaminants to be evaluated for development of regional background concentrations include:

- Carcinogenic polycyclic aromatic hydrocarbons (cPAHs)
- Dioxin/furan congeners
- Polychlorinated biphenyl congeners (PCBs)
- Lead

Based on existing data, cPAHs and dioxins/furans appear to be elevated in portions of Bellingham Bay away from the direct influence of sites and sources. Currently, there is insufficient existing data to determine whether areas of the bay have elevated concentrations of PCB congeners beyond the direct influence of sites and sources. Therefore, PCB congeners have been included among the analytes.

Arsenic and cadmium were not included because they do not appear to be elevated anywhere in the bay outside of clearly contaminated areas within sites. Mercury was not included for two reasons: 1) current concentrations represent legacy contamination primarily from a single historic source, and 2) concentrations of mercury in the bay are rapidly recovering due to natural processes.

The spatial distribution of lead was not initially evaluated in the same manner as other metals. However, it was discussed as a possible contaminant of concern at the August 19th Bellingham Bay workshop to discuss the draft sampling and analysis plan, as well as in subsequent reviewer comments. The same concerns were not raised about other metals, including arsenic, cadmium, and mercury. As a means of addressing these comments and concerns, lead has been added to the analyte list.

Phthalates were also evaluated for potential inclusion, as these may be ubiquitous contaminants originating from urban diffuse sources. However, in Bellingham Bay, phthalates did not appear to be elevated above benthic criteria outside of cleanup sites and are not considered bioaccumulative contaminants. Therefore, they were not included among the analytes.

2.6. Summary of the Conceptual Bay Model

The AOI was defined as a hydraulically connected marine environment that excluded areas directly influenced by potential sources (e.g., active or historical outfalls), known cleanup sites, and dredged disposal sites, as well as areas more representative of natural background conditions (as defined in WAC 173-204-505) such as the Nooksack River delta and areas of the bay furthest from or least affected by local sources within the embayment (Figure 11). Specifically, the AOI boundaries were determined as described below.

Exclusion areas for sites and sources:

1. Cleanup sites along the shoreline were excluded based on clearly elevated levels of the bioaccumulative contaminants of concern. These included all contiguous and obviously elevated areas within the Little Squalicum Creek, I&J Waterway, Whatcom Waterway, RG Haley, Cornwall Ave Landfill, and Harris Ave. Shipyard sites. Due to the lack of data offshore of these sites, a 75 m (~250 ft) buffer was used around the outermost samples.
2. Starr Rock and other historic dredged material disposal sites were excluded based on their mapped locations (Tetra Tech and HRA 1995) and likely or known contamination present at these disposal sites.
3. The area around the Post Point outfall was excluded due to clear elevations of contaminants within the depositional zone and overlap with Harris Ave. Shipyard. The same buffer zone (75 m or ~250 ft) was used as for contaminated sites.
4. The area around the former Georgia-Pacific outfall was excluded due to potential areas of remaining influence in the immediate vicinity of the outfall.
5. Areas within the Outer Squalicum and Inner Squalicum Harbors were excluded because they have either been recently dredged or represent enclosed areas with ongoing sources or sediment cleanup sites and are expected to have different contaminant profiles from other areas of the bay.

Exclusion areas for natural background and natural features:

6. Areas below the 90/90 UTL of the natural background distribution, as defined by the Bold Plus data set (SCUM II; Ecology 2014a), were excluded from the regional background AOIs. Boundaries were drawn approximately half-way between existing data above and below the 90/90 UTL. A larger area of the bay was within natural background for dioxins/furans. Therefore, the regional background AOI for PAHs is larger than that for dioxins/furans (Figure 11).
7. Shallow areas <6 ft MLLW (~2 m) in depth were excluded for logistical sampling reasons. These include all areas within the Nooksack River delta and south along the shoreline, some areas within undredged portions of the waterways, and very narrow areas along the southeast shoreline.

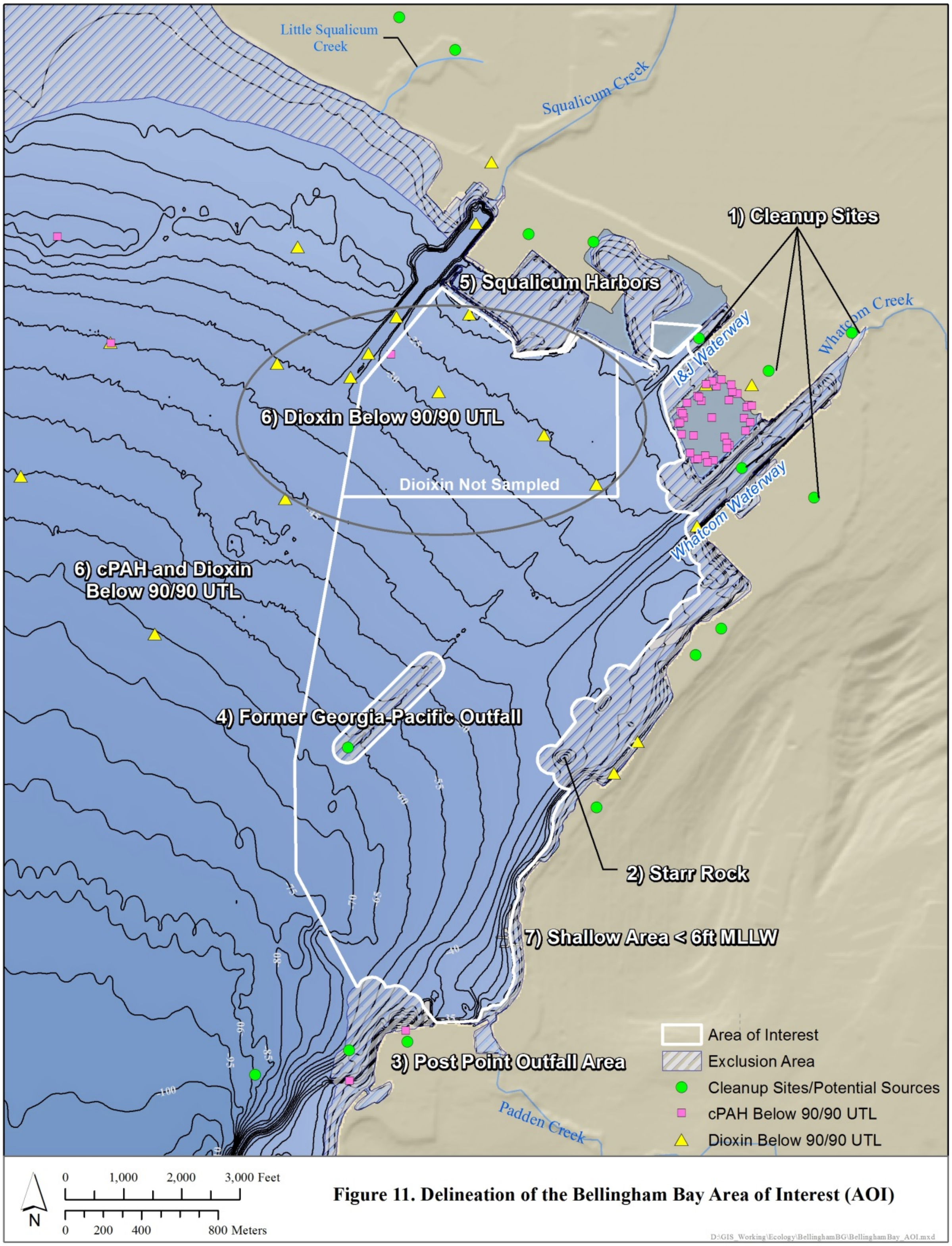

Figure 11. Delineation of the Bellingham Bay Area of Interest (AOI)

3.0 Study Design

This section describes the study design for the data collection effort in Bellingham Bay. Several key study objectives were taken into consideration in the development of the study design:

- Produce a data set with temporal consistency;
- Determine the minimum number of samples needed to calculate regional background;
- Define a minimum distance between sampling locations to minimize spatial bias;
- Randomly select sediment sampling locations to meet collective study objectives.

The following sections discuss the development and the details of the study design.

3.1. Sample Number and Density

The same dioxin/furan congener and cPAH data that were used to define the regional background AOI boundaries were used to estimate the number of samples needed to characterize regional background concentrations. PCB congener data were too sparse to use for this evaluation, so sample size was determined by dioxin/furan and cPAH data only. Lead will be sampled and analyzed at the same locations as cPAH and PCB congeners.

The precision of the data set was calculated as the width of the 95% upper confidence level (UCL) of the mean, expressed as a percentage of the mean. Precision of the mean expressed in this way is a common frame of reference for quantifying uncertainty in the population estimates that are necessary for the calculation of the background threshold value. A precision of 25% was the designated target, consistent with previous regional background studies (Ecology 2014b).

Ten dioxin/furan samples collected between 2007 and 2012 were present within the AOI (Figure 11). Only recent samples were used to best represent current conditions. These data were normally distributed (correlation coefficient of normal QQ-plot = 0.98; Shapiro-Wilk test p = 0.8) with no outliers. The data were fairly homogeneous with low variance (i.e., mean = 13.34 ng TEQ/kg, coefficient of variance (CV) = 0.354). For these normally distributed data, a *t*-interval was used to estimate the 95% UCL and associated precision (i.e., precision = $t_{0.05(1),(n-1)}\, CV/\sqrt{n}$).

The target precision of 25% is expected to be met with as few as eight samples, assuming that the newly collected data will have the same mean, variance, and distribution as the current dataset. However, a larger sample size is desirable to provide better spatial coverage of the AOI and increase confidence that the new data will meet project objectives.

A sample size of 23 for dioxins has an expected precision of approximately 13% and should provide enough samples to sufficiently characterize the shape of the concentration distribution, while providing similar power to the other regional background datasets from Port Gardner and the North Olympic Peninsula. This target sample size should be sufficient even if several samples cannot be collected in the field due to site conditions, if several samples are designated as outliers, and/or if the newly collected data differ in distribution from the available results.

The existing Bellingham Bay cPAH data set consisted of 16 samples collected between 2006 and 2012. These data followed a skewed gamma distribution (correlation coefficient of gamma QQ-plot = 0.98; Kolmogorov-Smirnov test, $p = 0.99$). There were two influential concentrations from locations near the southwestern boundary of the AOI with concentrations greater than 90 µg TEQ/kg. Without these two high concentrations, the data appeared to be normally distributed. The mean for all data was 43 µg TEQ/kg with a CV of 0.59. The target precision of 25% is expected to be met with a sample size of at least 22, assuming that the newly collected data have the same mean, variance, and distribution as the current dataset.

The AOI for all analytes (determined by the dioxin/furan data) encompasses 3.91 km^2, while the AOI for cPAHs, lead, and PCBs includes an additional 1.17 km^2 in the northwest corner (Figure 11). Twenty-three sampling locations within the smaller AOI are targeted, with a spatially proportionate number of locations required from the larger cPAH, lead, and PCB AOI (i.e., [23 dioxin samples/3.91 km^2] × 1.17 km^2 = 7 additional locations).

Thus, 23 sampling locations are targeted for full chemical analysis (i.e., dioxin/furan congeners, cPAH, lead, and PCB congeners) within the dioxin/furan AOI and an additional seven locations for cPAH, lead, and PCB congeners from the remaining area of the PAH AOI. These sample sizes are expected to be more than sufficient to meet precision targets, so no secondary samples will be collected as was done for previous efforts (Ecology 2013b; Ecology 2013c; Ecology 2014b). Similar to other regional background sampling efforts (Ecology 2013b; Ecology 2013c; Ecology 2014b), the locations were selected using a random design and an element of spatial balance to avoid bias if there appear to be concentration trends.

The spatially balanced random sampling design was developed using a Reverse Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Theobald et al, 2007). This method requires the use of a probability raster grid specifying the probability (0 to 1) that a given raster cell will be selected relative to other cells. To account for the minimum sampling interval, a site sampling grid with a 250 m (~820 ft) resolution inclusion probability raster was created within the AOI polygon. This raster acts as a uniformly spaced sampling grid ensuring that the minimum distance between any two randomly placed sampling locations is at least 250 m (~820 ft). For this case, all cells were assigned a value of one, which allows for an equal probability of an individual cell being selected.

The RRQRR method and the 250 m (~820 ft) buffer distance were selected for several reasons:

- Locations are randomly selected using this method;
- This buffer distance is large enough to achieve a fairly uniform spatial coverage throughout the AOI, yet small enough to avoid forcing the random locations onto a regular grid due to space restrictions in this small AOI. A regular systematic grid design

  with a random start was one possible sampling approach, but might have imposed unexpected bias in the results if there were spatial trends driven by particular features of the bay which were aligned (or completely missed) by the orientation of the grid;

  - Because of the small size of the AOI, a buffer distance less than the 500 m buffer used at Port Gardner and the North Olympic Peninsula (Ecology 2013b; Ecology 2013c; Ecology 2014b) was necessary to fit the target number of samples within the AOI. The chosen buffer distance of 250 m is expected to result in a spatially uncorrelated data set This distance is less than 500 m, the distance shown to not have autocorrelation for the available Bellingham Bay data, and greater than 200 m, the distance shown to have significant autocorrelation for the available Port Gardner Bay data (Appendix C. Background Memorandum).

Through this spatially balanced selection process, the 23 dioxin/furan congener sample locations were randomly placed within the dioxin specific AOI. The 7 additional cPAH, lead, and PCB congener samples were then randomly placed in the subset of the AOI, making sure all samples remained at least 250 m (820 ft) apart.

If the results from this balanced/random design are found to be spatially autocorrelated, the data can be subsampled or methods that account for autocorrelation can be used to generate appropriate summary statistics. Otherwise, the samples can be assumed to be independent and the appropriate summary statistics estimated.

3.2. Sediment Sampling Locations

A total of 30 sediment sampling locations will be occupied as part of this investigation.

The objective in siting these 30 locations was to provide a minimum number of spatially balanced random sampling locations at least 75 m (~250 ft) apart within the AOIs pre-determined to be representative of regional background conditions for each analyte. The following data collection activities have been identified and are summarized in Table 1:

- Collect 30 surface sediment (0–12 cm) grab samples using a spatially balanced random design placed within the separate AOIs designated as representing regional background conditions for each analyte.
- Submit sediment samples from the 23 samples located in the dioxin/furan AOI for analysis of the following bioaccumulative contaminants:
  - Dioxin/furan congeners
  - PCB congeners
  - cPAHs
  - Lead

- Submit sediment samples from the seven samples located in the remaining area of the PAH AOI for the analysis of the following bioaccumulative contaminants:
    - PCB congeners
    - cPAHs
    - Lead
- Submit all 30 sediment samples for analysis of sediment conventionals (grain size distribution, total solids, and TOC).
- Archive sediment from each location for additional analysis or re-analysis as needed.

The proposed sediment sample locations are presented in Figure 12. Target coordinates are provided in Table 2.

Table 1. Sediment sample locations and analyses for Bellingham Bay.

Sampling Location	Sediment Conventionals[1]	cPAH	Lead	Dioxin/Furan Congeners	PCB Congeners	Archive[2]
BB-01	X	X	X	--	X	X
BB-02	X	X	X	--	X	X
BB-03	X	X	X	--	X	X
BB-04	X	X	X	--	X	X
BB-05	X	X	X	--	X	X
BB-06	X	X	X	--	X	X
BB-07	X	X	X	--	X	X
BB-08	X	X	X	X	X	X
BB-09	X	X	X	X	X	X
BB-10	X	X	X	X	X	X
BB-11	X	X	X	X	X	X
BB-12	X	X	X	X	X	X
BB-13	X	X	X	X	X	X
BB-14	X	X	X	X	X	X
BB-15	X	X	X	X	X	X
BB-16	X	X	X	X	X	X
BB-17	X	X	X	X	X	X
BB-18	X	X	X	X	X	X
BB-19	X	X	X	X	X	X
BB-20	X	X	X	X	X	X
BB-21	X	X	X	X	X	X
BB-22	X	X	X	X	X	X
BB-23	X	X	X	X	X	X
BB-24	X	X	X	X	X	X
BB-25	X	X	X	X	X	X
BB-26	X	X	X	X	X	X
BB-27	X	X	X	X	X	X
BB-28	X	X	X	X	X	X
BB-29	X	X	X	X	X	X
BB-30	X	X	X	X	X	X

Notes

cPAH-carcinogenic polycyclic aromatic hydrocarbons **PCB**-polychlorinated biphenyls

1-sediment conventionals include total organic carbon (TOC), total solids, and grain size distribution

2-sediment archived for potential analysis or reanalysis

-- not analyzed

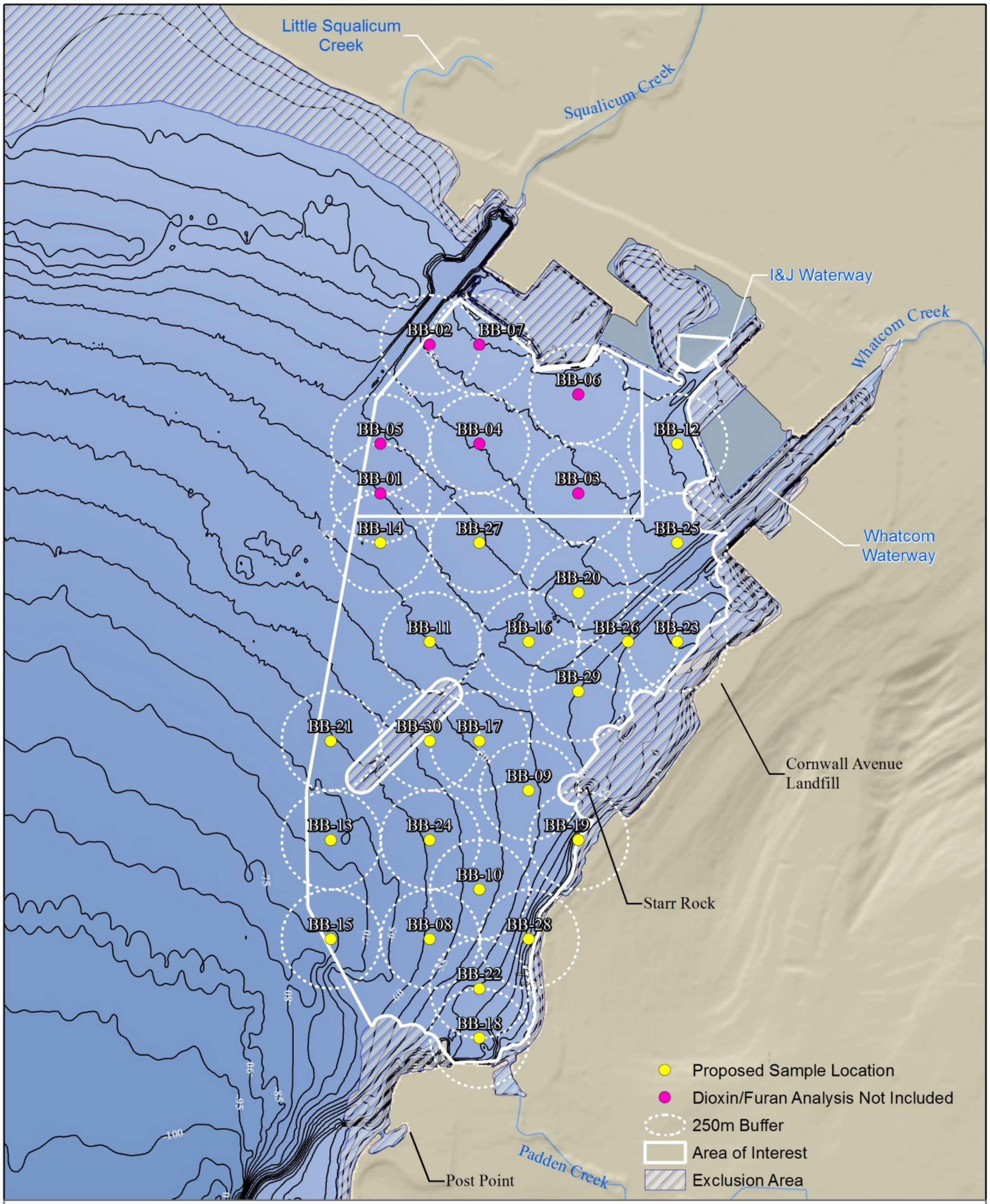

Figure 12. Proposed regional background sediment sampling locations in Bellingham Bay

4.0 Sample Collection and Handling Methods

This section describes the methodology for positioning, sample collection, processing, identification, documentation, equipment decontamination, and waste handling for the proposed field investigation. Section 4.0 presents the laboratory methods for chemical analysis.

4.1. Sampling Platforms

The R/V *Kittiwake*, owned and operated by Mr. Charles Eaton of Bio-Marine Enterprises will be used for the surface sediment grabs in Bellingham Bay.

4.2. Station Positioning and Navigation

NewFields will ensure that vessel navigation provides accurate station positioning, and that sample locations and water depths are recorded. A differential global positioning system (DGPS) will be used aboard the R/V *Kittiwake* for station positioning. A U.S. Coast Guard differential correction signal will be utilized to obtain a minimum accuracy of ±3 m. The DGPS receiver will be placed above the block on the sampling device deployment boom to accurately record the position of the sampling device.

Sampling location coordinates will be calculated in advance and programmed into the R/V *Kittiwake*’s navigation system. Upon sampling device deployment, the actual position will be recorded once the device reaches the seafloor and the deployment cable is in a vertical position. Latitude and longitude station coordinates will be recorded in degrees decimal minutes using the 1983 North American Datum (NAD83). In the event a successful grab cannot be obtained at the target location, Ecology will be notified and additional attempts may be made at a revised location. If a proposed target location cannot be sampled (after discussion with Ecology) due to unforeseen conditions (i.e., shoaling, rocky substrate, etc.), the location will be abandoned. One such condition is water depth. Samples will not be collected in depths < 6 ft MLLW (~2 m). Water depths will be measured using the winch meter wheel and verified by the ship’s fathometer. Table 2 provides the target coordinates for the sample locations.

4.1. Sediment Sample Collection

Surface sediment samples will be collected at 30 locations in Bellingham Bay. Table 3 lists the sediment samples to be collected and analyzed, the number of QA/QC samples, sample container, volume, and preservation requirements.

Table 2. Target coordinates for sampling locations.

StationID	Easting	Northing	Longitude	Latitude
	(SPN NAD83)	(SPN NAD83)	(NAD83)	(NAD83)
BB-01	1234003.58	641885.70	-122.517896	48.747433
BB-02	1234823.79	644346.33	-122.514720	48.754225
BB-03	1237284.42	641885.70	-122.504301	48.747629
BB-04	1235644.00	642705.91	-122.511173	48.749778
BB-05	1234003.58	642705.91	-122.517970	48.749680
BB-06	1237284.42	643526.12	-122.504449	48.752124
BB-07	1235644.00	644346.33	-122.511321	48.754274
BB-08	1234823.79	634503.81	-122.513829	48.727254
BB-09	1236464.21	636964.44	-122.507256	48.734094
BB-10	1235644.00	635324.02	-122.510506	48.729550
BB-11	1234823.79	639425.07	-122.514275	48.740739
BB-12	1238924.84	642705.91	-122.497578	48.749974
BB-13	1233183.37	636144.23	-122.520773	48.731650
BB-14	1234003.58	641065.49	-122.517822	48.745185
BB-15	1233183.37	634503.81	-122.520624	48.727155
BB-16	1236464.21	639425.07	-122.507478	48.740837
BB-17	1235644.00	637784.65	-122.510728	48.736293
BB-18	1235644.00	632863.39	-122.510284	48.722808
BB-19	1237284.42	636144.23	-122.503785	48.731896
BB-20	1237284.42	640245.28	-122.504154	48.743134
BB-21	1233183.37	637784.65	-122.520922	48.736146
BB-22	1235644.00	633683.60	-122.510358	48.725055
BB-23	1238924.84	639425.07	-122.497284	48.740983
BB-24	1234823.79	636144.23	-122.513978	48.731749
BB-25	1238924.84	641065.49	-122.497431	48.745479
BB-26	1238104.63	639425.07	-122.500682	48.740935
BB-27	1235644.00	641065.49	-122.511025	48.745283
BB-28	1236464.21	634503.81	-122.507035	48.727352
BB-29	1237284.42	638604.86	-122.504006	48.738638
BB-30	1234823.79	637784.65	-122.514126	48.736244

Notes

SPN NAD83: Washington State Plane North, North American Datum 1983.

NAD83: North American Datum 1983.

Table 3. Sediment sample collection, analysis, containers, and holding times.

Analyses	Grain Size	Total Solids, TOC	SIM cPAH	Lead	PCB Congeners	Dioxin/Furan Congeners	Archive
Container(s)	16-oz HDPE	8-oz glass	8-oz glass	4-oz glass	8-oz amber glass		16-oz glass
Preservative	4°C	4°C/-18°C	4°C/-18°C	4°C/-18°C	4°C/-18°C		-18°C
Holding Time	6 months	14 days/ 6 months	14 days/ 1 year	14 days/ 1 year	14 days/ 1 year		1 year
Dioxin AOI[1]	23X	23X	23X	23X	23X	23X	23A
Dioxin Exclusion Area[1]	7X	7X	7X	7X	7X	-	7A
Duplicates[2]	2X	2X	2X	2X	2X	2X	-
Triplicates[2,3]	2X	2X	-	-	-	-	-
CRM	-	-	-	-	1X	1X	-
Equipment Rinsate[4]	-	-	2X	2X	-	-	-
Rinsate Blank[4]	-	-	X	X	-	-	-
Sample Totals	**34**	**34**	**35**	**35**	**33**	**26**	**30**

Notes

X: sample to be collected and submitted for analysis/testing.

A: sample to be archived **-**: no sample will be collected at this location.

HDPE: high-density polyethylene **CRM**: certified reference material.

1. See Table 1 and Figure 12 for AOI delineation.

2. Frequency of analysis is 1 per 20 samples (5%).

3. Triplicate analysis for sediment conventional parameters only.

4. Equipment rinsate and rinsate blanks conducted for cPAH only.

4.2. Surface Sediment Grabs

Surface sediment grabs will be collected for chemical analysis from the R/V *Kittiwake* using a stainless steel 0.2-m^2 dual van Veen (0.1 m^2 per bucket).

Established deployment and recovery procedures for the grab sampling gear, described in PSEP, will be followed to ensure recovery of the best possible samples and minimize risks to personnel and equipment (PSEP 1997a). Once a grab sample is retrieved, the overlying water will be carefully siphoned off one side of the sampler. If the sample is judged to be acceptable according to PSEP specifications, the penetration depth will be measured with a decontaminated stainless steel ruler, and sample quality, color, odor, and texture will be described in the sample log (Appendix A).

If needed, multiple grab samples will be collected and composited for each sampling location to provide sufficient volume for chemical analysis. The general procedure for collecting sediment using a grab sampler is as follows:

1. Make logbook and field form entries as necessary throughout the sampling process to ensure accurate and thorough record-keeping.
2. Position the sampling vessel at the targeted sampling location.
3. Set the sampler jaws in the open position, place the sampler over the edge of the boat, and lower the sampler to the bottom.
4. Record the location using the DGPS; measure and record the water depth.
5. Retrieve the sampler and place it securely in the sampling vessel.
6. Examine the sample for the following sample acceptance criteria:
    a. The sampler is not overfilled with sample so that the sediment surface is pressing against the top of the sampler.
    b. The sample does not contain large foreign objects (i.e., trash or debris). A sample that is rock/gravel fill will be rejected in favor of depositional material (i.e., sand/silt/clay).
    c. Overlying water is present indicating minimal leakage.
    d. Overlying water is not excessively turbid indicating minimal sample disturbance.
    e. Sediment surface is relatively flat and/or intact without any indications of disturbance or winnowing.
    f. A penetration depth has been achieved that allows the collection of the upper 10 cm of sediment whenever feasible. In instances where 10 cm penetration is not possible due to sandy sediments, the maximum penetration depth will be recorded.
    g. If sample acceptance criteria are not achieved, the sample will be rejected and another sample collection attempt will be made.
    h. If multiple attempts within 50 m of a given target location do not produce an

acceptable sample, the sampling location will be relocated.

7. Siphon off any overlying surface water.
8. Collect samples for total sulfides analysis directly from the grab sampler and place the sediment aliquots in appropriate, pre-cleaned, labeled sample containers (Table 3). Add approximately 2 mL of zinc acetate preservative to the jar, fasten the lid and shake until mixed.
9. Measure and collect the top 12 cm with a stainless steel spoon, avoiding any sediment that is in contact with the inside surface of the grab sampler, then place the sediment into a stainless steel bowl and cover with aluminum foil.
10. Record the following observations of sediment sample characteristics on the field form (Appendix A); repeat steps 4 through 11 if more sample volume is required.
    a. Texture
    b. Color
    c. Biological organisms or structures (i.e., shells)
    d. Presence of debris (i.e., natural or anthropogenic objects); estimated percentage of wood debris
    e. Presence of oily sheen or obvious contamination
    f. Odor (e.g., hydrogen sulfide, petroleum)
11. Wash excess sediment back into the water away from any areas remaining to be sampled.
12. Percent fines will be determined by rinsing 100 mL of sediment through a 63.5-µm sieve until the water is clear. Percent fines are equal to 100 minus the volume of remaining sediment.
13. Once sufficient sediment volume has been collected and homogenized to a consistent texture, samples will be placed in the appropriate, pre-cleaned, labeled sample containers, placed in a cooler maintained at 4ºC, and prepared for shipment to the analytical laboratory.
14. Confirm all relevant documentation has been completed, entries are accurate, and paperwork has been signed.
15. Decontaminate all sampling equipment before proceeding to the next sampling location.

A single replicate sample will be collected from each target sampling location, with the exception of field duplicates and QA/QC samples to be collected randomly at the field supervisor’s discretion.

4.3. Sample Identification, Containers, and Labels

Samples will be identified based on the project, sampling area, location, and sample type. All samples collected during will be labeled clearly and legibly. Each sample will be labeled with a unique alphanumeric sample identification number that identifies characteristics of the sample as follows:

Project	Study Area	Location Number	Sample Type
RB14-	BB-	01-	S

Project consists of four characters describing the project (RB12 = Regional Background 2012).

Study Area consists of two characters describing the sampling area (BB = Bellingham Bay).

Location Number consists of two characters identifying the station location number.

Sample Type consists of one to two characters indicating the sample type. S denotes a sediment sample. Sediment QA/QC samples are further identified with D = duplicate, T = triplicate, ER = equipment rinsate, RB = rinsate blank.

Equipment rinsate and rinsate blank samples will be identified by process, but the date will be substituted in place of the Location Number.

Sample labels will be self-adhering, waterproof material. An indelible pen will be used to fill out each label. Each sample label will contain the project name (Bellingham Bay Regional Background Sediment Investigation), sample identification, date and time of collection, analyses, preservative (as applicable), and the initials of the person preparing the sample. In addition, a unique, sequentially numbered jar tag will be placed on each sample container for tracking purposes. Jar tag numbers will be recorded in a Sample Container Logbook (Appendix A). Sample labels and jar tags will be protected by packaging tape wrapped around the entire jar to prevent loss or damage of the labels during handling and storage.

4.4. Sample Storage and Delivery

All samples will be stored in insulated coolers and preserved by cooling to a temperature of 4ºC or as required by analytical methods. Maximum sample holding and extraction times will be strictly adhered to by field personnel and the analytical and testing laboratories.

Preparation of jars for shipment will be performed in the following manner:

1. Wipe or decontaminate the outside of filled, capped sample bottles to ensure there is no sample residual on the outside of the container. Secure sample lid jars with electrical tape to prevent leakage.
2. Label jars with prepared labels. Each set of samples will have a unique sample ID and jar tag number.
3. Secure labels with clear packaging tape.
4. Record the samples in Sample Container Logbook (see Appendix A) and the Chain of Custody forms.
5. Place sample containers in plastic bubble-pack bags, or wrap in bubble pack and secure with packaging tape.
6. Prepare an empty insulated cooler by placing three to four ice packs in a garbage bag at the bottom of the cooler. Place sample containers in a garbage bag and fill with the

sample bottles. Add additional bags of ice as needed to surround the bag containing the samples.

7. Seal the cooler with strapping tape and a custody seal. Samples for chemical analyses will be shipped via overnight courier to the analytical laboratory once per day or whenever a cooler is filled, and accompanied by the chain-of-custody record, which identifies the shipment contents. The chain-of-custody will be signed by the individual relinquishing samples to the onsite laboratory representative. The field personnel will be responsible for:
    a. Packaging the samples;
    b. Signing the chain-of-custody before placing inside the cooler to be sealed;
    c. Applying a shipping label, an air bill, a custody seal, and strapping tape to the cooler; and
    d. Shipping the samples in accordance with the maximum holding time allowed for the analyses to be performed.

A separate chain-of-custody form will be filled out for each analytical laboratory. The chain-of-custody will be signed by the individuals relinquishing the samples and will be placed inside the cooler before it is sealed.

All sediment samples will be retained for a minimum of 6 months from the time they were received using standard laboratory handling procedures. They may be removed from the laboratory prior to the end of the 6-month period only at the direction of the contractor project manager in consultation with Ecology.

4.5. Field Documentation

A complete record of field activities will be maintained. Documentation necessary to meet QA objectives for this project include field notes and field forms (Appendix A), sample container labels, and chain-of-custody forms. The field documentation will provide descriptions of all sampling activities, sampling personnel, and weather conditions, and will record all modifications, decisions, and/or corrective actions to the study design and procedures identified in this work plan.

4.5.1. Field Notebooks

All handwritten documentation must be legible and completed in permanent waterproof ink. Corrections must be marked with a single line, dated, and initialed. All documentation, including voided entries, must be maintained within project files.

The Field Manager will keep the field logbook(s) on site during field operations. Daily activities will be recorded in a bound field logbook of water-resistant paper. Separate logbooks consisting of bound, paginated field forms will be kept for surface sediment grab descriptions, and an inventory of sample containers (separate from constituent of concern [COC] documentation).

Examples of the various field forms to be used are presented in Appendix A. All entries will be made legibly, in indelible ink, and will be signed and dated. Information recorded will include the following:

- Date, time, place, and location of sampling;
- Onsite personnel and visitors;
- Daily safety discussion and any safety issues;
- Quality control samples (e.g., duplicate samples, field blanks, etc.);
- Calibration of field equipment (including make and model of equipment);
- Field measurements and their units;
- Observations about site, location, and samples (i.e., weather, current, odors, appearance); and
- Equipment decontamination verification.

Field logbooks are intended to provide sufficient data and observations to enable participants to reconstruct events that occur during project field activities. Entries should be factual, detailed, and objective. Unless restricted by weather conditions, all original data recorded in field logbooks and on sample identification tags, chain-of-custody records, and field forms will be written in waterproof ink. If an error is made, the individual responsible may make corrections simply by crossing out the error and entering the correct information. The erroneous information should not be obliterated. All corrections must be initialed and dated.

4.5.2. Chain-of-Custody Procedures

The field crew will retain samples at all times until contractor personnel deliver samples to the appropriate laboratory. All samples will be held and transported in coolers with ice or frozen gel-packs at approximately 4°C.

Chain–of-custody forms will be initiated at the time of sample collection to ensure that all collected samples are properly documented and traceable through storage, transport, and analysis. When all line items on the form are completed or when the samples are relinquished, the sample collection custodian will sign and date the form, list the time, and confirm the completeness of all descriptive information contained on the form. Each individual who subsequently assumes responsibility for the sample will sign the chain-of-custody form and provide the reason for assuming custody. The field chain-of-custody terminates when the laboratory receives the samples. The FM should retain a copy of the completed, signed, chain-of-custody form(s) for project files.

4.6. Equipment Decontamination

Sample processing equipment (i.e., spoons, bowls, and reusable containers from which samples are transferred to sample jars) will be washed with a laboratory-grade detergent (e.g., Liquinox or Alconox) and water solution, rinsed with site or tap water, and will undergo a final distilled water rinse prior to field operations. Decontaminated equipment will be wrapped or covered with aluminum foil. Sub-sampling and processing equipment will be decontaminated before use at each station in order to prevent cross-contamination of samples. Any deviations from these procedures will be documented in the field notebook.

Personal non-disposable field equipment (i.e., boots, waterproof gloves, and garments) will be rinsed with water and brushed clean prior to leaving the immediate vicinity of the sample collection area. Special attention will be given to removing mud that may adhere to boot treads.

4.7. Waste Disposal

During the field investigation, field personnel will be responsible for securing appropriate waste containers, and placing wastes in labeled storage containers, performing appropriate testing, preparing wastes for disposal, and proper disposition of wastes.

Excess sediment sample not submitted to the laboratories, and disposable protective clothing, sampling equipment, and packaging are the two types of waste the activities described in this work plan will generate.

4.7.1. Sediment Samples

Small quantities of excess sediment and rinsate water generated during sample processing will be returned to the site. Care will be taken to not dispose of sediment and/or rinsate at locations targeted for subsequent sampling.

4.7.2. Disposable Protective Clothing and Sampling Equipment

Used PPE, such as protective Tyvek suits or gloves, and sampling equipment, such as aluminum foil and paper towels, and any packaging material that cannot be recycled, will be placed in plastic storage bags and disposed of as municipal waste.

5.0 Laboratory Analytical Methods

All of the analytical methods used in this program will be performed in accordance with the PSEP guidelines. The laboratory analysis will be consistent with PSEP guidelines (PSEP 1997a, b, c), any recent modifications proposed during the SMARM, and/or the most current laboratory recommendations. Each laboratory participating in this program will institute internal QA/QC plans. Analyses will be required to conform to accepted standard methods and internal QA/QC checks prior to final approval.

5.1. Chemical Analyses

Analytical Resources, Inc. (ARI), and AXYS Analytical Services will conduct the chemical analysis. Table 4 presents the sample preparation methods, analytical methods, and practical quantitation limits (PQL) for the target conventionals, cPAH compounds, lead, and dioxin/furan congeners. Each sample will also be analyzed for the full list of PCB congeners. The congeners and congener pairs obtainable by EPA method 1668A are presented in Table 5.

The analytical results from this investigation will be used for the determination of regional background concentrations. Accordingly, the data quality objectives are stricter than those required under most sediment characterizations as the intent of any background study is to obtain as few non-detects and as many unqualified results as possible. The PQLs required for analysis in this study are lower than most standard methods provide. Efforts were made for many of the analytes to find methods that provide lower PQLs.

Few requirements exist for the selection of PQLs. MTCA guidance does stipulate that where the PQL is used as a cleanup level, it must meet the more stringent of the following conditions (WAC 173-340-707(2)(a) and (b)):

- The PQL is no greater than ten times the method detection limit (MDL).
- The PQL is no greater than that established by the U.S. EPA and used to establish requirements in 40 CFR 136, 40 CFS 141-143, or 40 CFR 260-270.

For all target analytes, the PQL is within a factor of ten of the MDL.

cPAH will be analyzed in select ion monitoring (SIM) mode. An additional low end point will be added to the calibration standard for dioxin/furan and PCB congener analysis to provide for lower reporting limits. The PQL values listed for dioxin/furan and PCB congeners in Tables 4 and 5 are lower method calibration limits (LMCL), which is defined by the lower limit of the calibration curve. The LMCL is equivalent to the PQL in that it meets the definition provided in WAC 173-204-505: “PQL means the lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods."

The PQLs listed may be subject to modification due to elevated sample concentrations, heterogeneous samples (sediment), and potential matrix interferences that may preclude obtaining the desired quantification limit. Specifically:

- The standard reporting limit for cPAH compounds is 5.0 µg/kg using EPA method 8270 SIM. If necessary, ARI can achieve a PQL as low as 0.5 µg/kg using a low-level version of 8270 SIM, but only in samples where the concentration is below the standard reporting limit. ARI will prescreen a solvent shake-out of the sample for potential high concentrations and analyze using the appropriate method.
- Matrix interferences for PCB congeners were noted with samples collected for the Port Gardner Regional Background Characterization. To minimize these interferences with the Bellingham Bay Characterization, Axys may need to conduct an additional alumina column cleanup prior to analysis.

In the event either laboratory is unable to meet the PQLs additional clean-up measures may be used. If the PQLs still cannot be met, the reasons for the deviation will also be reported.

Table 4. Target analytes, methods, and practical quantitation limits (PQL).

Analyte	Preparation Method	Analytical Method	PQL
Conventional Parameters			
Grain size	---	PSEP	---
Total Solids (%)	---	PSEP	0.1
Total Organic Carbon (%)	---	PSEP	0.10
cPAHs (µg/kg DW)			
Benzo(a)pyrene	EPA 3546	8270-SIM PAH*	5.0
Benz(a)anthracene	EPA 3546	8270-SIM PAH*	5.0
Benzo(b)fluoranthene	EPA 3546	8270-SIM PAH*	5.0
Benzo(k)fluoranthene	EPA 3546	8270-SIM PAH*	5.0
Chrysene	EPA 3546	8270-SIM PAH*	5.0
Dibenz(a,h)anthracene	EPA 3546	8270-SIM PAH*	5.0
Indeno(1,2,3-cd)pyrene	EPA 3546	8270-SIM PAH*	5.0
Metals (mg/kg DW)			
Lead	EPA 3050B/3051	EPA 200.8	0.1
Dioxin/Furan Congeners (ng/kg DW)‡			
2,3,7,8-TCDD	EPA 1613B/3540C	EPA 1613B (CS-0.2)	0.2
1,2,3,7,8-PeCDD	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
1,2,3,4,7,8-HxCDD	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
1,2,3,6,7,8-HxCDD	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
1,2,3,7,8,9-HxCDD	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
1,2,3,4,6,7,8-HpCDD	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
OCDD	EPA 1613B/3540C	EPA 1613B (CS-0.2)	2.0
2,3,7,8-TCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	0.2
1,2,3,7,8-PeCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
2,3,4,7,8-PeCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
1,2,3,4,7,8-HxCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
1,2,3,6,7,8-HxCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
1,2,3,7,8,9-HxCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
2,3,4,6,7,8-HxCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
1,2,3,4,6,7,8-HpCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
1,2,3,4,7,8,9-HpCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	1.0
OCDF	EPA 1613B/3540C	EPA 1613B (CS-0.2)	2.0

Notes

SIM-select ion monitoring **PQL**-practical quantitation limit **DW**-dry weight

CS-0.2-additional low-level calibration point **cPAH-**carcinogenic polycyclic aromatic hydrocarbons

* Samples will undergo a prescreening process at ARI and low concentration samples will be analyzed by a low-level variant of 8270-SIM with a reporting limit of 0.5 µg/kg.

‡ Values listed for dioxin/furan congeners are the lower method calibration limits (LMCL) defined by the lowest concentration on the calibration curve. The LMCL is functionally equivalent to the PQL.

Table 5. PCB congener methods and practical quantitation limits (PQL).

Analyte	Preparation Method	Analytical Method	PQL
*PCB-156/157	EPA 1668A	EPA 1668A (CS-0.2)	0.8
see below	EPA 1668A	EPA 1668A (CS-0.2)	0.4
PCB Congeners and Congener Pairs (ng/kg DW) for Prep Method EPA 1668A and PQL of 0.4			
PCB-1	PCB-48	PCB-110/115	PCB-164
PCB-2	PCB-50/53	PCB-111	PCB-165
PCB-3	PCB-52	PCB-112	PCB-167
PCB-4	PCB-54	PCB-113/90/101	PCB-169
PCB-5	PCB-55	PCB-114	PCB-170
PCB-6	PCB-56	PCB-117/116/85	PCB-171/173
PCB-7	PCB-57	PCB-118	PCB-172
PCB-8	PCB-58	PCB-120	PCB-174
PCB-9	PCB-59/62/75	PCB-121	PCB-175
PCB-10	PCB-60	PCB-122	PCB-176
PCB-11	PCB-61/70/74/76	PCB-123	PCB-177
PCB-12/13	PCB-63	PCB-126	PCB-178
PCB-14	PCB-64	PCB-127	PCB-179
PCB-15	PCB-66	PCB-128/166	PCB-180/193
PCB-16	PCB-67	PCB-130	PCB-181
PCB-17	PCB-68	PCB-131	PCB-182
PCB-19	PCB-69/49	PCB-132	PCB-183/185
PCB-21/33	PCB-72	PCB-133	PCB-184
PCB-22	PCB-73	PCB-134/143	PCB-186
PCB-23	PCB-77	PCB-136	PCB-187
PCB-24	PCB-78	PCB-137	PCB-188
PCB-25	PCB-79	PCB-138/163/129/160	PCB-189
PCB-26/29	PCB-80	PCB-139/140	PCB-190
PCB-27	PCB-81	PCB-141	PCB-191
PCB-28/20	PCB-82	PCB-142	PCB-192
PCB-30/18	PCB-83/99	PCB-144	PCB-194
PCB-31	PCB-84	PCB-145	PCB-195
PCB-32	PCB-88/91	PCB-146	PCB-196
PCB-34	PCB-89	PCB-147/149	PCB-197/200
PCB-35	PCB-92	PCB-148	PCB-198/199
PCB-36	PCB-94	PCB-150	PCB-201
PCB-37	PCB-95/100/93/102/98	PCB-151/135/154	PCB-202
PCB-38	PCB-96	PCB-152	PCB-203
PCB-39	PCB-103	PCB-153/168	PCB-204
PCB-41/40/71	PCB-104	PCB-155	PCB-205
PCB-42	PCB-105	PCB-156/157*	PCB-206
PCB-43	PCB-106	PCB-158	PCB-207
PCB-44/47/65	PCB-107/124	PCB-159	PCB-208
PCB-45/51	PCB-108/119/86/97/125/87	PCB-161	PCB-209
PCB-46	PCB-109	PCB-162	--

Notes

PQL-practical quantitation limit **DW**-dry weight **CS-0.2**-additional low-level calibration point

5.2. Analytical Laboratory Reporting

Analytical laboratory reports will be accompanied by sufficient backup data and QC results to enable independent reviewers to evaluate the quality of the data results. Analytical data will be reported in the units specified by the PQLs listed in Tables 4 and 5.

All PQLs will be met. If matrix interferences exist that prevent meeting the listed PQL, the reason will be listed in the laboratory narrative. All non-detect sample results for cPAH will be reported to the method detection limit and detected results less than the target PQL will be qualified.

Non-detect results for dioxin/furan and PCB congeners will be reported at the sample specific detection limit (SDL). All detected congener results less than the LMCL/PQL will be qualified.

The analytical laboratory deliverables will include the following:

- Case narrative (including any problems encountered, protocol modifications, and/or corrective actions taken);
- Sample analytical and QA/QC results with units;
- All protocols used during analyses;
- Any protocol deviations from the approved sampling plan;
- Surrogate recovery results;
- MS/MSD results;
- Laboratory duplicate/triplicate results;
- Blank results;
- Sample custody records (including original chain-of-custody forms); and
- Electronic analytical results in Ecology’s Environmental Information Management (EIM) format.

6.0 Quality Assurance Project Plan

The purpose of the project QA/QC is to provide confidence in the project data results through a system of quality control performance checks with respect to data collection methods, laboratory analysis, data reporting, and appropriate corrective actions to achieve compliance with established performance and data quality criteria. This section presents the QA/QC procedures to ensure that the investigation data results are defensible and usable for their intended purpose.

6.1. Measurements of Data Quality

The tolerable limits for the data reported by the laboratory will be measured with regard to precision, accuracy, representativeness, completeness, and comparability.

Precision is a measure of mutual agreement among individual measurements of the same property under prescribed conditions. Precision will be assessed by the analysis of matrix spike/matrix spike duplicates (MS/MSDs), field duplicate and triplicates, and laboratory control sample/laboratory control sample duplicates (LCS/LCSD). The calculated relative percent differences (RPDs) for field duplicates and triplicates and MS/MSD pairs will provide information on the precision of sampling and analytical procedures, and the RPDs for LCS/LCSD pairs will provide information on precision of the analytical procedures.

Accuracy is the degree to which an observed measurement agrees with an accepted reference or true value. Accuracy is a measure of the bias in the system and is expressed as the percent recoveries of spiked analytes in MS/MSD and LCS/LCSD samples. Accuracy will also be evaluated through the surrogate spikes in each sample. The laboratory control limits for surrogates will be used for the project.

Representativeness expresses the degree to which data accurately and precisely represent an actual condition or characteristic at a particular sampling point. Representativeness is achieved by collecting samples representative of the matrix at the time of collection. Representativeness can be evaluated using replicate samples, additional sampling locations, and blanks.

Completeness refers to the amount of measurement data collected relative to that needed to assess the project’s technical objectives. It is calculated as the number of valid data points achieved divided by the total number of data points requested by virtue of the study design. For this project, completeness objectives have been established at 95 percent.

Comparability is based on the use of established USEPA-approved methods for the analysis of the selected parameters. The quantification of the analytical parameters is based on published methods, supplemented with well-documented procedures used in the laboratory to ensure reproducibility of the data.

6.2. Quality Assurance and Quality Control for Chemistry Sediment Samples

Field and laboratory QA/QC samples will be used to evaluate the data precision, accuracy, representativeness, and comparability of the analytical results.

6.2.1. Field QA/QC for Sediment Chemistry

Field QC samples will be collected during sampling to quantitatively measure and ensure the quality of the sampling effort and the analytical data. Field QC samples include field duplicates, equipment rinsate, and rinsate blanks. QC samples are to be handled in the same manner as the environmental samples collected. Brief descriptions of the field QC samples are provided below.

6.2.1.1. Field Duplicates and Triplicates

Field duplicates and triplicates are collected at the same time as the original sample using identical sampling techniques. Field duplicate sample results (triplicates for sediment conventional parameters) are used to assess the precision of the sample collection process and to help determine the representativeness of the sample. Field duplicates/triplicates will be collected at a five percent frequency. The duplicates/triplicates will be designated for the same analysis as the original samples. The field duplicates/triplicates will be collected from the same homogenate as the original sample.

6.2.1.2. Equipment Rinsate and Rinsate Blanks

The equipment rinsate blank and decontamination water (rinsate) blank provide a quality control check on the potential for cross contamination by measuring the effectiveness of the sampling and processing decontamination procedures. The equipment rinsate sample consists of de-ionized water rinsed across sample collection and processing equipment after they have been used to collect a sample and have been decontaminated for use at the next sampling location. Equipment rinsate samples will be collected at a five percent frequency. The decontamination water blank is an unadulterated sample of the de-ionized water used to create the rinsate blank, analyzed to ensure no contaminants were present in the rinse water. Equipment blank samples will not be required when using disposable sample equipment. A single rinsate blank will be collected for this sediment characterization.

6.2.2. Laboratory QA/QC for Sediment Chemistry

One laboratory matrix spike and matrix spike duplicate will be analyzed for every 20 samples submitted or for each analytical batch of samples (if less than 20 submitted) for the analysis of cPAHs and TOC. The combination of these spiked samples will provide information on the accuracy and precision of the chemical analysis, and to verify that the extraction and measured concentrations are acceptable. The MS/MSDs will be analyzed in accordance with USEPA methods for each respective analyte.

One laboratory replicate will be analyzed for all constituents (except grain size, TOC, and total solids) for every 20 samples submitted or for each analytical batch of samples (if less than 20 submitted). Laboratory triplicates will be analyzed for grain size, TOC, and total solids. These QA/QC samples will be analyzed in accordance with the respective USEPA method and will be used to evaluate the precision of the analytical method.

One laboratory method blank and LCS will be analyzed for all constituents (except grain size and total solids) for each analytical batch of 20 samples to assess potential laboratory contamination and accuracy. A LCSD will be analyzed if required by the method, or if the laboratory does not have enough sample volume to prepare an MS/MSD.

Laboratory control samples, ongoing precision and recovery samples, and surrogate spikes will be used as defined by the analytical methods and equipment calibration requirements. The Puget Sound specific reference material will be analyzed for dioxin/furan and PCB congeners.

6.3. Data Validation

The data generated as part of this investigation will undergo an independent quality assurance review and data validation. A QA2 (Stage 4) chemistry data review will be conducted that examines the complete analytical process from calculation of instrument and method detection limits, practical quantification limits, final dilution volumes, sample size, and wet-to-dry ratios to quantification of calibration compounds and all analytes detected in blanks and environmental samples (PTI 1989a; USEPA 2009).

The QA2 independent data validation will be conducted by EcoChem, Inc. of Seattle, WA.

7.0 Data Analysis and Reporting

This section describes the data analysis and reporting requirements for the data collection activities described in this SAP.

7.1. Analysis of Sediment Chemistry Data

The sediment chemistry data will be summarized and presented in tables indicating sediment locations, detected contaminants, detection limits that exceed target PQLs, and data qualifiers assigned by the laboratory or during the data validation efforts. Concentrations of relevant COPCs will be mapped to show spatial distributions.

For reporting, dioxin/furan and PCB congeners will be normalized to the toxicity of 2,3,7,8-TCDD (tetrachlorodibenzo-p-dioxin) using toxic equivalent factors (TEFs) updated by the WHO in 2005 (Van den Berg et al. 2006). TEQs for dioxin/furan congeners and PCB congeners will be reported separately. The toxic equivalent quotient (TEQ) is equivalent to the sum of the concentrations of individual congeners multiplied by their TEF (potency relative to 2,3,7,8-TCDD). Non-detected values will be assessed as zero, half of the sample specific detection limit, and at the sample specific detection limit for data reporting purposes. The sample specific detection limit is essentially a method detection limit that is unique to the sample and matrix being analyzed.

PCB congeners will also be reported as total PCBs. Total PCBs is the sum of all detected congeners. In a rare case where no PCB congener is detected, the highest detection limit will be used to represent the total PCB concentration.

The concentrations for cPAH will be determined by normalizing individual cPAH to the toxicity of benzo(a)pyrene using TEFs present in Ecology’s guidance document *Evaluating the Toxicity and Assessing the Carcinogenic Risk of Environmental Mixtures Using Toxicity Equivalency Factors* (Ecology 2007). Non-detected values will be reported and assessed as zero, half of the method detection limit, and at the method detection limit for data reporting purposes.

TEQ values for cPAHs, PCBs, and dioxin/furans will also be calculated using Kaplan-Meier estimates of the sum when non-detected compounds are present (Helsel 2010). The final TEQ sums will be qualified to indicate the level of censoring within each sample.

7.2. Calculation of the Regional Background Concentration

The regional background statistic of interest is the 90/90 upper tolerance limit (UTL), which can be used as the cleanup screening level (CSL). In addition, basic statistics, such as minimum, median, and maximum concentrations will be calculated. These summary statistics will be calculated on a single data distribution, excluding outliers.

The distribution of the data will be evaluated for the presence of potential outliers using graphical tools (e.g., boxplots and Q-Q plots) in conjunction with formal outlier tests (e.g., Dixon’s or Rosner’s test) for identifying samples with extreme concentrations for a single analyte or TEQ. Some samples may not have extreme concentrations for individual analytes, but may still exhibit very different patterns within the suite of PCBs, cPAHs, or dioxin/furan congeners identified using multivariate methods. The presence of samples with very different congener patterns may signify unique contaminant sources. Once identified, these samples, along with their surrounding areas, may be excluded from the regional background distribution.

Multivariate outlier investigations will use Mahalanobis distances. Mahalanobis distance is a metric very similar to Euclidean distance (i.e., the familiar metric used to calculate the distance between two points on a line). To identify multivariate outliers, the Mahalanobis distance is calculated as the distance between each observation and the center of mass for the remaining observations, scaled to the covariance among congeners in the direction of that observation. A large distance in a direction in which the data covary (i.e., are correlated) is more likely than a smaller distance in a direction which lacks correlation. An observation that does not fall within the “cloud of scatter” of other data points is identified as a potential multivariate outlier. Robust estimates for the centroid and covariance are used to avoid contaminating these estimates by the very outliers that this method is intended to identify.

Outliers will contaminate a distribution, producing higher variance estimates and subsequently greater uncertainty in the tolerance limit. Any outliers identified will be discussed with the project team, and the regional background will be calculated both with and without the outlier(s) to determine their impact. Any concentrations deemed likely to be from outside of regional background will be excluded from the calculations of regional background.

After the removal of any outliers, goodness-of-fit tests and graphical displays (e.g., Q-Q plots) will be used to identify the best-fit distributional form for the data. For the calculation of the 90/90 UTL, if the assumption of a particular parametric distribution is not deemed appropriate for the data, non-parametric methods such as the bootstrap or order statistics will be used, as appropriate. In all cases where concentrations are present below detection, methods appropriate for left-censored data will be used. All of the statistical tools required are available in ProUCL 4.1.00 (US EPA 2010), with the exception of the multivariate pattern analysis. The multivariate analysis tools are available in Scout version 1.00.01 (US EPA 2008, runs only up to Windows

98), and R (R Development Core Team 2011); as well as in other commercially available statistical software.

Summary statistics will be reported for each analyte in the bay and compared to the Bold natural background distribution (SCUM II; Ecology 2014a) to determine which analytes have a regional background concentration higher than natural background and to identify the proposed regional background concentrations for those analytes.

7.3. Reporting Procedures

A written data report documenting all activities associated with collection, transportation, and chemical analyses of sediment samples will be prepared. The chemical and QA/QC reports will be included as appendices. At minimum, the Data Summary Report will include:

- A summary of the purpose of the investigation;
- Description of sampling and analysis activities;
- Protocols used during sampling and testing, and an explanation of any deviations from the sampling plan protocols or the approved work plan;
- Methods used for station positioning, sample collection locations reported in latitude and longitude to the nearest tenth of a second (NAD83);
- Maps showing actual locations of sampling stations;
- Maps and data tables of sediment chemistry data (results in mg/kg organic carbon, and dry weight);
- Summary statistics, outliers, and uncertainties associated with calculation of regional background and issues related to analytical variability;
- Comparison to the natural background distribution;
- Data interpretation and determination of regional background concentrations;
- Chain-of-custody records;
- Analytical laboratory reports;
- Copies of field and sampling logs as appendices; and
- QA/QC summary; and
- Data validation reports.

8.0 References

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Appendices

Appendix A. Field Forms

Appendix B. Health and Safety Plan

Bellingham Bay Regional Background Sediment Characterization
Bellingham Bay, WA

Health and Safety Plan

Prepared for:

Washington State Department of Ecology
Toxics Cleanup Program
300 Desmond Drive
Lacey, Washington 98504

Prepared by:

NewFields
115 2nd Avenue North, Suite 100
Edmonds, Washington 98020

July 2014

1.0 Introduction

This Site-Specific Health & Safety Plan (HASP) has been developed as part of the Regional Background Sediment Characterization for Bellingham Bay. This plan is intended to incorporate sampling activities in support of the bay-wide sediment collection, and must be re-evaluated should project conditions change.

The procedures and protocols in this plan have been established to ensure that a mechanism is in place to address project personnel in the event that hazards from field work or site contamination are encountered during the project. This plan addresses typical on-site activities such as collection of contaminated sediment samples and marine vessel use. This HASP is not designed to replace existing procedures or to address all health and safety procedures that could be required during typical emergency response activities.

Compliance with this HASP is required from all authorized NewFields project personnel, project support personnel, and visitors who enter the work areas of this project. No field work will be conducted without meeting the requirements of this HASP.

The content of this HASP may change or undergo revision based upon unexpected field conditions, modifications to the technical scope of work or additional information made available to health and safety (H&S) personnel. Any proposed changes must also be reviewed and approved by designated NewFields personnel.

1.1 Project Location

Project work will be conducted in Bellingham Bay, WA. In-water work in Bellingham Bay will be conducted from the R/V *Kittiwake* under contract with BioMarine Enterprises.

1.2 Personnel and Emergency Contact Information

Table 1 lists relevant project personnel and local emergency contact information. Additional detailed emergency information is found in Section 7.0 along with written hospital directions and accompanying maps.

All project personnel, project support personnel, and visitors present during field work must sign in the space provided in Table 1 prior to initiating project work. A signature below indicates commitment to implement this plan and to ensure that project fieldwork is conducted safely. A signature below also indicates review and approval of the plan and agreement that the anticipated hazards are correct and that planned hazard controls are sufficient.

Table 1. Project Personnel and Local Emergency Contact Information

Project Personnel		
Project Manager, Tim Hammermeister		(206) 890-8667
Field Manager, Will Hafner		(425) 318-0420
Health and Safety Officer, Jasper Boas		(425) 314-0977
WDOE, Chance Asher		(360) 407-6914
Emergency Contact Information		
Bellingham Police Department		911 or (360) 778-8800
Fire Department Whatcom County Fire and Rescue		911 or (360) 671-2411
Ambulance		911
Hospital: 2901 Squalicum Parkway Bellingham, WA 98225		(360) 738-5400
U.S. Coast Guard		(360) 417-5800
National Response Center (NRC) for Oil/Chemical Spills		(800) 424-8802
Poison Control Center		(800) 222-1222
Name	Signature	Date

2.0 Health and Safety Personnel

The following briefly describes the health and safety designations and general responsibilities for this project.

2.1 Project Manager – NewFields

The Project Manager or designee has overall executive responsibility for all activities and personnel on the site during all project activities described in this HASP.

2.2 On-Site Health and Safety Officer

The HSO is responsible for the development of safety protocols and procedures, all hazardous aspects of this project, implementation, and enforcement of this HASP. The HSO has the authority to modify this HASP based on actual site working conditions and procedures. The HSO will also be responsible for the resolution of any outstanding health and safety issues which arise during the conduct of site work.

Health and safety-related duties and responsibilities will be assigned only to qualified individuals by the HSO. The HSO has stop-work authorization, which will be executed upon determination of an imminent safety hazard, emergency situation, or other potentially dangerous situation, such as extreme weather conditions. An Authorization to Proceed with work will be issued by the HSO after such action. The HSO or designee will initiate and execute contact with support facilities and personnel when this action is appropriate. The HSO may periodically conduct QA/QC surveys of the health and safety procedures implemented onsite.

3.0 Site and Project Description

Bellingham Bay is located in the Northern reaches of Puget Sound in Whatcom County. It is separated from the Strait of Georgia on the west by the Lummi Peninsula, Portage Island, and Lummi Island. It is bordered on the east by Bellingham, Washington, to the southeast by the Chuckanut Mountains, and to the south by Samish Bay. The current investigation will involve sediment chemistry collection throughout the eastern portion of the Bay to determine local background concentrations of the analytes of concern.

3.1 Scope of Work

Under direction of the Washington Department of Ecology (Ecology), NewFields will conduct a sediment chemistry evaluation at locations throughout the bay. The objective of the study is to determine regional background concentrations for selected contaminants in Bellingham Bay. Sediment sampling is proposed at up to 30 locations in Bellingham Bay. A more detailed description of the scope of work and maps of the sample locations can be found in the Sampling and Analysis Plan (SAP).

3.2 Sediment Sampling

Surface sediment samples will be collected for chemical analyses using a dual van Veen grab sampler deployed from the R/V *Kittiwake*, operated by Charles Eaton of BioMarine enterprises. Hazards associated with grab sampling are primarily physical in nature. Slipping/tripping hazards are present on the sampling vessel when the deck is wet. There are numerous pinch points on the sampling equipment as well as the vessel itself. All personnel will be trained in the operation and deployment of the field gear, and will receive a vessel-specific safety briefing from Charles Eaton, owner and operator of the R/V *Kittiwake*. All members of the sampling crew will wear slip-resistant boots, safety glasses, nitrile gloves, personal flotation devices (PFDs).

Sediment samples will be processed on deck once the vessel is repositioned to minimize pitch and roll. The sediment will be subsampled for chemistry analysis using a stainless steel spoon and pre-cleaned laboratory jars. Equipment decontamination includes potential contact with decontamination chemicals (Liquinox/Alconox) and will be mediated by the use of nitrile gloves.

4.0 Hazard Assessment

This section summarizes hazards that may exist during project related tasks.

4.1 Task Specific Hazard Assessment

For the field sampling tasks described in Section 3, the overall hazard level is low. Hazards encountered during this sampling program are due to physical safety hazards associated with the field operations. Types of potential hazards associated with the field sampling effort are summarized in Tables 2. Potential hazards while working at the site include, but are not limited to, the following:

- Physical hazards from use of sampling equipment and operations on a vessel
- Physical hazards from working conditions (e.g., slips/trips/falls, drowning, hypothermia).
- Physical hazards from operating a motor vehicle to transit to and from the work site.

As described below, protective equipment and safe working procedures will help prevent accidents caused by these hazards. Exposure to harmful microbial organisms or other organisms in the sediments is not expected during this program.

Table 2. Sediment Sampling – Types of Potential Hazards

Physical Hazards

Name of Physical Hazard	Source	Exposure Level/ Potential	Exposure Limit
Boating Operations	boat deck	Likely	N/A
Heat (ambient)	sun	Likely	N/A
Cold Weather Operations	boat deck area	Likely	N/A
Heavy Manual Lifting/Moving	van Veen grab	Likely	N/A
Slips/Trips/Falls	boat deck area	Likely	N/A
Inclement Weather – Snow, rain	boat deck area	Likely	N/A
Material Handling	sediment	Likely	N/A
Vehicular Travel	van shuttle	Likely	N/A
Working Over Water	boat deck area	Likely	N/A

Biological Hazards

Name of Biological Hazard	Source	Exposure Level/ Potential	Exposure Limit
Insect bites and stings	boat area	Likely	N/A

Control Measures Used

Engineering Controls:	
Level of PPE: D	
Location: on boat deck, stream/intertidal	**PPE Equipment:** Chemical-resistant steel toe boots or waders, PVC Bib-style overalls (and jacket with hood as necessary), splash-proof safety goggles, nitrile gloves, PFD Type III. Long sleeve protective clothing and insect repellant is recommended during dusk and dawn to mitigate the risk of insect bites.
Work Practices:	• Frequent changes of disposable nitrile gloves • Wash hands and face with soap and water after each sampling event • Take shower at end of workday • Check extension cords are intact and connections are not in contact with wet surfaces.

NA = Not applicable.

4.2 Physical Hazards

The following is a general discussion of the hazards that may be encountered on site. Information on any contaminants encountered during this project may be found in standard health and safety references, such as the NIOSH "Pocket Guide to Chemical Hazards." Internet site: http://www.cdc.gov/niosh/npg/npg.html

4.2.1 Sampling Vessel Operations

The physical hazards associated with the deployment and retrieval of sampling equipment result from their weight and the method of deployment. Only appropriate personnel whose presence is required will be deploying and retrieving sampling gear. Under circumstances of potentially dangerous waves or winds, the sampling leader will employ best professional judgment to ensure safe field operations.

To avoid injuries from slipping on wet surfaces, rubber boots or waders with appropriate tread will be worn when working on the work deck or loading/unloading heavy equipment from the vessel. No overhead gear will be deployed, however, hard hats will be worn if overhead hazards exist. Sample handling equipment, containers, deck lines, not in immediate use will be kept clear of walkways and work areas until needed. Each time operations at a given location have been completed, excess sediment on the deck will be washed overboard to prevent slipping, minimize personnel exposure to potentially contaminated sediment, and limit cross-contamination between sample locations.

Life vests will be provided for and worn by all personnel working on the deck, or as directed by the Site Safety Officer or vessel operator.

If someone falls overboard, maneuver the boat’s stern away from him. Shift into neutral immediately (kill the motor if you do not have a gearshift) and throw a buoyant cushion or life jacket near the victim (try to get it close, but do not aim directly at the victim). Make sure you are well clear of the person in the water before shifting into gear again. Circle around quickly, selecting a course that will allow you to approach the person with the boat headed into the wind. Approach him slowly, taking care to come alongside and not over him. Stop the motor before attempting to get the victim aboard. When alongside, extend a paddle or boathook to him, or one end of a line. With the motor stopped, lead him around to the stern, where the freeboard is the lowest, if there is enough space at the transom for him to get aboard without contacting the motor. If this is not feasible, help the victim aboard over the side as far aft as possible. To avoid capsizing while the victim is coming aboard, other passengers should shift their weight to the opposite side to maintain trim as much as possible. When helping a person aboard, hold him under the armpits and lift gently.

4.2.2 Motor Vehicle Operation

Motor vehicles will be used to transport field personnel, equipment, and supplies to the sampling sites or laboratories. Only sampling team personnel with valid driver’s licenses and liability insurance (per local state laws) will operate motor vehicles required for work activities. All field staff will use best professional judgment at all times to ensure safe operation of motor vehicles, including:

- Operators are to practice defensive driving and drive in a courteous manner;
- Be aware of pedestrians and give them the right-of-way;
- All vehicles are to be operated in a safe manner and in compliance with statutory traffic regulations and ordinances;
- Verifying safety seat belts are in proper operating order;
- Seat belts are to be worn by the driver and all passengers whenever the vehicle is in motion;
- No persons are allowed to ride in the back of any vehicles, unless equipped with seatbelts
- Vehicles are to be driven in conformance with local speed limits;
- Avoid excessively long driving periods;
- Personnel who are impaired by fatigue, illness, alcohol, illegal or prescription drugs, or who are otherwise physically unfit, are not allowed to drive;
- Personnel are to avoid using cellular phones or engaging in other distractions while driving; and
- Motor vehicle accidents are to be reported to the responsible law enforcement agency, the NewFields manager, and the NewFields HSO.

4.2.3 Weather

If severe weather occurs that may affect the safety of site workers, the NewFields PM or their designee shall stop affected field operations. The PM or their designee will resume operations when weather conditions improve to acceptable levels.

4.2.4 Heat and Cold Stress

Depending on the time of year and weather conditions, cold or heat stress may be a potential problem. The PM will ensure that the heat and cold stress programs are implemented and that adequate rest breaks and liquid (i.e., water, Gatorade) consumption occur.

Proposed work/rest schedules will be dependent upon the weather conditions encountered and the level of personal protective equipment being utilized by on-site personnel. The PM or designee will establish work/rest schedules prior to the commencement of the project tasks and will adjust as needed.

4.2.5 Illumination

If work activities occur before sunrise and/or after sunset, lighting will be provided at each work area to meet the requirements of 29 CFR 1910.120(m). The Standard states that while any work is in progress, the general site areas shall be lighted to not less than 5 foot-candles; excavation, waste areas, access ways, active storage areas, loading platforms, and field maintenance areas shall be lighted to not less than 3 foot-candles; and first aid stations not less than 30 foot-candle.

4.2.6 Slip, Trip and Fall Hazards

As in any work area, it is expected that the ground may be uneven, the surface may be unreliable due to surface evenness, debris may be present, work is being performed on poly sheeting, and wet or muddy areas may exist. Therefore, the potential for slipping, tripping, and falling is present, especially considering that encapsulating suits and respiratory protection will which can impede vision. Severe trip hazards will be identified prior to commencement of project activities and demarcated by flags or caution tape.

4.2.7 Manual Lifting

Manual lifting of heavy objects such as coolers with samples may be required. Failure to follow proper lifting technique can result in back injuries and strains. Site workers will be instructed to use power equipment to lift heavy loads whenever possible and to evaluate loads before trying to lift them (i.e. they should be able to easily tip the load and then return it to its original position). Carrying heavy loads with a buddy and proper lifting techniques, 1) make sure footing is solid, 2) make back straight with no curving or slouching, 3) center body over feet, 4) grasp the object firmly and as close to your body as possible, 5) lift with legs, and 6) turn with your feet, don't twist, will be stressed. Back injuries are a serious concern as they are the most common workplace injury, often resulting in lost or restricted work time, and long treatment and recovery periods. In addition, hand digging for pipes may present lifting/ergonomic hazards.

4.2.8 Other Physical Hazards

Incorporating the following basic safety procedures can prevent many of the most common causes of injury or accident during field sampling:

- Implement good housekeeping practices, including immediate cleanup of spills and safe storage of all materials. All equipment or materials not in immediate use will be removed from the immediate work area.
- Use proper lifting and moving techniques to prevent back or muscle strain or injury. Any heavy equipment, boxes, coolers etc. should be tested before lifting and if it is too heavy, the equipment should be broken into smaller components or assistance requested. Lifting should be done with the legs, not the back.
- Use extra caution when handling sharp tools or sampling devices and when possible, wear protective gloves.

4.2.9 Biological Hazards

The project location and timing of proposed fieldwork is such that risks from biological hazards are low.

5.0 Work Clothing and Levels of Personal Protection

The PM or designee will recommend appropriate levels of protective clothing to be worn in the event that hazardous materials are encountered. The sediment field sampling activities described in this site-specific HASP will be performed in Level D or modified Level D PPE, as specified in below. If site conditions include hazards that exceed the protection of Level D or modified Level D PPE, work will be halted and personnel will immediately exit the area while site conditions and PPE levels are re-evaluated by the Site Supervisor and HSO.

Definition of Levels of Protection:
Level D: Work coveralls
Gloves
Appropriate work boots
Hardhat (if overhead gear is present)
Safety glasses with side shields or splash goggles as needed
A respirator is not required.

Level C: Chemical-resistant disposable coveralls
Chemical-resistant outer gloves
Chemical-resistant inner gloves
Appropriate leather work boots with chemically resistant outer boots or chemically resistant rubber boots
Hardhat
Full or half face air-purifying respirator (APR) with combination HEPA - P,O,N 100 (dusts, fumes, aerosols) and chemical cartridge as appropriate for hazard.

Level B: Chemical-resistant disposable coveralls
Chemical-resistant outer gloves
Chemical-resistant inner gloves
Appropriate leather work boots with chemically resistant outer boots or chemically resistant rubber boots
Hardhat
Supplied air – air-line or self-contained breathing apparatus (SCBA).

Level A: Fully encapsulating chemical-resistant/gas-tight suit
Attached chemical-resistant outer gloves
Chemical-resistant inner gloves
Attached chemical-resistant boots
SCBA.

5.1 Donning and Doffing

Manufacturer’s procedures for donning and removing PPE ensembles will be followed in order to prevent damage to PPE, reduce and eliminate migration from the work area and a transfer of contaminants to the wearer's body or others.

5.2 Storage and Inspection

Protective equipment will be stored and maintained in the company vehicles on site or in the work trailer. Items such as gloves, protective suits, and hearing protection will be kept within a suitable storage area. Table 3 lists PPE storage and cleaning procedures.

Employees are responsible for inspecting personal protective equipment prior to donning, during use and at the end of the shift. Defective equipment shall be removed from service and reported to the PM. All reusable equipment will be maintained in a sanitary condition, in accordance with the manufacturer’s recommendations.

Table 3. Level D Storage and Cleaning Procedures.

Level D Storage Procedures: In the Field laboratory, decontamination solutions such as nitric acid, methanol and acetone will be stored in dedicated cabinets and the outside doors labeled with flammable and acid labels respectively. Alconox soap powder does not require special storage and will be placed on a shelf. Any plastic containers containing Alconox will be labeled as such.
Level D Cleaning Procedures: Cleaning procedures for PPE require that hard hats, nitrile gloves, rain gear, boots, and personal floatation devices be brushed thoroughly with a solution of Alconox and rinsed with tap water after each sampling event.

6.0 Emergency Plan

Emergency situations can be characterized as an accident or injury to the field personnel. Emergency phone numbers are listed in Section 1 of this Health and Safety Plan. In case of emergency, it is important that the following Incident Reporting Procedure be observed:

It is important to assure the rapid and accurate transfer of information appropriate personnel in the event of an emergency situation. To simplify the procedure, emergency situations can be reported by dialing 911. This includes incidents requiring police assistance, fire department, or medical emergencies.

Be sure to provide the following information to the dispatcher:

1. Caller full name
2. The nature of the incident (i.e., "fire")
3. The location of the incident (i.e., street location and nearest intersection), the more specific the better
4. What you need (i.e. "Fire Department and First Aid")
5. If you are able, where you will meet emergency responders (i.e., at the end of West Street, near train tracks)
6. If applicable, a call back number or your cell phone number (e.g., "I'll be at the scene; my cell phone number is 123-4567")
7. Status of the situation (e.g., is the situation stabilized or “I have the fire under control”)
8. If anyone is injured or in need of emergency assistance (e.g., "A mechanic working on a pump was burned").

6.1 Site Emergency Coordinator

Site Emergency Coordinator: Jasper Boas (HSO)

6.2 Personnel Injury

In the event of an emergency situation, the local emergency response group will be called. In case of a life-threatening situation, emergency first aid may be applied on-site as deemed necessary. The individual should be cleaned up and/or decontaminated and then transported to the nearest medical facility if needed.

The local rescue squad shall be contacted for transport as necessary in an emergency. Since some situations may require transport of an injured party by other means, transportation by automobile may be required.

6.3 Personnel Exposure Treatment

SKIN CONTACT: Use copious amounts of soap and water. Wash and/or rinse affected area thoroughly, then provide appropriate medical attention. Eyes should be thoroughly rinsed with water for at least 15 minutes.

INHALATION: Move to fresh air and, if necessary, decon/transport to hospital.
INGESTION: Decontaminate and transport to emergency medical facility.
PUNCTURE WOUND OR LACERATION: Decontaminate, if possible, and transport to emergency medical facility.

7.0 Hospital

The following is the hospital nearest to Bellingham Bay:

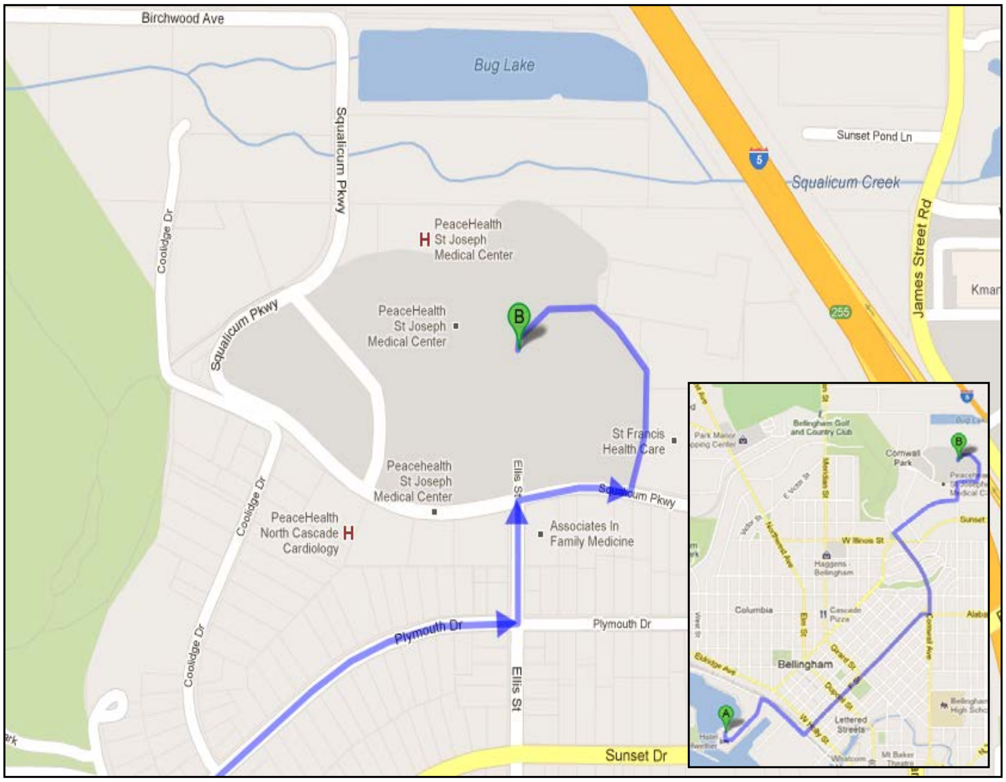
St Joseph Hospital
2901 Squalicum Parkway
Bellingham, WA 98225
(360) 738-5400

Nearest Hospital to Bellingham Bay

1) From Bellingham Marina, head south on Bellwether Way
2) Turn right onto Roeder Ave
3) Take 1st left onto F St.
4) Turn right on Alabama St.
5) Take 1st left onto Cornwall Ave
6) Turn right onto Plymouth Dr.
7) Take 2nd left onto Ellis St.
8) Take 1st right onto Squalicum Pkwy
9) Take 1st left onto Levin Ln.
10) Hospital will be on the right

Note: For non-emergency treatment, an urgent care clinic is located en route to the hospital:

The Walk-In Health Clinic
2220 Cornwall Ave
Bellingham, WA 98225
(360)734-2330



Appendix C. Background Memorandum

Characterizing Natural or Regional Background Populations for Washington Department of Ecology – Final Draft – February 18, 2013

1.0 Introduction

Washington Department of Ecology (Ecology) contracted with TerraStat Consulting Group to help identify statistical tools that could be used to distinguish between populations of Natural Background and Regional Background, as well as how to best summarize available data for background for the different objectives required under Sediment Cleanup programs. Statistical tools that can be used to separate a dataset into distinct populations with overlapping concentrations generally rely on either *a priori* description of the underlying characteristics for one of the populations so that separation of a mixture distribution can be accomplished; or data sets with sufficient spatial coverage such that the concentration surfaces can be modeled and locations where changes in the concentrations occur can be identified. Neither of these scenarios is met by the data that are generally available for Puget Sound background sites, so this work product ultimately became the description of a process for describing and generating appropriate summary statistics from existing Regional Background and/or Local Natural Background data sets.

TerraStat reviewed existing approaches to the description of Background that have been used by various agencies; these definitions and approaches are briefly touched on in Section 2. Knowledge from Ecology staff, from other agency approaches, and about the statistical tools appropriate for the type of data available for Puget Sound Background areas was integrated to describe a process for identifying and characterizing Background. A description of the process and important considerations to this process are included in Section 3; applications to three Puget Sound case studies are included in Section 4. Final recommendations regarding the description of Background are provided in Section 5.

2.0 Approaches to Background

TerraStat reviewed approaches to Background as described in USEPA guidance (US EPA 1995, US EPA 2002), and as used by WDOE for several local sites (summarized by NewFields 2011), by OR DEQ for the lower Willamette River, and by the ACOE for DMMP sites (DMMP 2011). These approaches all started with the *a priori* selection of the geographic boundaries that constitute background and then proceeded to summarize the background data set in different ways for different purposes.

Some working definitions of background in use by EPA in the CERCLA (Superfund) program (US EPA 2002) are "substances or locations that are not influenced by the releases from a site, and are usually described as naturally occurring or anthropogenic:

1) Naturally occurring - substances present in the environment in forms that have not been influenced by human activity *[matches Ecology's definition for 'Natural Background']*; and,
2) Anthropogenic - natural and human-made substances present in the environment as a result of human activities (but not specifically related to the CERCLA site in question)" *[matches Ecology's definition of 'Regional Background']*.

In the EPA documents reviewed, the background data set is not extracted and statistically separated from a larger dataset, but rather it is acquired via appropriate sampling within the boundaries of the area expected to meet the background definition. EPA emphasizes that background sampling is a strategic, biased sampling event with sampling to occur "in areas expected to be outside the area influenced by the site." So information about the fate and transport of contamination from the site, as well as best professional judgment (BPJ) must be used to identify the background areas. It is also recommended that possible concentration outliers should be identified and decisions regarding these outliers be made by the project team (US EPA 2010).

The reviewed approaches used by Washington DOE, Oregon DEQ, and Puget Sound DMMP all define the geographic boundaries for the background population using BPJ and knowledge about the site, which is consistent with EPA's recommendations. Once the background population has been identified, the summary statistics suited to the intended application may be calculated (e.g., central tendency value such as 95UCL on the mean for exposure related questions, or an upper threshold of the distribution such as 90/90 UTL for a not-to-exceed value for station-by-station comparisons).

3.0 Background Considerations & Recommendations

As with any sampling or analysis plan, it is important to clearly state the objective up front. Sampling Objective: To characterize a "Background" population in order to set clean-up goals for a site, and to delineate site clean-up boundaries. Caveats:

- Current DOE guidance utilizes several definitions of "Background", including Puget Sound-wide Natural Background, Local Natural Background, and Regional Background. The method(s) proposed herein will not separate the available data into these separate populations; but they will allow the proper estimation of summary statistics from whatever boundaries are considered to constitute the relevant background population.
- We provide no statistical recommendations for how to separate Local Natural from Regional Background –pattern matching requires knowledge of the source pattern; and

existing sampling locations may be insufficient to adequately describe the spatial patterns needed to statistically identify boundaries of the different types of background.

- Identifying the site-influenced areas needs to be done first with site knowledge combined with spatial contouring. Areas near known point sources, or areas adjacent to those point sources with elevated concentrations, are excluded *a priori* from the possible background population. If there are obvious trends away from the site, then a boundary can be determined with the help of contour mapping.
- Methods to identify univariate and multivariate outliers should be used, and samples that are clearly different from the others should probably be excluded from the background population.

3.1 Designing a Sampling Plan to Characterize Background

The ideal situation where a new survey is designed specifically to characterize background involves first determining an appropriate boundary for the Local Natural or Regional Background area, and then taking a spatially-balanced random sample that uniformly covers the area using a systematic random sample (e.g., random samples within a grid). Other methods for achieving a spatially-balanced random sample can also be used (e.g., generalized random tessellation stratified [GRTS] sampling used by US EPA [2011], and implemented via the RRQRR algorithm in GIS), but are not generally necessary for this situation. If there are areas that are found to have elevated concentrations and are suspected to be due to a point source, the boundary of the regional background area can be adjusted after sampling (i.e., the areas with high concentrations and their corresponding data can be excluded). If the gridded samples are found to be spatially autocorrelated, the gridded data points can be sub sampled or methods that account for autocorrelation can be used to generate summary statistics. Otherwise, the set of samples taken on the grid can be assumed to be an independent random sample, and the appropriate summary statistics can be easily generated in ProUCL (for example).

3.2 Working With Existing Data to Characterize Background

The following recommendations address situations when compilations of existing data sets are being used to characterize background. In these cases, the “ideal” design may not have been used to generate the background data set, and the background area may have been sampled non-uniformly and non-randomly.

For the case studies examined in this report, sampling points were located unevenly through space and time, and collected for different purposes. In these case studies, the boundary of the characterized area is delineated by the locations of the existing samples and these existing sampling locations may be insufficient to fully characterize the background population.

Within the compilation of data available to use for background, there may be non-randomness, non-independence, and more than one population represented. The simplest statistics (e.g., 95th UCL on the mean) assume an independently and identically distributed (i.i.d.) random sample. If the dataset violates these basic assumptions, then the simple statistics may be biased, and the variance poorly estimated. These basic assumptions are relevant to a number of available methods for summarizing data (i.e., bootstrapping, generating a trend surface via interpolation, kriging, etc.).

Given a data set consisting of multiple studies, there are three main steps to be followed to define a background concentration distribution and produce unbiased estimates of summary statistics. These are:

- Step 1. Delineate Background by excluding areas near known point sources, and areas suspected to be of a different population based on proximity to local influences (e.g., developed shorelines). Initial evaluation of the compiled data should include identification of possible outliers.
- Step 2. Determine the extent of autocorrelation and/or trend in samples from the background area.
- Step 3. Generate upper bound estimates for the regional background concentration distribution using an independent subset of the data based on the results from Steps 1 and 2.

3.2.1 Step 1. Drawing Background Boundaries

Unless new data are collected, the background population will be defined by the area that has been sampled. However, the sample locations should be examined to ensure that areas near known point sources are excluded. In this stage it is also important to identify possible outliers indicative of an unsuspected source signal, potential mixture distributions due to the presence and blending of two or more strong and different local signals (e.g., Bellingham Bay), and to determine spatial gaps in the background data set. For example are there internal areas which have not been sampled, but which should be included in the background population? Is the existing boundary too limited, and more sampling is required? Or, is the existing boundary too broad, and should some areas with unusual contamination patterns be excluded until more information is available?

If the samples were not all collected using a random or systematic random design within the total area (e.g., some samples were targeted to address questions regarding local sources), then adjustments to the data set are needed to reduce the risk of bias in the summary statistics from over-sampling sub-regions of the population. We recommend two possibilities for this adjustment: 1) adjust the boundary of the background population to be a union of circles surrounding each sampled point. If the circles do not overlap, the samples then comprise a systematic sample of the population thus defined. Or, 2) use a spatial interpolation method (e.g., kriging, or area weighted averaging) to estimate a concentration surface for a larger background boundary. There may not be enough data to accomplish the latter alternative, and the boundary for the former alternative may not be acceptable. In that case, more data must be collected. These two alternatives are discussed in more detail in Section 3.2.3.

3.2.2 Step 2. Examine Trend Characteristics and Autocorrelation of Samples within the Background Data Set

The presence of trends, differences in mean concentrations, and spatial autocorrelation within a data set require special attention. Ignoring trends or autocorrelation can result in biased estimates of population parameters and summary statistics that are not representative of the entire background population.

Spatial autocorrelation is important to identify so that only the independent samples may be used. Clusters of samples that targeted a particular sub-region of the background area should not be allowed to overly emphasize conditions of that sub-region in the description of the entire background area.

If there are concentration trends, or areas with clearly different concentrations (i.e., separate strata), these should be removed prior to estimating autocorrelation (i.e., autocorrelation is estimated from data that exhibit no trend and have a zero mean). In this report, a relatively simplistic approach to evaluating trends is used; an in-depth evaluation and description of a trend surface is beyond the scope of this report. For each case study in Section 4.0, several surface concentration models were used to evaluate potential trends in concentrations. Least squares polynomial surface models of orders 0 to 4 (i.e., from no trend up to a 4th order polynomial) were considered. (The total number of samples for the case studies is 26 to 27, which is probably too few for adequate fitting of the 4th order polynomial model. However, it is considered for illustration purposes.) The five polynomial regression models were compared using Aikake Information Criterion corrected for sample size (AIC_c, Burnham and Anderson, 2002). Note that the AIC_c is based on the maximum likelihood, which is a function of the residuals, and this metric may be somewhat compromised if autocorrelation is present in the residuals. For final trend models, the process is iterative – trend should be re-evaluated after autocorrelation is removed. Autocorrelation is not expected to have a large effect on the trend evaluation in this context of these case studies, mainly due to limitations of the spatial distribution of the small data sets.

There are many methods for evaluating spatial autocorrelation (e.g., using GIS or other spatial statistics packages). The simple method used here could be done manually in MS Excel, or in R (R Development Core Team, 2011). The case studies do not have a regularly spaced grid of samples, so the boundary of autocorrelation is estimated by evaluating correlation among pairs of points within a certain distance of each other. An autocorrelation boundary can be estimated if there are a reasonable number of points that are close enough together to be autocorrelated. Pairs of sample points are grouped into bins of similar distances. For example, if there are at least six pairs of points within 200m of each other, the distance bins could be 0-200m, then 200-400m, etc. Theoretically, any existing positive autocorrelation would be highest in the first bin. The autocorrelation is estimated by Pearson's linear correlation coefficient between concentrations for all possible station pairs within a distance bin.

The presence of autocorrelation should be tested on the residuals from the best-fit trend model (i.e., the de-trended data). The closest distance that could be tested for autocorrelation was the smallest distance yielding at least six pairs. In spatial statistics literature, six is a small number of pairs on which to test the autocorrelation (e.g., Journel and Huijbregts, 1978), and is considered to be a bare minimum for a correlation test. For this small sample size, a significance test of the autocorrelation within each distance bin used $\alpha = 0.20$ in order to limit Type II errors (i.e., failing to reject the null hypothesis when autocorrelation is present). This binned hypothesis testing approach is useful given the data limitations (i.e., insufficient pairs of samples at sequentially increasing distances) and the objective of estimating the minimum distance between independent samples. If the data were to be used to estimate a kriged trend surface, then a smoothed autocorrelation function is required, where autocorrelation is described as a continuous function of distance.

3.2.3 Step 3. Calculate Summary Statistics

In the preceding two steps, the valid background samples and the background population boundary have been identified, along with potential trends and autocorrelations within the data set. At this point, we consider two methods for generating appropriate summary statistics in the presence of autocorrelation and/or trends:

> Method 1. Adjust the background boundary to be simply the union of the set of independent circles (radius > autocorrelation range) surrounding the existing sampling locations, and treat samples from these independent circles as an independent data set; or
>
> Method 2. Generate a concentration surface for the defined background boundary and use the surface for generating upper bound estimates (e.g., 95 UCL on the mean and 90/90 UTL).

For Method 1, the boundary of the background population is redefined to be exactly the area that has been independently and systematically sampled. This is simply a union of circles around each sampled point, with the radius of the circles greater than or equal to the autocorrelation range. Only one observation within each circle can be used, so that the data set is a uniform independent sample from the defined population. The radius can be larger than the autocorrelation range in order to make the background boundary larger, but this may cause overlapping circles and require subsampling to maintain a uniform and independent systematic sample of the defined population. It also increases the uncertainty, because now a single observation is representative of a larger (unsampled) area, where the concentrations are unknown. If there are unsampled gaps among the sampled locations, these areas are not actually part of the background population as defined. Without information about whether the concentrations in the unsampled gap areas are homogeneous or trending, it is perhaps an overstatement of the available information to assert that the concentrations remain constant within these unsampled areas. Consequently, the background population as defined may not be contiguous.

Method 1 is a fairly simple and reasonable choice if the area that has been sampled reflects an adequate boundary for background. This method requires minimal assumptions, and does not extrapolate beyond, or interpolate between points.

Method 2 may be desirable if the area described by the union of circles around each sampled point is not acceptable, and more samples cannot be collected. For this method, a concentration surface is generated by kriging or another surface contouring method to estimate concentrations for the areas between the sampled points. Method 2 can be complex and requires more assumptions about the behavior of the data, but it is the only way to estimate concentrations across a broader boundary area. For example, if a large unsampled area is located between two areas of high concentrations, then the surface model would predict concentrations in that area to be similar to neighboring concentrations, rather than simply excluding that area from the described population. Uncertainty in the estimate of the concentrations in interpolated areas reflects prediction error from the model, so the upper bound on the mean for the total background area will quickly increase as you spatially interpolate or extrapolate beyond your data. This approach is not advisable when the data are sparse. Note that the simplest trend surface model would use Thiessen polygons to divide the area into polygons represented by one sampled point. This is a model that assumes constant concentrations within each polygon, and estimates of uncertainty are not readily available (although bootstrapping could be used).

3.2.3.1 Process for Estimating Summary Statistics from Existing Data Using Method 1

The autocorrelation distance *d* is defined to be the smallest distance between data points for which independence can be assumed. This distance may be derived from site-specific data, results from similar data sets in other areas, or best professional judgment (BPJ). To estimate background summary *statistics using Method 1:*

a. Establish a sample boundary radius $r \geq d$. The larger the radius, the larger the boundary of the background area, but the smaller the overall sample size may be (only one sample per circle is permitted). There is a tradeoff between a large background area with high uncertainty and a smaller, perhaps non-contiguous background area with lower uncertainty.
b. Identify all samples greater than *r* away from all other samples. These samples are assumed to be independent, random observations given our estimated autocorrelation range. If this captures all of the samples (i.e., only one sample per circle), then the existing data are i.i.d. random samples from the background population and summary statistics can be generated on this dataset, with no need to subset the data. Otherwise:
c. Identify clusters that have two or more samples within *r* of each other. Permute all possible ways of selecting one or more independent samples (>*r* apart) from each cluster.
d. Combine the samples from b) and c) to form all the possible combinations of samples from the data set that are > *r* apart from every other sample. For each of these permutations, generate summary statistics (mean, variance, 95 UCL on the mean, 90th percentile, and 90/90 UTL).
e. Use the distribution of each statistic (e.g., 95 UCL on the mean) to find the best summary statistic for the population (e.g., the maximum 95UCL on the mean will be most likely to capture the true background population mean). Each of the individual UCLs represents a slightly different background boundary, but each is a possible representation of the regional background. The permutation distributions of these summary statistics reflect part of the uncertainty in the background boundary. A highly variable distribution of background 95 UCLs indicates that different background boundaries can produce widely different results, an indicator of small-scale changes in concentration and the need, perhaps, for a re-evaluation of the first steps of the background boundary definitions (i.e., Steps a and b).

3.3 Sampling to Augment Existing Background Data

For existing background data sets, there are likely to be four features that could be improved by additional sampling: 1) temporal consistency; 2) spatial extent; 3) sampling density; and 4) sample size adequacy:

Temporal consistency: Placing new samples in the areas with outdated sample results may be a priority.

Spatial extent: For the spatial extent (boundaries) of the background population, BPJ is required to decide whether the outer boundaries are sufficient to fully capture the target background conditions. Addressing the boundary question uses BPJ and possibly geophysical modeling information about the mechanisms distributing the sediments throughout the area from anthropogenic contributions (e.g., what are the boundaries of influence from non-point source runoff) or natural sources (e.g., what are the boundaries of influence from river sediments).

Sampling density: If the sampling locations are sparsely distributed, then the union of overlapping circles for the point locations sampled may not result in a contiguous background area. Large unsampled or under-sampled areas within the background area should be sampled to reduce uncertainty. Existing data may indicate that trends are present, so sampling at fairly regular intervals along that trend is recommended. Bathymetry and hydrologic flow patterns provide information about sedimentation or disturbance patterns. This information can be used to identify areas within the background population that have potentially different contamination levels, and where additional sampling is recommended.

Overall Sample Size: If more data are needed to satisfy one or more of the three features described above, grid sampling is recommended. The minimum grid size should be *d* (the autocorrelation range). The actual grid size will be determined by budget in most cases, but sample sizes needed for a desired estimate of precision can be estimated using existing data. These calculations, however, assume that additional samples will have the same mean and variance as the existing data, which may not be a valid assumption when sampling from a patchy distribution or a trending surface. At best it provides an informed guess regarding the change in precision of the mean estimate (i.e., width of the 95UCL on the mean) with additional samples.

4.0 Case Study Examples

Ecology provided dioxin/furan TEQ concentrations (ng/kg, dry weight) for three case study sites: Fidalgo Bay, Port Gardner, and Bellingham Bay. For each of these case studies, we illustrate the process of defining the regional background boundaries, evaluating concentration trends in the data, estimating the autocorrelation distance, and using Method 1 (Section 3.2.3.1) to estimate upper bound summary statistics.

4.1 Fidalgo Bay Case Study

Ecology staff used BPJ to identify samples that were too near to point sources, or were from a different area-of-influence and therefore considered to be inappropriate for comparison to

Fidalgo Bay Site concentrations. The sampling locations are shown in Figure D-1; the grid overlaid on the map is a 0.5 km square grid used simply to illustrate the scale of the distance between samples. The latitude and longitude for the sampling locations and their associated TEQ concentrations (ng/kg, dry weight) are provided in this Appendix, Table A-1.

4.1.1 Trends and Autocorrelation in Fidalgo Bay

The first step in estimating the autocorrelation range is to remove any existing trends that may be present in the samples. For the Fidalgo Bay data set the first-order polynomial (i.e., a linear trend) fits the trend surface best (indicated by the lowest AICc for all trend surface models considered). There appears to be a linear increasing trend to the northwest (Figure D-2).

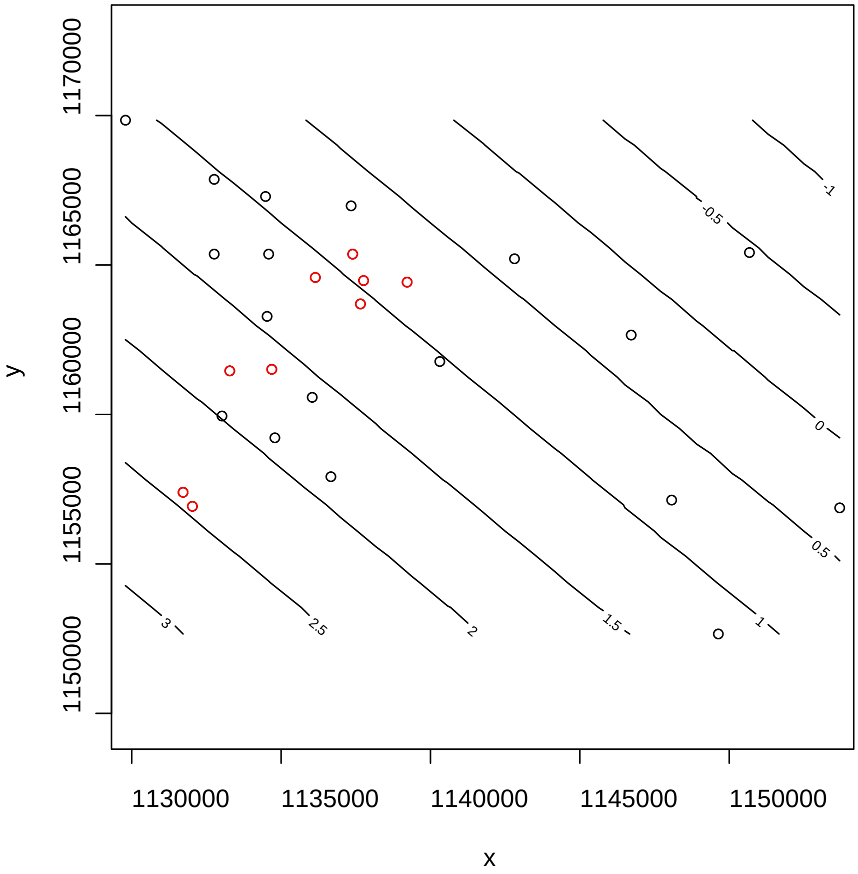


Figure D-2. Fidalgo Bay sample locations with contours based on first-order polynomial fit. Samples that are <460m from other samples are highlighted in red.

The maximum distance between the six closest pairs of points in Fidalgo Bay is approximately 460m apart, so bin sizes are set to multiples of 460m. The data points within the first distance bin are highlighted with a different color in Figures D-1 and D-2. A distance of 460 m is the smallest autocorrelation range that we can test with these data. There may be autocorrelation present at smaller distances, but we cannot test whether the correlation is significant because of insufficient numbers of data pairs available for that distance. The correlation results after removing the linear trend from the data are shown in Table D-1.

Table D-1. Autocorrelation Results for Fidalgo Bay.

Bin Endpoints (m)	N	Pearson's Correlation Coefficient	one-tailed p-value for parametric test
0-460	6	0.338	0.512
460 – 920	33	0.246	0.168
920-1380	42	0.0894	0.573
1380 – 1840	59	-0.00570	n/a

The autocorrelation coefficient decreases with distance (Table D-1). The autocorrelation in the first bin is not significantly different from zero (α=0.20). Sample sizes after the first bin increase dramatically, so it is appropriate to use a lower α-level to assess significance in the second bin (e.g., α=0.10 or 0.05), from which we would conclude that the autocorrelation is not significantly different from zero in this distance range (460 – 920 m). We varied the size of the first bin, and the autocorrelation was evaluated for pairwise distances from zero to increasingly larger maximum distances, up to 914m, but no strong correlations were seen at any of these distances. There are insufficient samples close to each other to estimate autocorrelation less than 460m. There may be autocorrelation at smaller ranges, but it is not a testable hypothesis on this dataset, so we could assume that the data set is roughly uncorrelated at the distances that were sampled. However, we don't want to underestimate autocorrelation, so we also compare the estimation results by subsampling the data (*Method 1,* Section 3.2.3.1) based on a minimum separation distance of approximately 460m (for convenience we round up to 500m).

4.1.2 Method 1 Applied to Fidalgo Bay

Subsets of independent samples were generated from the full data set, as described above. The autocorrelation range used in this approximation was 500m.

There were 27 samples from acceptable non-site affected stations in Fidalgo Bay. Of these 27 samples, 15 were more than 500m away from any other samples. The remaining 12 samples were grouped into three clusters of two or more samples each. All permutations were constructed of independent samples within each of these clusters and combined with the other 15 samples (24 possible permutations). For each of the permutations, summary statistics for TEQ values were generated (i.e., mean, variance, bootstrapped 95 UCL on the mean, and 90/90 UTL for the best fit gamma distribution). The distributions of these TEQ summary statistics are shown in Figure D-3. The red lines indicate the values calculated by assuming that the data are uncorrelated at the distances that were sampled (i.e., we have an independent data set). We can see that the full data set (n=27) produced a 95 UCL on the mean (1.55 ng/kg TEQ) that was lower than some of the permutations. For the permutations, 95UCL values range from 1.4 to 1.8 ng/kg TEQ. For the 90/90 UTL, permutation values ranged from 2.5 to 3.6 ng/kg, and the observed data had a TEQ value of 3.1 ng/kg.

4.1.3 Fidalgo Bay Conclusions and Recommendations

The trend surface regression models indicate a linear trend in Fidalgo Bay background concentrations. For this case study, the observed data can be used to estimate background population characteristics as is, or, to ensure independence, after the data have been sub sampled to generate a set of independent observations using the autocorrelation range (at 500 m). From the permutation distribution of UCLs, we could choose the maximum value (1.9 ng/kg) as this is the value most likely to capture the true mean, even though the coverage will likely exceed 95%.

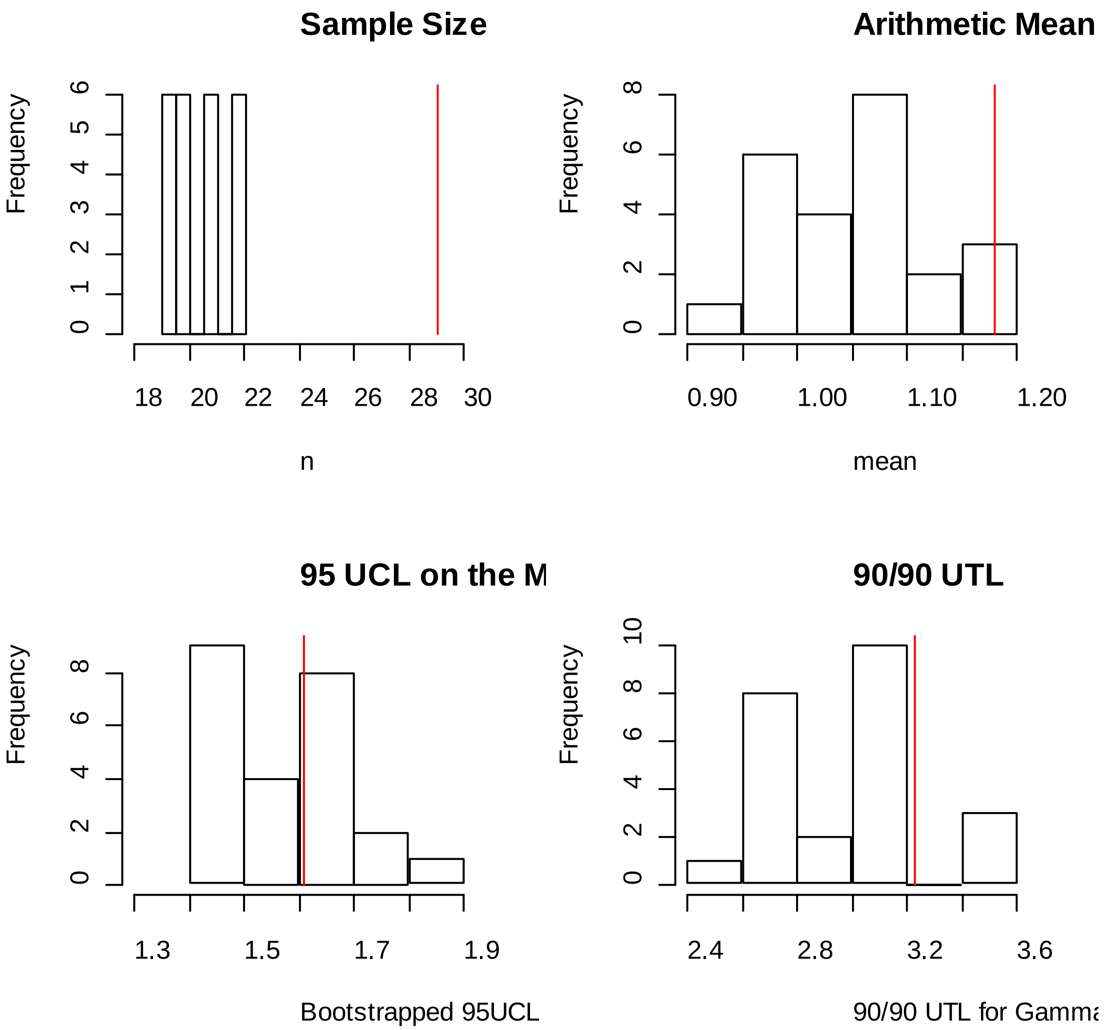


Figure D-3. Distribution of summary statistics on TEQ values (ng/kg, dry wt) for the permutations of independent samples (>500m) at Fidalgo Bay. The red lines indicate the values for the observed data set.

For sample adequacy, we consider the following:

Temporal consistency: The data within background areas are collected from 2007 and 2010, so time period is probably not an issue and all these data are useable.

Number of samples:_The existing data are not significantly different from a gamma distribution (ProUCL, alpha=0.05). We plot the number of samples vs. the width of the gamma confidence interval on the mean (Figure D-4). The figure shows that our sample size of 27 provides a UCL width that is 37% of the mean; we're not on the steepest part of the curve but are on a part of the curve where it's starting to flatten out for our sampled population. Doubling the sample size is expected to decrease the UCL half-width to 24%, assuming that the mean and the variance stay the same. This assumption may not be realistic given that there is a trend in these data – samples collected from a different area will affect both the mean and the variance, so this graph provides simply a ballpark estimate of expected sample size adequacy.

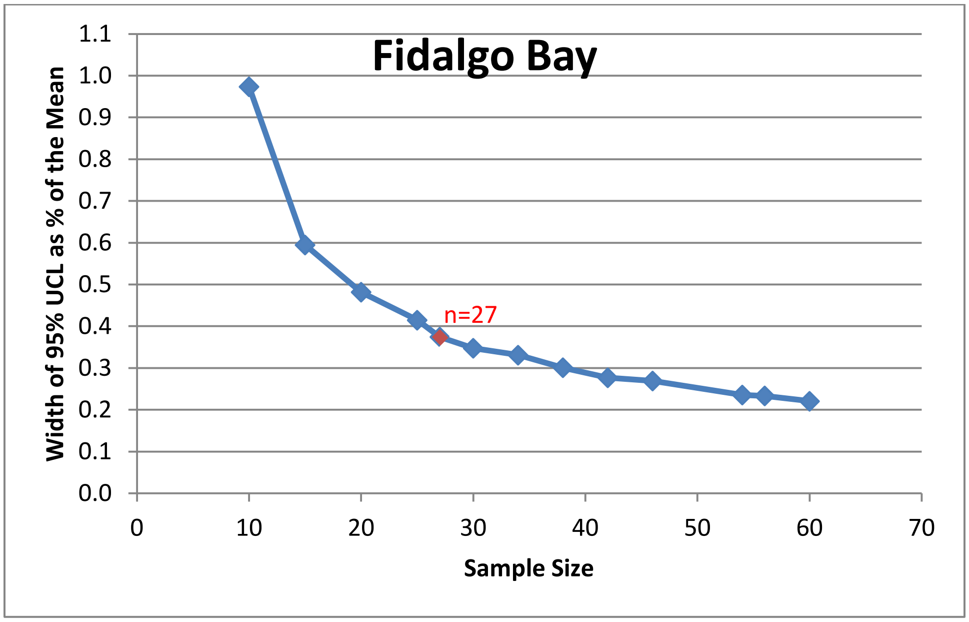


Figure D-4. Sample size vs. precision of the mean using Fidalgo Bay data, fit using a gamma distribution.

Spatial Extent: The best trend surface was a 1st order polynomial, decreasing to the northwest away from the Anacortes shoreline. Currently, most of the samples are closer to Anacortes in Fidalgo Bay, so these might describe Regional Background, whereas samples in Padilla Bay describe Local Natural Background, for example. There are rather few samples in Padilla Bay, so if this area is included as part of Regional or Local Natural Background, it would be wise to place more samples on that side of the Bay.

Sampling Density: Based on the autocorrelation range test, we recommend samples no closer than 500m apart (rounding up from 460m). This minimum spacing is expected to achieve independent samples. Any new samples would be placed as evenly as possible within the desired boundaries for the background population, and at least 500m away from any other new or existing samples.

- Option #1: Spatial extent for regional background is a line drawn from Anacortes west to Hat Island and south to March Point. Take 5-10 more samples within any of the available grid squares, trying to achieve uniform distribution of samples throughout the area and minimum separation between samples of 500m. Pros: this provides a good spatial coverage within the delineated regional background of

Fidalgo Bay. Cons: none, assuming that the boundary for background is sufficient.

- Option #2: Include Padilla bay in the Background characterization. Pursue Option #1, plus additional 5-10 samples from Padilla Bay. Use a grid approach to try to achieve a uniform distribution throughout the area with minimum separation of 500m. Pros: larger background area; provides data to test if Padilla Bay is a separate population. Cons: The higher cost over Option #1 may not be necessary; the shallower depths and the large Intertidal areas in Padilla Bay may make this an inappropriate background data set for the subtidal sites in Fidalgo Bay.

- Option #3: Include Padilla Bay in the Background characterization, and fill as many squares as possible in both Fidalgo and Padilla Bay, increasing the grid size to 1km (we exchange small scale accuracy for broad scale information). Pros: More information about both areas and a dataset that may be sufficient for drawing a surface contour map. Cons: Cost and potentially sampling overkill.

4.2 Port Gardner Case Study

Ecology staff used BPJ to identify samples that were too near to point sources, or were from a different area-of-influence and therefore considered to be inappropriate for comparison to Port Gardner site concentrations. The sampling locations are shown in Figure D-5; the grid overlaid on the map is a 0.5 km square grid used simply to illustrate the scale of the distance between samples. The latitude and longitude for the sampling locations and their associated TEQ concentrations (ng/kg, dry weight) are provided in this Appendix, Table A-2.

4.2.1 Trend and Autocorrelation in Port Gardner

For the Port Gardner data set, the trend surface is best fit by the third order polynomial (the model with the lowest AICc; Figure D- 6).

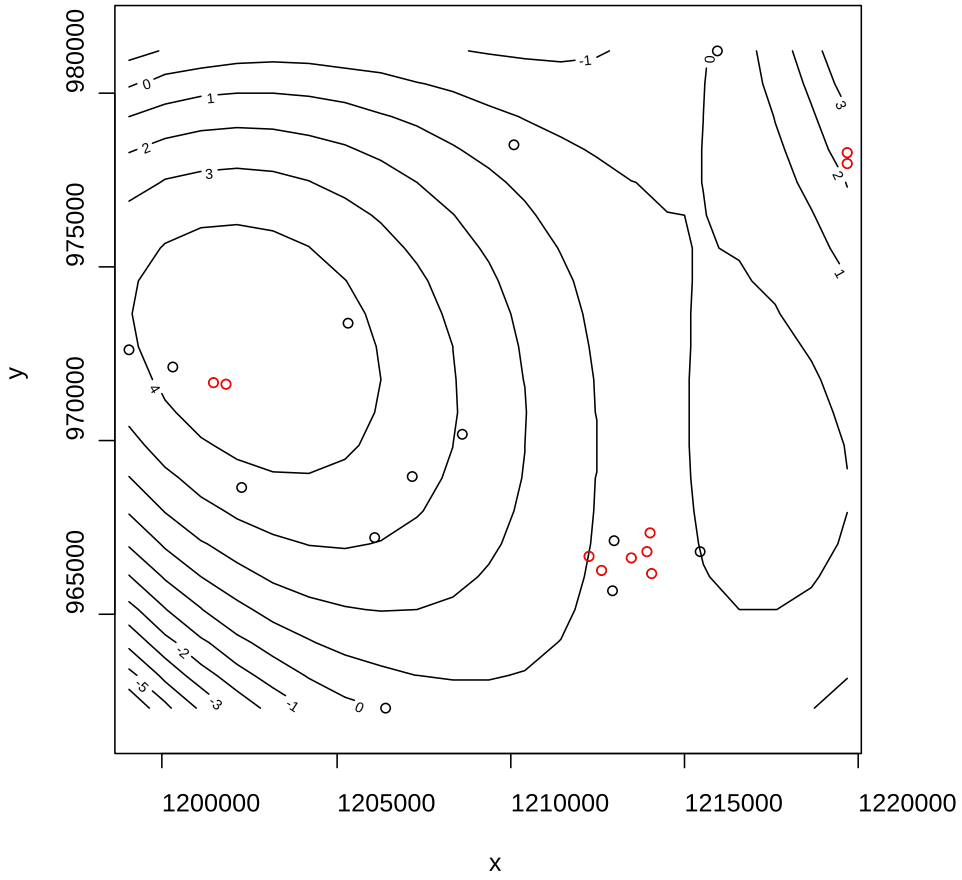


Figure D-6. Port Gardner sample locations with contours based on third-order polynomial fit. Samples that are <200 m from other samples are highlighted in red.

The maximum distance between the six closest pairs of points is 200m, so the bin sizes were set to multiples of 200 m. The autocorrelation results are shown in Table D-2.

Table D-2. Autocorrelation Results for Port Gardner data.

Bin Endpoints (m)	N	Pearson's Correlation Coefficient	one-tailed p-value for parametric test
0-200	6	0.735	0.048
200-400	15	-0.261	n/a
400-600	15	-0.0598	n/a
600-800	5	-0.300	n/a

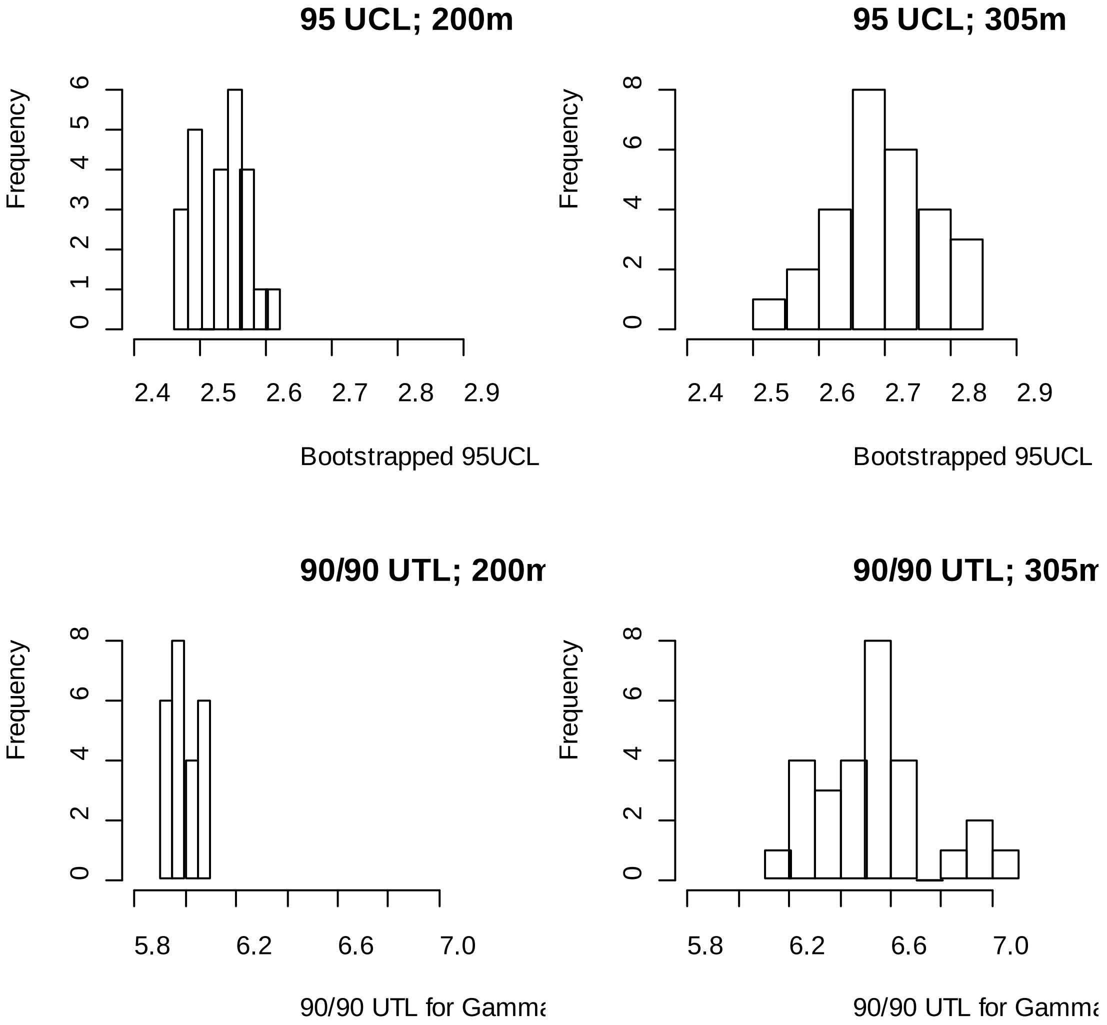
With the polynomial trend removed, there is evidence that samples within 200m of each other are still correlated. We are limited by the number of samples and the distances among them in our estimation process of the autocorrelation range. The data indicate that samples within 200m of one another should not be treated as independent samples. The minimum distance for independence is at least 200m. Samples between 200m and 400m apart were not correlated, though this appears to be strongly influenced by a single elevated sample in the cluster of stations near Weyerhaeuser (the cluster of stations close to shore in Figure D-5).

4.2.2 Method 1 Applied to Port Gardner

Subsets of independent samples were generated from the full data set, as described above. The autocorrelation range used in this approximation was 200m. There were 26 samples from acceptable non-site affected stations in Port Gardner. Of these 26 samples, 17 were more than 200m away from any other samples. The remaining nine samples were grouped into four clusters of two or more samples each. All permutations were constructed of independent samples within each of these clusters and combined with the other 17 samples (24 possible permutations).

There were a few samples that were just beyond 200m apart, so we also calculated results for autocorrelation range of 305m. For this range, there were 14 samples more than 305m away from any other samples. The remaining 12 samples were grouped into four clusters of two or more samples each, and all permutations were constructed of independent samples within each of these clusters and combined with the other 14 samples (28 possible permutations).

Sample sizes ranged from 18 to 20 for the permutations at 305m distance; and were always 21 for the permutations at 200m distance. Arithmetic mean values were higher for the 305m distance: ranging from 1.86 to 2.01ng/kg TEQ compared to a range of 1.77 to 1.84 ng/kg TEQ for the 200m distance. The distributions of the 95UCL and the 90/90 UTL values for the TEQ of these two sets of permutations are shown in Figure D-7. The larger values for the 305m distance partially reflects the smaller sample size (even for an identical distribution, a smaller n generates a larger UCL and UTL because of the greater uncertainty). But the larger values in the 305m distance permutations also indicate the presence of some small scale spatial variability, as observed in the tight cluster of samples near Weyerhaeuser (the cluster of stations close to shore in Figure D-5).


95 UCL; 200m

95 UCL; 305m

90/90 UTL; 200m

90/90 UTL; 305m

Figure D-7. Distribution of 95UCL and 90/90 UTL for TEQ values (ng/kg, dry wt) for the permutations of independent samples in Port Gardner using 200m autocorrelation range (left side), or 305m autocorrelation range (right side).

4.2.3 Port Gardner Conclusions and Recommendations

The autocorrelation investigation and the trend surface regression models indicate that there is trend and/or patchiness in Port Gardner background concentrations of TEQ values (ng/kg, dry weight). Using an independent subset of the existing data will describe the area sampled (the union of the circles around our points sampled), but there are large areas un-sampled with uncertainty about what concentrations might be found there. The differences in the results for the autocorrelation range of 200m vs. 305m indicate the patchy nature of TEQ concentrations in at least some of the areas (although this could only be tested for the dense sample cluster near Weyerhaeuser). This means that interpolation could lead to erroneous conclusions about area averages.

For sample adequacy, we consider the following:

Temporal consistency: The data within background areas are collected from 2004 to 2010. The data from 2004 are all from the Weyerhaeuser sampling, which were also found to be highly influential in the subsetting exercise. Additional sampling in this area may be desirable to describe more current conditions in the area.

Number of samples: The existing data are bimodal, and are not well fit by any parametric distribution (ProUCL). For this data set we can't generate any assumptions about sample size adequacy.

Spatial Extent: The best trend surface was a 3rd order polynomial, indicating patchiness with low concentrations near Weyerhaeuser; higher concentrations near the DMMP disposal site. This site would benefit from additional samples placed out beyond the DMMP disposal site (to see how far out those concentrations extend), and the area between Jetty Island and the disposal site. It may also be desirable to sample the area north and northwest of the current northern boundary of the existing data in order to capture what influence the Snohomish River may have on the bay concentrations.

Sampling Density: Based on the autocorrelation tests, we recommend samples at least 400m – 500m apart. This sampling interval will miss some of the small scale spatial variability that is present, but would allow efficient description of a larger area. In addition, a grid spacing of 500m is expected to achieve independent samples. Any new samples would be placed as evenly as possible within the desired boundaries for the defined background population, and at least 500m away from any other new or existing samples.

- Option #1: Modify the spatial boundary for <u>regional background</u> to exclude everything north to northwest of the line drawn from the southern point of Jetty Island out into Possession Sound. Take at least 10 more samples within any of the available grid squares (500m grid), trying to achieve uniform distribution of samples throughout the area and minimum separation between samples of 500m. <u>Pros:</u> A smaller boundary allows a greater sampling density within the area considered representative of regional background. Excluding the areas on the Snohomish River delta may be justified if the project locations are not heavily influenced by the river. <u>Cons:</u> the spatial boundary may be too limited.

- Option #2: Modify the spatial boundary to exclude the deeper subtidal areas, and include only the areas strongly influenced by the Snohomish River. <u>Pros:</u> A smaller boundary allows a greater sampling density within the area considered representative of local background. Excluding the areas outside of the Snohomish River influence may be justified if the project locations are primarily influenced by the river. Cons: the spatial boundary may be too limited.

- Option #3: Combine Options 1 and 2 to describe a larger background area. Sample in as many grid squares as is affordable, increasing the grid size to 1km (exchange small scale accuracy for broad scale information). Try to achieve a uniform distribution throughout the area and minimum separation between all new and existing data of 0.5-1km. Pros: A broader area is defined that allows the description of an overall background average; if separate populations are present near the mouth of the Snohomish River vs. subtidal Possession Sound, it may be apparent by these data. Cons: Cost.

4.3 Bellingham Bay Case Study

Ecology staff used BPJ to identify samples that were too near to point sources, or were from a different area-of-influence and therefore considered to be inappropriate for comparison to Bellingham Bay site concentrations. The sampling locations are shown in Figure D-8; the grid overlaid on the map is a 0.5 km square grid used simply to illustrate the scale of the distance between samples. The latitude and longitude for the sampling locations and their associated TEQ concentrations (ng/kg, dry weight) are provided in this Appendix, Table A-3.

4.3.1 Trend and Autocorrelation in Bellingham Bay

For the Bellingham Bay data set, the second-order polynomial provides the best fit (the model with the lowest AICc) for the trend surface model (Figure D-9).

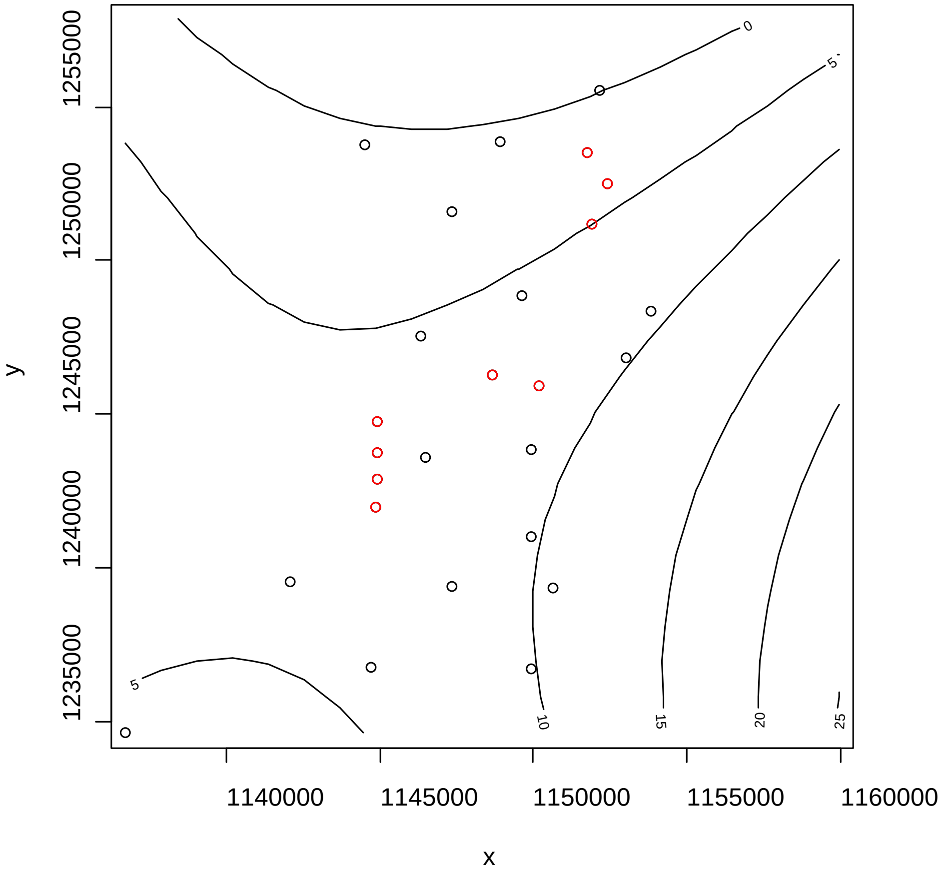


Figure D-9. Bellingham Bay sample locations with contours based on second-order polynomial fit. Samples that are <472 m from other samples are highlighted in red.

The maximum distance between the six closest pairs of points is 472m, so the bin sizes are set to multiples of 472m. This is the smallest autocorrelation range that we can test with these data. There may be autocorrelation present at smaller distances, but we cannot test whether the correlation is significant because of insufficient numbers of data pairs available for that distance. The correlation results after removing the trend from the data are shown in Table D-3.

Table D-3. Autocorrelation results for Bellingham Bay data.

Bin Endpoints (m)	N	Pearson's Correlation Coefficient	one-tailed p-value for parametric test
0 – 472	6	0.315	0.543
472 – 945	23	-0.118	n/a
945 - 1416	41	-0.0704	n/a
1416 - 1890	42	-0.218	n/a

There is no evidence of autocorrelation in the 0-472m range. There may be autocorrelation at smaller ranges, but it is not a testable hypothesis on this dataset, so we could assume that the data set is roughly uncorrelated at the distances that were sampled. However, we don't want to underestimate autocorrelation, so we also test the estimation results by subsampling the data based on a minimum separation distance of 472m (round up to 500m).

4.3.2 Method 1 applied to Bellingham Bay

Subsets of independent samples were generated from the full data set, as described above, using an autocorrelation range of 500m, slightly larger than the smallest autocorrelation range that could be tested.

There were 26 samples from acceptable non-site affected stations in Bellingham Bay. Of these 26 samples, 16 were more than 500m away from any other samples. The remaining ten samples were grouped into three clusters of two or more samples each. All permutations were constructed of independent samples within each of these clusters and combined with the other 16 samples (12 possible permutations). The distributions of summary statistics for these permutations are shown in Figure D-10. The red lines indicate the values calculated by assuming that the data are roughly uncorrelated at the distances that were sampled. We can see that the full data set (n=26) produced a lower 95 UCL on the mean (7.3 ng/kg TEQ, dry weight) than some of the random permutations. For the permutations, 95UCL values range from 7.0 to 7.7 ng/kg TEQ. For the 90/90 UTL, permutation values ranged from 14.5 to 15.9, and the observed data had a value of 14.6 ng/kg TEQ.

One of the clusters of samples had substantial variability in the reported TEQ values: 1.5, 1.6, and 6.3 ng/kg. The first two concentrations were reported for samples from the 0-12cm horizon; the last for a sample from the 0-55cm horizon. This was the only sample included in this background data set that was collected beyond the 0-12cm depth horizon. Permutation results excluding this deeper horizon sample had 95 UCL values ranging from

7.0 to 7.4 ng/kg, and 90/90 UTL values ranging from 14.5 to 15.3 ng/kg. So, this sample definitely had an effect on the upper range of the estimates, but it's unknown whether it reflects greater contamination at depth or overall small scale spatial variability in surface concentrations.

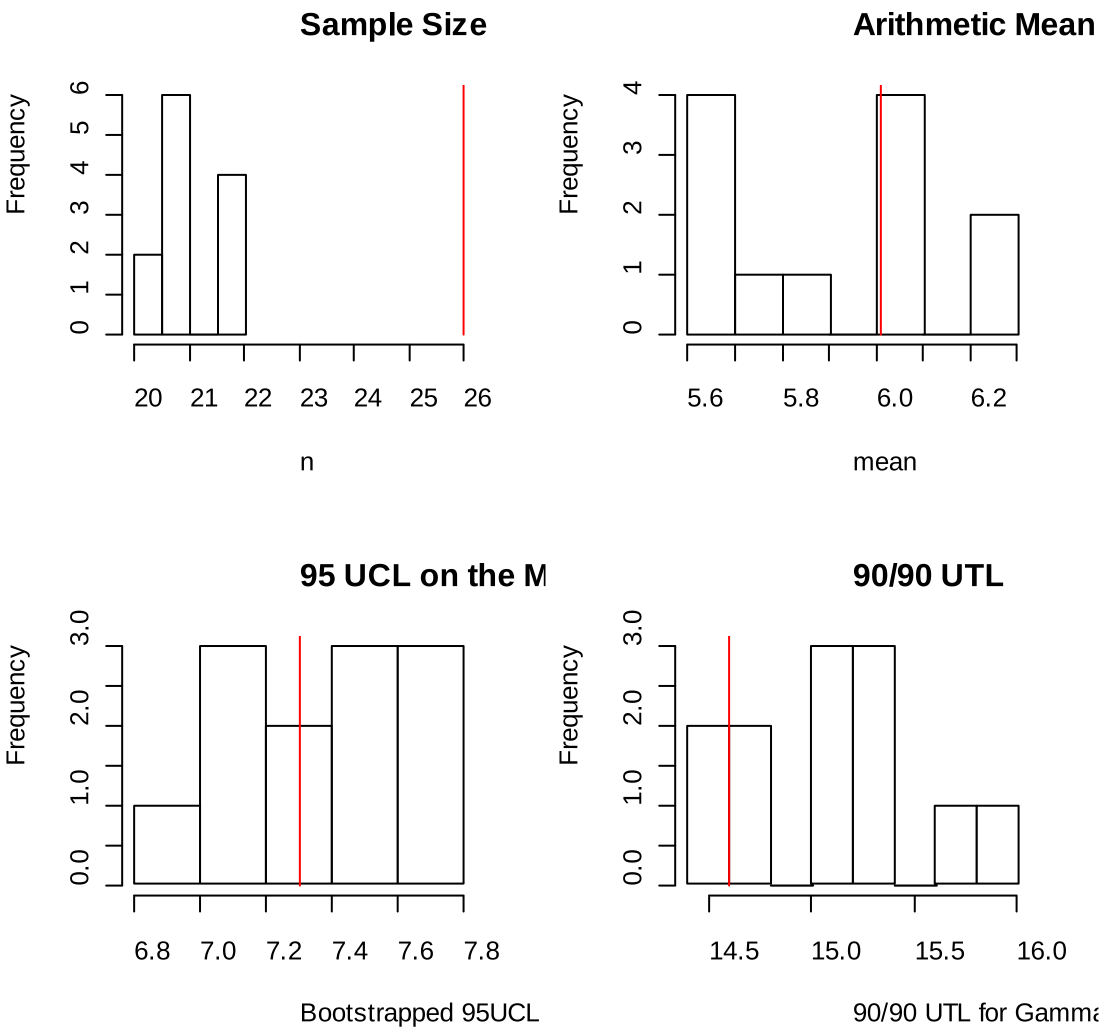


Figure D-10. Distribution of summary statistics TEQ values (ng/kg, dry weight) for the permutations of independent samples (>500m) at Bellingham Bay. Red lines indicate the values for the observed data set.

4.3.3 Bellingham Bay Conclusions and Recommendations

The trend surface regression models indicate that there is significant trend in Bellingham Bay background concentrations. The autocorrelation investigation indicated that the data could be considered independent as sampled, but there are large areas un-sampled with uncertainty about what concentrations might be found there.

Given the strong appearance of trends, and potentially two competing trends (one from the southern shoreline of Bellingham Bay, and another from the Nooksack River in the north), this site would benefit from additional samples. Where the boundary is drawn depends on BPJ regarding the relevance of the Nooksack River influence on the Regional Background concentrations. An independent sampling interval would be 500m, but the large area that needs to be sampled justifies using a larger sampling interval (e.g., 1000m) if needed. For sample adequacy, we consider the following:

Temporal consistency: The data within the background area are collected from 2007 to 2010, so time period is probably not an issue and all these data are useable.

Number of Samples: The existing data are not significantly different from either the normal or the gamma distributions (ProUCL, alpha=0.05). For this sample size calculation, we use the gamma distribution because it allows for more potential skewness in the distribution and a more conservative sample size calculation. We plot the number of samples vs. the width of the gamma confidence interval on the mean (Figure D-11). The figure shows that our sample size of 26 provides a UCL width that is 32% of the mean for the area sampled; we're close to the part of the curve where it's starting to flatten out for our sampled population indicating incrementally smaller advantage from each additional sample. Doubling the sample size is expected to decrease the UCL half-width to about 20%, assuming that the mean and the variance stay the same. This assumption may not be realistic given that there is a trend in these data – samples collected from a different area will affect both the mean and the variance, so this graph provides simply a ballpark estimate of expected sample size adequacy.

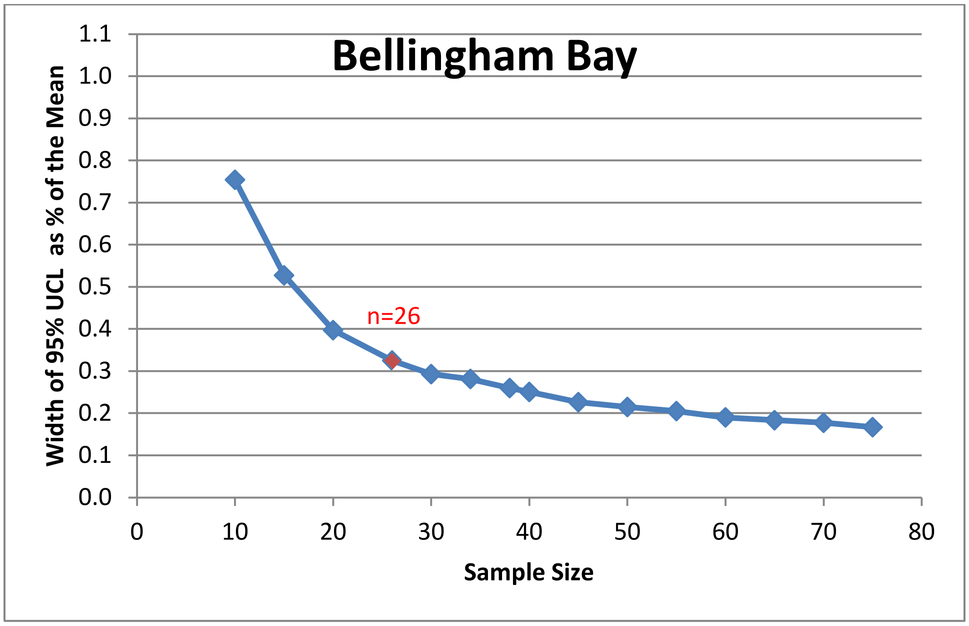


Figure D-11. Sample size vs. precision of the mean using Bellingham Bay data, fit

with a gamma distribution.
Spatial Extent: The best trend surface was a 2^{nd} order polynomial, showing a strong trend decreasing away from the Bellingham shoreline along the SE portion of the Bay, and a weaker trend that decreases approaching the northern portion of the Bay and the Nooksack River delta. Where the boundary for background is drawn depends on BPJ regarding the relevance of the Nooksack River influence on the Regional Background concentrations.

Sampling Density: Based on the autocorrelation tests, we recommend samples no closer than 0.5km apart to get a data set of independent samples.

- Option #1: Draw the spatial boundary to be just outside of the existing sampling locations, and take an additional 10 samples within any of the available 500m grid squares within that boundary. As much as possible try to achieve spatial evenness, and a minimum separation of 500m. Pros: Maximizes the use of the existing data and fills some data gaps for this background boundary. Cons: If the northern area influenced by the Nooksack River is more of a local natural background, this data set will be a combination of two blending populations.

- Option #2: Draw the spatial boundary to exclude some of the existing locations in the northern portion of the bay where the Nooksack River may be influencing concentrations. Take an additional 10 samples within any of the available 500m grid squares within this area, trying to achieve spatial evenness and a minimum separation of 500m. Pros: Same cost as Option 1, but a smaller boundary allows a greater sampling density within the area considered representative of regional background. Excluding the areas of the bay with strong Nooksack River influence may be justified if the project locations are more strongly regionally influenced similar to what's found in the southern portion of the Bay. Cons: the spatial boundary may be too limited (encompasses an area generally within 3km of the shoreline) and therefore may be focused too much on the upper concentration end of the trend.

- Option #3: Draw the spatial boundary further out into the Bay to try to identify where the two trends meet. The grid size could be increased to 1km (exchange small scale accuracy for broad scale information). Try to achieve a uniform distribution throughout the area and minimum separation of 0.5-1km. Pros: A broader area is defined that allows better understanding of the two local influences (i.e., the river and the urban area), and therefore a better description of an overall background average. Cons: Cost, and sampling overkill if the regional background is what's needed for project comparison.

5.0 General Recommendations

The approach used by agencies (US EPA, OR DEQ, WA DOE, and ACOE) for describing background involves the initial definition of the population. Given a narrative description of Regional Background, or Local Natural Background, the spatial boundaries for the appropriate background are a site-specific question and must be drawn using existing data from the area, information about fate and transport of contamination from the site, regional influences, as well as best professional judgment.

Once the data within the presumed background area have been compiled, it is fairly simple to fit a selection of modeled trend surfaces, and look for autocorrelation in the residuals. The trend surface provides some information about spatial variability and local patchiness in the concentrations, which can assist in helping determine the best locations for additional sampling. The presence of observable trends also indicates that a random sample (or even a random subset of the existing data) may inadequately describe background areas that have <u>not</u> been uniformly sampled. Treating a non-uniform sample from a trending population as if it were i.i.d. can result in biased estimates of the mean and the 95UCL on the mean. Existing data may be insufficient to detect the presence of a trend (i.e., just because we don’t detect a trend doesn’t mean it’s not there). The optimal sampling design in the presence of trends is one that achieves spatial evenness. Since there is no harm in assuming that trends are present, the optimal design should always attempt to achieve uniform spatial coverage using systematic random samples, or more complex designs such as GRTS sampling (US EPA 2011).

The autocorrelation investigation helps uncover the magnitude of spatial autocorrelation in existing background data sets. Using the autocorrelation range estimate, we can assume that samples outside of this distance range can be considered effectively independent. The sampling density of the existing data set may be insufficient to measure the true autocorrelation range, but it should be sufficient to provide an approximate minimum separation distance to define the grid size for future sampling. If the existing data set does contain dense clusters of samples, then the autocorrelation investigation allows those data to be treated appropriately for the calculation of background summary statistics by selecting independent subsets of the data (i.e., Method 1).

Finally, we emphasize that Method 1 described herein only allows description of the areas that are directly sampled (the union of circles around the sampled data points). Any extrapolation beyond, or interpolation between the sampled locations is avoided. Spatial modeling (Method 2) can provide estimates for interpolated concentrations across a broader area but has the disadvantages that it can be complex, requires more assumptions about the behavior of the data, and cannot be done adequately when the data are sparse.

6.0 References

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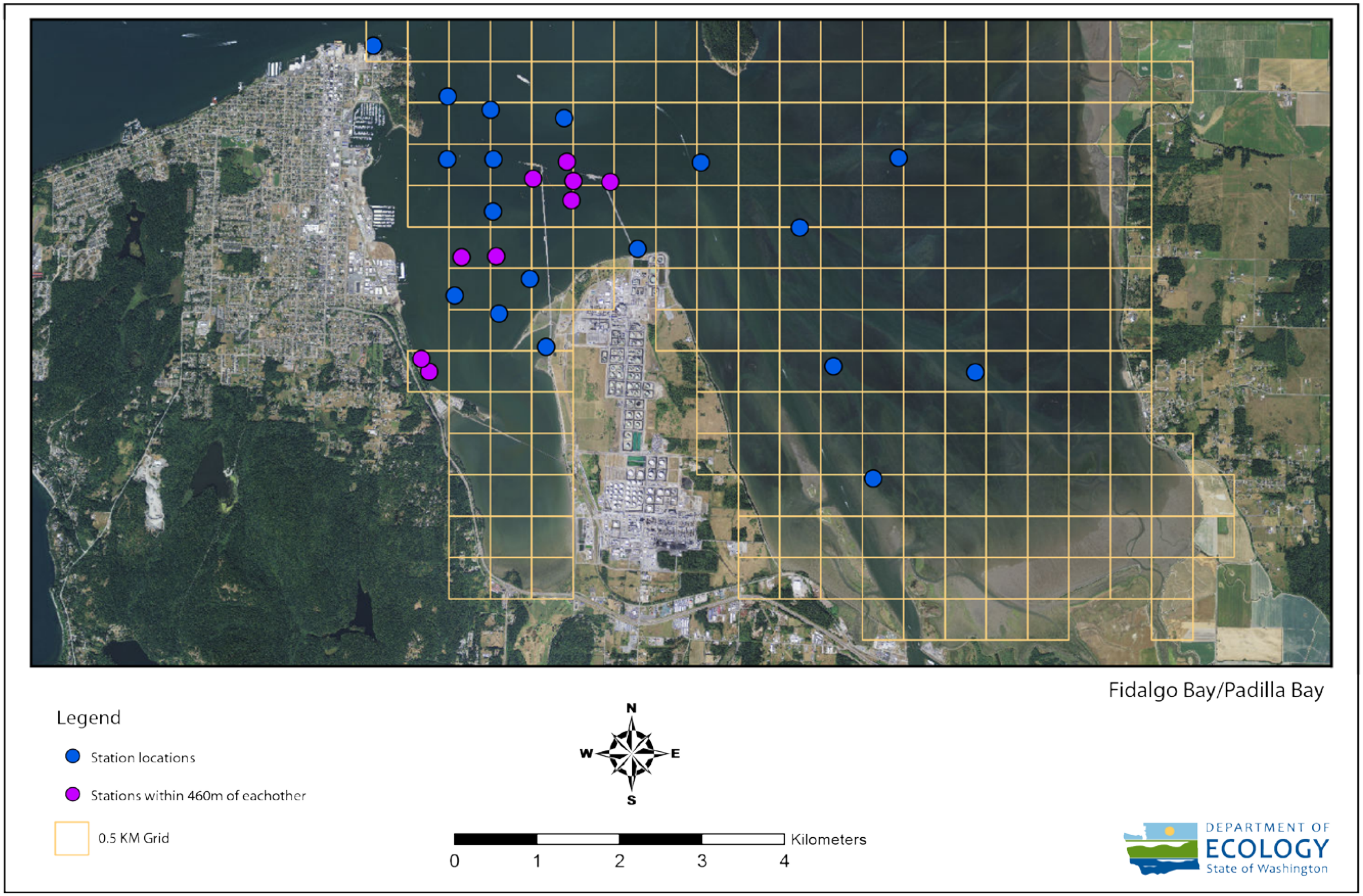

Figure 1. Map of Fidalgo Bay case study site, showing locations of existing data.

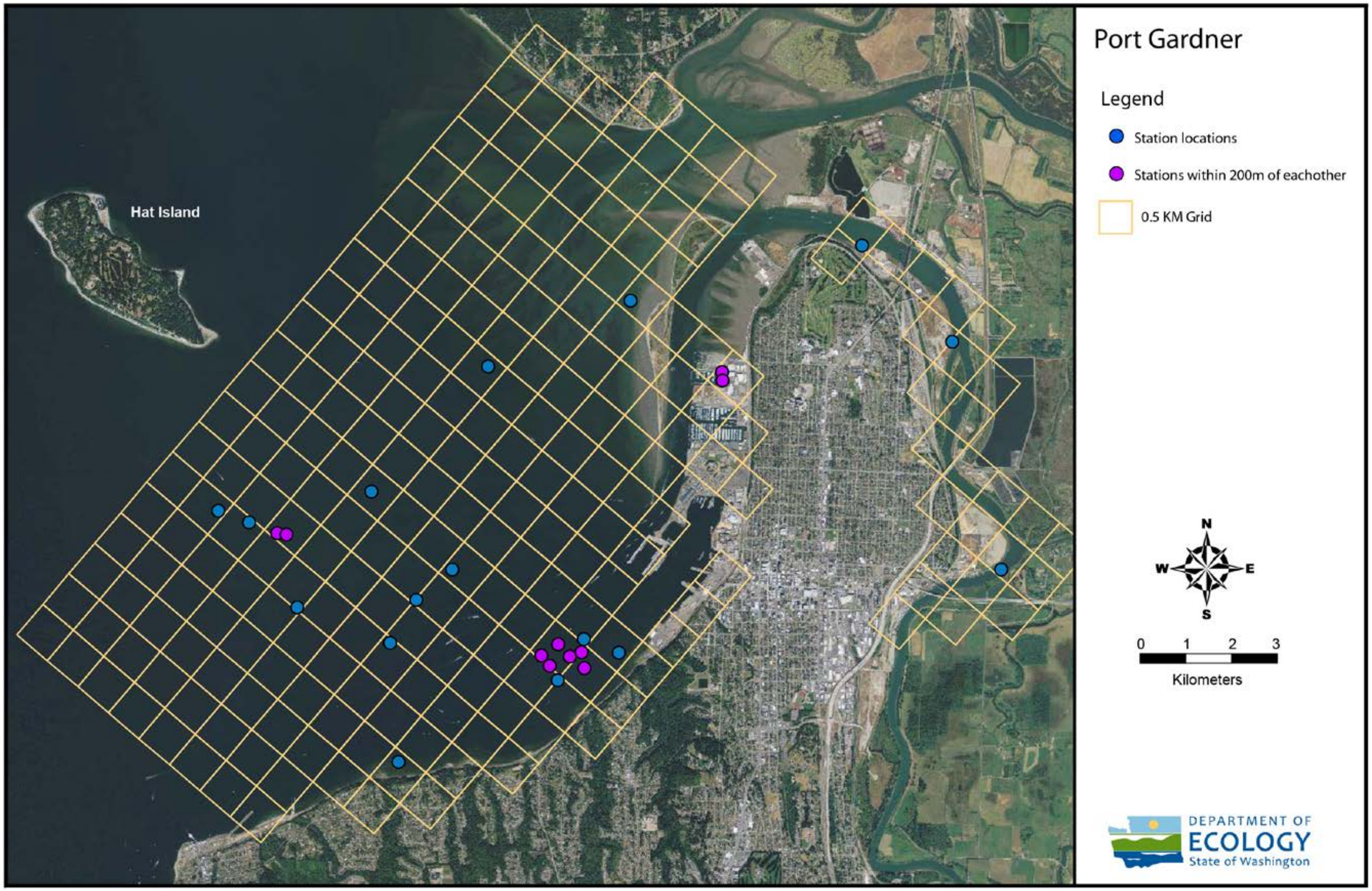

Figure 5. Map of Port Gardner case study site, showing locations of existing data.

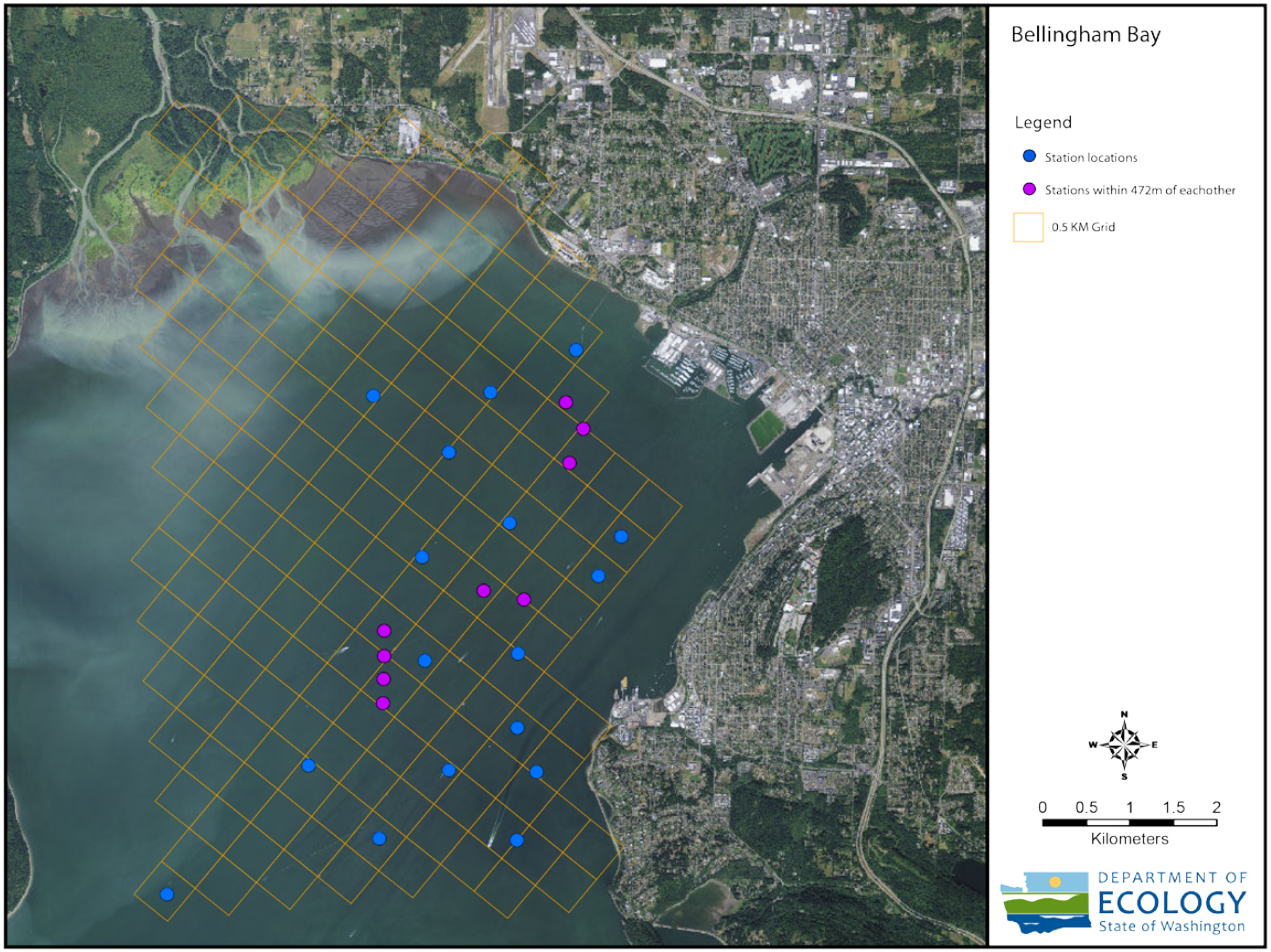

Figure 8. Map of Bellingham Bay case study site, showing locations of existing data.

Table A-1. Fidalgo Bay Case Study TEQ Data for Marine Sediments used as Regional Background

StudyID	LocationID	Study Location Name	FieldActivity StartDate	SampleID	Latitude	Longitude	Study_Type	Location_Setting	TEQ Conc (pptr)
FBCPDX48	FSID6858-PB-10	PADILLABAY-10	6/8/2010	SDS-PB-10	48.476283	-122.5225	SiteInvestigation	Intertidal	0.56
FBCPDX48	FSID6858-CT-05	CLAMCOLLECTIONSITE-05	6/14/2010	SDS-CT-05	48.488004	-122.5969	SiteInvestigation	Intertidal	1.3
FIDALG08	FB-A3-42	FB-A3-42	9/4/2007	FB-A3-42	48.486639	-122.5956	InitialInvestigation	Estuary	3.4
FBCPDX48	FSID6858-PB-08	PADILLABAY-08	6/8/2010	SDS-PB-08	48.488383	-122.5295	SiteInvestigation	Intertidal	0.24
FBCPDX48	FSID6858-PB-09	PADILLABAY-09	6/8/2010	SDS-PB-09	48.48815	-122.5063	SiteInvestigation	Intertidal	0.13
FBCPDX48	FSID6858-FB-10	FIDALGOBAY-10	6/8/2010	SDS-FB-10	48.493153	-122.5844	SiteInvestigation	Intertidal	2
FIDALG08	FB-A3-41	FB-A3-41	9/4/2007	FB-A3-41	48.4897	-122.5766	InitialInvestigation	Intertidal	3.8
FBCPDX48	FSID6858-CPD-12	CUSTOMPLYWOODMILL-12	6/10/2010	SDS-CPD-12	48.495	-122.5918	SiteInvestigation	Intertidal	1.7
FIDALG08	FB-A2-38	FB-A2-38	8/30/2007	FB-A2-38	48.497	-122.5795	InitialInvestigation	Subtidal	1.9
FIDALG08	FB-A3-25	FB-A3-25	9/5/2007	FB-A3-25	48.4992	-122.5908	InitialInvestigation	Subtidal	1.9
FBCPDX48	FSID6858-FB-09	FIDALGOBAY-09	6/8/2010	SDS-FB-09	48.4994	-122.5851	SiteInvestigation	Intertidal	1.3
FIDALG08	FB-A2-35	FB-A2-35	8/30/2007	FB-A2-35	48.5006	-122.562	InitialInvestigation	Intertidal	0.72
FBCPDX48	FSID6858-PB-07	PADILLABAY-07	6/7/2010	SDS-PB-07	48.503367	-122.5356	SiteInvestigation	Intertidal	0.22
FBCPDX48	FSID6858-FB-07	FIDALGOBAY-07	6/8/2010	SDS-FB-07	48.504233	-122.5859	SiteInvestigation	Intertidal	0.79
FBCPDX48	FSID6858-FB-08	FIDALGOBAY-08	6/8/2010	SDS-FB-08	48.50565	-122.573	SiteInvestigation	Intertidal	0.67
FBCPDX48	FSID6858-FB-04	FIDALGOBAY-04	6/8/2010	SDS-FB-04	48.509783	-122.5935	SiteInvestigation	Intertidal	1.1
FBCPDX48	FSID6858-FB-05	FIDALGOBAY-05	6/8/2010	SDS-FB-05	48.509917	-122.586	SiteInvestigation	Intertidal	0.41
FBCPDX48	FSID6858-FB-06	FIDALGOBAY-06	6/8/2010	SDS-FB-06	48.510183	-122.5742	SiteInvestigation	Intertidal	0.33
FIDALG08	FB-A2-03	FB-A2-03	8/30/2007	FB-A2-03	48.5079	-122.5794	InitialInvestigation	Subtidal	1.8
FIDALG08	FB-A2-06	FB-A2-06	8/30/2007	FB-A2-06	48.5078	-122.5668	InitialInvestigation	Subtidal	1.4
FIDALG08	FB-A2-05	FB-A2-05	8/31/2007	FB-A2-05	48.5078	-122.5728	InitialInvestigation	Subtidal	2.7
FBCPDX48	FSID6858-PB-05	PADILLABAY-05	6/7/2010	SDS-PB-05	48.510167	-122.552	SiteInvestigation	Intertidal	0.57
FBCPDX48	FSID6858-PB-06	PADILLABAY-06	6/7/2010	SDS-PB-06	48.5112	-122.5197	SiteInvestigation	Intertidal	0.13
FBCPDX48	FSID6858-FB-02	FIDALGOBAY-02	6/8/2010	SDS-FB-02	48.515283	-122.5866	SiteInvestigation	Intertidal	0.51
FBCPDX48	FSID6858-FB-03	FIDALGOBAY-03	6/8/2010	SDS-FB-03	48.514567	-122.5746	SiteInvestigation	Intertidal	0.46
FBCPDX48	FSID6858-FB-01	FIDALGOBAY-01	6/8/2010	SDS-FB-01	48.516633	-122.5937	SiteInvestigation	Intertidal	0.31
FIDALG08	FB-A4-20	FB-A4-20	9/5/2007	FB-A4-20	48.5219	-122.6061	InitialInvestigation	Subtidal	1.4

Dioxin data downloaded from EIM. TEQs were calculated using TEFs from WAC Tables, found at: http://apps.leg.wa.gov/wac/default.aspx?cite=173-340-900. TEQs were calculated using substitution of non-detects at one-half the detection limit.

Table A-2. Port Gardner Case Study TEQ Data for Marine Sediments used as Regional Background

StudyID	LocationID	Study Location Name	FieldActivity StartDate	SampleID	Latitude	Longitude	Location_Setting	TEQ Conc (pptr)
DMMP_Dioxin_2005-07	DMMP-PGT15	PGT15	6/29/2006	PGT15-A	47.98630	-122.3020	SUBTIDAL	4.30
DMMP_Dioxin_2005-07	DMMP-PGT13	PGT13	6/29/2006	PGT13-A	47.98505	-122.2968	SUBTIDAL	4.20
DMMP_Dioxin_2005-07	DMMP-PGT11	PGT11	6/29/2006	PGT11-A	47.98392	-122.2921	SUBTIDAL	4.40
DMMP_Dioxin_2005-07	DMMP-PGP08_1	PGP08_1	6/29/2006	PGP08_10cm	47.98380	-122.2905	SUBTIDAL	3.90
DMMP_Dioxin_2005-07	DMMP-PGP07_1	PGP07_1	6/30/2006	PGP07_10cm	47.97562	-122.2885	SUBTIDAL	3.80
DMMP_Dioxin_2005-07	DMMP-PGP01_1	PGP01_1	6/30/2006	PGP01_10cm	47.98880	-122.2765	SUBTIDAL	5.00
DMMP_Dioxin_2005-07	DMMP-PGB01	PGB01	6/29/2006	PGB01_10cm	47.97192	-122.2728	SUBTIDAL	3.40
PortGardner_08	A1-46B	A1-46B	9/4/2008	A1-46B-S	47.95856	-122.2710	ESTUARY	0.18
DMMP_Dioxin_2005-07	DMMP-PGP09_1	PGP09_1	6/29/2006	PGP09_10cm	47.97679	-122.2686	SUBTIDAL	3.20
DMMP_Dioxin_2005-07	DMMP-PGB09_1	PGB09_1	6/30/2006	PGB09_10cm	47.98029	-122.2627	SUBTIDAL	3.00
PortGardner_08	A2-02	A2-02	9/4/2008	A2-02-S	48.00314	-122.2575	ESTUARY	0.18
KIMCLK04	KIMCLK04AKC-7	AKC-7	2/26/2004	AKC-7SD	47.97088	-122.2476	Subtidal	0.66
KIMCLK04	KIMCLK04AKC-3	AKC-3	2/26/2004	AKC-3SD	47.96972	-122.2461	Subtidal	0.28
KIMCLK04	KIMCLK04AKC-5	AKC-5	2/26/2004	AKC-5SD	47.97218	-122.2447	Subtidal	0.51
KIMCLK04	KIMCLK04AKC-6	AKC-6	2/26/2004	AKC-6SD	47.96814	-122.2447	Subtidal	1.20
KIMCLK04	KIMCLK04AKC-2	AKC-2	2/26/2004	AKC-2SD	47.97086	-122.2427	Subtidal	0.61
KIMCLK04	KIMCLK04AKC-1	AKC-1	2/26/2004	AKC-1SD	47.97131	-122.2408	Subtidal	0.42
KIMCLK04	KIMCLK04AKC-8	AKC-8	2/26/2004	AKC-8SD	47.97282	-122.2405	Subtidal	0.72
KIMCLK04	KIMCLK04AKC-4	AKC-4	2/26/2004	AKC-4SD	47.96955	-122.2403	Subtidal	0.21
PortGardner_08	A1-31B	A1-31B	9/4/2008	A1-31B-S	47.97136	-122.2346	ESTUARY	0.18
PortGardner_08	A2-08	A2-08	9/4/2008	A2-08-S	48.01088	-122.2340	ESTUARY	0.26
AODE6677	AO6677-462.1	A/H-SED-1	12/10/2010	SED-1	48.00310	-122.2184	Subtidal	2.55
AODE6677	AO6677-465	A/H-SED-4	12/10/2010	SED-4	48.00217	-122.2183	SUBTIDAL	2.10
PortGardner_08	A2-30	A2-30	9/12/2008	A2-30-S	48.01762	-122.1954	ESTUARY	0.42
PortGardner_08	A2-32	A2-32	9/4/2008	A2-32-S	48.00702	-122.1800	ESTUARY	0.16
PortGardner_08	A2-37B	A2-37B	9/4/2008	A2-37B-S	47.98164	-122.1710	ESTUARY	0.18

Dioxin data downloaded from EIM. TEQs were calculated using TEFs from WAC Tables, found at: http://apps.leg.wa.gov/wac/default.aspx?cite=173-340-900. TEQs were calculated using substitution of non-detects at one-half the detection limit.

Table A-3. Bellingham Bay Case Study TEQ Data for Marine Sediments used as Regional Background

StudyID	LocationID	Study Location Name	FieldActivity StartDate	SampleID	Upper Depth (cm)	Lower Depth (cm)	Latitude	Longitude	Setting	TEQ Conc (pptr)
DMMP_Dioxin_2005-07	DMMP-BBB04	BBB04	7/19/2007	BBB04	0	10	48.6998	-122.5846	Subtidal	4.3 J
DMMP_Dioxin_2005-07	DMMP-BBP04	BBP04	7/19/2007	BBP04	0	10	48.7137	-122.5631	Subtidal	5.2 J
DMMP_Dioxin_2005-07	DMMP-BBP01	BBP01	7/19/2007	BBP01	0	10	48.7062	-122.5517	Subtidal	5.5 J
DMMP_Dioxin_2005-07	DMMP-BBP02	BBP02	7/19/2007	BBP02	0	10	48.7136	-122.5411	Subtidal	8.5 J
BELSEDDF	BBDIOX-10	BBDIOX-10	6/9/2010	BBDIOX-10	0	12	48.7064	-122.5303	Subtidal	11 J
DMMP_Dioxin_2005-07	DMMP-BBT05	BBT05	7/20/2007	BBT05	0	10	48.7254	-122.5517	Subtidal	7.2 J
DMMP_Dioxin_2005-07	DMMP-BBP03	BBP03	7/19/2007	BBP03	0	10	48.7204	-122.5517	Subtidal	7 J
DMMP_Dioxin_2005-07	DMMP-BBT04	BBT04	7/19/2007	BBT04	0	10	48.7230	-122.5517	Subtidal	7 J
DMMP_Dioxin_2005-07	DMMP-BBT06	BBT06	7/20/2007	BBT06	0	10	48.7281	-122.5518	Subtidal	6.8 J
BELSEDDF	UWI 32	UWI 32	6/10/2010	UWI 32	0	12	48.7250	-122.5453	Subtidal	2.6 J
BELSEDDF	BBDIOX-11	BBDIOX-11	6/9/2010	BBDIOX-11	0	12	48.7182	-122.5307	Subtidal	6.7 J
DMMP_Dioxin_2005-07	DMMP-BBB02	BBB02	7/20/2007	BBB02	0	10	48.7136	-122.5275	Subtidal	10 J
BELSEDDF	BBDIOX-9	BBDIOX-9	6/10/2010	BBDIOX-9	0	12	48.7260	-122.5309	Subtidal	10 J
BELSEDDF	UWI 277	UWI 277	6/9/2010	UWI 277	0	12	48.7359	-122.5462	Subtidal	5.7 J
Bellinghambay08	HART17_BBDXSS05	Bellingham Bay Dioxin BBDx-SS-05	9/18/2008	BBDX-SS-05	0	12	48.7326	-122.5365	Subtidal	12
BELSEDDF	BBDIOX-1A	BBDIOX-1A	6/15/2010	BBDIOX-1A	0	12	48.7317	-122.5302	Subtidal	11 J
BELSEDDF	BBDIOX-3A	BBDIOX-3A	6/15/2010	BBDIOX-3A	0	12	48.7527	-122.5545	Subtidal	0.57 J
BELSEDDF	BBDIOX-4	BBDIOX-4	6/11/2010	BBDIOX-4	0	12	48.7470	-122.5425	Subtidal	1.7 J
BELSEDDF	BBDIOX-6	BBDIOX-6	6/11/2010	BBDIOX-6	0	12	48.7397	-122.5327	Subtidal	3 J
Bellinghambay08	HART17_BBDXSS04	Bellingham Bay Dioxin BBDx-SS-04	9/19/2008	BBDX-SS-04	0	12	48.7344	-122.5186	Subtidal	13 J
BELSEDDF	UWI 29	UWI 29	6/9/2010	UWI 29	0	11	48.7386	-122.5153	Subtidal	6 J
BELSEDDF	UWI 35	UWI 35	6/11/2010	UWI 35	0	10	48.7534	-122.5363	Subtidal	1.4 J
BELSEDDF	BBDIOX-5	BBDIOX-5	6/15/2010	BBDIOX-5	0	12	48.7462	-122.5236	Subtidal	1.6 J
DMMP O&M Squalicum	Sq-15	Sq-15	9/7/2010	Sq-15	0	55	48.7498	-122.5216		6.29 J
Bellinghambay08	HART17_BBDXSS01	Bellingham Bay Dioxin BBDx-SS-01	9/19/2008	BBDX-SS-01	0	12	48.7526	-122.5244	Subtidal	1.5
BELSEDDF	BBDIOX-2	BBDIOX-2	6/10/2010	BBDIOX-2	0	9	48.7581	-122.5231	Intertidal	0.7 J

Dioxin data downloaded from EIM. TEQs were calculated using TEFs from WAC Tables, found at: http://apps.leg.wa.gov/wac/default.aspx?cite=173-340-900.
TEQs were calculated using substitution of non-detects at one-half the detection limit.